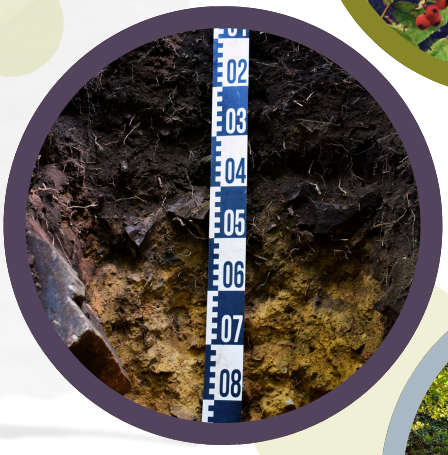
Mendel University in Brno

The Soil Environment

at Mont Beuvray, Bibracte











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Brno 2026

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Abstract

This publication provides an overview of the sites environmental conditions on the Mont Beuvray massif, with particular emphasis on the soil environment and forestry management at this exceptional ecological and historic landscape. The massif is characterised by soils developed on strongly acidic, base-poor silicate substrates, predominantly Cambic Umbrisols and Dystric Cambisols. Soil formation has been substantially shaped by long-term colluvial accumulation driven by historical deforestation and settlement activity, the latter evidenced by artefact-rich horizons at the summit intra muros. The mineral soil fraction is inherently low in clay content and sorptive capacity, rendering soils highly erodible. Biological activity across the massif reflects the high molecular diversity of the organic matter, which, while associated with inherently low decomposition rates, renders the soil carbon pool particularly sensitive to canopy disturbance or climate-driven warming. Forest management must therefore prioritise continuous soil surface protection, avoiding large-scale canopy disturbance that would trigger organic matter mineralisation, nutrient leaching and/or erosion. Gradual stand regeneration through small-scale silvicultural interventions, combined with ameliorative pioneer species, will be essential for maintaining ecological stability. Given the outstanding archaeological significance of the locality, sustainable forest management represents not only an ecological necessity but also a prerequisite for the long-term preservation of the site's cultural heritage.

Content

Preface..... 10

Methods..... 12

General taxonomic soil description..... 16

Humus forms..... 20

Soil moisture dynamics..... 24

Soil biochemistry..... 26

High-resolution spatial data..... 28

THE SOILS OF MONT BEUVRAY – CATALOGUE OF THE SITES..... 34–157

General site conditions and related forest recommendations..... 158

Summary..... 162

Abbreviations

BS	base cations
CEC	cation exchange capacity
CN	carbon nitrogen ratio
ECEC	effective cation exchange capacity
GPS	global position system
CHM	canopy height model
OF	organic fermented horizon
OH	organic humufication horizon
OL	organic litter horizon
pF	moisture retention curve
pH_{KCl}	soil reaction potential exchaneable
pH_{water}	soil reaction active
Q10	the temperature sensitivity of soil respiration.
RS20	soil respiration
RSG	reference soil group
Shannon	soil molecular diversity index
TN	total nitrogen
TOC	total carbon
UAV	unmanned aerial vehicle
WRB	World Reference Base for Soil Resources



Preface

Dear reader,

This publication offers an introduction to the soils of Mont Beuvray and the natural environmental processes that shape them. We hope it will deepen understanding of this remarkable landscape and serve as a practical resource for the forest management measures needed to safeguard such a significant cultural and archaeological site. The publication is divided into eight chapters. The central section is devoted to the description and evaluation of 30 soil profiles, providing a comprehensive account of the soil environment across the Mont Beuvray massif. These profiles are organised into five categories according to the predominant tree species, ensuring broad representation of the forest's composition. The concluding chapter sets out foundational forestry measures suited to the sustainable management of the area in the context of ongoing climate change, whilst preserving the distinctive character of the cultural and natural heritage site that is Bibracte, a 'Grand Site de France'.

The story behind this book began in 2022, when the Department of Geology and Soil Science at the Faculty of Forestry and Wood Technology (FFWT), Mendel University in Brno, Czech Republic, joined the multidisciplinary European Innovation Partnership (PEI-AGRI) project A Forestry Research Laboratory at the Mont Beuvray Protected Area – Phase 1: 2022–2023, led by the European Archaeological Centre at Bibracte, France. Fieldwork was carried out between September and November 2022, during which soil pits were excavated, sampled, and documented at selected sites across the Mont Beuvray massif. This work continued into June 2023, by which point a total of 30 soil profiles had been excavated and described using a consistent research design, with each profile recorded across its entire vertical section and composite samples collected from three sampling points in the organic and organomineral horizons. The samples were subsequently analysed at the FFWT's own soil laboratories, with further analyses conducted at its Morava laboratory; the results being compiled into a comprehensive report from Autumn 2023 onwards.

Phase 2 of the PEI-AGRI project, A Forestry Research Laboratory at the Mont Beuvray Protected Area, ran from 2024 to 2026 and focused primarily on forest management in the Bibracte region. During this phase, the FFWT collected climate and hydrological data and assessed local soil biochemistry, with particular emphasis on quantifying the topsoil humus layer. A field GIS survey of the study area was also conducted using drones. Together, these analyses provide a comprehensive picture of the area's natural environment and offer valuable data to inform the forest management measures needed to adapt to the effects of ongoing climate change, whilst preserving the unique character of this remarkable cultural site.

We would like to express our sincere gratitude to the entire team at the European Archaeological Centre at Bibracte, in particular Director Vincent Guichard and Project Manager Jean Cacot, for their support in carrying out this research. Without their cooperation, this publication would not have been possible.

Our warm thanks also go to Prof. Erika Gömöryová for her thorough review of the manuscript and her valuable expert comments, and to Assoc. Prof. Dušan Vavříček for his systematic and in-depth insights into pedological (soil) classification.



Methods

The soil survey was conducted across 30 study sites divided into five treatments: four different forest types and an open area (clearcut), with six replicates per treatment. Soil profiles were excavated as sampling pits to depths ranging from 70 to 120 cm. Soils were classified according to the World Reference Base for Soil Resources (IUSS Working Group WRB 2022), while humus forms were classified following Zanella et al. (2011). Exchangeable aluminium (Al^{3+}) concentration [mmol kg^{-1}] was determined according to Sokolov (1939).

Soil samples were collected from individual pedogenic horizons, including the organic humification horizon (OH) and the underlying mineral horizons. Samples were taken both as undisturbed cores for the determination of bulk density, porosity, and water holding capacity, and as mixed samples for the analysis of chemical soil properties. Soil texture was determined by laser diffraction for the clay (< 0.002 mm), silt (0.002–0.05 mm) – subdivided into fine silt (0.002–0.02 mm) and coarse silt (0.02–0.05 mm) – and sand (0.05–2 mm) fractions. Aggregate stability was assessed using the slaking index according to Rémy and Marin-LaFlèche (1974). Soil reaction was determined as active (pH/H_2O) and potential exchangeable (pH/KCl) in a 1:2.5 w/v suspension of soil in water or 0.2 M KCl, respectively. Cation exchange capacity (CEC [$mmol^+ kg^{-1}$]) was determined as effective (ECEC) the summation method. Exchangeable base cations (Ca, Mg, K [mg kg^{-1}]) were determined from $BaCl_2$ extracts, while available P was determined using the Mehlich II extractant (Mehlich 1978). For organic substrates, available nutrients (P, Mg, Ca, K) were determined from Göhler extracts (0.52 M acetic acid (CH_3COOH) and 0.05 M sodium acetate ($C_2H_3NaO_2$)) at a substrate-to-extractant ratio of 1:10 w/v (Soukup 1987).

Total carbon (TOC) and total nitrogen (TN) were determined by elemental analysis using a Vario Macro Cube elemental analyser (Elementar, Germany). Prior to analysis, samples were sieved to 2 mm and milled to a maximum particle size of 0.25 mm; measurements were performed by combustion at 1125 °C using approximately 100 mg (±5 mg) of dry material.

To better characterise podzolisation processes, Al, Fe, Si, and Mn were analysed in different operationally defined forms (amorphous, crystalline, and organically bound). Total nutrient contents were determined after mineralisation in hydrofluoric acid, followed by flame atomic absorption spectroscopy (Zbíral et al. 2011).

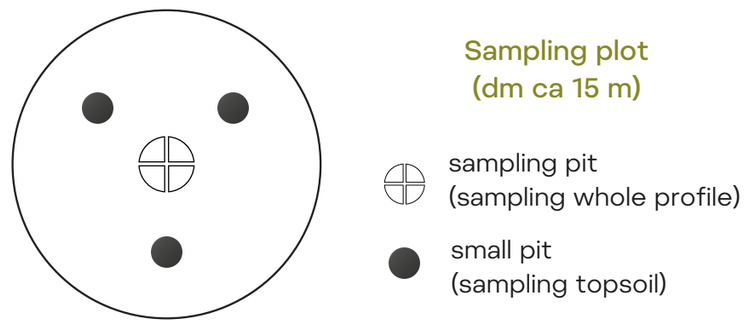
The hydraulic characteristics of the soils were determined using HYDRUS pedotransfer functions (Wösten et al., 1999), developed to estimate the hydraulic properties of European soils based on commonly available soil characteristics. The input data for individual horizons consisted of laboratory-determined properties, i.e. particle-size distribution and TOC, and derived parameters, i.e. bulk density (Kučera et al., 2025) and soil organic matter (converted from TOC using a coefficient of 1.72).

Based on these input data, the hydraulic parameters of the Mualem-van Genuchten model (1980) were calculated to describe the soil water retention curve. The volumetric soil water content was then calculated for the standard pF values of 0.0 (maximum water capacity), 1.0, 2.0 (field water capacity), 2.5, 3.4, and 4.2 (permanent wilting point). These unique hydraulic characteristics were determined for each organo-mineral and mineral soil horizon.

Soil moisture dynamics were evaluated using continuous measurements of volumetric soil water content at depths of 10, 30, and 60 cm, taken under three treatment types: a beech stand, a Douglas fir stand and a clear-cut area. Moisture was monitored using SMT100 soil moisture sensors (TRUEBNER GmbH, Germany), with data transmitted automatically to a cloud database every hour.

Annual precipitation totals and their seasonal distribution were assessed for the period 2023–2025 and compared with the observed soil moisture patterns. Precipitation was measured in an open area on the top clearcut site.

Subsequent analysis focused on seasonal and interannual variability in soil moisture levels at different depths and under different treatment conditions. Short-term responses to precipitation and drought events were assessed using topsoil moisture (10 cm), while mid- and long-term soil water dynamics were assessed from subsoil measurements at 30 cm and 60 cm.



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General taxonomic soil description

The soil cover as a whole reflects moderate to advanced pedogenic development within an environment of acidic volcanic rocks under acidic forest conditions, with an intensive anthropogenic history. Regarding WRB soil taxonomy, the Umbrisols Reference Soil Group (RSG) predominates owing to the presence of a diagnostic umbric horizon. Brunification processes have led to the development of a deeper cambic horizon (Bw), occurring within the less abundant Cambisols, within the Umbrisols, and uniquely also within Regosols exhibiting Brunic properties but not meeting all diagnostic criteria for cambic horizon classification. A non-negligible set of diagnostic criteria and properties is attributable to historical anthropogenic influence, either directly, in the form of pedoturbation and accumulation of anthropogenic materials, or indirectly, through erosion or acidification resulting from deforestation or changes in tree species composition.

Umbrisols, frequently exhibiting high organic matter content, silty texture, and granular to crumb structure in the upper horizons, tend to dominate. Presence of the umbric horizon was typically confirmed by TOC values above the WRB threshold (≥1.4–2.0%, depending on depth) and low base saturation. In many profiles, the umbric layer extended to 20–30 cm or more.

Cambisols occur in areas with stronger evidence of metamorphic features, where Bw horizons tend to develop below 30–40 cm. These soils generally display brownish hues (7.5YR–10YR) and have a medium subangular blocky structure. Cambisols tend to occur on lower slopes or transitional convex-concave terrain, where they frequently alternate with Umbrisols owing to surface accumulation processes. One soil profile was classified as a Technosol due to the presence of construction debris and artefacts exceeding 20% by volume. Several profiles contain charcoal or isolated artefacts (e.g. ceramics, brick fragments) in quantities insufficient to meet Technosol criteria; these have been classified as Anthrosols.

The principal qualifiers reflect the dominant soil properties and formation processes: (1) abundant artefacts, exceeding the 20% threshold in one case (Technosol RSG); (2) umbric properties resulting from accumulation processes; (3) characteristically silty texture associated with low bulk density and increased erodibility; and (4) elevated stoniness throughout the profile.

Hydromorphic features are relatively uncommon, being largely confined to areas adjacent to streams and watercourses or to broader valley sedimentation basins. The generally high permeability of these soils means that redoximorphic features are rarely expressed. Supplementary qualifiers similarly reflect texture class (predominantly siltic or loamic) at varying depths, the pronounced distribution of organic matter, stoniness, acidic chemistry, and solifluction.

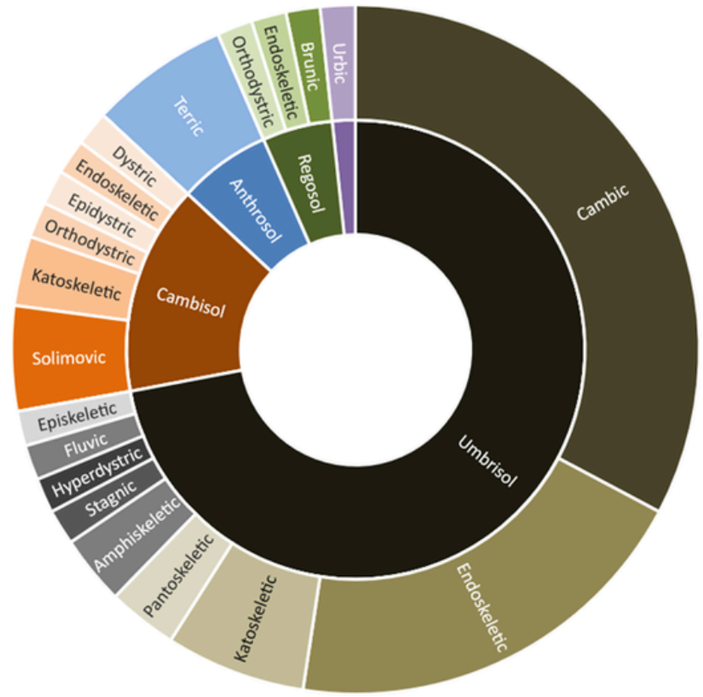


Figure 1: Reference Soil Groups and Principal qualifiers determined within the soil survey

Typical morphogenetic soil features

Metamorphic mineral horizons (Bw) are characterised by 10YR and 7.5YR hues, with Munsell soil color system values most frequently at 3–4 and chroma predominantly 6. Compared with the underlying substrate horizons, the metamorphic horizons display redder hues (towards 7.5YR) and lower values and chroma, which is indicative of active brunification processes within the cambic horizon. The lower boundary of the organo-mineral A horizon exceeds 20 cm in most profiles. Within the organo-mineral part of the profile, loam and sandy loam textures predominate, while the metamorphic horizon is characterised by sandy loam. Structure in the transitional zones towards the soil-forming substrate and within the substrate horizon itself is typically fine or simple grain, whereas the metamorphic horizon exhibits a predominantly fine-to-medium subangular blocky structure. The coarser texture and finer structure in the transitional and substrate zones are consistent with metamorphic development, as brunification leads to an increase in the clay fraction. Bulk density (along with related soil compaction) is generally low to very low, consistent with presumed solifluction and limited soil consolidation.

Index of terms in soil taxonomy

1. Reference Soil Groups (RSG)

Anthrosols: classified based on a terric horizon, meeting the criteria of long-term addition of material, less than 10% artefacts, more than 0.6% TOC, a rise in land surface through material accumulation, and a thickness of > 20 cm; the base saturation criterion is marginally fulfilled, being slightly below the threshold.

Technosols: classified based on an artefact content of > 20% combined with a concentrated artefact layer of < 50 cm.

Umbrisols: classified based on an umbric horizon, meeting the criteria of small structural aggregates, > 0.6% soil organic carbon (SOC), colour value and chroma < 3, base saturation < 50%, and thickness > 20 cm.

Cambisols: classified based on a cambic horizon, meeting the criteria of fine texture, aggregate structure, and colour development relative to the overlying and underlying layers.

Regosols: classified where no profile development is apparent, resulting from recent material accumulation that does not meet the criteria for an umbric horizon.

2. Principal and supplementary qualifiers

Brunic: development of metamorphic features consistent with a cambic horizon but not meeting all diagnostic criteria, particularly owing to coarse-textural material and occurrence at < 50 cm depth.

Cambic: presence of a cambic horizon within 50 cm depth, clearly overlain by an umbric horizon.

Carbonic: presence of a layer > 10 cm thick containing > 5% artefact-derived carbon (primarily charcoal).

Dystric/Orthodystric: exchangeable Al exceeding the sum of exchangeable Ca, Mg, K, and Na, accompanied by low pH(H_2O) (consistently < 5.5). Orthodystric was assigned where this condition persisted below 50 cm from the mineral surface.

Fluvic: soil material of fluvial (fluviatile) origin.

Humic: > 1% TOC to a depth of 50 cm from the mineral surface. Hyperhumic denotes > 5% TOC to 50 cm depth; Profundihumic denotes > 1.4% TOC to 100 cm depth.

Pachic: umbric horizon > 50 cm in thickness.

Protospodic: ammonium oxalate extraction of alluminium (Alox) > 1.5 times the lowest Al(ox) value recorded across all overlying mineral layers - indicative of micropodzolisation.

Skeletic: coarse fragment content (> 2 mm) > 40% by volume.

Solimovic: heterogeneous mixture of material transported downslope suspended in water. Transport is commonly driven by erosional wash or soil creep, and accelerated by land-use practices such as deforestation, tillage, timber extraction, and mechanical disturbance of the soil surface.

Stagnic: presence of redoximorphic features, with the area of oximorphic features > 25% and reducing conditions occurring for at least part of the year.

Terric: presence of a terric horizon, meeting the criteria of long-term addition of material, < 10% artefacts, > 0.6% TOC, a rise in land surface through material accumulation, and a thickness > 20 cm; the base saturation criterion is marginally fulfilled, being slightly below the threshold. Texture specification is Siltic/Loamic

Transportic: evidence of material movement by intentional human activity, with < 10% artefacts.

Texture specification (Loamic/Siltic): texture class grouped into qualifiers, with Loamic encompassing sandy loam, loam, sandy clay loam, silty clay loam, and clay loam; and Siltic encompassing silt and silt loam.

Urbic: artefact content > 20%, represented principally by settlement rubble and refuse (mainly fragments of amphorae, bricks, and similar materials).

3. Specifiers of depth distribution of features

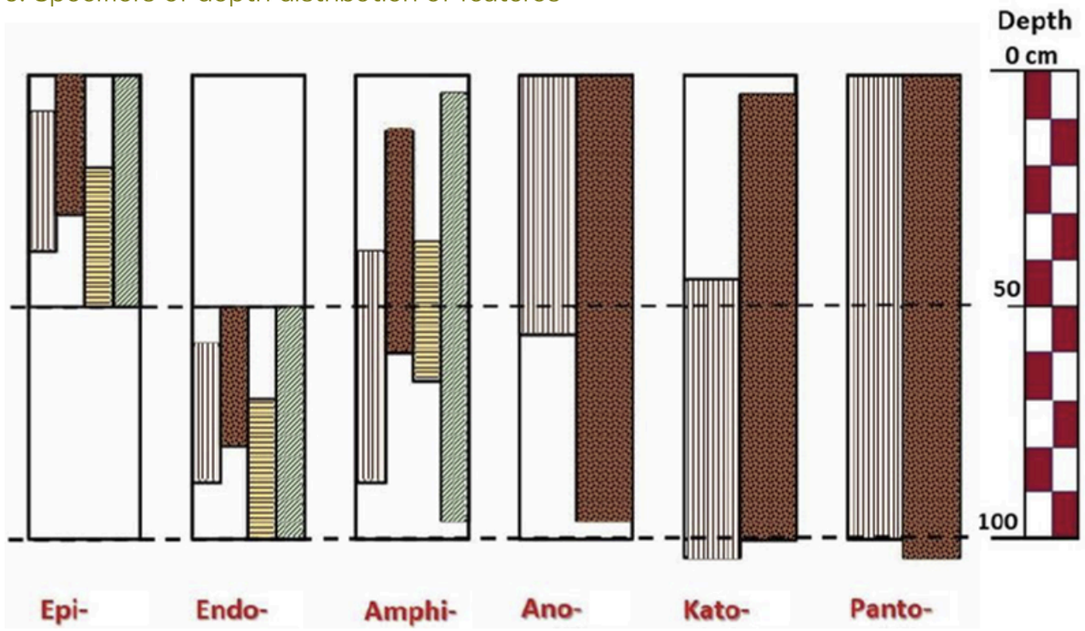


Figure 2: Optional qualifiers related to depth range of a feature distribution



Humus forms

The European humus reference base of Zanella et al. (2011) was used to classify humus forms at the study sites. Only terrestrial humus forms were identified, as none of the sites was significantly affected by waterlogging, excessive saturation, or submerged organic layers. For the organic layers (OL, OF, OH), thickness was the primary parameter recorded, with two exceptions: one site exhibited high decaying wood content in the OL+OF horizons, and another showed high root density within the organic horizons. Both cases gave rise to specific humus types described below.

For humus type classification, all organo-mineral horizons were assigned to biomacrostructured, biomesostructured, or biomicrostructured A horizon categories, based on their structure, consistence, and pH(H_2O), as all were of zoogenic origin (evidenced by visible droppings, fauna, typical structure).

The majority of forms were Terroforms (typical forms), with only a small number of sites represented by atypical Paraforms. The Paraforms identified were rhizoamphi (dominated by root material) beneath a silver fir stand, and lignoamphi (characterised by a high proportion of decaying wood) on a clearcut site.

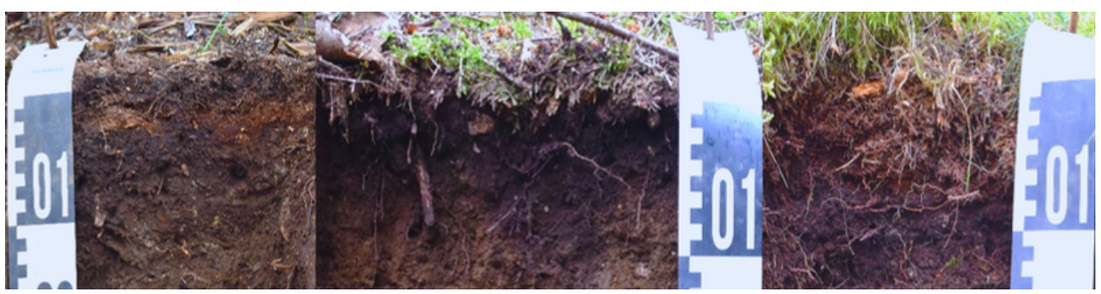


Figure 3: Comparison of atypical Paraforms on the sides (lignoamphi on the left, rhizoamphi on the right) with typical terroform (pachyamphi) in the middle

At the first level of classification, only two biological humus types were identified: amphi, representing 83% of sites, and moder, representing the remaining 17%. The principal distinction between the two is that amphi forms on, and is strongly associated with, biomesostructured A horizons, whereas moder develops on biomicrostructured and non-zoogenic A horizons.



Figure 4: Microstructured A horizon on the left and mesostructured A horizon on the right

At the subtype level, more than half of the sites (63%), across all variants, were classified as eumesoamphi, a subtype characteristic of biomesostructured organo-mineral horizons. Pachyamphi and dysmoder, both distinguished by a thick OH (humification) horizon, were the next most frequent, each accounting for 10% of sites. All remaining subtypes were each recorded at a single site only, representing 3% of the total.

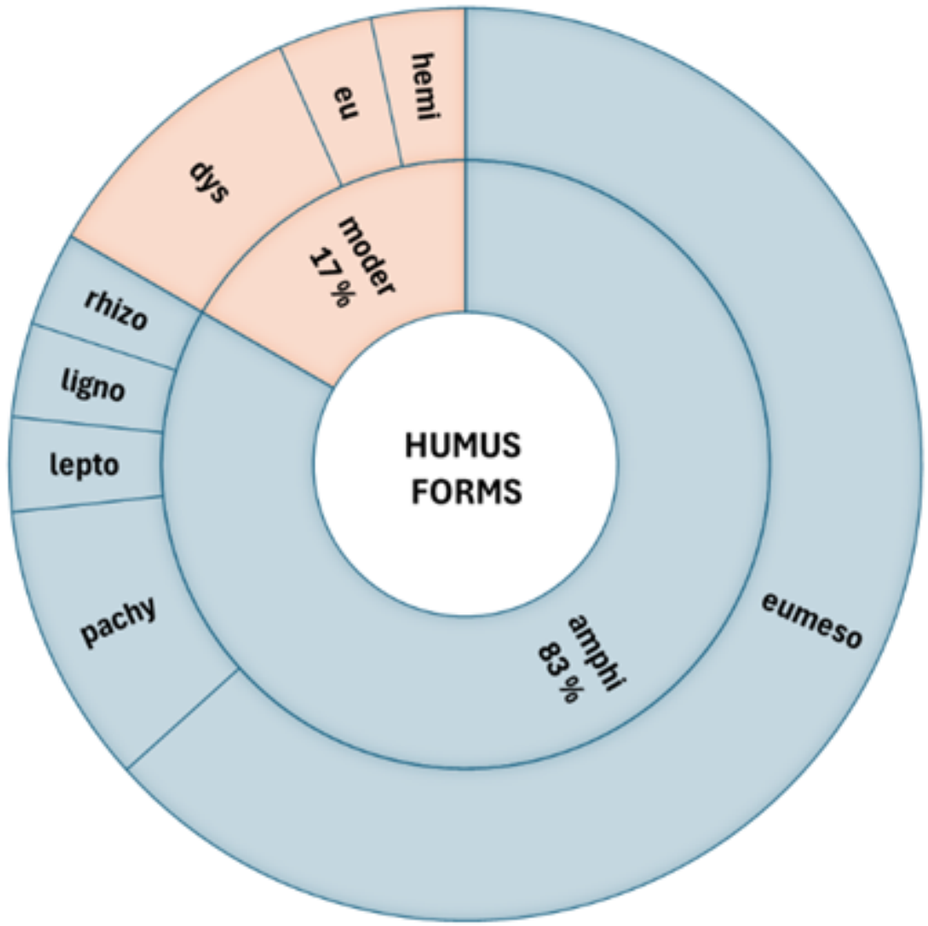


Figure 5: Humus types and subtypes representation amongst all studied stands

The eumesoamphi humus subtype was found in all site variants (see Fig. 6) and almost all inclinations (except 0–5 °; see Fig. 7), suggesting climate conditions as main factor affecting the humus type formation. Most diverse humus subtypes (4 subtypes) were found in European beech and mixed forest sites. Humus subtypes represented in just one stand may be formed due to specific site microclimate or conditions (trees density, age, height structure, understory).



Figure 6: Distribution of humus subtypes amongst forest stand variants



Figure 7: Distribution of humus subtypes amongst inclinations



Soil moisture dynamics

Precipitation totals differed substantially between years (Fig. 8), with 2024 representing the wettest year (1792 mm), followed by 2023 (1581 mm), whilst 2025 was markedly drier (817 mm by September). Rainfall distribution in 2024 was relatively even, whereas 2023 was characterised by strong autumn recharge. In contrast, spring 2025 received limited precipitation, resulting in reduced winter/spring soil water replenishment and a pronounced summer moisture deficit.

The even and well-distributed precipitation of 2024 corresponded with stable soil moisture across all depths and sites. In contrast, late summer 2023 was characterised by strong but temporary drying at the surface and mid-profile, followed by rapid autumn recharge. The year 2025 exhibited the most severe hydrological stress (Fig. 1), with reduced spring precipitation limiting soil water recharge prior to the growing season, and subsequent summer drying affecting both the surface layer and the 30 and 60 cm layers.

At 10 cm, soil moisture showed the strongest seasonal and interannual fluctuations. The beech stand maintained highest moisture levels throughout most of the study period, particularly in 2023 and 2024, indicating strong topsoil buffering capacity. The clearcut area showed pronounced seasonal drying, while Douglas fir consistently exhibited lowest surface moisture during drought periods (Fig. 8). In both 2023 and, especially, 2025, the summer drought led to extreme reductions in topsoil moisture across all treatments, with the most severe declines recorded under Douglas fir and on clearcut sites.

At 30 cm, variability was dampened but still reflected drought events. Beech maintained comparatively high moisture during wetter years, whilst the clearcut area showed relatively stable subsoil moisture despite pronounced surface drying. Douglas fir displayed intermediate behaviour at this depth (Fig. 8), with marked summer declines but clear recovery during wetter periods. The 2025 drought caused substantial moisture reductions across all treatment types at 30 cm, indicating that prolonged precipitation deficits affected the mid-profile regardless of treatment.

At 60 cm, soil moisture was generally high and stable during 2023–2024, particularly under beech and on the clearcut area. Douglas fir maintained moderate but consistently lower deep-soil moisture compared with the other treatments. Deep soil layers remained wet during 2023 and 2024 but experienced pronounced drying in summer 2025 (Fig. 8), demonstrating that cumulative moisture deficits eventually penetrated the entire soil profile.

Overall, soil moisture variability was governed by the interplay of treatment, soil depth, and precipitation regime. Whilst treatment influenced the magnitude of topsoil drying, prolonged rainfall deficits, especially in 2025, overrode treatment differences and led to substantial moisture depletion throughout the soil profile.

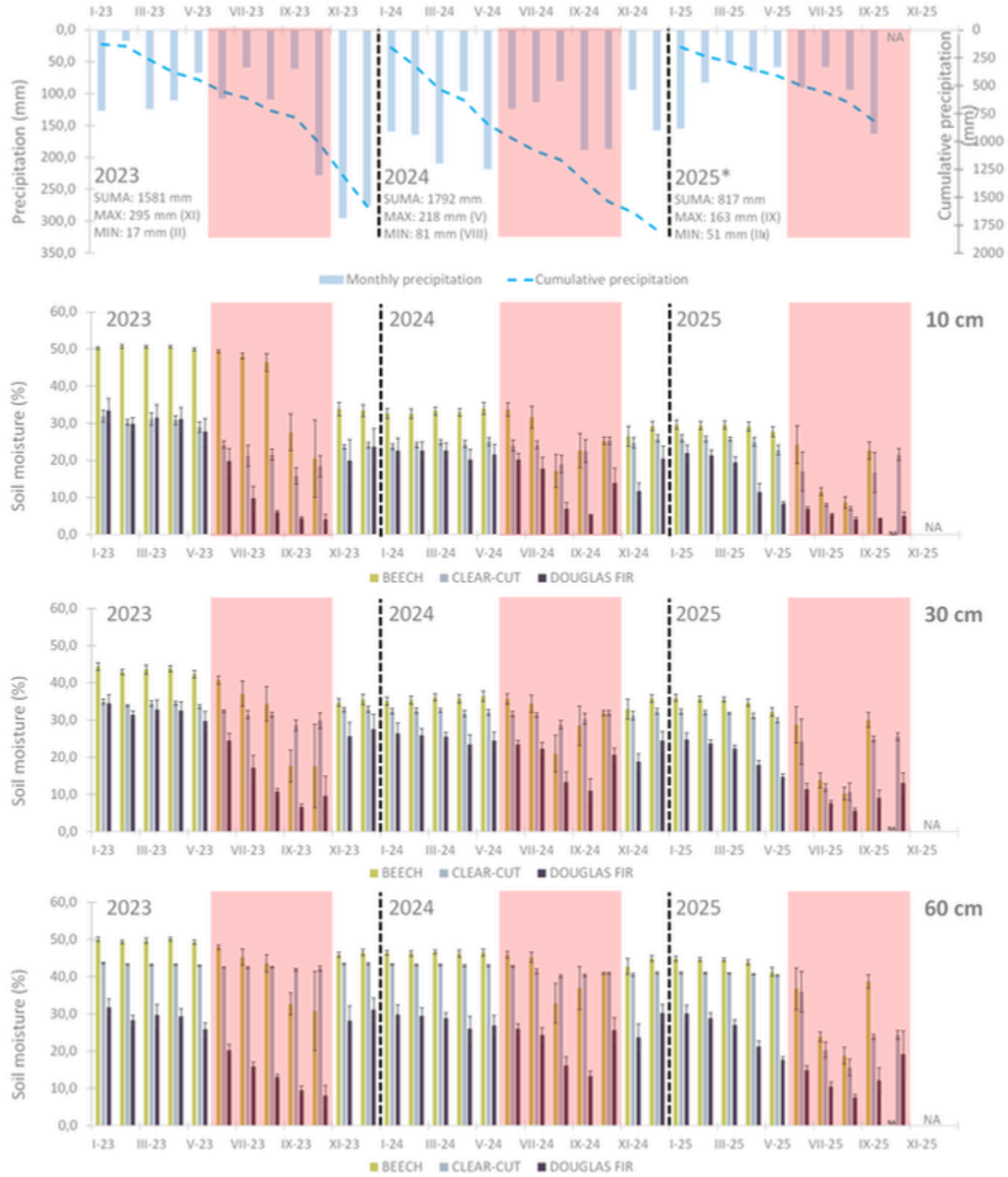


Figure 8: Courses of monthly mean soil moisture (±SD) across depths at the monitored sites



Soil biochemistry

RS20:

The RS20 parameter corresponds to the soil CO_2 emission flux at a normalised temperature of 20°C. This CO_2 flux is the result of the degradation of organic matter by soil microorganisms. This value is obtained in the laboratory through soil incubations, under controlled conditions. A high value indicates a significant flux of carbon from the soil to the atmosphere. While the degradation of organic matter leads to CO_2 emissions, it also releases mineral nutrients into the soil to support tree growth.

Q10:

The Q10 parameter describes the temperature sensitivity of soil respiration. It is determined through soil incubations carried out at different temperatures, during which the increase in CO_2 emissions is measured as temperature rises. This temperature-driven increase in soil respiration is a natural process resulting from the accelerated decomposition of soil organic matter by microorganisms under more favorable conditions. A higher Q10 value may indicate a stronger increase in soil CO_2 emissions in response to ongoing climate change.

Shannon:

The Shannon parameter is a diversity index that, in this study, refers to the diversity of organic molecules present in the soil. It is calculated following the characterization of soil organic matter using a thermal degradation technique (Py-GC-MS). Approximately 200 organic molecules were targeted and quantified across all soil samples to assess and compare their molecular diversity. According to the literature, this diversity may influence the decomposition of soil organic matter. In this context, a high Shannon value indicates a high level of molecular diversity, which is generally associated with lower rates of organic matter decomposition and therefore lower soil CO_2 emissions.

How to read the charts

The charts show the global distribution of values measured across the mont Beuvray area, as represented by the orange (RS20), gray (Q10), or green (Shannon) distribution curve. The small blue square indicates the parameter value at the specific location corresponding to the soil sample presented on the page.















High-resolution spatial data

A primary output of the Bibracte unmanned aerial vehicle (UAV) survey has been a high-resolution orthophoto (3.1 cm ground sampling distance; Fig. 9), providing detailed aerial coverage of the study area. At this resolution, it is possible to distinguish individual trees and their crowns, assess canopy condition, identify canopy gaps and clearings, and precisely delineate forest boundaries. The orthophoto is equally suitable for mapping road networks, open areas, and other landscape features.



Figure 9: Orthomosaic of entire area

A further key output has been the Canopy Height Model (CHM; Fig. 10), representing the height of vegetation above the ground surface. This model enables:

- estimation of individual tree heights,
- differentiation of forest development stages,
- identification of dominant and suppressed trees,
- and, to some extent, discrimination of tree species based on their vertical structure.

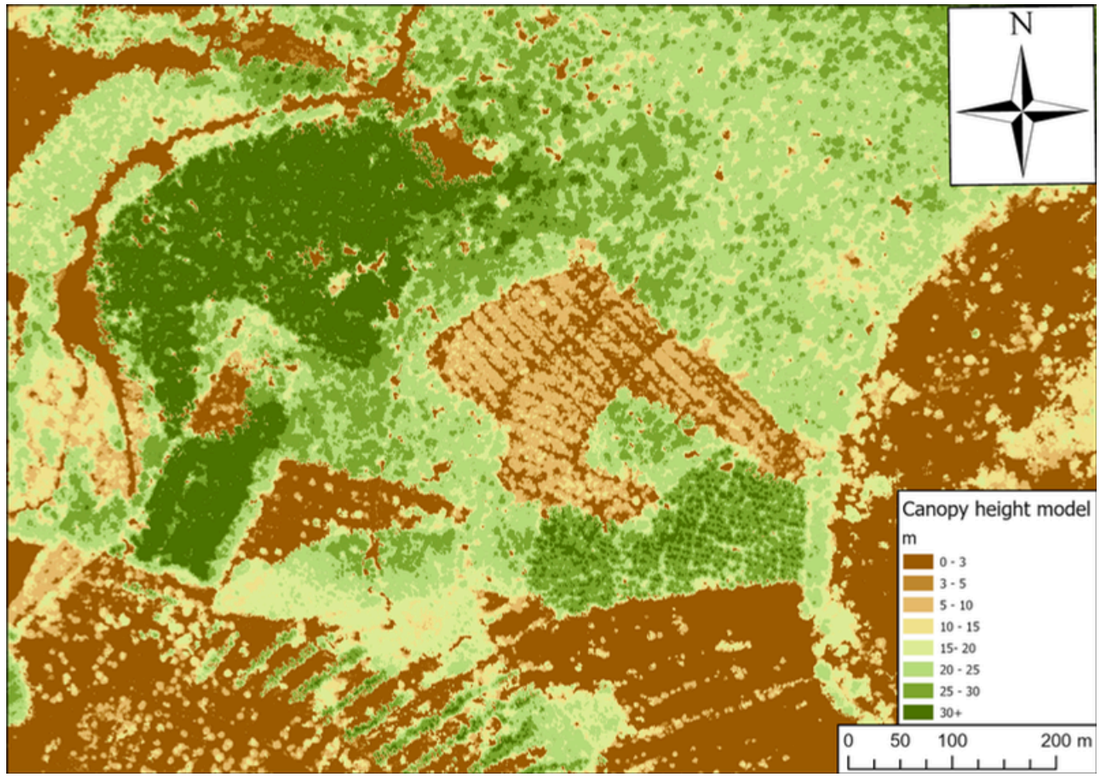


Figure 10: Canopy Height Model (CHM)

From the CHM, individual tree crowns were automatically delineated and treetops detected (Fig. 11). A set of structural parameters was then calculated for each delineated crown, including:

- maximum tree height,
- crown area,
- equivalent crown diameter,
- and additional height-based statistics (e.g. mean height and selected percentiles).

These outputs are applicable to:

- forest inventory,
- timber volume estimation,
- analysis of forest structure,
- planning of management interventions,
- and monitoring of change over time.



Figure 11: Tree crown delineation

More detailed characterisation of forest structure is afforded by the photogrammetric point cloud (Fig. 12), which captures the three-dimensional form of tree crowns.



Figure 12: 3D visualization of the photogrammetric point cloud

A wide range of structural metrics can be derived from the point cloud, serving both as inputs to predictive models and as direct descriptors of forest structure:

Height-related metrics:

- maximum height,
- mean height,
- upper percentiles representing the dominant canopy layer.

Structural variability:

- standard deviation,
- coefficient of variation,
- skewness and kurtosis of the height distribution.

Vertical forest structure:

- proportion of points within defined height strata (e.g. 0–2 m, 2–5 m, 5–10 m), enabling characterisation of forest stratification.

Canopy closure:

- proportion of points above a given height threshold (e.g. 2 m), serving as an indicator of canopy density and directly applicable to forest condition assessment, disturbance monitoring, and ecological analyses.

The derived datasets are also of considerable relevance to archaeological research, particularly at sites such as Bibracte. Using orthophotos and height models, it is possible to:

- identify archaeological features visible at the ground surface,
- analyse spatial relationships between vegetation and archaeological structures,
- document the site in a non-invasive manner.

It should be noted, however, that UAV photogrammetry is inherently limited to features visible at the ground surface or indirectly indicated by vegetation patterns (e.g. variations in canopy height or density). Unlike airborne laser scanning (LiDAR), this approach does not permit direct observation of terrain beneath dense forest canopies.

Applications

Forestry:

- rapid stand inventory without extensive field measurement,
- estimation of tree heights and forest structure,
- support for management planning.

Ecology:

- assessment of structural biodiversity,
- habitat identification,
- long-term monitoring of environmental change.

Landscape monitoring:

- detection of forest damage (wind, drought, pest outbreaks),
- tracking of landscape dynamics through repeat surveys,
- evidence-based support for land management decisions.

Summary

The described workflow transforms UAV-based imagery into detailed spatial information on individual trees and forest structure, yielding data of practical value for forestry, ecology, and archaeological applications.

References

Dalponte, M., & Coomes, D. A. (2016). Tree-centric mapping of forest carbon density from airborne laser scanning and hyperspectral data. Methods in Ecology and Evolution, 7(10), 1236–1245. https://doi.org/10.1111/2041-210X.12575

Roussel, J. R., Auty, D., Coops, N. C., Tompalski, P., Goodbody, T. R., Sánchez Meador, A., Bourdon, J. F., de Boissieu, F., & Achim, A. (2020).

lidR: An R package for analysis of airborne laser scanning (ALS) data. Remote Sensing of Environment, 251, 112061. https://doi.org/10.1016/j.rse.2020.112061



The Soils at Mont Beuvray

Catalogue of the Sites

European Beech 1-6

Silver Fir 7-12

Douglas Fir 13-18

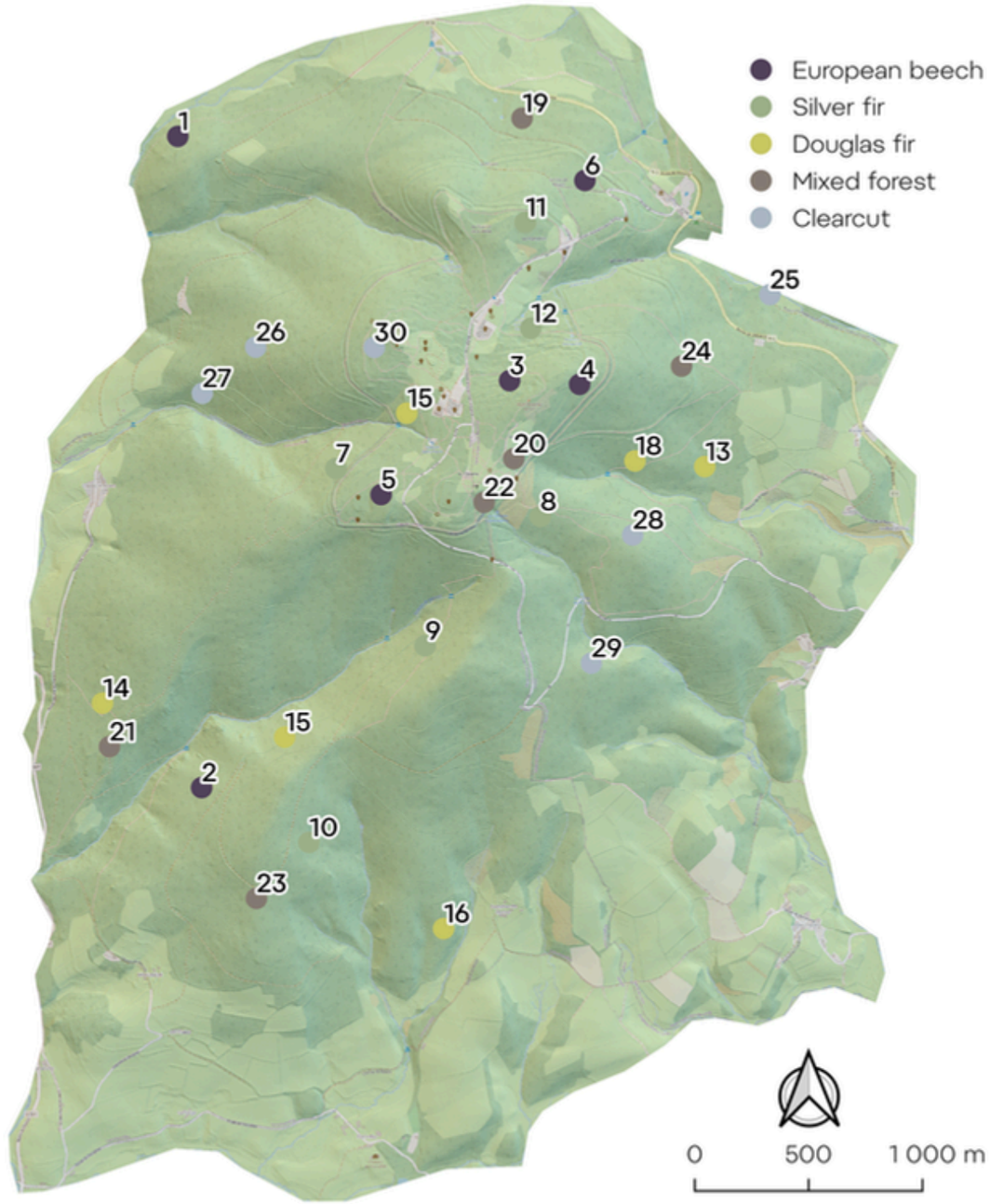
Mixed forest 19-24

Clearcut 25-30





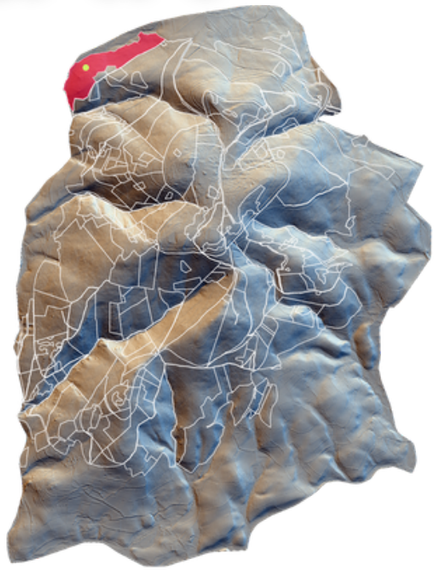




Source: © OpenStreetMap

site 1

EUROPEAN BEECH



GPS (N):	4.0195850°
GPS (E):	46.9350610°
Localization:	extramuros
Altitude:	542 m a.s.l.
Inclination:	16°
Exposure:	SE

The profile is located in the lower part of a long straight slope (inclination 16°, south-east exposure). The tree layer consists of beech with a minimal admixture of oak and holly (90% beech, 10% oak and ilex). The herbaceous layer is practically absent (only moss; acidophilous beech forests). The upper part of the soil profile likely contains some eolian material.





The profile is strongly acidic throughout. The upper mineral horizon is sandy loam, grading to silt loam in the cambic subsoil, where high silt content increases susceptibility to structural degradation. ECEC is low to moderate and dominated by acid cations. Base saturation is low especially within topsoil (22 %) and slightly more favourable in deeper layers (ca. 45-60 %). The aluminum/base cations ratio exceeds 1 in the upper horizon, indicating potential aluminium stress. Available phosphhorus is low to moderate, potassium is sufficient, while calcium and magnesium are limited. Organic carbon content is high in the topsoil with a balanced C/N ratio. Maintaining a diverse tree species composition, including the promotion of ameliorative species (e.g., common hornbeam, sycamore), is recommended. Large-scale clear-cutting should be avoided, as it increases the risk of water surface runoff and structural degradation of the silt-rich topsoil.

Soil Taxonomic Unit:

Endoskeletic Cambic Umbrisol (Amphisiltic, Humic, Epiloamic, Solimovic)

Stratigraphy:
OLn-OLv-OFzo-OH-meAh-Ah/Bw-Bw-BwC

Humus form:
Eumesoapmhi

OLn (2 cm):	Loose, continuous beech and oak litter.
OLv (1 cm):	Loose, continuous beech and oak litter.
OFzo (1.5 cm):	Amphigenic (zooedaphone; frequent mycelia), thick, continuous.
OH (1.5 cm):	Thick, with gradient Hr-Hh.



meAh (0-32.0 cm)
Color: 10YR 3/3 (dark brown), texture class: loamy sand, stoniness: 25% (angular coarse gravel), structure: medium granular, bulk density: very loose, moisture: slightly moist, root density: <2 mm: 90-130 pcs/dm^2, >2 mm: 40 pcs/dm^2. Umbric, with gradient of organic matter and root density near upper boundary.

Ah/Bw (32.0-42.0 cm)
Color: 10YR 4/4 (dark yellowish brown), texture class: silt loam, stoniness: 30% (angular stones), structure: fine subangular blocky, bulk density: very loose, moisture: dry, root density: <2 mm: 40 pcs/dm^2, >2 mm: 10 pcs/dm^2. All stones sizes with dominance of coarse gravel.

Bw (42.0-60.0 cm)
Color: 10YR 4/6 (dark yellowish brown), texture class: silt loam, stoniness: 40% (angular stones), structure: medium subangular blocky, bulk density: very loose, moisture: dry, root density <2 mm: 110 pcs/dm^2, >2 mm: 10 pcs/dm^2. Admixture of silt fraction in fine sand loam.

BwC (>60.0 cm)
Color: 10YR 6/6 (brownish yellow), texture class: silt loam, stoniness: 70% (angular stones), structure: very fine subangular blocky, bulk density: loose, moisture: dry, root density <2 mm: 3 pcs/dm^2, >2 mm: 2 pcs/dm^2.

Soil with running cambic soil forming process below umbric horizon which origins from historical accumulation process and presently high root density. Physiological depth max. 80 cm.



SOIL CHARACTERISTICS

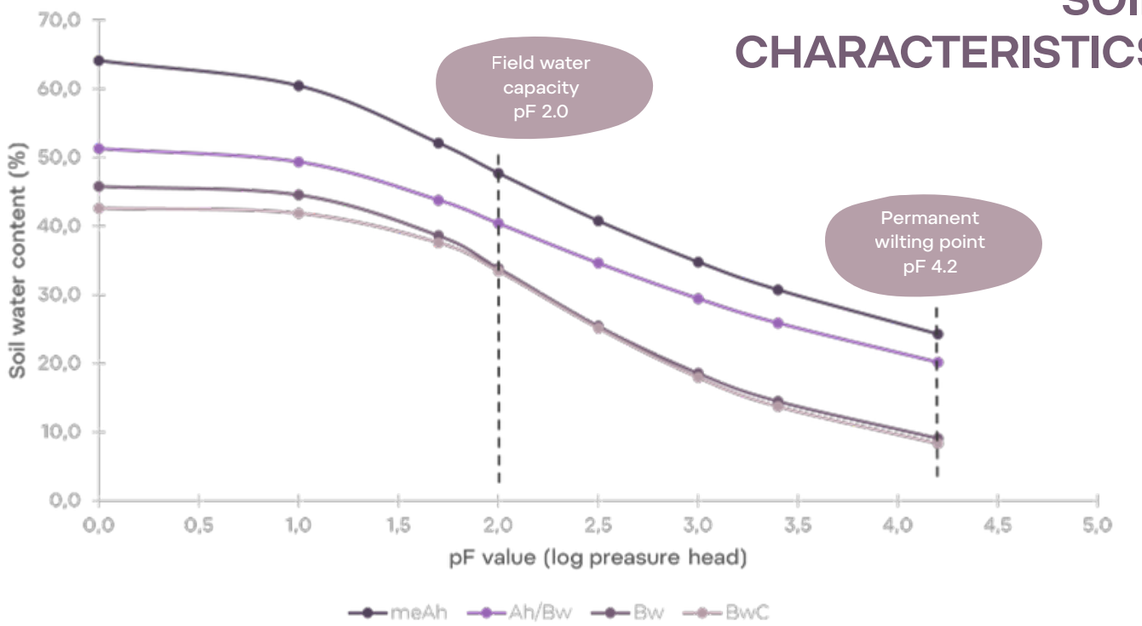


Figure 1A: Water retention curve showing the relationship between soil water content and pF value

This profile No. 1 shows a clear vertical differentiation of physical and hydrological properties, closely linked to changes in bulk density and organic matter content (Table 1A). The surface meAh horizon is characterized by very low bulk density (0.7 g/cm^3) and high organic matter content (16.4%), which together contribute to the highest maximal water capacity (64.1%) and field water capacity (47.7%, Fig. 1A). At the same time, saturated hydraulic conductivity reaches 47.8 cm/day at meAh (Table 1A), confirming hight infiltration and water redistribution in the topsoil horizon.

With increasing depth, bulk density rises progressively to 1.4 g/cm^3 in the BwC horizon, accompanied by a sharp decline in organic matter (3.2%). This densification is reflected in decreasing maximal water capacity (42.6%) and field water capacity (33.5%) in the deepest layer. Saturated hydraulic conductivity also decreases markedly, reaching only 10.9 cm/day in BwC, which suggests restricted vertical water movement in compacted subsoil horizons.

Table 1A: Soil properties of particular horizons - profile No. 1

Soil Horizon	Maximal Water Capacity (% vol.)	Field Water Capacity (% vol.)	Permanent Wilting Point (% vol.)	Available Water Capacity (% vol.)	Saturated Hydraulic Conductivity (cm/day)	Bulk Density (g/cm^3)	Organic Matter (% wt.)
meAh	64.1	47.7	24.2	23.5	47.8	0.7	16.4
Ah/Bw	51.3	40.4	20.2	20.2	36.9	1.1	7.4
Bw	45.8	33.9	9.1	24.8	18.5	1.3	4.6
BwC	42.6	33.5	8.3	25.1	10.9	1.4	3.2

In contrast to the declining trend of total water retention, the permanent wilting point decreases substantially with depth (from 24.2% in meAh to 8.3% in BwC, Fig. 1A). As a result, available water capacity remains relatively balanced across the profile and even slightly increases in the Bw (24.8%) and BwC (25.1%) horizons compared to the topsoil horizons. This indicates that although deeper horizons store less total water storage, a larger proportion of this water is potentially available to plants due to lower retention at high suction pressures.

European Beech

Table 1B: Micronutrients content

Soil Horizon	P	Ca	Mg	K	Cation-exchange Capacity	Base Saturation
	mg/kg				mmol/kg	%
OH	62	695	272	273	323.1	19.9
meAh	3	204	78	133	103.2	22.5
Ah/Bw	2	203	58	98	48.1	46.0
Bw	5	190	57	98	37.9	49.8
BwC	7	178	40	104	30.3	57.1

Table 1C: Soil texture characteristics and soil reaction

Soil Horizon		Texture Class	Slaking Index	Battance Class	pH_{water}	pH_{KCl}
OH					3.8	3.2
meAh	●	sandy loam	0.86	non battant	4.0	3.7
Ah/Bw	●	loam	1.06	non battant	4.4	4.1
Bw	●	silt loam	1.71	assez battant	4.5	4.1
BwC	●	silt loam	2.52	tres battant	4.7	4.2

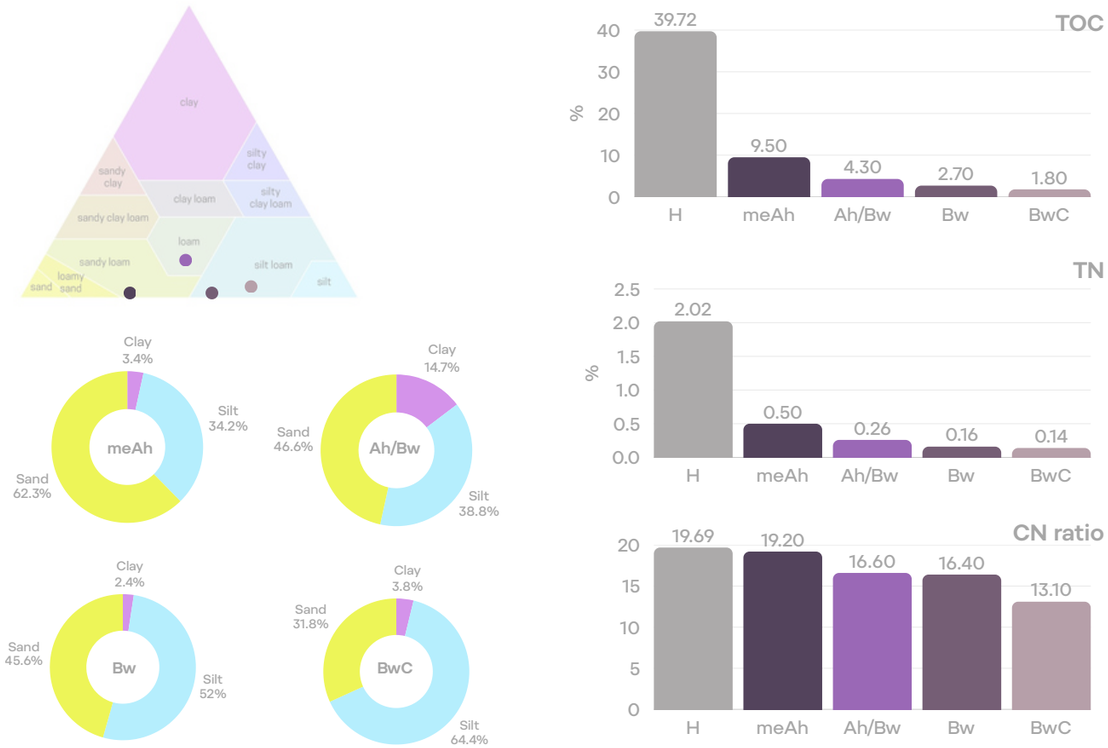


Figure 1B: Soil texture

Figure 1C: Soil carbon and nitrogen characteristics

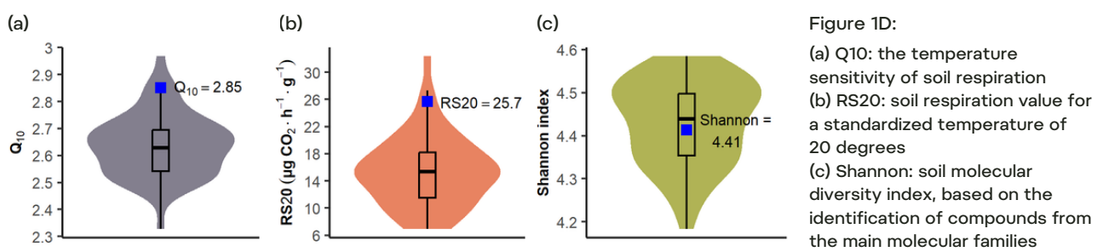
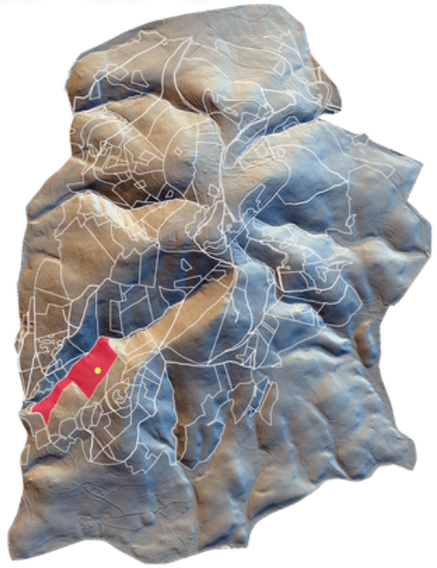


Figure 1D:
(a) Q10: the temperature sensitivity of soil respiration
(b) RS20: soil respiration value for a standardized temperature of 20 degrees
(c) Shannon: soil molecular diversity index, based on the identification of compounds from the main molecular families

site 2

EUROPEAN BEECH



GPS (N):	4.0204730°
GPS (E):	46.9093030°
Localization:	extramuros
Altitude:	519 m a.s.l.
Inclination:	18°
Exposure:	NW

The profile is located in the lower part of a long straight slope (inclination 18°, north-west exposure). The tree layer consists of beech (all unmanaged coppice forest). There is a large amount of stoniness moving down the slope by gravity on the surface and in the topsoil. The herbaceous layer is practically absent.





The soil body is dominated by silt with loamy texture, while slaking susceptibility increases with depth due to decreasing organic matter. The soil is strongly to moderately acidic (pH 4.1–4.5) with moderately saturated sorption complex and relatively balanced base cations. Aluminum/base cations ratios indicate no significant risk of aluminium toxicity. Nutrient contents are generally sufficient; potassium is slightly elevated but without apparent antagonistic effects. Under the mature beech stand, regeneration should rely on small-scale cuts and moderate thinnings to maintain canopy cover and prevent expansion of nitrophilous vegetation. Although the stand approaches the structure of (i.e., absent herb layer) due to strong beech competition, diversification of the next generation under a partially opened canopy with European silver fir, small-leaved lime and sycamore is recommended to enhance ecosystem stability and nutrient cycling. As holly tends to spread spontaneously, its systematic manual reduction is advisable.

Soil Taxonomic Unit:

Episkeletic Cambic Umbrisol (Amphiloamic, Episiltic, Humic, Hyperdystric, Solimovic)

Stratigraphy:
OL–OFzo–OH–miAh–miAh/Bw–Bw(s)

Humus form:
Eumoder

OL (4 cm):	Thick, light, continuous beech litter (leaves, twigs, beechmasts).
OFzo (1 cm):	Amphigenic (mycelia and zooedaphone).
OH (1.5 cm):	Continuous, dry, thick, amphigenic.



miAh (0–26.0 cm)

Color: 10YR 3/2 (very dark grayish brown), texture class: loamy sand, stoniness: 70% (angular stones), structure: very fine granular, bulk density: very loose, moisture: very dry, root density: <2 mm: 150 pcs/dm^2, >2 mm: 40 pcs/dm^2. Umbric; discontinuous stoniness (70% downto 10 cm; 40% within 10–26 cm).

miAh/Bw (26.0–49.0 cm)

Color: 10YR 4/3 (brown), texture class: loamy sand, stoniness: 25% (angular medium gravel), structure: very fine granular, bulk density: very loose, moisture: dry, root density: <2 mm: 80 pcs/dm^2, >2 mm: 8 pcs/dm^2. Granular structure combined with fine subangular blocky.

Bw(s) (>49.0 cm)

Color: 7.5YR 5/8 (strong brown), texture class: sandy loam, stoniness: 40% (angular coarse gravel), structure: fine angular blocky, bulk density: very loose, moisture: dry, root density <2 mm: 15 pcs/dm^2, >2 mm: 2 pcs/dm^2.

Umbrisol with running brunification process and slight accumulation of free iron. High stoniness lead to high permeability; thick organomineral horizon bears solifluction features, probably linked with epizodic deforestation.



SOIL CHARACTERISTICS

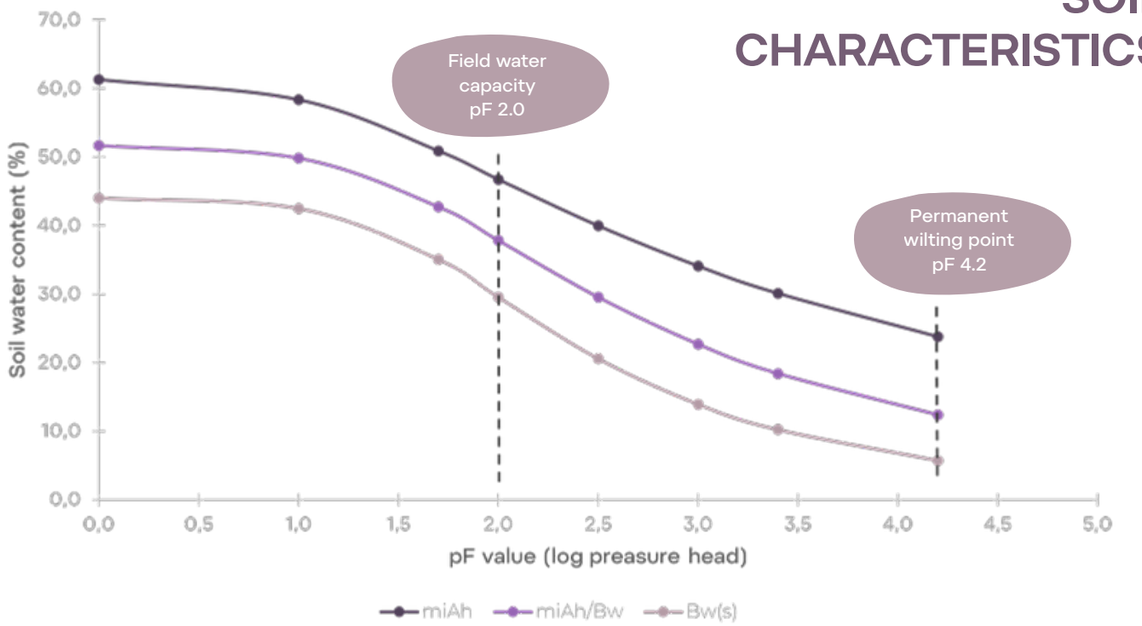


Figure 2A: Water retention curve showing the relationship between soil water content and pF value

Profile No. 2 shows a gradual vertical differentiation of hydro-physical properties (Fig. 2A), mainly expressed by increasing bulk density and decreasing organic matter content with depth (Table 2A). The topsoil miAh horizon (0.8 g/cm³; 15.3% organic matter) shows high maximal (61.3%) and field water capacity (46.7%). Despite a relatively high permanent wilting point (23.8%), available water capacity reaches 22.9%. Saturated hydraulic conductivity is moderate (17.7 cm/day), indicating balanced retention and water movement. In the transitional miAh/Bw horizon, bulk density increases (1.1 g/cm³) and organic matter decreases (6.4%), leading to lower maximal (51.7%) and field capacity (37.8%). However, a marked decrease in permanent wilting point (12.4%) results in the highest available water capacity within the profile (25.4%). Hydraulic conductivity increases to 36.2 cm/day, suggesting enhanced permeability. The deepest Bw(s) horizon (1.4 g/cm³; 3.3% organic matter) shows further declines in maximal (44.0%) and field capacity (29.5%). Although the permanent wilting point decreases to 5.7%, available water capacity remains relatively stable (23.8%). Hydraulic conductivity (27.4 cm/day) remains comparatively high despite increased compaction.

Table 2A: Soil properties of particular horizons - profile No. 2

Soil Horizon	Maximal Water Capacity (% vol.)	Field Water Capacity (% vol.)	Permanent Wilting Point (% vol.)	Available Water Capacity (% vol.)	Saturated Hydraulic Conductivity (cm/day)	Bulk Density (g/cm³)	Organic Matter (% wt.)
miAh	61.3	46.7	23.8	22.9	17.7	0.8	15.3
miAh/Bw	51.7	37.8	12.4	25.4	36.2	1.1	6.4
Bw(s)	44.0	29.5	5.7	23.8	27.4	1.4	3.3

Overall, available water capacity remains relatively uniform throughout the profile (22.9-25.4%), indicating balanced soil water retention and a potentially stable supply of water available to plants despite changes in compaction with depth.

European Beech

Table 2B: Micronutrients content

Soil Horizon	P	Ca	Mg	K	Cation-exchange Capacity	Basic Saturation
	mg/kg				mmol/kg	%
OH	72	660	220	350	320.6	20.0
miAh	3	121	76	150	98.7	18.9
miAh/Bw	4	121	70	47	36.4	47.8
Bw(s)	20	106	56	41	22.8	56.1

Table 2C: Soil texture characteristics and soil reaction

Soil Horizon		Texture Class	Slaking Index	Battance Class	pH_{water}	pH_{KCl}
OH					3.6	3.1
miAh		silt loam	0.98	non battant	4.1	3.8
miAh/Bw		sandy loam	1.23	non battant	4.5	4.2
Bw(s)		sandy loam	1.76	assez battant	4.5	4.3

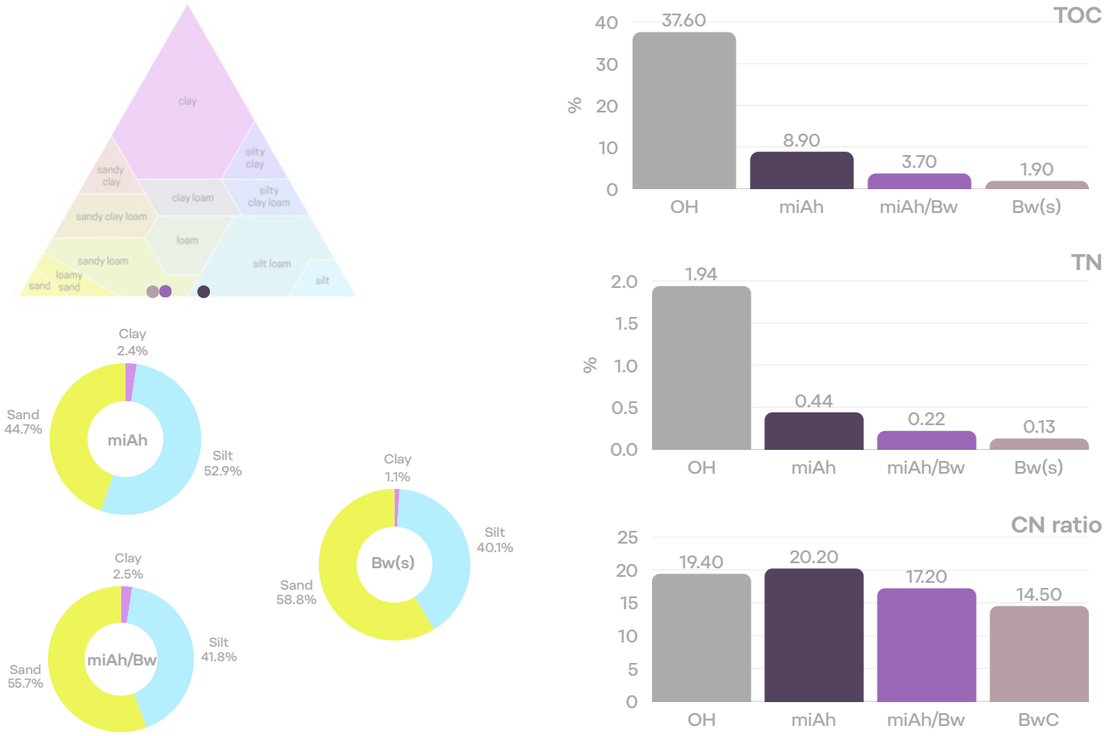


Figure 2B: Soil texture

Figure 2C: Soil carbon and nitrogen characteristics

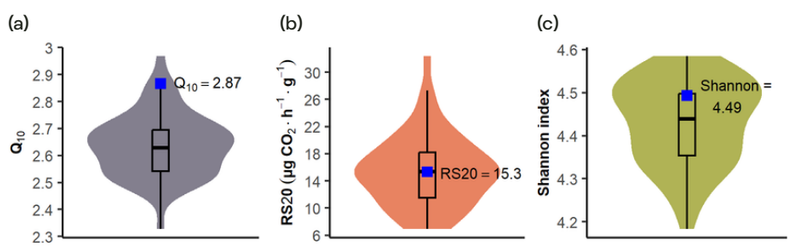
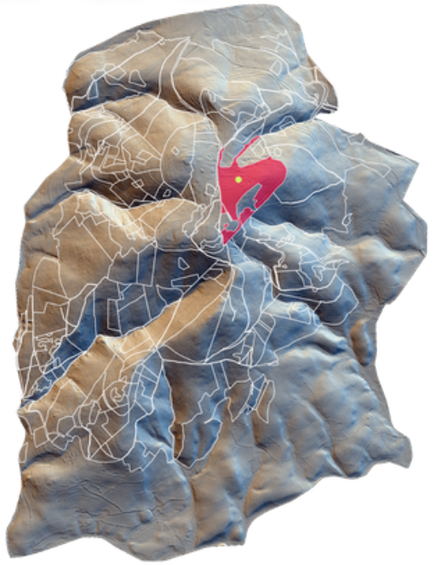


Figure 2D:
(a) Q10: the temperature sensitivity of soil respiration
(b) RS20: soil respiration value for a standardized temperature of 20 degrees
(c) Shannon: soil molecular diversity index, based on the identification of compounds from the main molecular families

site 3

EUROPEAN BEECH



GPS (N): 4.0385370°
GPS (E): 46.9252370°
Localization: intramuros (2nd rampart)
Altitude: 795 m a.s.l.
Inclination: 12°
Exposure: NNW

The profile is located in the middle section of a long slope with numerous anthropogenic features - small depressions, ridges and terraces (inclination 12°, north-north-west exposure). The tree layer consists of beech, the shrub layer consists of ilex, the herbaceous layer is sporadeous (only moss and fern).





Accumulation processes at this site are mainly related to long-term anthropogenic activity rather than to purely natural sedimentation. The thick humus-rich horizon contributes to relatively high aggregate stability, although stability gradually decreases with depth. Total nutrient pools in the soil-forming substrate are moderate to high, particularly for phosphorus, which likely reflects historical anthropogenic inputs. In the strongly acidic and permeable soil environment, part of phosphorus may be retained by iron and aluminum oxyhydroxides or associated with dissolved organic matter. Despite high acidity and low base saturation, the Intramuros position provides relatively balanced total nutrient budgets, although available nutrients are slightly imbalanced, particularly due to lower calcium availability. Gradual diversification of the current beech stand by admixture of small-leaved lime, sycamore, Scots elm and ash under a moderately opened canopy is recommended, together with control of expanding holly.

Soil Taxonomic Unit:

Terric Anthrosol (Carbonic, Endoskeletic, Hyperdystric, Loamic, Prototechnic)

Stratigraphy:
OLn-OLv-OFzo-OH-meAh-meAuBw-meAuBw/C-C

Humus form:
Eumesoamphi

OLn (2 cm):	Continuous monospecific litter of broad leaves (beech + admixed ilex).
OLv (3 cm):	Continuous monospecific discolored litter of broad leaves (beech + admixed ilex).
OFzo (1 cm):	Amphigenic (dominance of mycelia, less zooedaphone), compacted with mycelia.
OH (1 cm):	Loose, dark, continuous.



meAh (0-38.0 cm)
Color: 10YR 2/1 (black), texture class: loam, stoniness: 30% (angular coarse gravel), structure: fine granular, bulk density: loose, moisture: dry, root density: <2 mm: 120 pcs/dm^2, >2 mm: 50 pcs/dm^2. Umbric.

meAuBw (38.0-63.0 cm)
Color: 10YR 3/3 (dark brown), texture class: silty clay loam, stoniness: 40% (angular boulders), structure: medium granular, bulk density: loose, moisture: moist, root density: <2 mm: 60 pcs/dm^2, >2 mm: 15 pcs/dm^2.Structure combined with medium subangular blocky (30%).

meAuBw/C (63.0-73.0 cm)
Color: 10YR 4/4 (dark yellowish brown), texture class: sandy loam, stoniness: 70% (angular boulders), structure: fine angular blocky, bulk density: loose, moisture: moist, root density <2 mm: 40 pcs/dm^2, >2 mm: 5 pcs/dm^2.

C (>73.0 cm)
Color: 10YR 3/4 (dark yellowish brown), texture class: sandy loam, stoniness: 95% (angular boulders), structure: very fine angular blocky, bulk density: intermediate, moisture: moist, root density <2 mm: 2 pcs/dm^2, >2 mm: <1 pc/dm^2.

Soil developed on slope lome accumulation material within terrace relief. Deep organomineral matter stratification documents diffferent phases of accumulation with the first transition zone in approx. 30-40 mm (recent processes; clear-to-abrupt transition) and with the second transformation within approx. 60-75 cm (older processes; diffuse distinctness and broken shape). Initial pedogenic features in AB horizon; deep rooting zone and perspective edatop marks high stand stability and physiological perspective.



SOIL CHARACTERISTICS

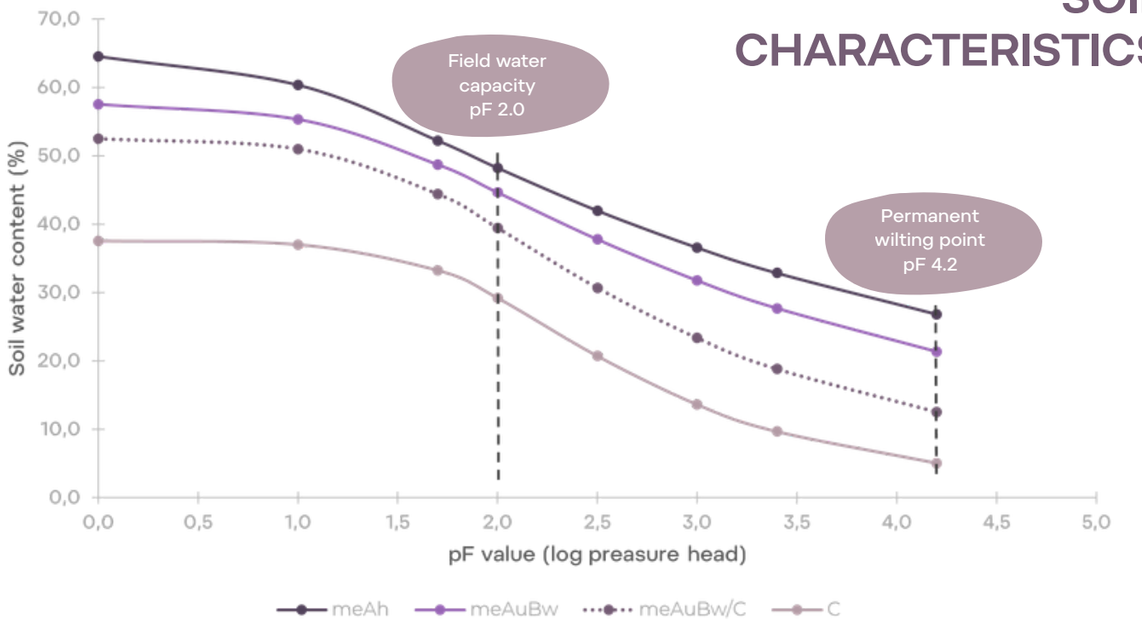


Figure 3A: Water retention curve showing the relationship between soil water content and pF value

The surface meAh horizon has low bulk density (0.7 g/cm³) and high organic matter (18.9%), with maximal water content 64.5% and field capacity 48.2%. Available water capacity is 21.4%, and saturated hydraulic conductivity is 18.2 cm/day.

The meAuBw and meAuBw/C horizons show gradual increases in bulk density (0.9–1.1 g/cm³) and decreases in organic matter (11.9–6.5%), with corresponding declines in maximal and field water capacities. Available water capacity remains stable (23–26.9%), and hydraulic conductivity varies slightly (18.1–21.6 cm/day).

The C horizon differs most strongly from other above-mentioned horizons: it is dense (1.6 g/cm³), very low in organic matter (1.4%), with the lowest maximal (37.6%) and field water capacity (29.2%). Despite a very low permanent wilting point (5.1%), available water capacity remains relatively high (24.2%), but saturated hydraulic conductivity drops to 12.6 cm/day, reflecting reduced total porosity and compact mineral subsoil.

Table 3A: Soil properties of particular horizons - profile No. 3

Soil Horizon	Maximal Water Capacity (% vol.)	Field Water Capacity (% vol.)	Permanent Wilting Point (% vol.)	Available Water Capacity (% vol.)	Saturated Hydraulic Conductivity (cm/day)	Bulk Density (g/cm³)	Organic Matter (% wt.)
meAh	64.5	48.2	26.8	21.4	18.2	0.7	18.9
meAuBW	57.5	44.6	21.4	23.3	18.1	0.9	11.9
meAuBw/C	52.5	39.4	12.5	26.9	21.6	1.1	6.5
C	37.6	29.2	5.1	24.2	12.6	1.6	1.4

Overall, organic matter sharply declines, and bulk density rises toward the C horizon, reducing total maximal water capacity while maintaining plant-available water (21–27%) across the whole soil profile.

European Beech

Table 3B: Micronutrients content

Soil Horizon	P	Ca	Mg	K	Cation-exchange Capacity	Basic Saturation
	mg/kg				mmol/kg	%
OH	79	746	306	255	344.0	20.2
meAh	22	81	73	68	96.4	18.0
meAuBw	30	70	59	44	46.4	31.1
meAuBw/C	16	67	56	35	36.7	37.4
C	20	63	54	29	26.0	50.0

Table 3C: Soil texture characteristics and soil reaction

Soil Horizon		Texture Class	Slaking Index	Battance Class	pH_{water}	pH_{KCl}
OH					3.7	3.1
meAh		silt loam	0.85	non battant	4.4	3.9
meAuBw		silt loam	1.03	non battant	4.6	4.2
meAuBw/C		silt loam	1.40	peu battant	4.6	4.3
C		silt loam	4.07	tres battant	4.6	4.4



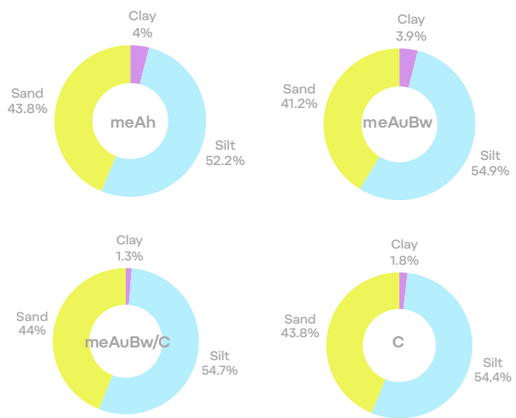


Figure 3B: Soil texture

TOC

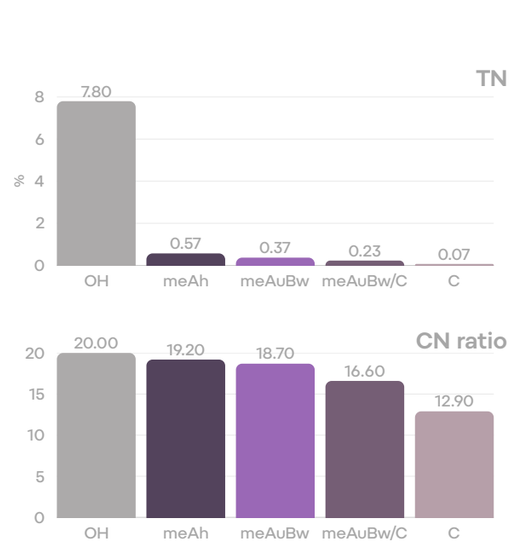


Figure 3C: Soil carbon and nitrogen characteristics

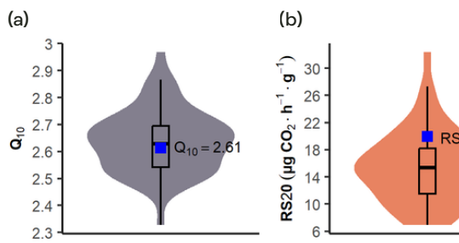
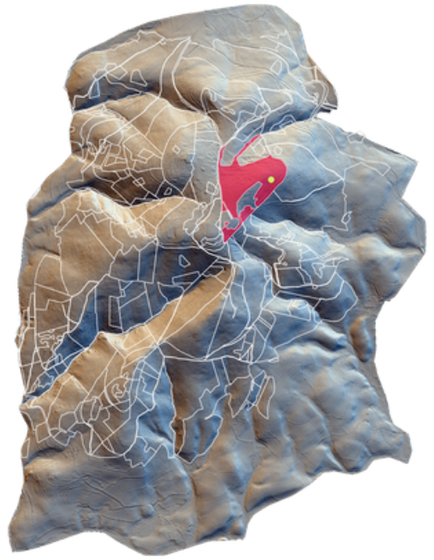


Figure 3D:
(a) Q10: the temperature sensitivity of soil respiration
(b) RS20: soil respiration value for a standardized temperature of 20 degrees
(c) Shannon: soil molecular diversity index, based on the identification of compounds from the main molecular families

site 4

EUROPEAN BEECH



GPS (N):	4.0425690°
GPS (E):	46.9250530°
Localization:	intramuros (2^{nd} rampart)
Altitude:	583 m a.s.l.
Inclination:	10°
Exposure:	SSE

The profile is located on a straight slope between two anthropogenic terraces, approximately 50 m below the summit plateau (inclination 10°, south-souhteast exposure). Anthropogenic material has a significant impact on soil composition. The tree layeer consists of predominant beech (90%), oak and ilex (10%). The hebaceous layer is absent (only moss).





High organic carbon content contributes to stable soil aggregates and a low slaking index, indicating limited erosion risk, which is further supported by the gentle slope. Total phosphorus content is relatively high, whereas its plant-available fraction remains very low. Other nutrients occur in low to moderate amounts and show a certain imbalance, particularly with respect to calcium. The soil is very deep and rich in organic carbon, reflecting the Intramuros position and long-term anthropogenic accumulation processes. Sandy loam texture indicates high permeability and ongoing leaching, although base saturation remains moderate within favourable cation exchange capacity values. The European beech stand shows good ecological stability. Management should focus on maintaining stand diversity by controlling the expansion of holly and supporting admixture of forest species such as small-leaved lime, sycamore, European silver fir and locally Scots elm in lighter canopy gaps.

Soil Taxonomic Unit:

Terric Anthrosol (Anoloamic, Carbonic, Orthodystric, Pantoloamic, Pantoskeletic, Prototechnic)

Stratigraphy:
OL-OFzo-OH-meAh-miAh-Ahtu-Bw-BwC

Humus form:
Eumesoapmhi

OL (4 cm):	Thick, light, continuous beech litter.
OFzo (2 cm):	Amphigenic (mycelia and zooedaphone).
OH (1.5 cm):	Continuous, dry, thick.

meAh (0-5.5 cm)

Color: 10YR 2/2 (very dark brown), texture class: sandy loam, stoniness: 40% (angular coarse gravel), structure: medium granular, bulk density: very loose, moisture: very dry, root density: <2 mm: 130 pcs/dm^2, >2 mm: 40 pcs/dm^2. Dark, high organic matter content.

miAh (5.5-22.5 cm)

Color: 7.5YR 2.5/2 (very dark brown), texture class: sandy loam, stoniness: 55% (angular boulders), structure: very fine granular, bulk density: very loose, moisture: very dry, root density: <2 mm: 120 pcs/dm^2, >2 mm: 20 pcs/dm^2. Character of umbric horizon; partially mechanically transported; result of past deforestation and human intensive acitivity.

Ahtu (22.5-51.5 cm)

Color: 7.5YR 3/2 (dark brown), texture class: silt loam, stoniness: 65% (angular stones), structure: fine granular, bulk density: very loose, moisture: dry, root density <2 mm: 110 pcs/dm^2, >2 mm: 10 pcs/dm^2. Sparse artefacts; partially mechanically transported; result of past deforestation and human intensive activity.

Bw (51.5-77.5 cm)

Color: 10YR 3/4 (dark yellowish brown), texture class: sandy loam, stoniness: 70% (angular stones), structure: fine polyhedral, bulk density: loose, moisture: dry, root density <2 mm: 60 pcs/dm^2, >2 mm: 5 pcs/dm^2.

BwC (>77.5 cm)

Color: 10YR 3/4 (dark yellowish brown), texture class: sandy loam, stoniness: 80% (angular stones), structure: very fine massive, bulk density: loose, moisture: dry, root density <2 mm: 80 pcs/dm^2, >2 mm: 3 pcs/dm^2.



Soil with accumulation of organic matter in A horizon with recognizable stratification to A1 and A2, both with character of umbric horizon. Sparse appearence of artefacts in A2 (fragments of ceramics). Hight abundance of coarse fragments in whole profile, increasing with depth. Deep root distribution (physiological depth more than 100 cm), potentially water-limited habitat.
Stand of European beech dominance (90%) with admixture of oak (10%) in a stage of mature stand and with spontaneous regeneration of beech (seedlings). Understory vegetation is represented dominantly with ilex. Herbs cover max. 1%; canopy closure approx. 80-85%.



SOIL CHARACTERISTICS

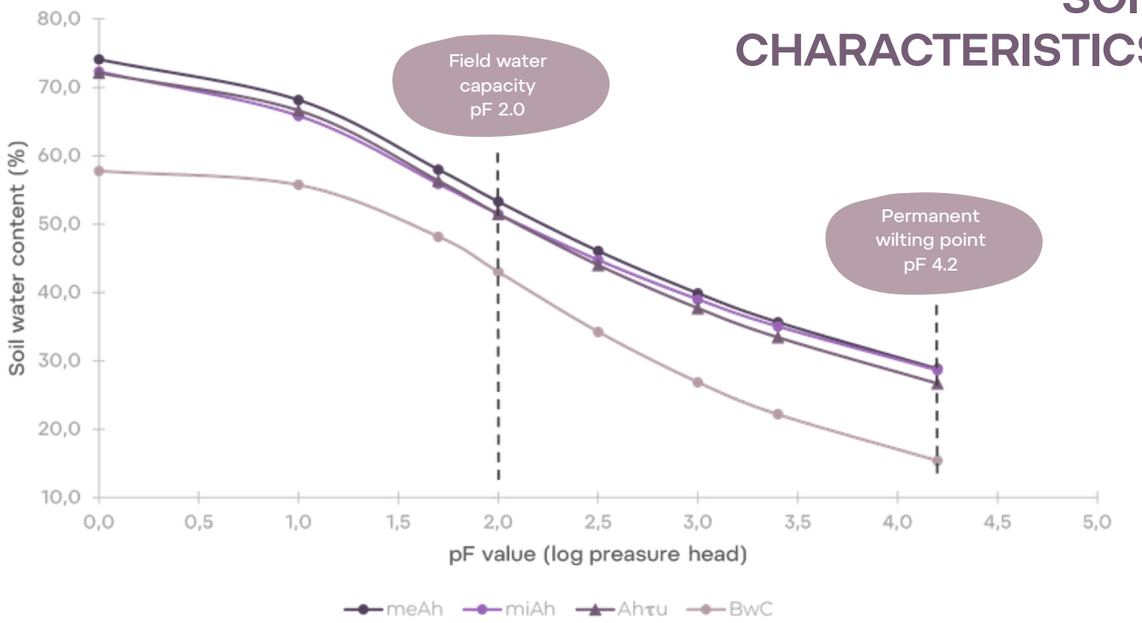


Figure 4A: Water retention curve showing the relationship between soil water content and pF value

Profile No. 4 exhibits strong vertical differentiation in hydro-physical properties, similar to above-mentioned descripted profile No. 25 (Table 4A, Fig. 4A). The surface meAh and miAh horizons have very low bulk density (0.4-0.5 g/cm³, Table 4A) and high organic matter content (27-39%), with maximal water contents above 72% and field capacities above 51% (Fig. 4A). The available water capacity is 22.8-24.5% and the saturated hydraulic conductivity is high (44.6-69.7 cm/day), reflecting the high proportion of macropores and the rate of surface rainwater infiltration. The next technical Ahτu horizon shows slightly increased bulk density (0.6 g/cm³) and reduced organic matter (21.4%), with minor decreases in maximal and field water capacities (72.1% and 51.5%). The available water capacity remains high (24.8%) and the saturated hydraulic conductivity is 45.5 cm/day.

Table 4A: Soil properties of particular horizons - profile No. 4

Soil Horizon	Maximal Water Capacity (% vol.)	Field Water Capacity (% vol.)	Permanent Wilting Point (% vol.)	Available Water Capacity (% vol.)	Saturated Hydraulic Conductivity (cm/day)	Bulk Density (g/cm³)	Organic Matter (% wt.)
meAh	74.1	53.3	28.8	24.5	69.7	0.4	39.3
miAh	72.3	51.4	28.6	22.8	44.6	0.5	27.4
Ahτu	72.1	51.5	26.7	24.8	45.5	0.6	21.4
BwC	57.8	43.0	15.4	27.6	34.2	1.0	8.5

The deepest BwC horizon is clearly distinct from the upper organic-rich horizons. Bulk density rises sharply to 1.0 g/cm³, and organic matter drops to 8.5%. Maximal (57.8%) and field water capacities (43.0%) are substantially lower, while the permanent wilting point decreases to 15.4%, resulting in the highest available water capacity in the profile (27.6%). Saturated hydraulic conductivity declines to 34.2 cm/day, reflecting increased compaction and reduced pore connectivity compared to the highly total porous surface meAh and miAh horizons.

Table 4B: Micronutrients content

Soil Horizon	P	Ca	Mg	K	Cation-exchange Capacity	Basic Saturation
	mg/kg				mmol/kg	%
OH	52	306	112	206	307.8	9.7
meAh	12	312	165	274	222.6	19.1
miAh	7	219	108	156	114.6	21.5
Ahτu	11	208	96	118	60.7	39.0
BwC	9	205	62	111	72.2	77.8

Table 4C: Soil texture characteristics and soil reaction

Soil Horizon		Texture Class	Slaking Index	Battance Class	pH_{water}	pH_{KCl}
OH					3.4	2.8
meAh	●	sandy loam	0.81	non battant	3.5	3.0
miAh	●	sandy loam	0.77	non battant	4.2	3.8
Ahτu	●	sandy loam	0.65	non battant	4.5	4.4
BwC	●	sandy loam	0.99	non battant	4.5	4.6

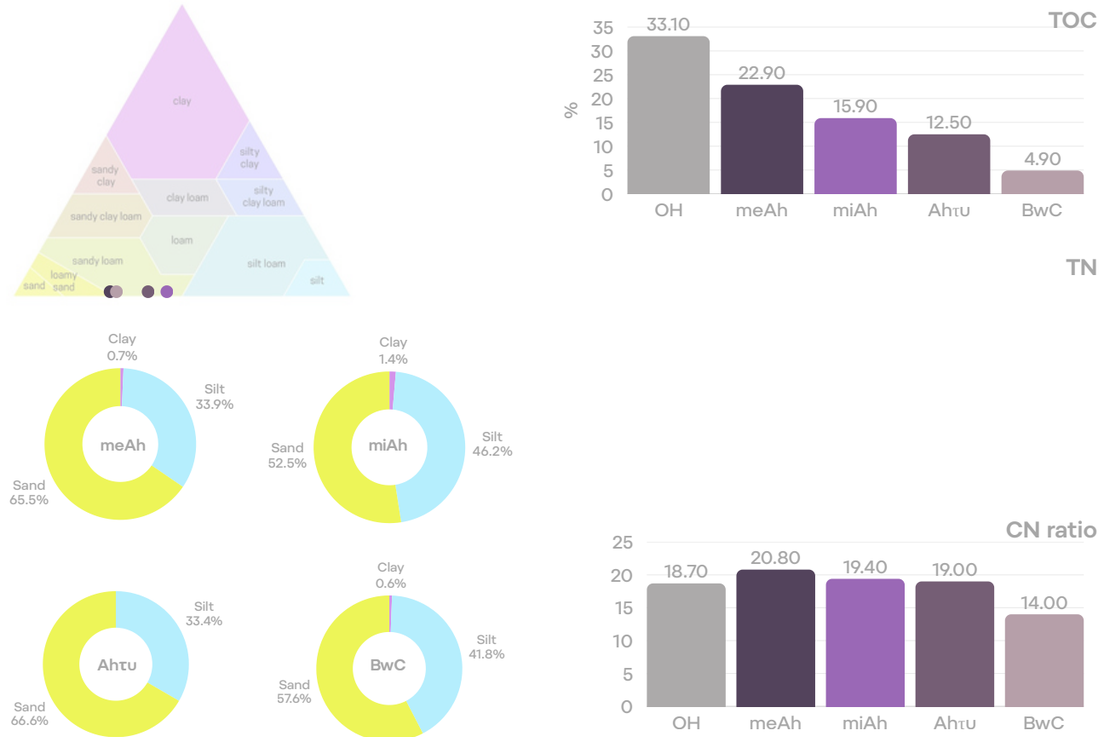


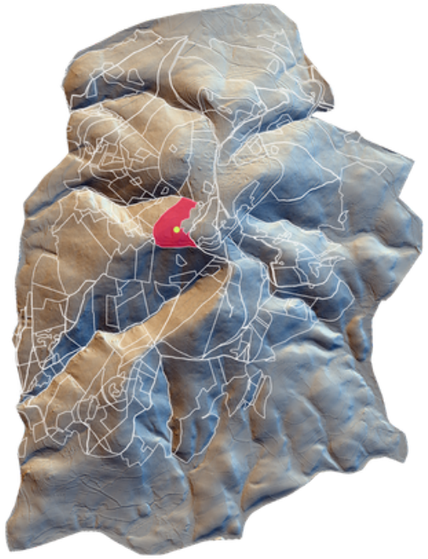
Figure 4C: Soil texture

Figure 4C: Soil carbon and nitrogen characteristics

European Beech

site 5

EUROPEAN BEECH



GPS (N):	4.0310410°
GPS (E):	46.9207970°
Localization:	intramuros (2nd rampart)
Altitude:	788 m a.s.l.
Inclination:	5°
Exposure:	WNW

The profile is located on a gentle slope with anhropogenic terraces, approximately 20 m below the summit plateau (inclination 5°, west-north-west exposure). The tree layer consists of predominant beech (90%) and oak (10%). Ilex makes up to 50% of the shrub layer. The hebaceous layer is absent.





The soil shows relatively good resistance to erosion due to stable aggregates (low slaking index), high permeability and the gentle slope. Soil reaction is strongly acidic and the sorption complex shows moderate cation exchange capacity with relatively balanced base cation proportions. Base saturation is lower in the surface horizon and increases with depth. High organic carbon content contributes to buffering of aluminium mobility and supports stable soil structure. Extremely high stoniness limits soil water storage and increases the importance of maintaining favourable forest microclimate. Forest management should therefore focus on gradual regeneration through small canopy gaps combined with periodic control of Ilex aquifolium. Slight reduction of thick beech litter through limited canopy opening may facilitate regeneration or underplanting of European silver fir, sycamore and locally mountain ash or wild service, increasing stand diversity and ecosystem stability.

Soil Taxonomic Unit:

Endoskeletic Cambic Umbrisol (Amphiloamic, Episiltic, Hyperdystric, Profundihumic, Solimovic, Technic, Transportic)

Stratigraphy:
OL-Fzo-OH-meAhu1-meAhu2-Bw-C

Humus form:
Pachyamphi

OL (3 cm):	Dominance of beech; admixture of holly.
OFzo (3 cm):	Rich in mycelia; enclaves of red rot (decaying dead wood).
OH (3 cm):	Loose, continuous, moist.



meAhu1 (0-7.0 cm)
Color: 10YR 2/2 (very dark brown), texture class: sandy loam, stoniness: 30% (angular medium gravel), structure: fine granular, bulk density: very loose, moisture: slightly moist, root density: <2 mm: 140 pcs/dm^2, >2 mm: 60 pcs/dm^2. Recent neoformation; sparse fragments of amphoras; clear distinctness and sooth shape of lower boundary.

meAhu2 (7.0-40.0 cm)
Color: 10YR 3/2 (very dark grayish brown), texture class: sandy loam, stoniness: 35% (angular coarse gravel), structure: medium granular, bulk density: loose, moisture: slightly moist, root density: <2 mm: 110 pcs/dm^2, > 2mm: 30 pcs/dm^2. Umbric; rich in fragments of amphoras; diffuse distinctness of lower boundary.

Bw (40.0-75.0 cm)
Color: 10YR 3/4 (dark yellowish brown), texture class: loam, stoniness: 60% (angular stones), structure: medium subangular blocky, bulk density: loose, moisture: slightly moist, root density <2 mm: 40 pcs/dm^2, >2 mm: 3 pcs/dm^2.

C (>75.0 cm)
Color: 10YR 5/4 (yellowish brown), texture class: sandy loam, stoniness: 75% (angular boulders), structure: very fine simple grain, bulk density: intermediate, moisture: slightly moist, root density <2 mm: 1 pc/dm^2, >2 mm: <1 pcs/dm^2.

Soil with anthropogenic topsoil development within soil of high stoniness.



SOIL CHARACTERISTICS

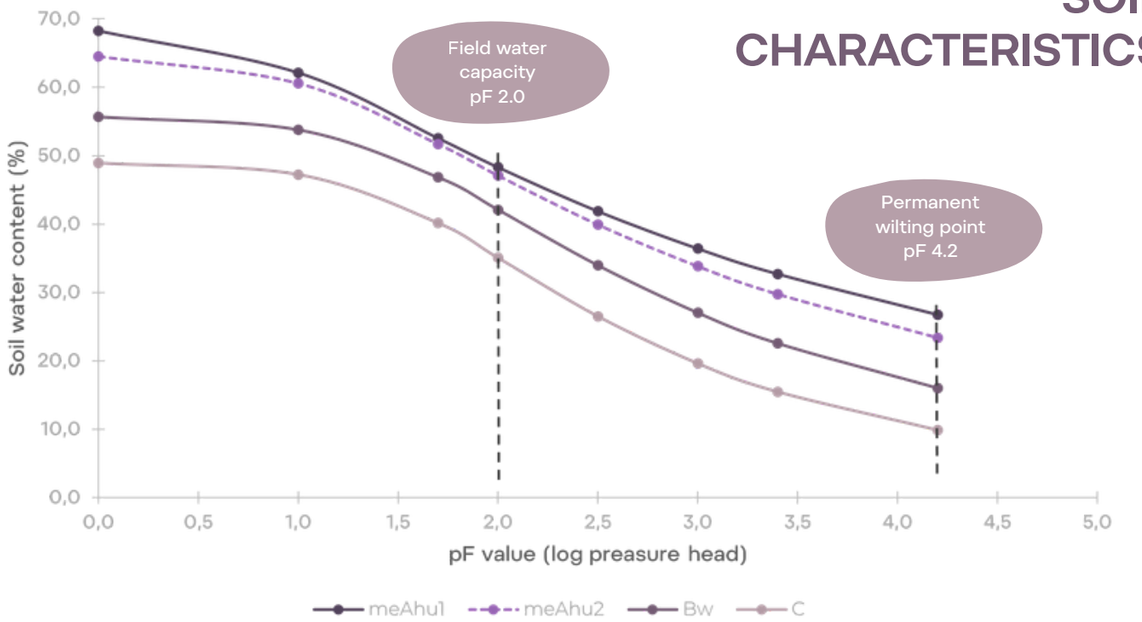


Figure 5A: Water retention curve showing the relationship between soil water content and pF value

Profile No. 5 displays a moderately layered soil profile with gradual changes in hydro-physical properties from the surface to the parent material. The surface meAhu1 horizon is characterized by very low bulk density (0.6 g/cm³, Table 5A) and very high organic matter content (21.9%), resulting in the highest maximal (68.3%) and field water capacities (48.3%, Fig. 5A). Saturated hydraulic conductivity is relatively low (18.1 cm/day), indicating moderate water movement. The second organic-rich horizon, meAhu2, shows a slight increase in bulk density (0.7 g/cm³) and a decrease in organic matter (16.0%). Maximal (64.5%) and field water capacities (47.1%) remain high, and available water capacity rises slightly to 23.7%. Hydraulic conductivity increases to 20.0 cm/day, suggesting moderately enhanced water flow compared to the uppermost horizon.

Table 5A: Soil properties of particular horizons - profile No. 5

Soil Horizon	Maximal Water Capacity (% vol.)	Field Water Capacity (% vol.)	Permanent Wilting Point (% vol.)	Available Water Capacity (% vol.)	Saturated Hydraulic Conductivity (cm/day)	Bulk Density (g/cm³)	Organic Matter (% wt.)
meAhu1	68.3	48.3	26.8	21.5	18.1	0.6	21.9
meAhu2	64.5	47.1	23.4	23.7	20.0	0.7	16.0
Bw	55.7	42.1	16.0	26.1	26.5	1.0	8.9
C	48.9	35.1	9.9	25.2	30.6	1.2	5.2

In the Bw horizon, bulk density increases further to 1.0 g/cm³ and organic matter decreases to 8.9%, while maximal (55.7%) and field water capacities (42.1%) decline. Available water capacity reaches 26.1%, and saturated hydraulic conductivity rises to 26.5 cm/day, indicating a shift toward more compact but still permeable subsoil conditions. The deepest C horizon exhibits the highest bulk density (1.2 g/cm³) and the lowest organic matter content (5.2%). Maximal (48.9%) and field water capacities (35.1%) are lowest in the profile, but available water capacity remains relatively high at 25.2%. Saturated hydraulic conductivity is highest (30.6 cm/day), reflecting rapid water movement through the porous parent material.

European Beech

Table 5B: Micronutrients content

Soil Horizon	P	Ca	Mg	K	Cation-exchange Capacity	Basic Saturation
	mg/kg				mmol/kg	%
OH	55	302	141	276	341.0	9.9
meAhu1	14	70	60	114	116.6	12.5
meAhu2	21	61	45	61	61.4	18.5
Bw	12	63	42	54	34.1	32.5
C	11	58	40	50	25.6	45.4

Table 5C: Soil texture characteristics and soil reaction

Soil Horizon		Texture Class	Slaking Index	Battance Class	pH_{water}	pH_{KCl}
OH					3.6	2.9
meAhu1		silt loam	0.88	non battant	4.1	3.6
meAhu2		silt loam	0.93	non battant	4.4	4.0
Bw		sandy loam	1.10	non battant	4.4	4.2
C		sandy loam	1.42	peu battant	4.4	4.2

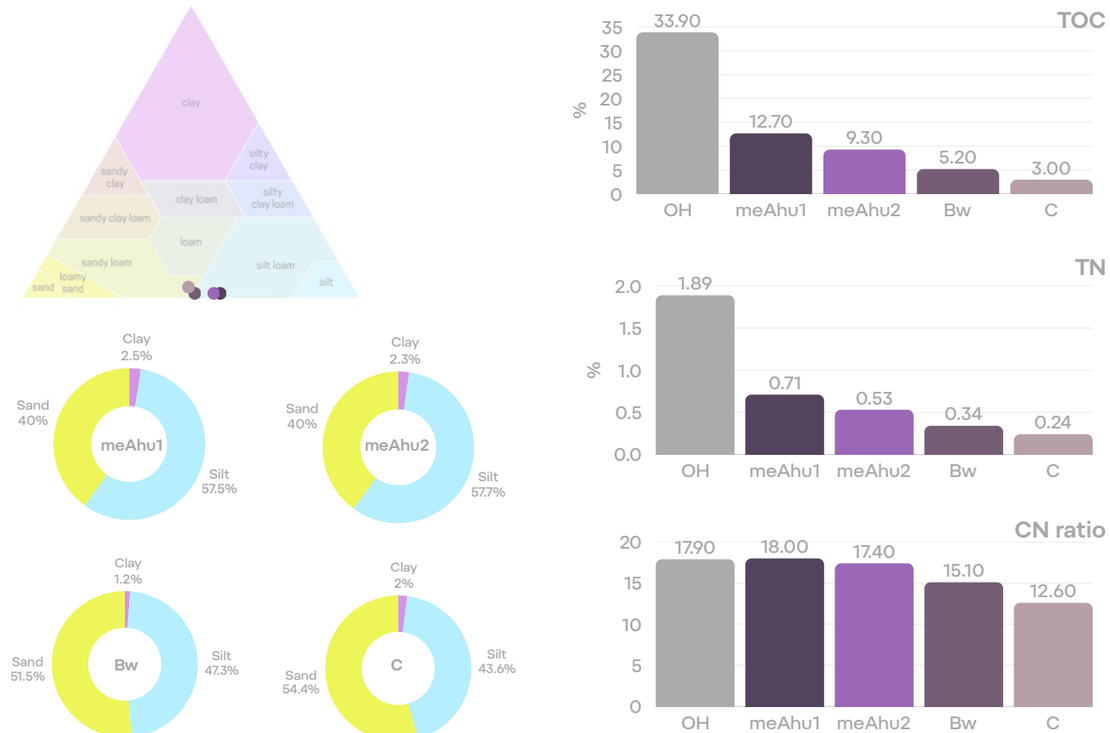
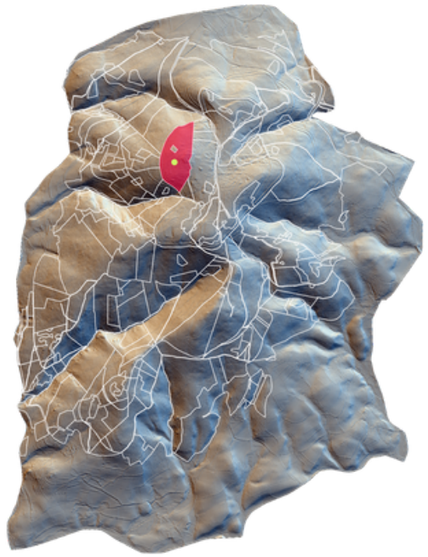


Figure 5B: Soil texture

Figure 5C: Soil carbon and nitrogen characteristics

site 6

EUROPEAN BEECH



GPS (N):	4.0430310°
GPS (E):	46.9331090°
Localization:	intramuros (1st rampart)
Altitude:	659 m a.s.l.
Inclination:	15°
Exposure:	E

The profile is located on a straight slope, approximately 40 m below the road cut (inclination 15°, east exposure). The tree layer consits of beech (80%), oak and chestnut. Holly makes up to 50% of the shrub layer. The herbaceous layer consists of blackberry and seedlings. Small and larger pieces of charcoal were found on the surface and in the topsoil.





The soil shows a gradual increase of fine particles with depth, from sandy loam in the humus-rich topsoil to silt loam in mineral horizons. While the organic surface layer exhibits stable aggregates, the deeper mineral horizons show lower aggregate stability and should not be exposed to disturbance during harvesting or timber transport. Soil reaction is strongly acidic with low base saturation and increased aluminium activity. Although total phosphorus content is relatively high, reflecting the Intramuros context, available phosphorus and calcium remain low, while other macronutrients occur in low to moderate concentrations. Organic carbon is very high in the topsoil but decreases sharply with depth. The closed canopy of European beech favours dense regeneration of Ilex aquifolium. Periodic manual control of this species is recommended to support regeneration or underplanting of target species such as European silver fir, sycamore, small-leaved lime, and locally also pioneer species including European aspen or silver birch.

Soil Taxonomic Unit:

Endoskeletic Cambic Umbrisol (Humic, Katosiltic, Orthodystric, Prototechnic, Solimovic)

Stratigraphy:
OL-OFzo-OH-meAh1-meAh2-Bw-BwC-C

Humus form:
Leptoamphi

OL (3 cm):	Loose, thick, continuous litter of beech.
OFzo (1.5 cm):	Amphigenic (mycelia and zooedaphone), moist.
OH (0.5 cm):	Discontinuous.

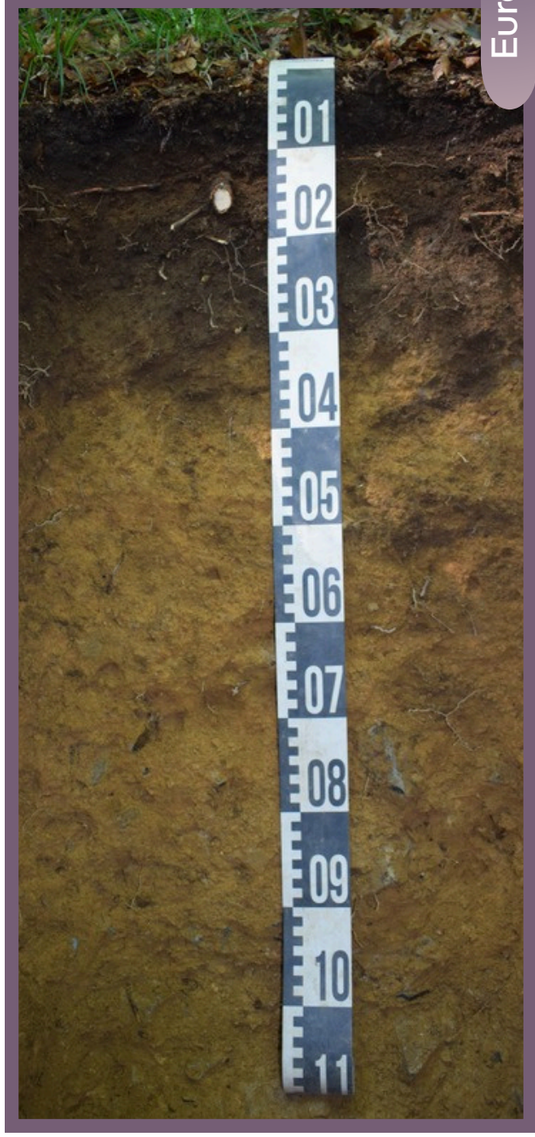
meAh1 (0-12.0 cm)
Color: 10YR 2/2 (very dark brown), texture class: loam, stoniness: 15% (angular coarse gravel), structure: coarse granular, bulk density: loose, moisture: dry, root density: <2 mm: 120 pcs/dm^2, >2 mm: 30 pcs/dm^2. Charcoal remains.

meAh2 (12.0-28.0 cm)
Color: 10YR 3/3 (dark brown), texture class: loam, stoniness: 15% (angular coarse gravel), structure: medium granular, bulk density: loose, moisture: dry, root density: <2 mm: 100 pcs/dm^2, >2 mm: 5 pcs/dm^2. Umbric.

Bw (28.0-66.0 cm)
Color: 10YR 4/6 (dark yellowish brown), texture class: silty clay loam, stoniness: 30% (angular coarse gravel), structure: medium subangular blocky, bulk density: loose, moisture: slightly moist, root density <2 mm: 25 pcs/dm^2, >2 mm: 3 pcs/dm^2.

BwC (66.0-88.0 cm)
Color: 10YR 5/6 (yellowish brown), texture class: sandy loam, stoniness: 60% (angular boulders), structure: fine subangular blocky, bulk density: intermediate, moisture: slightly moist, root density <2 mm: <1 pc/dm^2, >2 mm: <1 pcs/dm^2.

C (>88.0 cm)
Color: 10YR 5/4 (yellowish brown), texture class: silt loam, stoniness: 75% (angular boulders), structure: very fine simple grain, bulk density: intermediate, moisture: slightly moist, root density <2 mm: <1 pc/dm^2, >2 mm: 0 pcs/dm^2. Silt dominance in fine earth fraction.



Moderately deep soil evolution; topsoil with recent neoformation of humus and with markable admixture of charcoal. Mesophilous habitat at site of in situ soil development with polygenic loam admixture. Plagioclases fragments correspond with physical weathering of bedrock.



SOIL CHARACTERISTICS

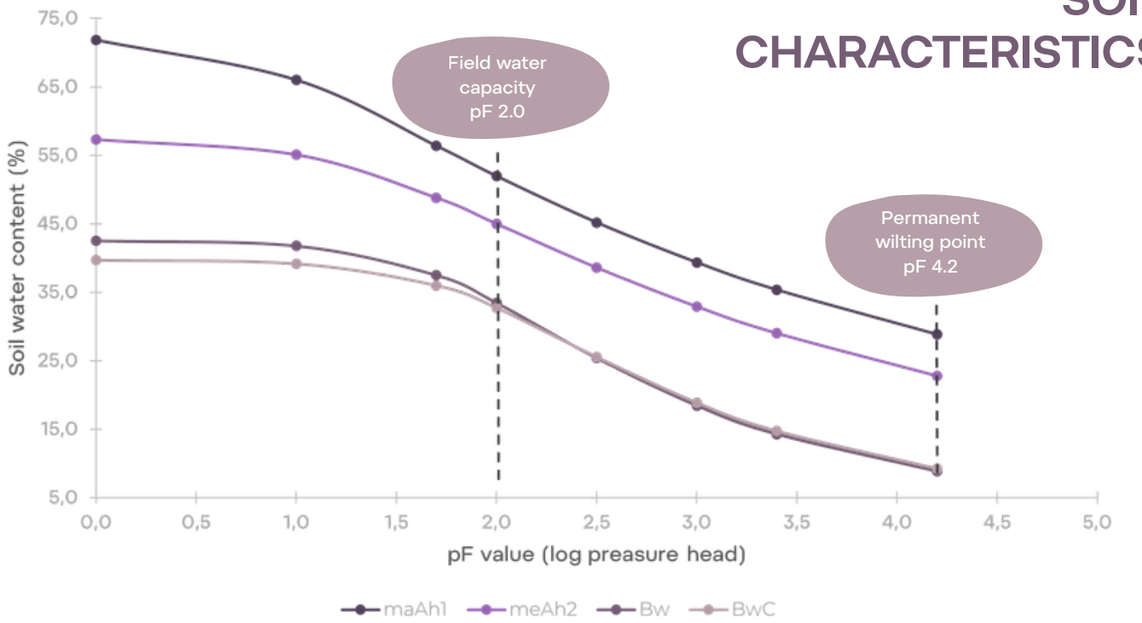


Figure 6A: Water retention curve showing the relationship between soil water content and pF value

This profile No. 6 shows a clear trend of increasing bulk density with depth, accompanied by a decrease in organic matter content. The topsoil maAh1 horizon is characterized by very low bulk density (0.5 g/cm³) and high organic matter content (28.2%), with maximal water content of 71.8% and field capacity of 52.0% (Fig. 6A). The available water capacity in this horizon is 23.1%, while saturated hydraulic conductivity is notably high at 69.6 cm/day. The second topsoil meAh2 horizon shows an increase in bulk density (0.9 g/cm³) and a decrease in organic matter content (10.9%), with corresponding reductions in maximal (57.3%) and field water capacities (45.0%). Available water capacity remains relatively stable at 22.2%, while hydraulic conductivity is much lower (24.6 cm/day).

Table 6A: Soil properties of particular horizons - profile No. 6

Soil Horizon	Maximal Water Capacity (% vol.)	Field Water Capacity (% vol.)	Permanent Wilting Point (% vol.)	Available Water Capacity (% vol.)	Saturated Hydraulic Conductivity (cm/day)	Bulk Density (g/cm³)	Organic Matter (% wt.)
meAh1	71.8	52.0	28.8	23.1	69.6	0.5	28.2
meAh2	57.3	45.0	22.8	22.2	24.6	0.9	10.9
Bw	42.5	33.5	8.8	24.6	11.2	1.4	3.2
BwC	39.7	32.7	9.2	23.5	8.8	1.5	2.0

The deeper Bw and BwC horizons are distinctly more compact, with bulk densities of 1.4 and 1.5 g/cm³, respectively, and very low organic matter (3.2–2.0%). Maximal water content decreases further to 42.5% and 39.7%, and field water capacity drops to 33.5% and 32.7%, respectively. Available water capacity in these horizons remains at 24.6% and 23.5%, but the saturated hydraulic conductivity is significantly lower at 11.2 cm/day and 8.8 cm/day, reflecting the increasing compaction and reduced porosity with depth. While available water capacity remains relatively stable across the horizons (ranging from 23.1% to 24.6%), there is a notable decline in saturated hydraulic conductivity with depth, indicating a less permeable, more compact subsoil horizons.

European Beech

Table 6B: Micronutrients content

Soil Horizon	P	Ca	Mg	K	Cation-exchange Capacity	Basic Saturation
	mg/kg				mmol/kg	%
OH	45	295	200	308	325.0	12.0
meAh1	10	76	98	237	143.5	15.0
meAh2	4	68	50	65	50.8	27.2
Bw	9	51	37	55	23.1	43.7
BwC	8	45	32	60	20.6	46.7
C	16	40	30	51	20.6	46.5

Table 6C: Soil texture characteristics and soil reaction

Soil Horizon		Texture Class	Slaking Index	Battance Class	pH_{water}	pH_{KCl}
OH					3.8	3.0
meAh1	●	sandy loam	0.78	non battant	3.8	3.2
meAh2	●	silt loam	1.11	non battant	4.3	3.9
Bw	●	silt loam	2.58	tres battant	4.3	4.4
BwC	●	silt loam	3.48	tres battant	4.3	4.0

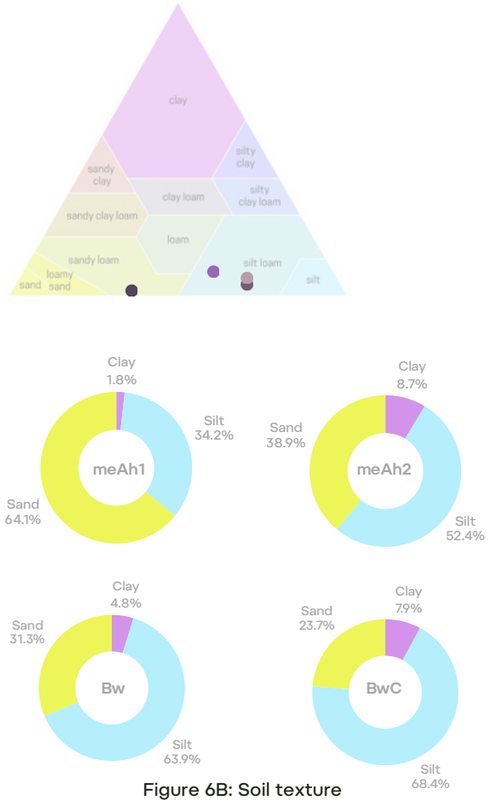
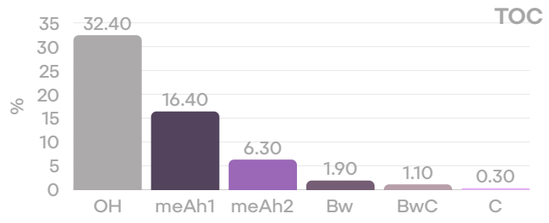
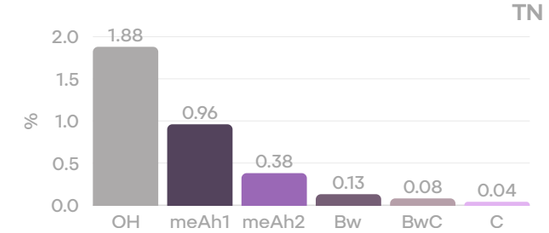


Figure 6B: Soil texture





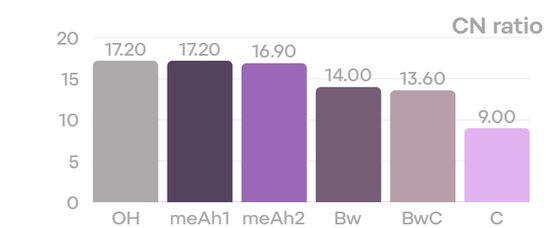
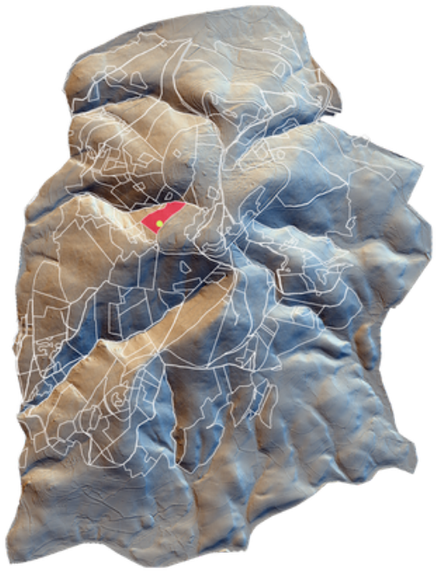


Figure 6C: Soil carbon and nitrogen characteristics

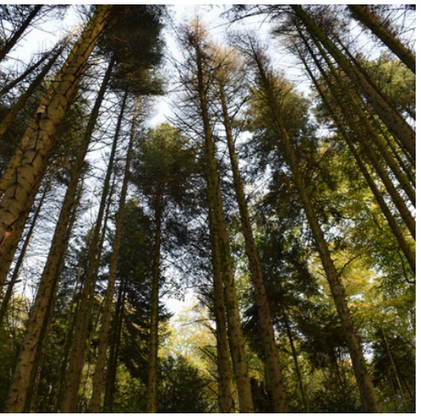
site
7

SILVER FIR

GPS (N):	4.0284570°
GPS (E):	46.9218520°
Localization:	extramuros
Altitude:	726 m a.s.l.
Inclination:	26°
Exposure:	W



The profile is located on a steep, straight slope, 30 meters below a plateau with an artificial embankment (inclination 26°, west exposure). The surface and topsoil are highly stoniness. The tree layer consists of declining silver fir (fungi pathogen). The both shrub layer and herbaceous layers are absent, only a foxglove can be found sporadically.





Sandy loam to silt loam textures indicate relatively high permeability and limited aggregate stability. The low clay content restricts sorption capacity and water retention in mineral horizons. Soil reaction is strongly acidic and base saturation is generally low, while cation exchange capacity is largely controlled by organic matter in humified horizons. The pronounced vertical gradient of soil properties highlights the importance of maintaining the epipedon and avoiding surface disturbance. The site is generally nutrient-poor, with potassium occurring in relatively favourable concentrations even in deeper horizons. Continuous stands of Abies alba should therefore be gradually diversified both horizontally and vertically to improve structural and species diversity. Advance underplanting and small-scale regeneration methods are advisable to limit rapid development of nitrophilous understory vegetation. Shade-tolerant species such as European silver fir, common hornbeam, sycamore or service tree (along lighter margins or within canopy gaps) and groupwise European beech are suitable.

Soil Taxonomic Unit:

Endoskeletic Cambic Umbrisol (Anohyperhumic, Pachic, Pantoloamic, Prototechnic, Solimovic, Transportic)

Stratigraphy:
OL-OFzo-OH-meAh-miAhτ1-miAhτ2-BwτCτ

Humus form:
Eumesoamphi

OL (3 cm):	Silver fir continuous litter with up to 7 cm deep pockets of accumulation - needles, cone scales, twigs).
OFzo (1 cm):	Continuous, admixed with fine-to-medium gravel (surface erosion).
OH (0.5 cm):	Thin, moist, mixed with undecomposed residuals.

meAh (0-10.5 cm)
Color: 7.5YR 2.5/2 (very dark brown), texture class: sandy loam, stoniness: 40% (angular coarse gravel), structure: fine granular, bulk density: very loose, moisture: slightly moist, root density: <2 mm: 70 pcs/dm^2, >2 mm: 10 pcs/dm^2. Recent organomineral horizon development of topical forest stand.

miAhτ1 (10.5-66.5 cm)
Color: 7.5YR 4/4 (brown) + 7.5YR 3/3 (dark brown), texture class: sandy loam, stoniness: 40% (angular stones), structure: very fine granular, bulk density: very loose, moisture: slightly moist, root density: <2 mm: 20 pcs/dm^2, >2 mm: 5 pcs/dm^2. Human-induced colluvial/slope deposit material. Alteration of separated humus-rich enclaves. Clear distnictness and wavy shape of lower boundary.

miAhτ2 (66.5-94.5 cm)
Color: 7.5YR 4/4 (brown) + 7.5YR 3/3 (dark brown), texture class: sandy loam, stoniness: 60% (angular stones), structure: fine subangular blocky, bulk density: very loose, moisture: slightly moist, root density <2 mm: 5 pcs/dm^2, >2 mm: 1 pc/dm^2. Human-induced colluvial/slope deposit material. Clear distinctness and smooth-to-wavy shape of lower boundary.

BwτCτ (>94.5 cm)
Color: 10YR 4/6 (dark yellowish brown), texture class: loam, stoniness: 90% (angular boulders), structure: very fine subangular blocky, bulk density: loose, moisture: moist, root density <2 mm: 1 pc/dm^2, >2 mm: <1 pc/dm^2. Structure combined with single grains (20%).



Soil developed on polygenic slope loam with evidently entirely accumulated material during intensive sedimentation events (probably linked with different phases and reasons, such like constructions, deforestation, pedoturbation etc.).
Topsoil scarified, with irregular organic matter distribution within medial-to-stepe slope.
Very loose soil with tendention to dessication and with high water permeability.



SOIL CHARACTERISTICS

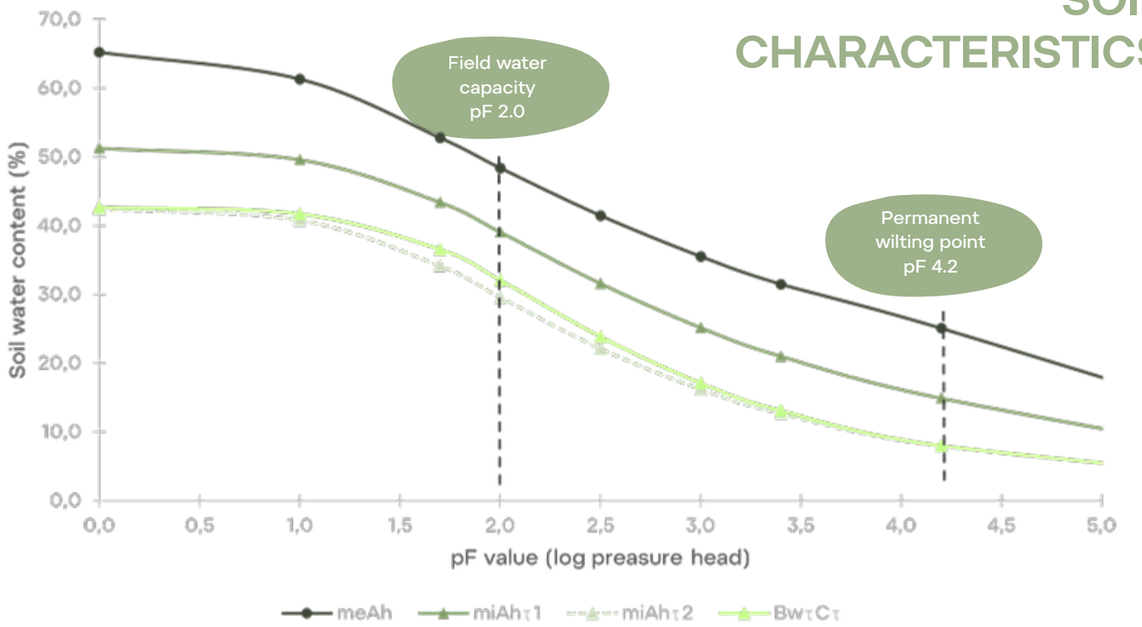


Figure 7A: Water retention curve showing the relationship between soil water content and pF value

Profile No. 7 is characterized by very favorable hydro-physical properties in the surface horizon, followed by a gradual increase in bulk density and reduction in organic matter with depth. The meAh horizon has extremely low bulk density (0.7 g/cm³) and very high organic matter content (18.3%), resulting in the highest maximal (65.2%) and field water capacities (48.4%) within the profile. Saturated hydraulic conductivity is also very high (38.3 cm/day¹), indicating high infiltration and pore continuity.

In the both technical miAhτ1 and miAhτ2 horizons, bulk density increases (1.1–1.4 g/cm³) and organic matter decreases (6.8–3.3%), resulting in a gradual decline in maximal (51.3–42.5%) and field water capacity (39.1–29.6%); however, saturated hydraulic conductivity remains relatively high (24.9–28.8 cm/day¹), indicating preserved high macroporosity despite increasing compaction.

Table 7A: Soil properties of particular horizons - profile No. 7

Soil Horizon	Maximal Water Capacity (% vol.)	Field Water Capacity (% vol.)	Permanent Wilting Point (% vol.)	Available Water Capacity (% vol.)	Saturated Hydraulic Conductivity (cm/day)	Bulk Density (g/cm³)	Organic Matter (% wt.)
meAh1	71.8	52.0	28.8	23.1	69.6	0.5	28.2
meAh2	57.3	45.0	22.8	22.2	24.6	0.9	10.9
Bw	42.5	33.5	8.8	24.6	11.2	1.4	3.2
BwC	39.7	32.7	9.2	23.5	8.8	1.5	2.0

In the deepest technical BwτCτ horizon, bulk density stabilizes at 1.4 g/cm⁻³ with slightly higher organic matter (3.8%). Water retention (maximal 42.7%, field 32.1%) and available water capacity (24.1%) indicate balanced storage properties, while saturated hydraulic conductivity decreases to 15.0 cm/day⁻¹.

Table 7B: Micronutrients content

Soil horizon	P	Ca	Mg	K	CEC	BS
	mg/kg				mmol/kg	%
OH	36	1165	266	198	339.9	25.0
meAh	14	216	84	115	116.6	21.9
miAhτ1	2	166	61	55	60.2	31.9
miAhτ2	3	150	51	48	34.8	48.2
BwτCτ	5	159	56	50	36.8	51.1

Table 7C: Soil texture characteristics and Soil reaction

Soil horizon		Texture class	Slaking index	Battance class	pH_{water}	pH_{KCl}
OH					3.8	3.4
meAh	●	sandy loam	0.88	non battant	3.6	3.3
miAhτ1	●	silt loam	1.43	peu battant	4.0	4.0
miAhτ2	●	sandy loam	1.81	battant	4.2	4.1
BwτCτ	●	silt loam	2.06	tres battant	4.1	4.1



TOC

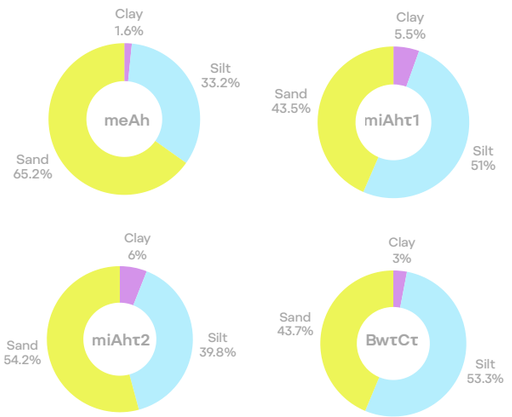


Figure 7B: Soil texture

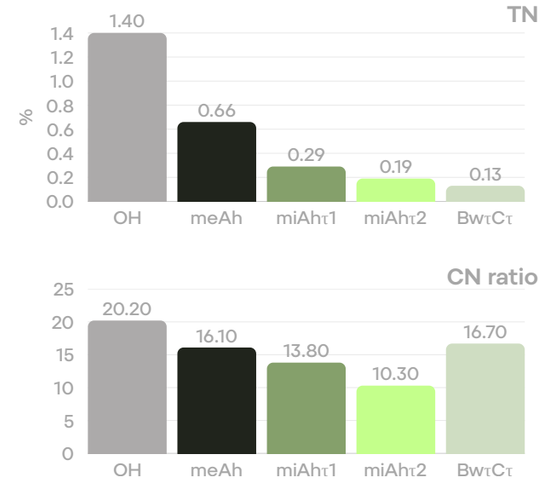


Figure 7C: Total soil carbon and nitrogen characteristics

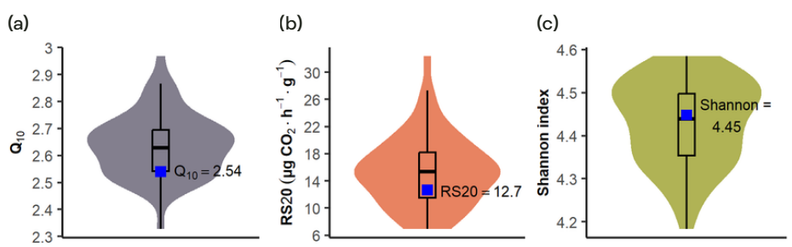
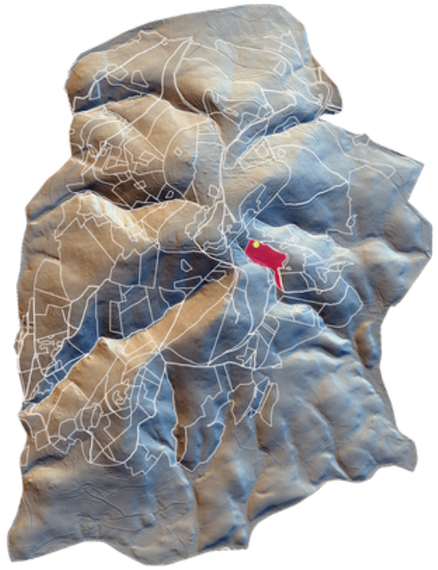


Figure 7D:
(a) Q10: the temperature sensitivity of soil respiration
(b) RS20: soil respiration value for a standardized temperature of 20 degrees
(c) Shannon: soil molecular diversity index, based on the identification of compounds from the main molecular families

site
8

SILVER FIR

GPS (N):	4.0402000°
GPS (E):	46.9198470°
Localization:	extramuros
Altitude:	730 m a.s.l.
Inclination:	15°
Exposure:	SW



The profile is located in the middle of the straight slope (inclination 15°, south-west exposure). The tree layer consists of silver fir not long after selective logging, tree canopy 60%. The herbaceous layer consists of scattered mosses, wavy hair-grass and holly. The profile is dominated by a silt loam texture.





Soil with very low clay content (mostly 1-3 %) and sandy loam texture shows high permeability and limited sorption capacity. Consequently, cation exchange capacity is largely controlled by humic substances, which increase ECEC in the topsoil. Organic matter also contributes to aggregate stability and water holding capacity. The permeable mineral soil indicates a potential risk of nutrient leaching, particularly after canopy opening and accelerated mineralization. The soil-forming substrate contains moderate phosphorus, potassium and magnesium but relatively low calcium, resulting in base cation ratios favouring potassium over divalent cations. Base cation ratios indicate a relative enrichment of potassium compared with calcium, reflecting weathering of potassium-bearing silicate minerals in the volcanic parent material. Forest management should avoid large-scale soil surface exposure, which could enhance mineralization, nitrogen release and soil carbon loss while reducing water retention. In this maturing stand, regeneration may start gradually through advance underplanting and support of spontaneous tree species diversification.

Soil Taxonomic Unit:

Endoskeletic Cambic Umbrisol (Anoloamic, Profundihumic, Prototechnic,Solimovic, Transportic)

Stratigraphy:
OL-OFzo-OH-miAh-miAu/Bw-Bw

Humus form:
Dysmoder

OL (2 cm):	Thick, light, continuous siver fir litter (needles, twigs, cone scales).
OFzo (1 cm):	Continuous, dry.
OH (1.5 cm):	Residual-to-humic; continuous, compact, with high hair root density.



miAh (0-35.5 cm)
Color: 10YR 3/2 (very dark grayish brown), texture class: loamy sand, stoniness: 30% (angular fine gravel), structure: very fine granular, bulk density: very loose, moisture: very dry, root density: <2 mm: 120 pcs/dm^2, >2 mm: 60 pcs/dm^2. Umbric, with graduating root density towards upper boundary (below 20 cm root density 60 pcs <2 mm/dm^2 and 20 pcs > 2 mm/dm^2). Sparse artefacts.

miAu/Bw (35.5-60.5 cm)
Color: 10YR 3/4 (dark yellowish brown), texture class: sandy loam, stoniness: 30% (angular coarse gravel), structure: very fine granular, bulk density: very loose, moisture: dry, root density: <2 mm: 20 pcs/dm^2, >2 mm: 7 pcs/dm^2. Granular structure combined with very fine subangular blocky; dusty, week aggregate stability.

Bw (60.5-80.5 cm)
Color: 10YR 4/6 (dark yellowish brown), texture class: sandy loam, stoniness: 70% (angular medium gravel), structure: fine subangular blocky, bulk density: very loose, moisture: dry, root density <2 mm: 10 pcs/dm^2, >2 mm: 5 pcs/dm^2. Subangular blocky structure combined with approx. 10% fine granular.

Soil with very thick organomineral horizon (umbric) with markable concentration of roots at 0-20 cm; high stoniness within whole profile; low structural aggregates development with week stability. Soil developed on acid volcanic rocks. Physiological depth >1 m (roots) and approx. 60 cm (zooedaphone - diplopods and other invertebrates).



SOIL CHARACTERISTICS

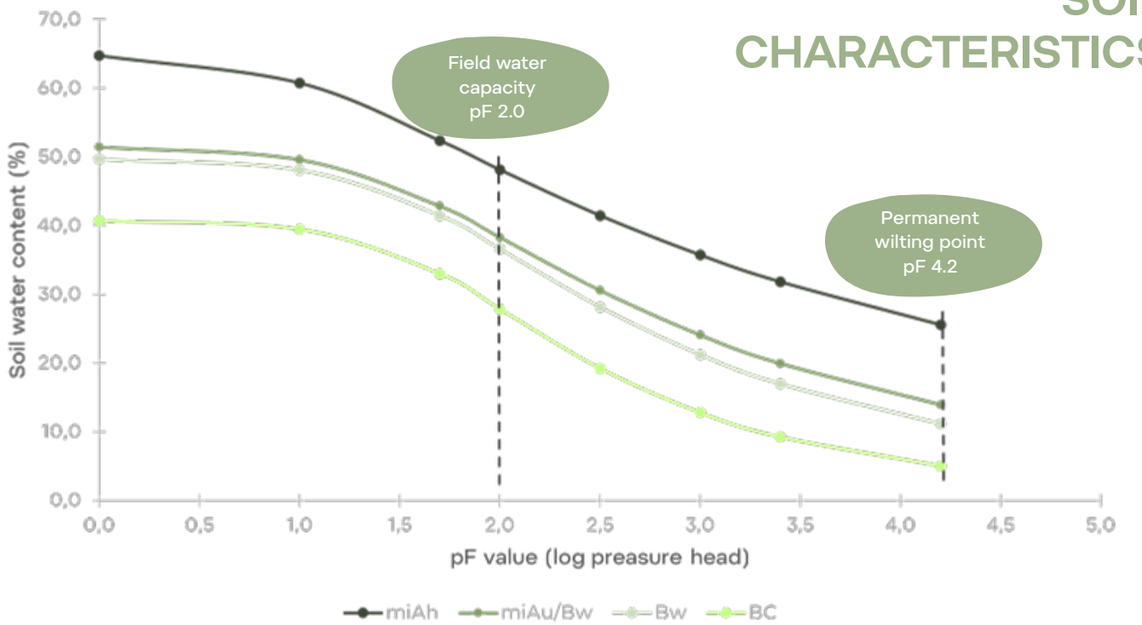


Figure 8A: Water retention curve showing the relationship between soil water content and pF value

Profile No. 8 (Fig. 8A, Table 8A), like profile No. 28 (Fig. 28A, Table 28A), shows a gradual shift in hydro-physical properties with depth, but with more pronounced differences in both water retention and hydraulic conductivity between horizons. The overall pattern still reflects a well-organized transition from more permeable, organic-rich topsoil to compacted mineral subsoil, but the differences are slightly more pronounced compared to profile No. 28. The miAh horizon has low bulk density (0.7 g/cm³) and high organic matter content (18.1%), leading to high maximal (64.8%) and field water capacities (48.1%). Saturated hydraulic conductivity is moderate (27.4 cm/day). In the miAu/Bw horizon, bulk density increases to 1.1 g/cm³, and organic matter drops to 7.4%. Water retention decreases (maximal 51.5%, field 38.3%), while available water capacity (24.4%) is relatively high. The saturated hydraulic conductivity increases to 31.0 cm/day, reflecting a more efficient transmission of soil water. In the Bw horizon, bulk density increases further (1.2 g/cm³), and organic matter decreases to 6.4%. Maximal water capacity (49.6%) and field water capacity (36.6%) decline, but available water capacity (25.4%) remains relatively high. Finally, in the deepest BC horizon, bulk density is higher (1.5 g/cm³) and organic matter is lower (2.6%), with further reductions in maximal (40.7%) and field water capacity (27.8%). Available water capacity decreases to 22.8%, and saturated hydraulic conductivity drops significantly to 22.2 cm/day, reflecting increased compaction and reduced permeability compared to both the Bw and miAu/Bw horizons in this profile.

Table 8A: Soil properties of particular horizons - profile No. 8

Soil Horizon	Maximal Water Capacity (% vol.)	Field Water Capacity (% vol.)	Permanent Wilting Point (% vol.)	Available Water Capacity (% vol.)	Saturated Hydraulic Conductivity (cm/day)	Bulk Density (g/cm³)	Organic Matter (% wt.)
miAh	64.8	48.1	25.5	22.6	27.4	0.7	18.1
miAu/Bw	51.5	38.3	13.9	24.4	31.0	1.1	7.4
Bw	49.6	36.6	11.1	25.4	22.1	1.2	6.4
C	40.7	27.8	5.0	22.8	22.2	1.5	2.6

Table 8B: Micronutrients content

Soil horizon	P	Ca	Mg	K	CEC	BS
	mg/kg				mmol/kg	%
OH	36	679	170	213	314.3	16.9
miAh	5	133	79	58	68.1	25.2
miAu/Bw	5	118	58	36	29.4	48.9
Bw	9	121	64	33	22.2	64.0
C	9	91	43	36	22.2	50.4

Table 8C: Soil texture characteristics and Soil reaction

Soil horizon		Texture class	Slaking index	Battance class	pH_{water}	pH_{KCl}
OH					3.6	3.2
miAh		sandy loam	0.81	non battant	4.4	4.1
miAu/Bw		sandy loam	1.06	non battant	4.7	4.5
Bw		sandy loam	1.20	non battant	4.7	4.7
C		sandy loam	2.09	tres battant	4.6	4.4

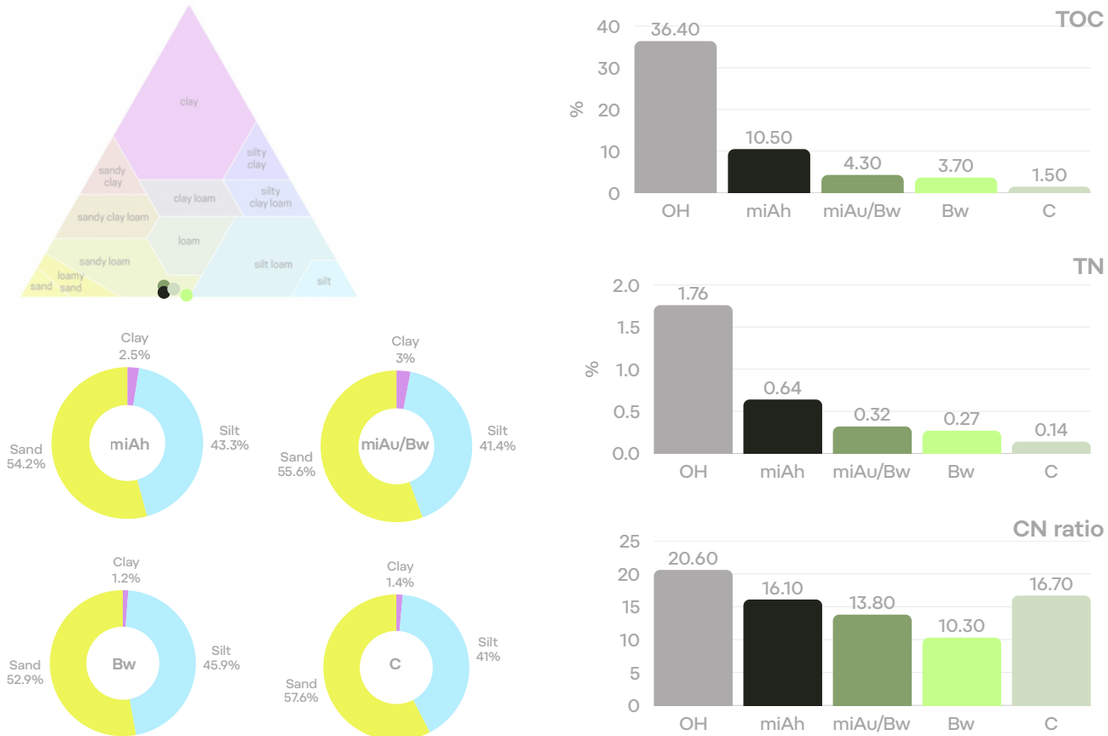


Figure 8B: Soil texture

Figure 8C: Total soil carbon and nitrogen characteristics

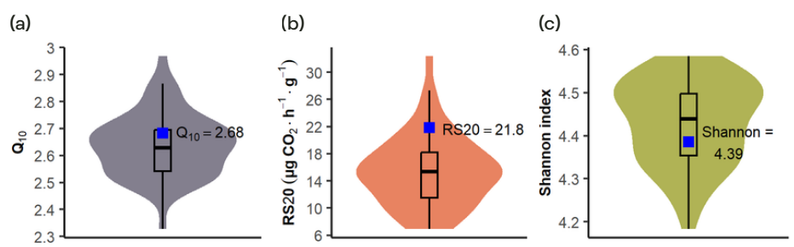
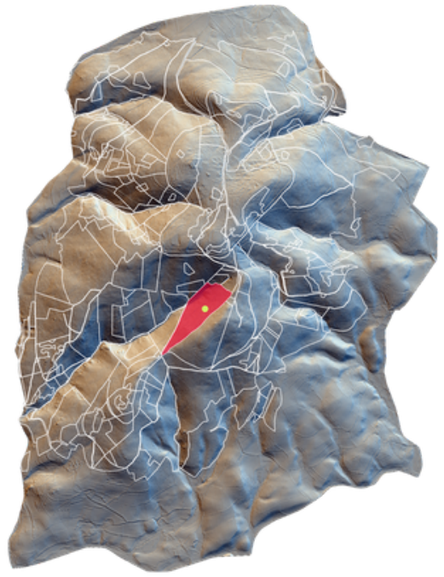


Figure 8D:
(a) Q10: the temperature sensitivity of soil respiration
(b) RS20: soil respiration value for a standardized temperature of 20 degrees
(c) Shannon: soil molecular diversity index, based on the identification of compounds from the main molecular families

site
9

SILVER FIR

GPS (N):	4.0334650°
GPS (E):	46.9147960°
Localization:	extramuros
Altitude:	656 m a.s.l.
Inclination:	32°
Exposure:	NW



The profile is located on a very steep, straight slope (inclination 32°, north-west exposure). There is a large amount of stoniness moving down the slope by gravity on the surface and in the topsoil (solifluction). The tree layer consists of silver fir with mixture of spruce designated for harvesting. The both shrub layer and herbaceous layers are absent.





The soil has a loamy-sandy texture with good aggregate stability; however, on the steep slope it remains highly vulnerable to erosion. Strongly acidic soil reaction corresponds with low to moderate cation exchange capacity and very low base saturation. Organic carbon content is moderate to high in the upper horizons, probably reflecting soil mixing processes, while the C/N ratio remains typical for forest soils. The parent material is relatively rich in potassium and phosphorus but poor in calcium and magnesium. High concentrations of exchangeable aluminium influence cation adsorption and may limit the uptake of calcium, magnesium and potassium. Considering the steep topography, clear-cutting should be avoided. Gradual regeneration with spatial and species diversification is recommended. Narrow regeneration strips (5–10 m wide) oriented along the fall line should be established within the Douglas fir stand. These strip openings can be planted with European larch and Scots pine and supplemented by natural regeneration of silver birch, European aspen and mountain ash. In the adjacent partially thinned stand, enrichment planting of European silver fir, European beech and additional ash species is recommended.

Soil Taxonomic Unit:

Katoskeletic Orthodystric Solimovic Cambisol (Pantoloamic, Profundihumic, Protospodic, Solimovic)

Stratigraphy:
OL-OFzo-OH-meAh-Bw(s)-Bw-Bw/C-C

Humus form:
Eumesoamphi

OL (2.5 cm): Continuous litter; dominantly silver fir needles, twigs and cone scales.

OFzo (0.5 cm): Thin, discontinuous, sporadically with fast decomposition and deposition within steeper slope.

OH (1 cm): Loose, thick, continuous, with fine-to-medium gravel.

meAh (0–10.0 cm)

Color: 10YR 3/2 (very dark grayish brown), texture class: sandy loam, stoniness: 40% (angular coarse gravel), structure: medium granular, bulk density: loose, moisture: dry, root density: <2 mm: 110 pcs/dm^2, >2 mm: 30 pcs/dm^2. Slightly markable eluviation (micropodzolization process).

Bw(s) (10.0–32.0 cm)

Color: 10YR 3/6 (dark yellowish brown), texture class: sandy loam, stoniness: 40% (angular coarse gravel), structure: fine subangular blocky, bulk density: very loose, moisture: slightly moist, root density: <2 mm: 120 pcs/dm^2, >2 mm: 30 pcs/dm^2. Sparse enclaves of organic matter accumulation; light, very loose, colored with slight admixture of sesquioxides.

Bw (32.0–58.0 cm)

Color: 7.5YR 4/4 (brown), texture class: sandy loam, stoniness: 45% (angular stones), structure: medium subangular blocky, bulk density: loose, moisture: slightly moist, root density <2 mm: 30 pcs/dm^2, >2 mm: 5 pcs/dm^2. Clear-to-gradual distinctness of lower boundary; humus accumulation in form of isolated enclaves.

Bw/C (58.0–98.0 cm)

Color: 10YR 4/6 (dark yellowish brown), texture class: sand, stoniness: 50% (angular stones), structure: very fine angular blocky, bulk density: loose, moisture: slightly moist, root density <2 mm: 20 pcs/dm^2, >2 mm: 3 pcs/dm^2. Sparse humus accumulation in form of isolated enclaves.

C (>98.0 cm)

Color: 10YR 5/6 (yellowish brown), texture class: sand, stoniness: 65% (angular stones), structure: very fine simple grain, bulk density: intermediate, moisture: dry, root density <2 mm: 3 pcs/dm^2, >2 mm: 1 pc/dm^2. Enclaves of decomposed roots.

Cambisol with markable physiological depth (roots within whole profile), developed within polygenic material (slope loam), with high water permeability. Slightly running podzolization process distincts weak eluvium in Ah and weak sesquioxides accumulation in B1. Relief typical with historical terracing and with slight solifluction.





SOIL CHARACTERISTICS

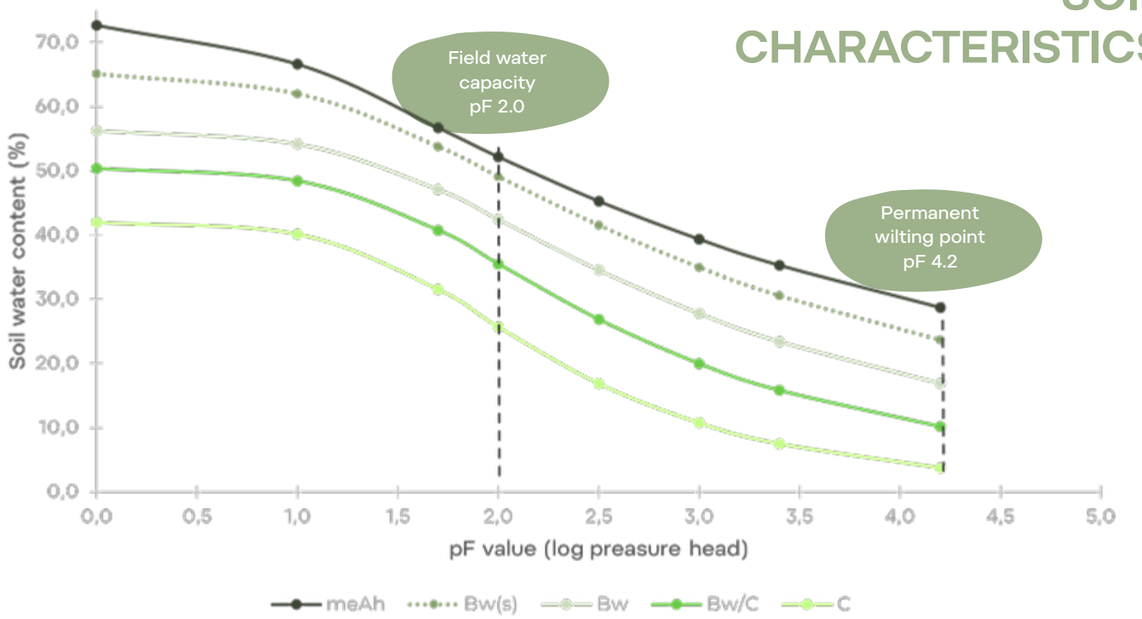


Figure 9A: Water retention curve showing the relationship between soil water content and pF value

Profile No. 9 (Fig. 9A, Table 9A) reveals a gradual shift in soil properties with depth. The changes in water retention, hydraulic conductivity, and organic matter content reflect the transition from organic-rich topsoil horizon to denser subsoil. The meAh horizon, with low bulk density (0.4 g/cm³) and high organic matter (40.6%), is highly efficient in retaining and transmitting water (maximal capacity 72.7%, field capacity 52.2%, hydraulic conductivity 59.7 cm/day). This makes it an important zone for water storage and hight rainwater infiltration. In the Bw and Bw(s) horizons, an increase in bulk density (from 0.8 to 1.0 g/cm³) and a decrease in organic matter content (from 15.3% to 9.9%) coincide with a significant reduction in water retention, with maximal retention dropping to 56.2%, field retention to 42.4%, and slight decline in hydraulic conductivity (from 29.4 cm/day). These changes indicate a transition towards more compacted subsoil horizons with reduced capacity for water movement.

Table 9A: Soil properties of particular horizons - profile No. 9

Soil Horizon	Maximal Water Capacity (% vol.)	Field Water Capacity (% vol.)	Permanent Wilting Point (% vol.)	Available Water Capacity (% vol.)	Saturated Hydraulic Conductivity (cm/day)	Bulk Density (g/cm³)	Organic Matter (% wt.)
meAh	72.7	52.2	28.7	23.5	59.7	0.4	40.6
Bw(s)	65.1	49.1	23.6	25.4	29.6	0.8	15.3
Bw	56.2	42.4	16.9	25.5	29.4	1.0	9.9
Bw/C	50.4	35.5	10.2	25.3	33.0	1.2	6.3
C	42.0	25.7	3.7	21.9	33.1	1.5	2.4

The Bw/C horizon shows further increases in bulk density (1.2 g/cm³) and a decrease in organic content (6.3%), with a corresponding drop in water retention (maximal 50.4%, field 35.5%) and hydraulic conductivity (33.0 cm/day). Finally, the C horizon represents most compacted layer with the highest bulk density (1.5 g/cm³) and lowest organic matter (2.4%). Water retention is lowest here (maximal 42.0%, field 25.7%), and hydraulic conductivity drops to its lowest value (33.1 cm/day), marking this as a very low-permeability zone of this profile.

Silver Fir

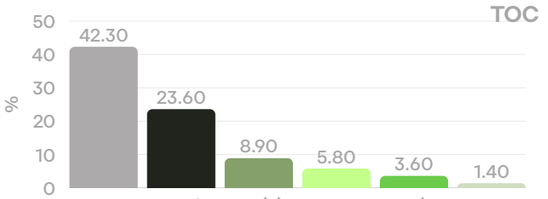
Table 9B: Micronutrients content

Soil horizon	P	Ca	Mg	K	CEC	BS
	mg/kg				mmol/kg	%
OH	66	721	294	224	382.1	17.3
meAh	7	194	94	152	209.1	13.7
Bw(s)	3	174	69	54	99.7	19.7
Bw	3	157	59	36	55.8	33.7
Bw/C	3	160	57	36	36.5	47.9
C	12	142	50	37	26.6	62.4

Table 9C: Soil texture characteristics and Soil reaction

Soil horizon		Texture class	Slaking index	Battance class	pH_{water}	pH_{KCl}
OH					3.6	3.1
meAh	●	sandy loam	0.80	non battant	3.5	3.2
Bw(s)	●	sandy loam	0.84	non battant	4.1	3.9
Bw	●	sandy loam	0.99	non battant	4.2	4.2
C	●	sandy loam	1.92	battant	4.2	4.3





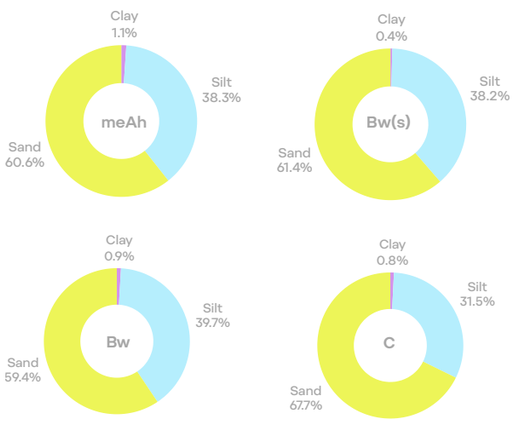


Figure 9B: Soil texture

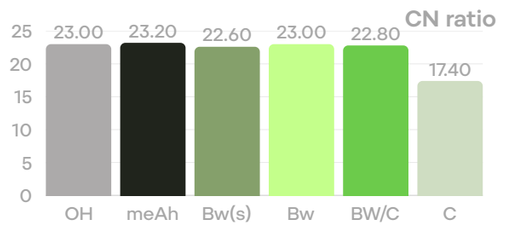


Figure 9C: Total soil carbon and nitrogen characteristics

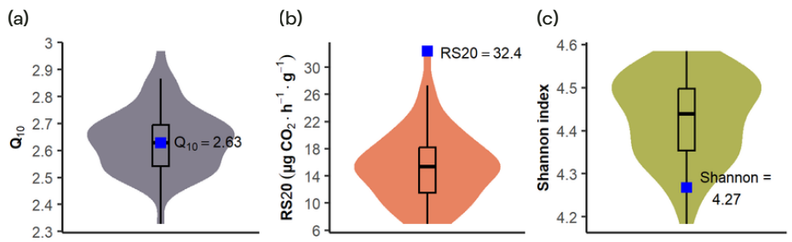


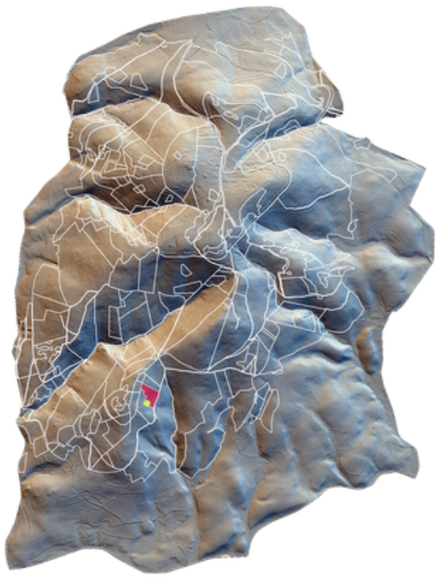
Figure 9D:
(a) Q10: the temperature sensitivity of soil respiration
(b) RS20: soil respiration value for a standardized temperature of 20 degrees
(c) Shannon: soil molecular diversity index, based on the identification of compounds from the main molecular families

site

10

SILVER FIR

GPS (N):	4.0266190°
GPS (E):	46.9070790°
Localization:	extramuros
Altitude:	590 m a.s.l.
Inclination:	25°
Exposure:	ESE



The profile is located in the middle section of a straight slope (inclination 25°, east-south east exposure). The tree layer consists of silver fir with a unique blend of douglas fir, spruce, and sweet chestnut. The herbaceous layer is practically absent. The weathered rock is very dusty.





Surface horizons have a loamy texture, while deeper layers become silt-rich, which increases susceptibility to erosion on the steep slope. Dystric soil properties correspond with a low base saturation of the sorption complex. Exchangeable bases are generally scarce and relatively balanced, without a marked dominance of potassium over divalent cations. The soil reaction is strongly acidic in the humus horizons, whereas base saturation moderately increases in the cambic horizon Bw. Despite these nutrient-poor conditions, the ecological amplitude of Abies alba allows its successful growth at this site. For long-term stability and soil protection, diversification of the stand is advisable. Admixture of ameliorative deciduous species such as sycamore, small-leaved lime, European aspen and locally wild service, together with support of advanced natural regeneration in canopy gaps, may improve nutrient cycling and stand structural stability.

Soil Taxonomic Unit:

Endoskeletic Cambic Umbrisol (Amphisiltic, Epiloamic, Humic, Solimovic)

Stratigraphy:
OL-OFzo-OH-miAh-meAh-Bw-BwC

Humus form:
Eumesoamphi

OL (1 cm):	Continuous, thin litter of silver fir and less douglas fir and chestnut.
OFzo (0.5 cm):	Amphigenic, thin, slightly moist.
OH (2 cm):	Thick, slightly moist, loose, dense rooting (200 pcs/dm^2).



miAh (0–5.5 cm)
Color: 10YR 3/2 (very dark grayish brown), texture class: sandy loam, stoniness: 10% (angular medium gravel), structure: very fine granular, bulk density: very loose, moisture: very dry, root density: <2 mm: 140 pcs/dm^2, >2 mm: 40 pcs/dm^2. Newly formed, with fascuculate hair roots.

meAh (5.5–28.5 cm)
Color: 10YR 3/4 (dark yellowish brown), texture class: sandy loam, stoniness: 15% (angular fine gravel), structure: medium granular, bulk density: very loose, moisture: dry, root density: <2 mm: 80 pcs/dm^2, >2 mm: 30 pcs/dm^2. Umbric, thick, with graduading root density to upper boundary.

Bw (28.5–59.5 cm)
Color: 7.5YR 4/6 (strong brown), texture class: sandy loam, stoniness: 30% (angular fine gravel), structure: medium subangular blocky, bulk density: very loose, moisture: dry, root density <2 mm: 70 pcs/dm^2, >2 mm: 15 pcs/dm^2. Silt admixture.

BwC (>59.5 cm)
Color: 10YR 5/6 (yellowish brown), texture class: silt loam, stoniness: 70% (angular stones), structure: fine subangular blocky, bulk density: intermediate, moisture: dry, root density <2 mm: 10 pcs/dm^2, >2 mm: 3 pcs/dm^2.

Moderately deep soil with thick umbric horizon and with very high root density near soil surface. Forest habitat with irregular uprooting. Slowed organic matter decomposition leads to humus accumulation. Very loose soil within whole pedon on acidic volcanic rock, which enriches especially deeper horizons in stoniness.



SOIL CHARACTERISTICS

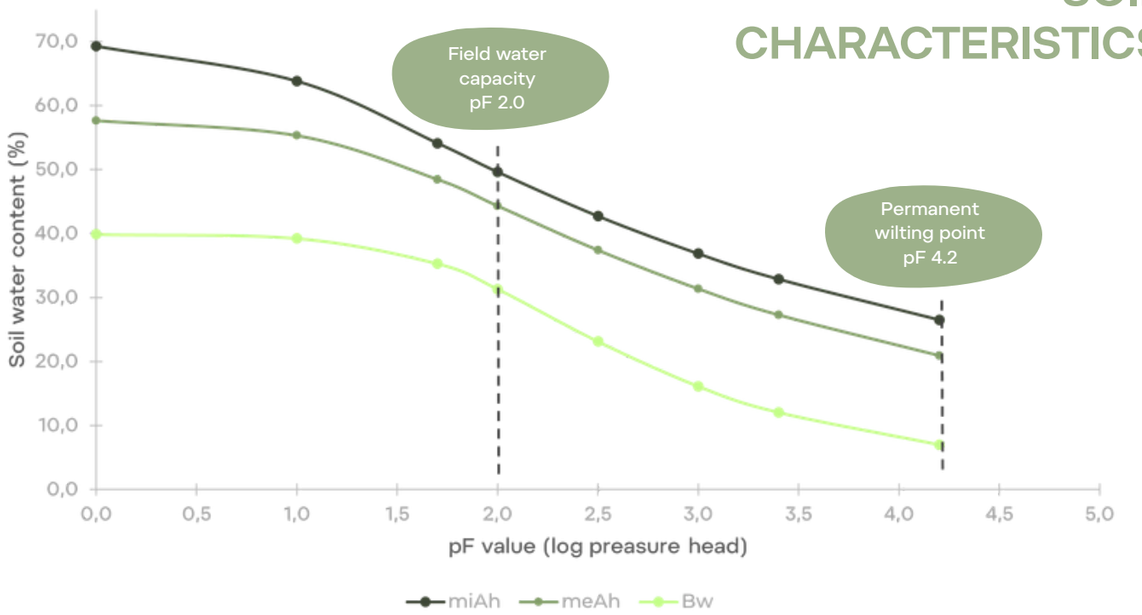


Figure 10A: Water retention curve showing the relationship between soil water content and pF value

Profile No. 10 exhibits pronounced vertical differentiation in hydro-physical properties, especially between the meAh and Bw horizons (Fig. 10A; Table 10A). The surface miAh horizon is characterized by very low bulk density (0.6 g/cm³) and high organic matter content (23.8%), resulting in the highest maximal water content (69.3%) and field water capacity (49.6%) within the profile. Despite a relatively high permanent wilting point (26.5%), the available water capacity remains substantial at 23.1%. Saturated hydraulic conductivity is also relatively high (38.5 cm/day), reflecting well-developed macroporosity and good water movement. The underlying meAh horizon also shows physical changes. Bulk density increases to 0.9 g/cm³, while organic matter content nearly halves (12.2%), causing reductions in maximal (57.7%) and field water capacity (44.3%). The permanent wilting point decreases to 20.9%, yielding a comparable available water capacity (23.4%) despite lower total retention. Saturated hydraulic conductivity declines slightly to 30.2 cm/day, indicating moderately reduced but still good permeability. The deepest Bw horizon represents a further transition toward denser mineral subsoil (1.5 g/cm³; 2.7% organic matter), with markedly lower maximal (39.9%) and field water capacity (31.3%). However, due to its very low permanent wilting point (7.0%), available water capacity slightly increases to 24.3%. Saturated hydraulic conductivity drops substantially to 11.1 cm/day, reflecting increased compaction and reduced total pore connectivity.

Table 10A: Physical-hydrological properties of particular horizons - profile No. 10

Soil Horizon	Maximal Water Capacity (% vol.)	Field Water Capacity (% vol.)	Permanent Wilting Point (% vol.)	Available Water Capacity (% vol.)	Saturated Hydraulic Conductivity (cm/day)	Bulk Density (g/cm³)	Organic Matter (% wt.)
miAh	69.3	49.6	26.5	23.1	38.5	0.6	23.8
meAh	57.7	44.3	20.9	23.4	30.2	0.9	12.2
Bw	39.9	31.3	7.0	24.3	11.1	1.5	2.7

The most pronounced differences occur between all horizons, where a substantial decline in organic matter and an increase in bulk density markedly reduce total water retention. Despite these contrasts in hydro-physical properties, available water capacity remains relatively stable throughout the profile (~23%), indicating that water accessible to plants is maintained across the soil horizons.

Table 10B: Micronutrients content

Soil horizon	P	Ca	Mg	K	CEC	BS
	mg/kg				mmol/kg	%
OH	48	680	199	389	291.2	20.6
miAh	3	133	84	133	130.9	14.4
meAh	1	95	52	60	51.3	25.9
Bw	1	87	43	42	26.8	47.6

Table 10C: Soil texture characteristics and Soil reaction

Soil horizon		Texture class	Slaking index	Battance class	pH_{water}	pH_{KCl}
OH					3.6	3.1
miAh	●	sandy loam	0.04	non battant	3.9	3.5
meAh	●	sandy loam	0.90	non battant	4.4	4.2
Bw	●	silt loam	2.65	tres battant	4.5	4.3

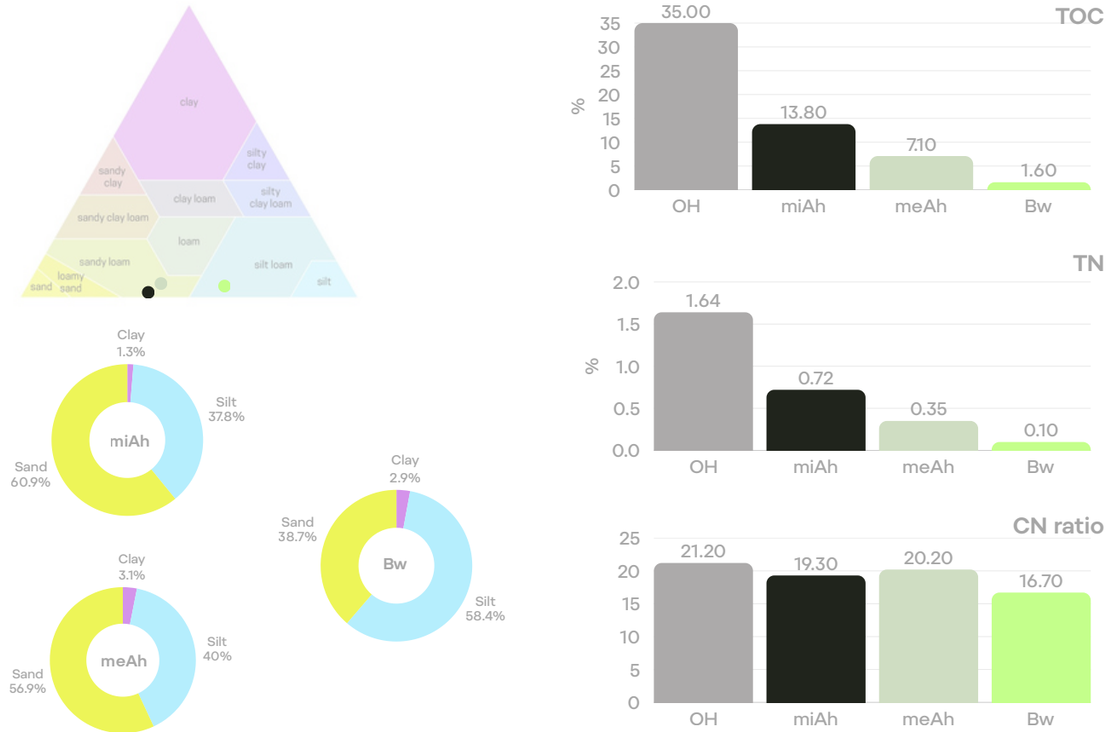


Figure 10B: Soil texture

Figure 10C: Total soil carbon and nitrogen characteristics

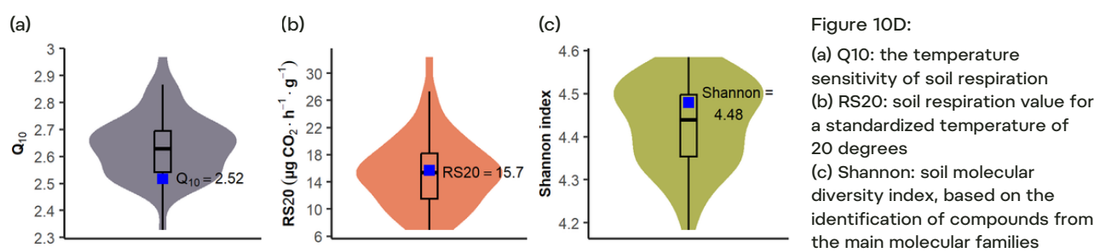
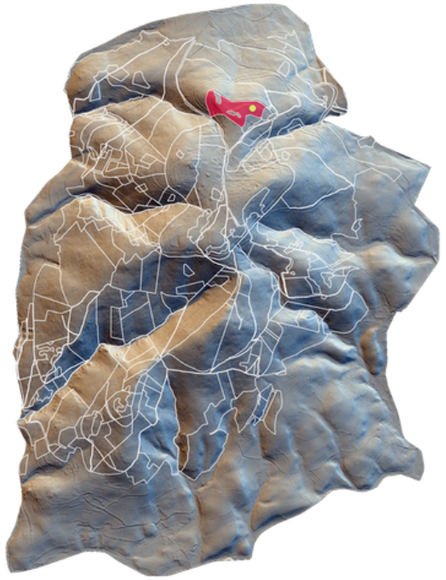


Figure 10D:
(a) Q10: the temperature sensitivity of soil respiration
(b) RS20: soil respiration value for a standardized temperature of 20 degrees
(c) Shannon: soil molecular diversity index, based on the identification of compounds from the main molecular families

Silver Fir

site
11

SILVER FIR



GPS (N): 4.0395620°
GPS (E): 46.9314850°
Localization: intramuros (2nd rampart)
Altitude: 740 m a.s.l.
Inclination: 5°
Exposure: E

The profile is located on a gentle slope (a small plateau), 50 meters below the ridge (inclination 5°, east exposure). The tree layer consists of silver fir mixed with sweet chestnut. Holly is found sporadically in the shrub layer. The herbaceous layer consist of wavy hair-grass with occasional moss and ferns. Anthropogenic findings (amphora shards) are occasionally visible on the surface and in the subsoil.





Considering soil mineralogy, organic matter content and gentle topography, the soil shows relatively good resistance to erosion. Soil reaction is very strongly acidic and the sorption complex is only moderately saturated with base cations. Nevertheless, nutrient contents and their ratios are relatively favourable compared with other sites in the study area, and the soil-forming material provides moderate reserves of calcium, magnesium, potassium and phosphorus. High organic matter content throughout the upper soil layers forms a substantial nutrient pool. Consequently, despite low concentrations in the exchange complex, the overall nutrient budget remains sufficient for forest growth. However, rapid canopy opening could stimulate accelerated nutrient mineralisation, particularly nitrogen release, and favour the expansion of nitrophilous vegetation. Therefore, gradual stand regeneration maintaining partial canopy cover and promoting a mosaic forest structure is recommended.

Soil Taxonomic Unit:
Terric Anthrosol (Carbonic, Endoskeletic, Loamic, Orthodystric, Technic)

Stratigraphy:
OL-OFzo-OH-meAh-meAhuτ1-Ahuτ2-Cτ

Humus form:
Rhizoamphi

OL (2 cm): Continuous, with roots of wavy hair-grass.
OFzo (7 cm): Thick, high fine root density (combination of wavy hair-grass and less silver fir).
OH (2 cm): Thin, dominance of residual Hr; sparse pockets of humus accumulation; amorphous.



meAh (0-3.0 cm)
Color: 10YR 2/2 (very dark brown), texture class: loam, stoniness: 15-20% (angular medium gravel), structure: fine granular, bulk density: very loose, moisture: dry, root density: <2 mm: 140 pcs/dm^2, >2 mm: 40 pcs/dm^2.

meAhuτ1 (3.0-25.0 cm)
Color: 10YR 3/2 (very dark grayish brown), texture class: loam, stoniness: 40% (angular medium gravel), structure: medium granular, bulk density: loose, moisture: dry, root density: <2 mm: 110 pcs/dm^2, >2 mm: 30 pcs/dm^2. Admixture of artefacts (fragments of amphoras). Structure: 40% admixture of medium subangular blocky.

Ahuτ2 (25.0-60.0 cm)
Color: 10YR 3/3 (dark brown), texture class: loam, stoniness: 40% (angular medium gravel), structure: medium subangular blocky, bulk density: loose, moisture: slightly moist, root density <2 mm: 80 pcs/dm^2, >2 mm: 15 pcs/dm^2. Sparse artefacts; partially mechanically transported; result of past deforestation and human intensive industrial activity.

Cτ (>60.0 cm)
Color: 10YR 3/4 (dark yellowish brown), texture class: loam, stoniness: 60% (angular medium gravel), structure: medium polyhedral, bulk density: loose, moisture: slightly moist, root density <2 mm: 10 pcs/dm^2, >2 mm: 2 pcs/dm^2. Transition to transported anthropogenic subsoil.

Anthropogenic soil defined by anthropogenic material and by accumulation of humus-rich sediment; artefacts near soil surface, as well as in the subsoil layers (markably in zone of ca. 40-60 cm); near subsoil admixture of acid volcanic bedrock.



SOIL CHARACTERISTICS

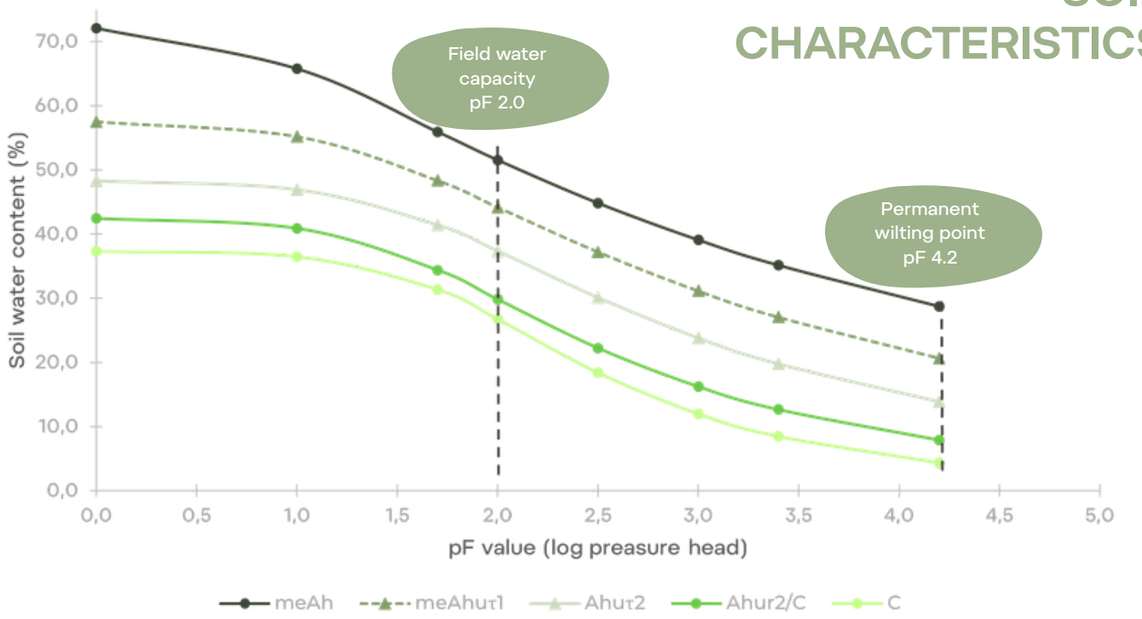


Figure 11A: Water retention curve showing the relationship between soil water content and pF value

Profile No. 11 shows pronounced vertical differentiation, with increasing bulk density and decreasing organic matter content from the surface to the deepest horizons. The topsoil meAh horizon (0.5 g/cm³; 26.3% organic matter) has the highest maximal (72.1%) and field water capacity (51.5%) in the profile. Despite a high permanent wilting point (28.7%), available water remains 22.8%. Saturated hydraulic conductivity is high (49.1 cm/day), reflecting a very porous, organic-rich structure. The underlying technical meAhυτ1 horizon (0.9 g/cm³; 11.7% organic matter) shows reduced maximal (57.5%) and field capacity (44.2%), with slightly higher available water (23.5%) and moderate conductivity (31.4 cm/day). The Ahυτ2 horizon (1.2 g/cm³; 5.8% organic matter) continues the trend of decreasing total retention (maximal 48.3%, field 37.3%) but maintains available water (23.5%) and lower conductivity (17.5 cm/day). In the Ahur2/C horizon (1.4 g/cm³; 3.8% organic matter), maximal (42.4%) and field capacity (29.8%) further decline, with available water slightly lower (21.9%) and conductivity moderate (25.4 cm/day). The deepest C horizon (1.6 g/cm³; 1.3% organic matter) exhibits the lowest total retention (maximal 37.3%, field 26.7%) but maintains available water (22.4%), with conductivity of 18.6 cm/day.

Table 11A: Soil properties of particular horizons - profile No. 11

Soil Horizon	Maximal Water Capacity (% vol.)	Field Water Capacity (% vol.)	Permanent Wilting Point (% vol.)	Available Water Capacity (% vol.)	Saturated Hydraulic Conductivity (cm/day)	Bulk Density (g/cm³)	Organic Matter (% wt.)
meAh	72.1	51.5	28.7	22.8	49.1	0.5	26.3
meAhυτ1	57.5	44.2	20.7	23.5	31.4	0.9	11.7
Ahυτ2	48.3	37.3	13.9	23.5	17.5	1.2	5.8
Ahυτ2/C	42.4	29.8	7.9	21.9	25.4	1.4	3.8
Cτ	37.3	26.7	4.3	22.4	18.6	1.6	1.3

Overall, available water capacity remains relatively stable (~22-24%) across all horizons despite strong decreases in organic matter and total soil water retention curve.

Table 11B: Micronutrients content

Soil horizon	P	Ca	Mg	K	CEC	BS
	mg/kg				mmol/kg	%
OH	38	391	243	165	363.3	12.4
meAh	88	125	129	223	169.2	18.4
meAhυτ1	69	104	77	74	82.7	22.6
Ahυτ2	100	91	59	47	44.5	39.3
Cτ	188	103	63	38	32.5	47.7

Table 11C: Soil texture characteristics and Soil reaction

Soil horizon		Texture class	Slaking index	Battance class	pH_{water}	pH_{KCl}
OH					3.5	3.2
meAh		sandy loam	0.89	non battant	3.5	2.9
meAhυτ1		sandy loam	0.98	non battant	4.1	3.7
Ahυτ2		silt loam	1.63	assez battant	4.1	4.0
Cτ		sandy loam	1.69	assez battant	4.1	4.1



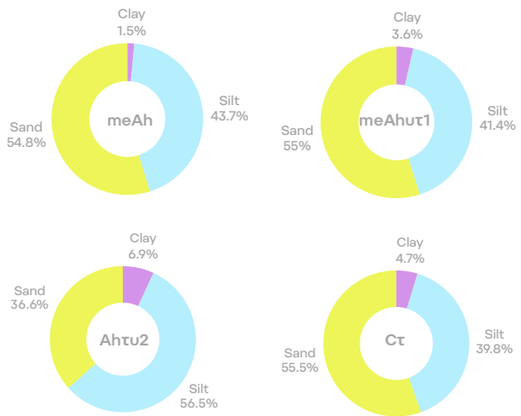


Figure 11B: Soil texture

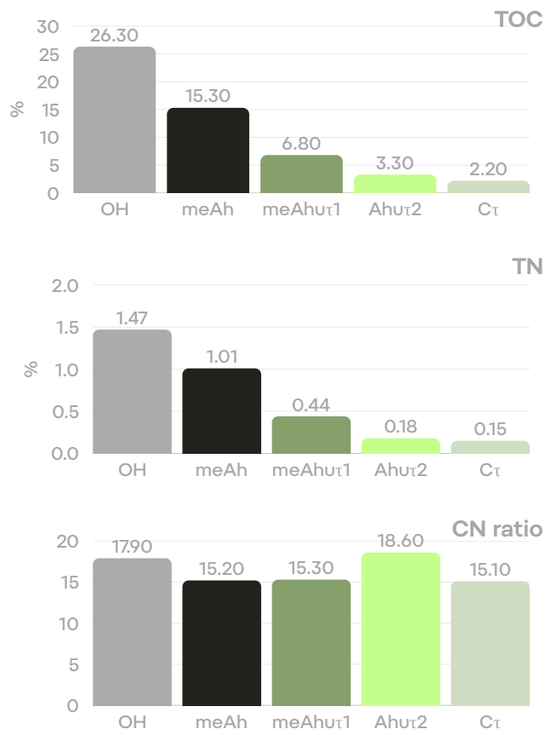


Figure 11C: Total soil carbon and nitrogen characteristics

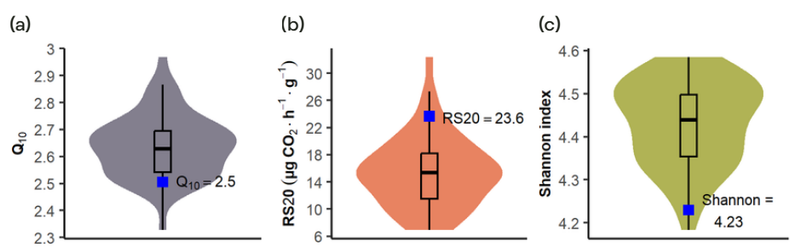
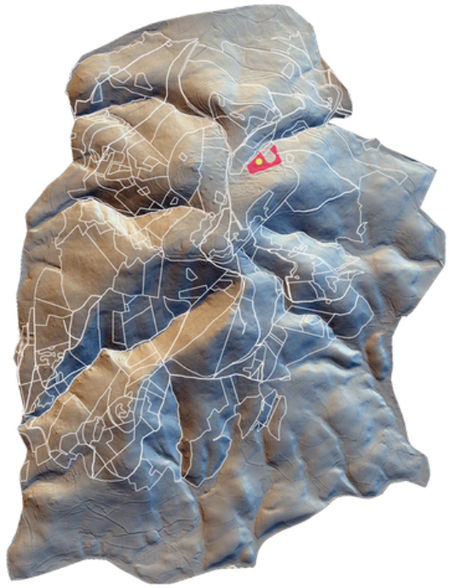


Figure 11D:
(a) Q10: the temperature sensitivity of soil respiration
(b) RS20: soil respiration value for a standardized temperature of 20 degrees
(c) Shannon: soil molecular diversity index, based on the identification of compounds from the main molecular families

Silver Fir

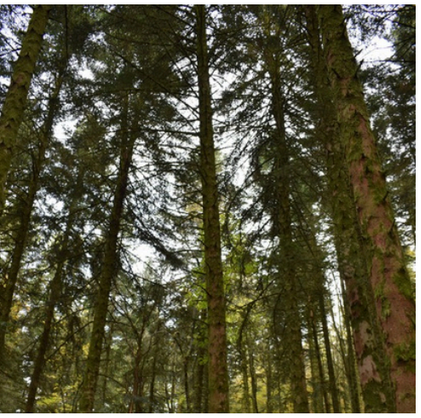
site
12

SILVER FIR



GPS (N): 4.0397950°
GPS (E): 46.9272940°
Localization: intramuros (2nd rampart)
Altitude: 740 m a.s.l.
Inclination: 14°
Exposure: NNE

The profile is located on a straight, distinctly terraced (anthropogenic) slope (inclination 14°, north-northeast exposure). The tree layer consits of silver fir. The shrub layer consists of holly covering approximately 30% of the area. The herbacaous layer is sparsely covered with mosses and ferns.





With respect to erosion risk, the soil can be considered relatively stable, partly due to a slightly higher proportion of fine soil fractions compared with other sites. Elevated organic carbon contents in the upper horizons support both water holding capacity and cation exchange capacity, which remain sufficient throughout the profile. The soil is notably rich in phosphorus and moderately supplied with other nutrients (calcium, magnesium and potassium), most likely reflecting its anthropogenic origin and redistribution processes within the permeable soil environment. Despite relatively high total nutrient pools in the substrate, the exchangeable nutrient fractions remain low, as indicated by the low base saturation. For forest management, diversification of the current Eurepean silver fir stand is advisable through small canopy gaps supporting natural regeneration and admixture of target tree species. Long-term stand stability will likely benefit from a mosaic spatial and temporal structure.

Soil Taxonomic Unit:

Urbic Technosol (Cambic, Humic, Katoskeletic, Loamic, Orthodystric, Solimovic, Transportic)

Stratigraphy:
OL-OFzo-OH-meAh-meAτ1-Aτ2-Cτu-Bwτub

Humus form:
Eumesoamphi

OL (2 cm): Loose, siver fir litter (needles, twigs, cone scales); covered by Sphagnum.

OFzo (1 cm): Thin, dry.

OH (0.5 cm): Thin, dry, discontinuous.

meAh (0-3.0 cm)
Color: 10YR 2/2 (very dark brown), texture class: sandy loam, stoniness: 15% (angular fine gravel), structure: fine granular, bulk density: loose, moisture: very dry, root density: <2 mm: 120 pcs/dm^2, >2 mm: 40 pcs/dm^2. Recent organomineral layer development.

meAhτ1 (3.0-23.0 cm)
Color: 10YR 3/3 (dark brown), texture class: sandy loam, stoniness: 15% (angular fine gravel), structure: fine granular, bulk density: loose, moisture: dry, root density: <2 mm: 90 pcs/dm^2, >2 mm: 30 pcs/dm^2.

Aτ2 (23.0-36.0 cm)
Color: 10YR 3/2 (very dark grayish brown), texture class: loam, stoniness: 15% (angular stones), structure: medium subangular blocky, bulk density: loose, moisture: slightly moist, root density <2 mm: 30 pcs/dm^2, >2 mm: 5 pcs/dm^2.

Cτu (36.0-64.0 cm)
Color: 10YR 3/4 (dark yellowish brown), texture class: loam, stoniness: 70% (angular stones), structure: fine subangular blocky, bulk density: loose, moisture: slightly moist, root density <2 mm: 10 pcs/dm^2, >2 mm: 2 pcs/dm^2. Fragments of bricks and amphoras, admixture of volcanic rocks.

Bwτub (>64.0 cm)
Color: 10YR 3/6 (dark yellowish brown), texture class: loam, stoniness: 40% (angular stones), structure: medium subangular blocky, bulk density: loose, moisture: slightly moist, root density <2 mm: 5 pcs/dm^2, >2 mm: <1 pc/dm^2. Buried cambic horizon with features of transport/pedoturbation. Fragments of bricks and amphoras, admixture of volcanic rocks.



Within the habitat, the anthropogenic soil is a part of terrace system of the slope - related to human activities. Soil with deep rooting (gradation of root density within 40 cm; physiological depth ca. 60 cm).



SOIL CHARACTERISTICS

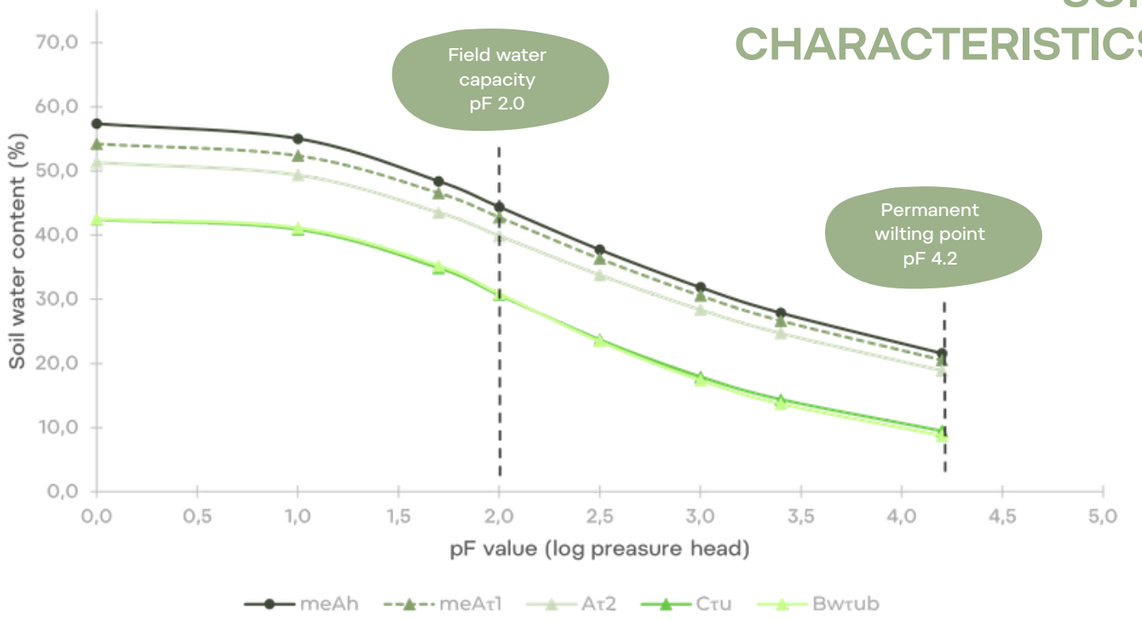


Figure 12A: Water retention curve showing the relationship between soil water content and pF value

Profile No. 12 displays clear vertical differentiation in hydro-physical properties (Fig. 12A; Table 12A). The surface meAh horizon has relatively low bulk density (0.9 g/cm³) and moderate organic matter content (11.6%), with maximal water content of 57.3% and field capacity of 44.4%. Available water capacity is 22.8%, and saturated hydraulic conductivity is 32.3 cm/day. The intermediate technical meAτ1 and Aτ2 horizons show gradual increases in bulk density (1.0–1.1 g/cm³) and decreases in organic matter (9.8–7.0%), accompanied by slight reductions in maximal and field water capacities. Available water capacity remains stable (21–22%), while conductivity between 18.7 and 38.8 cm/day.

Table 12A: Soil properties of particular horizons – profile No. 12

Soil Horizon	Maximal Water Capacity (% vol.)	Field Water Capacity (% vol.)	Permanent Wilting Point (% vol.)	Available Water Capacity (% vol.)	Saturated Hydraulic Conductivity (cm/day)	Bulk Density (g/cm³)	Organic Matter (% wt.)
meAh	57.3	44.4	21.6	22.8	32.3	0.9	11.6
meAτ1	54.2	42.8	20.5	22.3	18.7	1.0	9.8
Aτ2	51.3	39.9	18.9	21.0	38.8	1.1	7.0
Cτu	42.4	30.7	9.4	21.2	25.1	1.4	3.6
Bwτub	42.5	30.9	8.7	22.1	23.2	1.4	3.1

The deepest horizons, Cτu and Bwτub, are clearly distinct from the upper horizons. They have higher bulk density (1.4 g/cm³) and very low organic matter content (3.6–3.1%), reflecting compacted mineral subsoil. Maximal (42.4–42.5%) and field water capacities (30.7–30.9%) are substantially lower than in the horizons above, and permanent wilting points are very low (8.7–9.4%). Despite this, available water capacity remains relatively stable (~21–22%), while saturated hydraulic conductivity decreases moderately (23.2–25.1 cm/day), indicating reduced pore connectivity. These properties clearly distinguish the deepest mineral horizons from the upper, more total porous and organic-rich layers.

Table 12B: Micronutrients content

Soil horizon	P	Ca	Mg	K	CEC	BS
	mg/kg				mmol/kg	%
OH	22	296	197	174	331	10.6
meAh	28	60	70	91	89.9	18.8
meAτ1	36	52	57	54	65.1	20.1
Aτ2	75	55	56	51	54.4	24.6
Cτu	190	61	52	49	34.1	38.5
Bwτub	197	170	112	45	35.8	69.3

Table 12C: Soil texture characteristics and Soil reaction

Soil horizon		Texture class	Slaking index	Battance class	pH_{water}	pH_{KCl}
OH					3.6	3.1
meAh	●	sandy loam	0.97	non battant	4.3	3.7
meAτ1	●	silt loam	1.14	non battant	4.4	3.9
Aτ2	●	loam	1.08	non battant	4.4	3.9
Cτu	●	loam	1.83	battant	3.9	4.1
Bwτub	●	sandy loam	2.19	tres battant	3.9	4.1



Figure 12B: Soil texture

Figure 12C: Total soil carbon and nitrogen characteristics

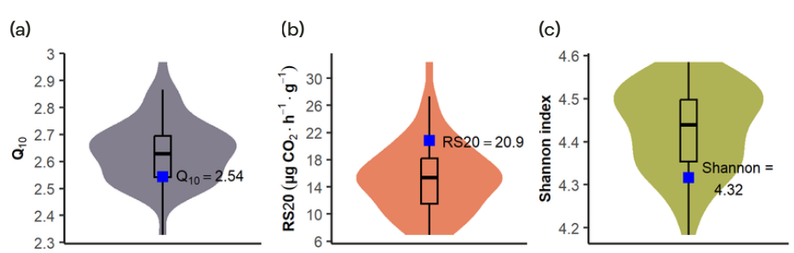


Figure 12D:
(a) Q10: the temperature sensitivity of soil respiration
(b) RS20: soil respiration value for a standardized temperature of 20 degrees
(c) Shannon: soil molecular diversity index, based on the identification of compounds from the main molecular families

Silver Fir

site

13

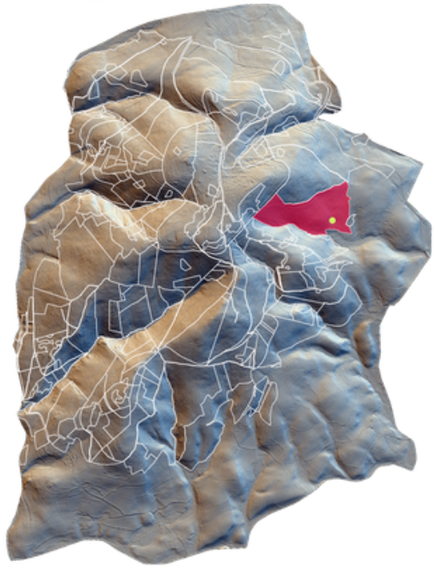
DOUGLAS FIR

Douglas Fir

Soil Taxonomic Unit:

Endoskeletic Cambic Umbrisol (Loamic, Solimovic)

GPS (N):	4.0497220°
GPS (E):	46.9217360°
Localization:	extramuros
Altitude:	583 m a.s.l.
Inclination:	17°
Exposure:	SE



The profile is located on a straight slope (inclination 17°, south-east exposure) with debris on the surface and topsoil as a consequence of the solifluction. The tree layer consists of douglas fir with mixture of sycamore and beech. The shrub layer consists of occasionally holly and bramble. The herbaceous layer is absent. Mosses and ferns can be found sporadically.





Stratigraphy:

OL-OFzo-OH-meAh1-meAh2-Bw-BwC-C

Humus form:

Pachyamphi

OL (2 cm): Douglas fir continuous litter of needles, twigs, branches and cones.

OFzo (0.5 cm): Dominance of fungi mycelia, grown through mosses.

OH (8.5 cm): Very thick, dark, sporadically accumulated in pockets, high root density.



meAh1 (0-7 cm)

Color: 10YR 3/3 (dark brown), texture class: loam, stoniness: 15% (angular fine gravel), structure: fine granular, bulk density: very loose, moisture: dry, root density: <2 mm: 120 pcs/dm^2, >2 mm: 30 pcs/dm^2. Wavy shape of lower boundary.

meAh2 (7.0-38.0 cm)

Color: 10YR 2/2 (very dark brown), texture class: loam, stoniness: 35% (angular coarse gravel), structure: medium granular, bulk density: loose, moisture: slightly moist, root density: <2 mm: 80 pcs/dm^2, >2 mm: 8 pcs/dm^2. Umbric.

Bw (38.0-72.0 cm)

Color: 10YR 4/6 (dark yellowish brown), texture class: clay loam, stoniness: 40% (angular fine gravel), structure: fine subangular blocky, bulk density: loose, moisture: slightly moist, root density <2 mm: 70 pcs/dm^2, >2 mm: 10 pcs/dm^2. Wavy shape of lower boundary.

BwC (72.0-91.0 cm)

Color: 10YR 5/6 (yellowish brown), texture class: silty clay loam, stoniness: 65% (angular medium gravel), structure: fine angular blocky, bulk density: loose, moisture: slightly moist, root density <2 mm: 30 pcs/dm^2, >2 mm: 2 pcs/dm^2.

C (>91.0 cm)

Color: 10YR 4/4 (dark yellowish brown), texture class: silty clay loam, stoniness: 70% (angular coarse gravel), structure: very fine simple grain, bulk density: loose, moisture: slightly moist, root density <2 mm: 10 pcs/dm^2, >2 mm: 2 pcs/dm^2. Markable admixture of loess (in-situ formed silt) material.

The soil profile shows relatively high erosion sensitivity of the mineral part due to the dominance of silt and very low clay content. This limits sorption capacity and water retention while promoting high permeability. Chemical properties confirm low cation exchange capacity in mineral horizons. The soil-forming substrate is strongly depleted in calcium and poor in magnesium, whereas potassium is relatively higher, which is reflected in base cation ratios throughout the profile. Calcium deficiency may reduce aggregate stability and buffering capacity and influence microbial composition, typically favouring fungal over bacterial communities. Elevated Al/Bc ratios indicate potential constraints for root development. In the continuous douglas fir stand, a gradual regeneration approach is advisable, including advance underplanting and spatially differentiated methods such as multiple small gaps or narrow cutting faces.

Soil with clear distinctness of individual horizons with abrupt-to-clear distinctness in transition zones; relatively long term in situ metamorphic processes leading to differenciation of cambic horizon. Weak development of structure and loose bulk density, together with inflexed bases of Douglas fir trunks corresponds with slow solifluction.
Topsoil affected with denudation processes (accumulation of fine gravel at soil surface) where neoformation of organic layers is linked with recent forest generation.
Silt admixture in subsoil corresponds with periglacial weathering.



SOIL CHARACTERISTICS

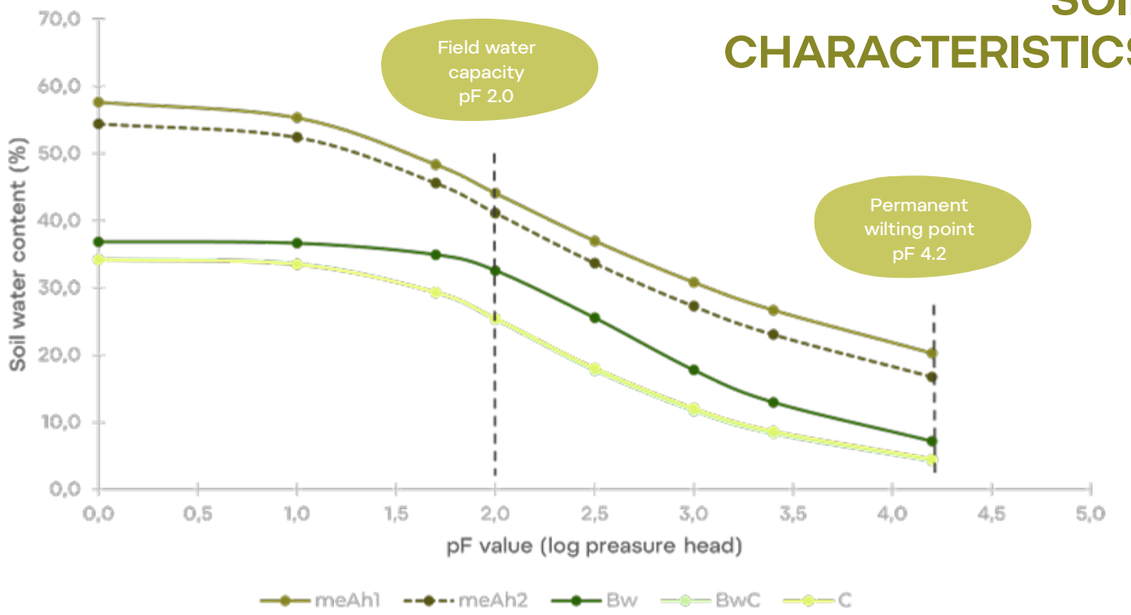


Figure 13A: Water retention curve showing the relationship between soil water content and pF value

Both meAh1 and meAh2 horizons have low bulk density (0.9–1.0 g/cm³) and higher organic matter (11.8–9.1%), resulting in high maximal (54.5–57.7%) and field water capacities (41.2–44.1%). Saturated hydraulic conductivity is very high (33.1–34.3 cm/day), indicating rapid infiltration and a well-connected soil structure. A marked change occurs in the Bw horizon, where bulk density increases significantly to 1.6 g/cm³ and organic matter declines to 1.6%. Although maximal water capacity drops to 36.9%, field water capacity remains relatively high (32.6%), and available water capacity reaches 25.4%. However, saturated hydraulic conductivity sharply decreases to 5.1 cm/day, indicating restricted vertical water movement due to compaction and reduced macroporosity. The BwC and C horizons remain strongly compacted (1.7 g/cm³) with minimal organic matter (0.9%). Water retention stabilizes (maximal ~34%, field ~25–26%), while hydraulic conductivity increases again (16.2–16.6 cm/day), probably likely due to soil water retention pores.

Table 13A: Soil properties of particular horizons – profile No. 13

Soil Horizon	Maximal Water Capacity (% vol.)	Field Water Capacity (% vol.)	Permanent Wilting Point (% vol.)	Available Water Capacity (% vol.)	Saturated Hydraulic Conductivity (cm/day)	Bulk Density (g/cm³)	Organic Matter (% wt.)
meAh1	57.7	44.1	20.3	23.8	33.1	0.9	11.8
meAh2	54.5	41.2	16.8	24.4	34.3	1.0	9.1
Bw	36.9	32.6	7.2	25.4	5.1	1.6	1.6
BwC	34.3	25.3	4.3	21.0	16.6	1.7	0.9
C	34.2	25.5	4.5	20.9	16.2	1.7	0.9

Available water capacity varies from 20.9% to 25.4% across the profile. Despite strong subsoil compaction, the profile overall retains a relatively good supply of plant-available water, with the most favorable soil water storage conditions occurring in the Bw horizon.

Douglas Fir

Table 13B: Micronutrients content

Soil horizon	P	Ca	Mg	K	CEC	BS
	mg/kg				mmol/kg	%
OH	15	373	72	111	240.8	11.3
meAh1	5	105	50	94	61.0	21.3
meAh2	4	86	36	67	42.1	23.9
Bw	11	94	38	56	21.6	49.1
BwC	19	109	46	55	19.5	59.0
C	20	67	25	55	20.2	40.7

Table 13C: Soil texture characteristics and Soil reaction

Soil horizon		Texture class	Slaking index	Battance class	pH_{water}	pH_{KCl}
OH					3.8	3.1
meAh1		sandy loam	1.00	non battant	3.8	3.7
meAh2		sandy loam	1.10	non battant	3.9	3.9
Bw		silt loam	5.10	tres battant	3.9	4.0
BwC		sandy loam	4.68	tres battant	4.6	3.9
C		sandy loam	4.78	tres battant	4.6	3.9

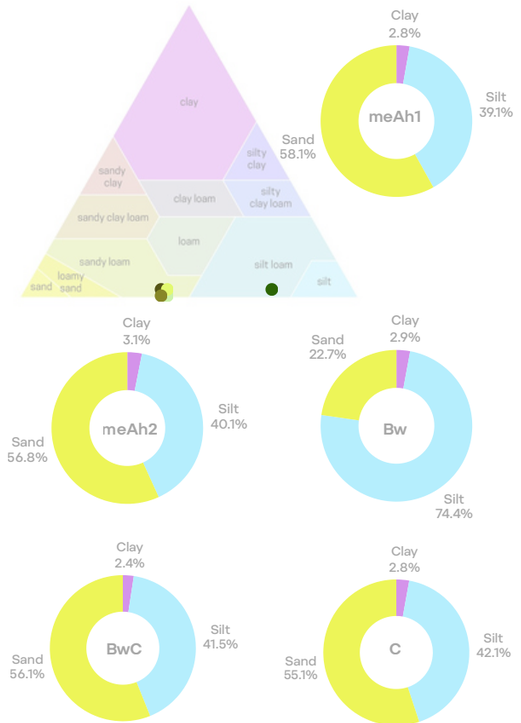


Figure 13B: Soil texture

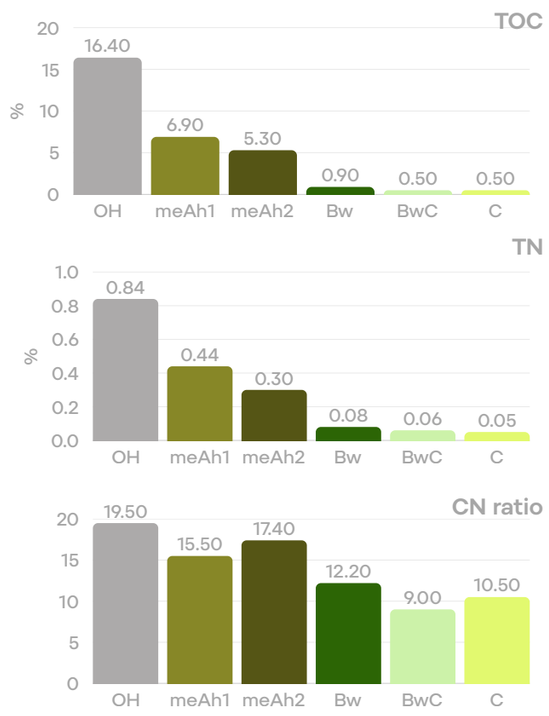


Figure 13C: Total soil carbon and nitrogen characteristics

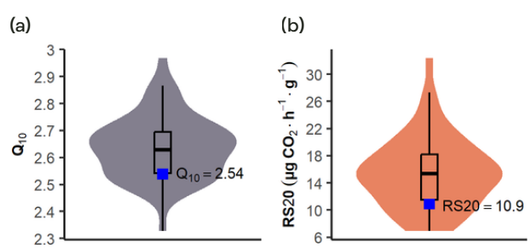
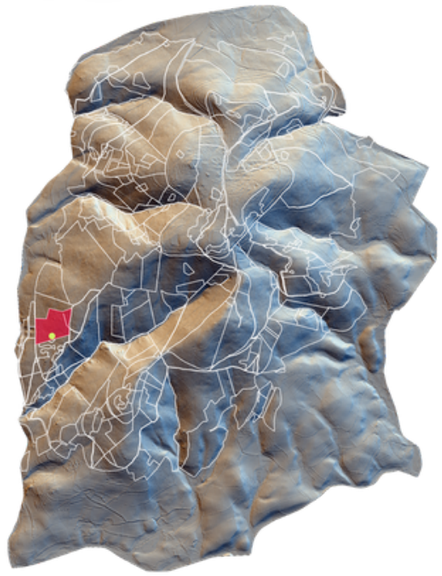


Figure 13D:
(a) Q10: the temperature sensitivity of soil respiration
(b) RS20: soil respiration value for a standardized temperature of 20 degrees
(c) Shannon: soil molecular diversity index, based on the identification of compounds from the main molecular families

site
14

DOUGLAS FIR

GPS (N):	4.014810°
GPS (E):	46.9126930°
Localization:	extramuros
Altitude:	490 m a.s.l.
Inclination:	15°
Exposure:	W



The profile is located at the lower part of a straight west slope (inclination 15°, west exposure). The tree layer consists of douglas fir (80%) with mixture of beech and sweet chestnut. The shrub layer is absent. The herbaccaous layer consists of moss (more than 50%), seedlings, bramble and fern can be found sporadically.





Siltic texture (silt exceeding 70 %) results in a high slaking index and increased erosion susceptibility, especially in deeper horizons with lower organic matter content. The soil is strongly acidic throughout the profile and shows low cation exchange capacity. Acid cations dominate the exchange complex, particularly in the organomineral horizon. The parent material is poor in calcium, while Mg is slightly higher and K reaches optimal to supra-optimal levels; available phosphorus remains very low despite higher total content in the subsoil. Thick humus layers represent a substantial nitrogen reservoir that may be rapidly mineralised after canopy opening, promoting nitrophilous vegetation. To prevent this, gradual regeneration and species diversification of the douglas fir stand are recommended. Suitable admixture species include European beech and European silver fir in gaps, European larch along cutting edges, and silver birch with European aspen; sycamore is suitable in lower slope positions.

Soil Taxonomic Unit:
Endoskeletic Cambic Umbrisol (Anosiltic, Humic, Solimovic)

Stratigraphy:
OL-OFzo-OH-meAh-Bw-BwC-C

Humus form:
Eumesoapmhi

OL (2 cm):

OFzo (2 cm): Sometimes discontinuous.

OH (0.5 cm): Discontinuous, sparse.



meAh (0–27.5 cm)
Color: 10YR 3/2 (very dark grayish brown), texture class: loam, stoniness: 25% (angular coarse gravel), structure: fine granular, bulk density: very loose, moisture: slightly moist, root density: <2 mm: 90 pcs/dm^2, >2 mm: 5 pcs/dm^2. Umbric; gradual transition to Bw (within 10 cm).

Bw (27.5–59.5 cm)
Color: 10YR 4/6 (dark yellowish brown), texture class: silty clay loam, stoniness: 35% (angular coarse gravel), structure: medium polyhedral, bulk density: intermediate, moisture: slightly moist, root density: <2 mm: 60 pcs/dm^2, >2 mm: 2 pcs/dm^2.

BwC (59.5–82.0 cm)
Color: 10YR 4/6 (dark yellowish brown), texture class: sandy loam, stoniness: 60% (angular stones), structure: fine polyhedral, bulk density: loose, moisture: moist, root density <2 mm: 10 pcs/dm^2, >2 mm: <1 pc/dm^2.

C (>82.0 cm)
Color: 10YR 5/6 (yellowish brown), texture class: silt loam, stoniness: 70% (angular boulders), structure: very fine massive, bulk density: intermediate, moisture: slightly moist, root density <2 mm: 3 pcs/dm^2, >2 mm: <1 pc/dm^2.

Moderately deep Umbrisol with development of cambic horizon on a leucocrate volcanic material; dominating silit fraction within whole profile. Evident but not extraordinary accumulation of an organic material from upper parts of slope. Slow transition of A to B horizon. Reduced organic layers thickness due to steep slope and gravitation/surface water movement of surface material.
Continuous old Douglas fir monocenosis with evident development of nitrophilous vegetation even after a slight access of light on soil surface. Beside thin organic layers, thicker branches slowly decompose and rather accumulate on soil surface.



SOIL CHARACTERISTICS

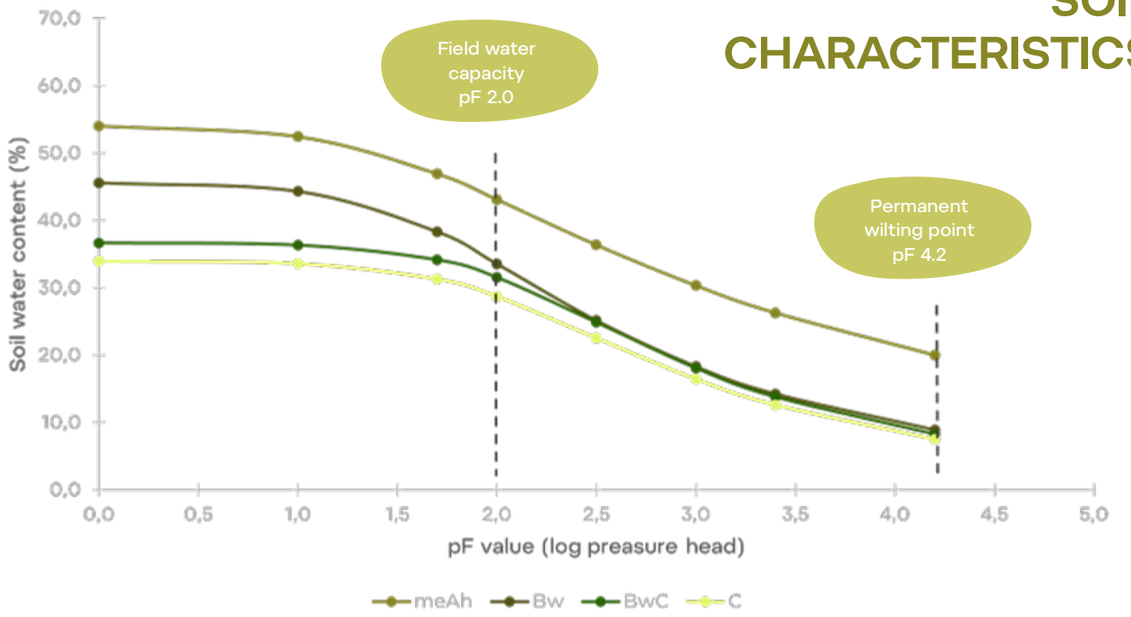


Figure 14A: Water retention curve showing the relationship between soil water content and pF value

Profile No. 14 shows distinct vertical variations in descripted soil water retention curves (Fig. 14A). The topsoil meAh horizon has a bulk density of 1.0 g/cm³ and 9.1% organic matter, with a maximal water capacity of 54.1% and field water capacity of 43.1%. Hydraulic conductivity at this horizon is 9.4 cm/day, indicating moderate water infiltration and redistribution. The underlying Bw horizon stands out due to its exceptionally high hydraulic conductivity (20.2 cm/day), which is significantly higher than in the other horizons. This suggests that the Bw horizon facilitates efficient water infiltration and redistribution despite the increase in bulk density (1.3 g/cm³) and the decrease in organic matter content (4.0%). At the same time, the available water capacity in the Bw horizon is 24.7%, indicating that while it stores less total soil water than the other horizons, it retains water that is readily available to plants.

Table 14A: Soil properties of particular horizons - profile No. 14

Soil Horizon	Maximal Water Capacity (% vol.)	Field Water Capacity (% vol.)	Permanent Wilting Point (% vol.)	Available Water Capacity (% vol.)	Saturated Hydraulic Conductivity (cm/day)	Bulk Density (g/cm³)	Organic Matter (% wt.)
meAh	54.1	43.1	20.0	23.1	9.4	1.0	9.1
Bw	45.6	33.6	8.9	24.7	20.2	1.3	4.0
BwC	36.7	31.6	8.3	23.3	6.6	1.6	1.8
C	34.0	28.7	7.5	21.2	9.1	1.7	0.8

In contrast, the deeper BwC and C horizons exhibit lower hydraulic conductivity (6.6 cm/day and 9.1 cm/day, respectively) and reduced water retention, reflecting compaction and lower permeability of these layers.

Douglas Fir

Table 14B: Micronutrients content

Soil horizon	P	Ca	Mg	K	CEC	BS
	mg/kg				mmol/kg	%
OH	11	305	73	115	234.5	10.3
meAh	3	86	36	60	32.3	31.8
Bw	7	81	32	54	20.5	41.3
BwC	9	99	42	57	18.9	57.8
C	13	89	48	55	26.4	35.5

Table 14C: Soil texture characteristics and Soil reaction

Soil horizon		Texture class	Slaking index	Battance class	pH_{water}	pH_{KCl}
OH					3.9	3.3
meAh		silt loam	1.39	non battant	4.6	3.9
Bw		silt loam	1.87	battant	4.6	4.0
BwC		silt loam	3.85	tres battant	4.6	4.0
C		silt loam	5.57	tres battant	4.6	4.1

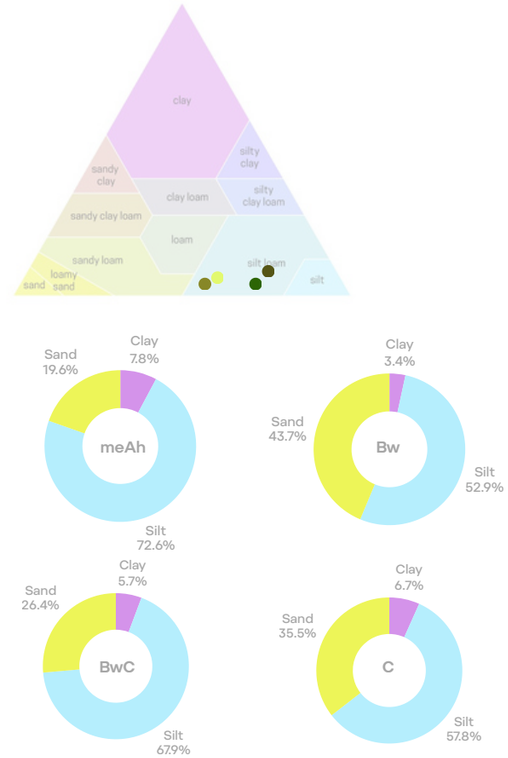


Figure 14B: Soil texture

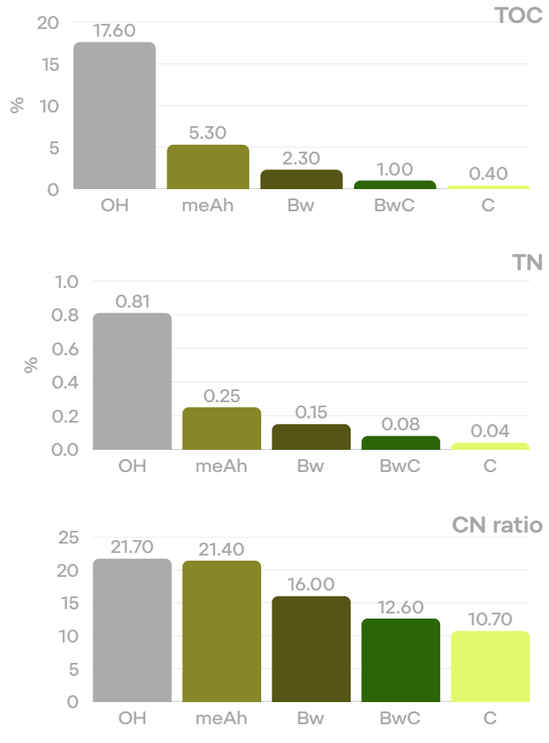


Figure 14C: Total soil carbon and nitrogen characteristics

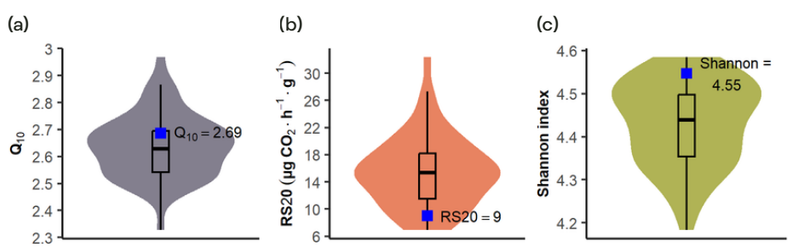


Figure 14D:
(a) Q10: the temperature sensitivity of soil respiration
(b) RS20: soil respiration value for a standardized temperature of 20 degrees
(c) Shannon: soil molecular diversity index, based on the identification of compounds from the main molecular families

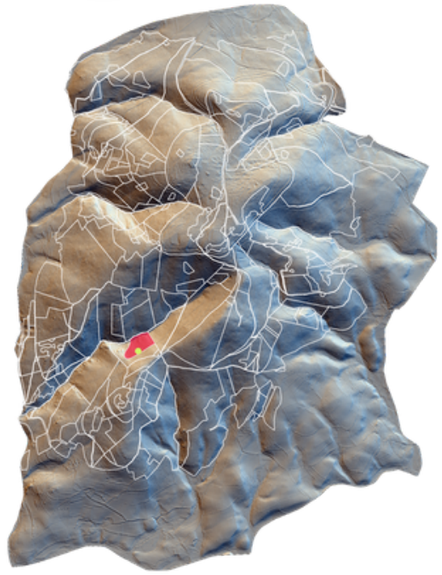
site

15

DOUGLAS FIR

Douglas Fir

GPS (N):	4.0252990°
GPS (E):	46.9112560°
Localization:	extramuros
Altitude:	557 m a.s.l.
Inclination:	33°
Exposure:	NW



The profile is located at the lower part of a steep, straight slope (inclination 33°, north-west exposure). The tree layer consists of monoculture of douglas fir. The herbaceous layer is essentially absent (with the occasional fern). On a steep slope, surface movement of material that affects douglas fir trees.





Soil texture is loamy, becoming more siltic in the subsoil, with dominance of silt and sand fractions. Very acidic soil conditions are documented by low pH values, while cation exchange capacity is moderate due to high organic matter in the topsoil. Base saturation strongly increases in the subsoil, where higher concentrations of calcium and magnesium occur. Elevated TOC throughout the profile reflects pedoturbation processes linked with the steep slope. The stabilising function of forest cover is therefore essential and erosion risk should be minimised by maintaining continuous soil protection. The douglas fir stand should be gradually divided into smaller sections with regeneration openings, combined with planting of European larch and European silver fir, supported by silver birch, European aspen and mountain ash or service tree. Northern red oak may also represent an economically and ecologically stabilising admixture species.

Soil Taxonomic Unit:

Katoskeletic Solimovic Epidystric Cambisol (Anosiltic, Humic, Solimovic)

Stratigraphy:

OL-OFzo-OH-meAh-Bw-BwC

Humus form:

Eumesoapmhi

OL (1 cm): Dry, thin, continuous douglas fir litter (needles, branches, cons).

OFzo (0.5 cm): Mycogenic (less amphigenic).

OH (0.5 cm): Discontinuous, locally accumulated in microdepresions, light, dry.



meAh (0-10.0 cm)

Color: 10YR 3/2 (very dark grayish brown), texture class: loamy sand, stoniness: 40% (angular coarse gravel), structure: medium granular, bulk density: very loose, moisture: very dry, root density: <2 mm: 130 pcs/dm^2, >2 mm: 40 pcs/dm^2.

Bw (10.0-63.0 cm)

Color: 10YR 4/4 (dark yellowish brown), texture class: sandy loam, stoniness: 55% (angular boulders), structure: very fine granular, bulk density: very loose, moisture: very dry, root density: <2 mm: 120 pcs/dm^2, >2 mm: 20 pcs/dm^2.

BwC(>63.0 cm)

Color: 10YR 3/4 (dark yellowish brown), texture class: loam, stoniness: 70% (angular boulders), structure: very fine angular blocky, bulk density: very loose, moisture: slightly moist, root density <2 mm: 30 pcs/dm^2, >2 mm: 7 pcs/dm^2.

Cambisol disturbed by slope solifluction within the main soil strata. High stoniness in deeper layers transiting to highly weathered bedrock (soil forming substrate). Trunks of Douglas fir are slightly edged due to slope movement (trees inclination until the roots reach subsoil and stabilize tree). Very loose profile, no evident marks of erosion.
Douglas fir stand in matured stage of development with larger distances of trees (canopy cover ca. 60%); absence of understory vegetation.



SOIL CHARACTERISTICS

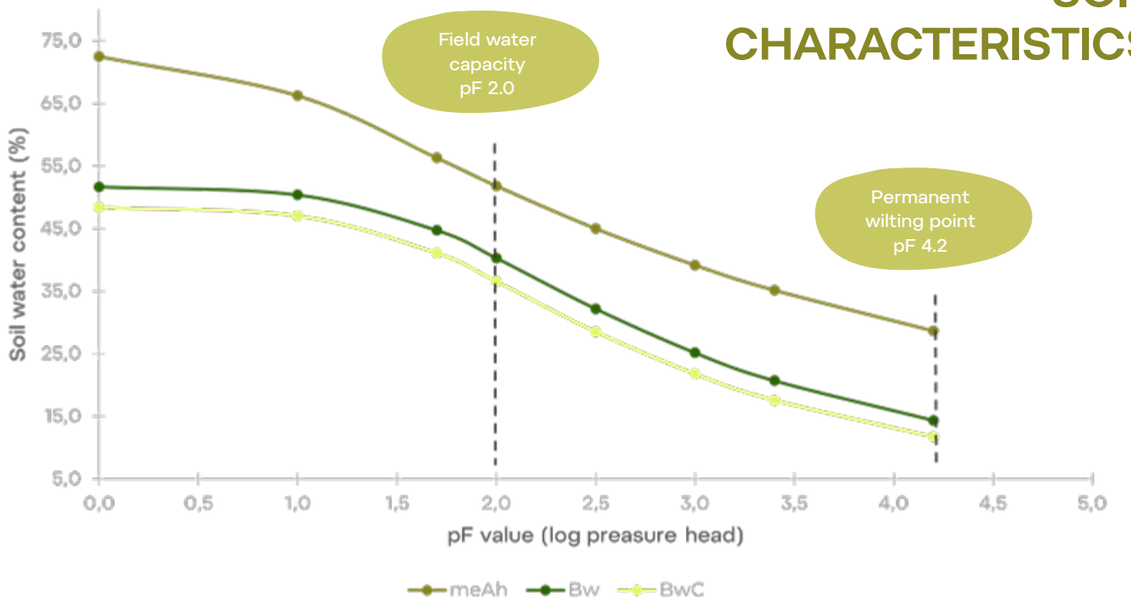


Figure 15A: Water retention curve showing the relationship between soil water content and pF value

Profile No. 15 also shows distinct changes in soil properties with depth. The surface organic-rich meAh horizon (35.0%, Table 15A) is characterized by very low bulk density (0.4 g/cm³), leading to a high maximal water capacity of 72.5% and a field water capacity of 51.8%. The exceptionally high saturated hydraulic conductivity of 51.3 cm/day in this horizon indicates high infiltration and redistribution of water through it. As we move to the Bw horizon, bulk density increases to 1.1 g/cm³ and organic matter decreases to 7.4%. This results in a reduced maximal water capacity (51.7%) and field water capacity (40.3%). The saturated hydraulic conductivity drops to 11.5 cm/day, suggesting a moderate reduction in water movement compared to the meAh horizon.

Table 15A: Soil properties of particular horizons – profile No. 15

Soil Horizon	Maximal Water Capacity (% vol.)	Field Water Capacity (% vol.)	Permanent Wilting Point (% vol.)	Available Water Capacity (% vol.)	Saturated Hydraulic Conductivity (cm/day)	Bulk Density (g/cm³)	Organic Matter (% wt.)
meAh	72.5	51.8	28.7	23.2	51.3	0.4	35.0
Bw	51.7	40.3	14.4	25.9	11.5	1.1	7.4
BwC	48.4	36.6	11.7	24.8	19.7	1.2	5.2

In the deeper BwC horizon, the bulk density further increases to 1.2 g/cm³ and organic matter content drops to 5.2%. The maximal water capacity and field water capacity decrease further to 48.4% and 36.6%, respectively. the saturated hydraulic conductivity increases slightly to 19.7 cm/day, indicating a minor improvement in water movement despite the increased compaction and reduced organic matter. However, the slight improvement in hydraulic conductivity suggests that water can still move through the soil, possibly through marcopores, despite the increased compaction. This complex interaction between soil texture and organic matter can affect soil water availability, and the overall functioning of the subsoil water storage in this profile.

Douglas Fir

Table 15B: Micronutrients content

Soil horizon	P	Ca	Mg	K	CEC	BS
	mg/kg				mmol/kg	%
OH	missing					
meAh	5	320	93	145	144.7	19.8
Bw	1	236	79	79	33.9	64.6
BwC	3	433	139	93	42.6	88.3

Table 15C: Soil texture characteristics and Soil reaction

Soil horizon		Texture class	Slaking index	Battance class	pH_{water}	pH_{KCl}
meAh		sandy loam	0.79	non battant	3.7	3.4
Bw		silt loam	1.42	peu battant	5.1	4.5
BwC		silt loam	1.51	peu battant	5.3	4.7

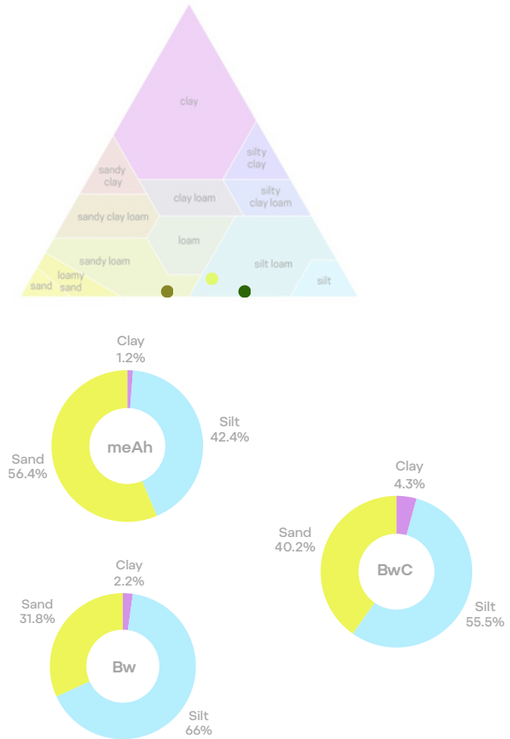


Figure 15B: Soil texture

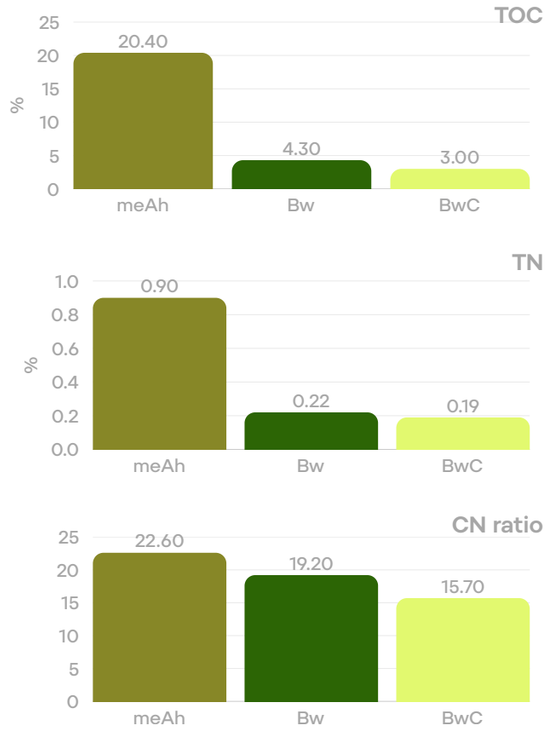


Figure 15C: Total soil carbon and nitrogen characteristics

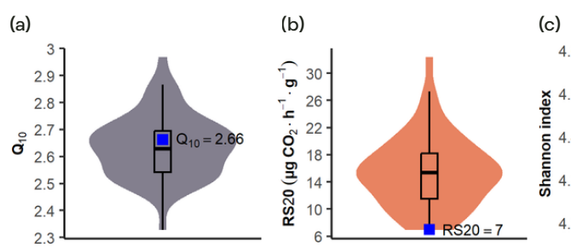
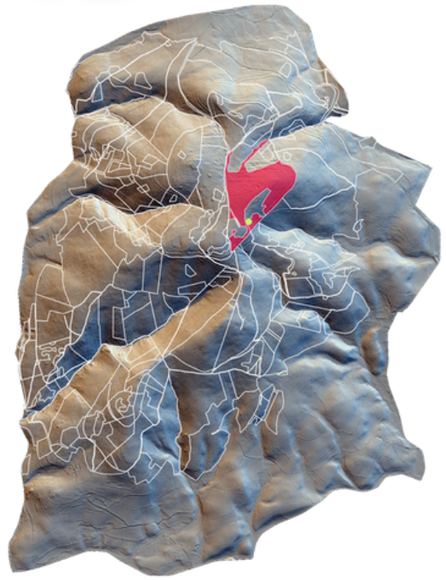


Figure 15D:
(a) Q10: the temperature sensitivity of soil respiration
(b) RS20: soil respiration value for a standardized temperature of 20 degrees
(c) Shannon: soil molecular diversity index, based on the identification of compounds from the main molecular families

site 16

DOUGLAS FIR

GPS (N):	4.0343180°
GPS (E):	46.9036040°
Localization:	extramuros
Altitude:	481 m a.s.l.
Inclination:	15°
Exposure:	SSE



The profile is located in the lower part of a gently sloping hillside (inclination 15°, south-southeast exposure). The tree layer consists of douglas fir with mixture of beech and crane. The shrub layer consists of holly and crane. The herbacaous layer consists of moss (prevailing) and fern.





The mineral subsoil is silt-rich and therefore potentially prone to erosion. Soil reaction is strongly acidic with low to moderate base saturation and a rather limited cation exchange capacity. The parent material is rich in total potassium and phosphorus but poor in calcium, reflecting the mineralogy of the silicate substrate. A part of phosphorus is likely immobilised by sorption to iron and aluminum hydroxides and by organic matter (even in low TOC content). Very high stoniness and relatively shallow humus-rich horizons restrict total nutrient pools and plant-available water. Consequently, the site is ecologically vulnerable and maintaining continuous soil cover is an essential principle of forest management. Support of advance natural regeneration prior to harvesting and admixture of dense-rooting species such as sycamore, European beech and locally Scots elm (in lighter canopy conditions) may improve soil structure, rooting density and microbial activity.

Soil Taxonomic Unit:

Katoskeletic Cambic Umbrisol (Amphisiltic, Humic, Solimovic)

Stratigraphy:

OL-OFzo-OH-meAh1-meAh2-Bw-C

Humus form:

Eumesoapmhi

OL (2 cm):	Thin, through grown with mosses; multispecies litter.
OFzo (1 cm):	Discontinuous.
OH (0.5 cm):	Very discontinuous.



meAh1 (0-6.0 cm)

Color: 10YR 2/2 (very dark brown), texture class: sandy loam, stoniness: 20% (angular medium gravel), structure: medium granular, bulk density: very loose, moisture: slightly moist, root density: <2 mm: 95 pcs/dm^2, >2 mm: 40 pcs/dm^2.

meAh2 (6.0-30.0 cm)

Color: 10YR 3/3 (dark brown), texture class: sandy loam, stoniness: 50% (angular coarse gravel), structure: medium granular, bulk density: loose, moisture: slightly moist, root density: <2 mm: 80 pcs/dm^2, >2 mm: 15 pcs/dm^2. Umbric.

Bw (30.0-60.0 cm)

Color: 10YR 4/6 (dark yellowish brown), texture class: sandy loam, stoniness: 80% (angular coarse gravel), structure: fine subangular blocky, bulk density: loose, moisture: dry, root density <2 mm: 30 pcs/dm^2, >2 mm: 3 pcs/dm^2.

C (>60.0 cm)

Color: 10YR 5/4 (yellowish brown), texture class: silt loam, stoniness: 90% (angular stones), structure: fine simple grain, bulk density: loose, moisture: dry, root density <2 mm: 5 pcs/dm^2, >2 mm: <1 pc/dm^2. Dominance of silt - periglacial weathering.

Soil corresponds with perspective conditions for forest stands sensu deep humic substances distribution and optimal stoniness within depth of ca. 30 cm. In deeper layers, predominating stones serve extreme soil conditions in cambic metamorphic horizon and alternates with silt fraction in fine earth.



SOIL CHARACTERISTICS

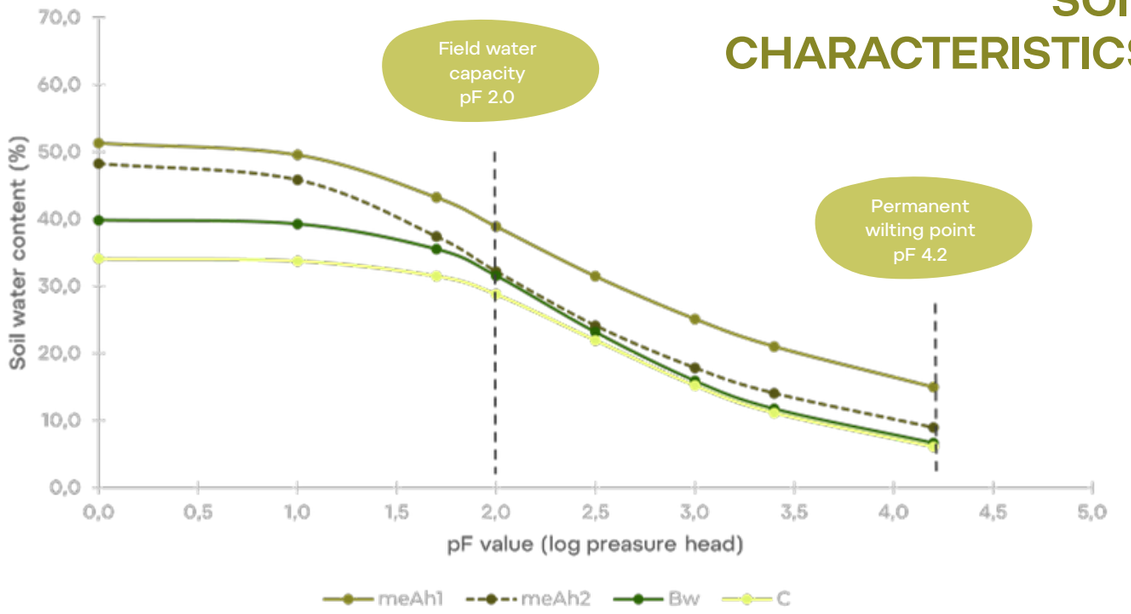


Figure 16A: Water retention curve showing the relationship between soil water content and pF value

Profile No. 16 exhibits the lowest organic matter content among all studied profiles, similar to profile No. 25 (Table 25A, Fig. 25A). Bulk density increases and organic matter decreases (Table 16A) from the surface to the deepest horizons, with pronounced differences between the upper and lower horizons. Overall, Profile 20 is notable for its relatively low organic matter, especially in the subsoil, and for the convergence of the soil water retention curves of meAh2, Bw, and C horizon (Fig. 16A), which collectively distinguish these horizons from the upper meAh1 horizon.

The upper meAh1 horizon (1.1 g/cm³; 7.7% organic matter) exhibits high maximal (51.3%) and field water capacity (38.9%), with available water at 23.9% and moderate saturated hydraulic conductivity (25.3 cm/day). In the underlying meAh2 horizon, bulk density increases (1.2 g/cm³) and organic matter decreases (5.7%), reducing maximal (48.3%) and field capacity (32.2%), while available water remains similar (23.2%) and conductivity rises sharply (56.1 cm/day).

The Bw horizon (1.5 g/cm³; 2.0% organic matter) shows further declines in retention (maximal 39.9%, field 31.6%) but slightly higher available water (24.9%) due to a low permanent wilting point (6.7%), with conductivity dropping to 10.9 cm/day. The deepest C horizon (1.7 g/cm³; 0.6% organic matter) has the lowest retention (maximal 34.1%, field 28.8%) and low conductivity (8.8 cm/day), yet available water remains reasonably stable (22.7%).

Table 16A: Soil properties of particular horizons – profile No. 16

Soil Horizon	Maximal Water Capacity (% vol.)	Field Water Capacity (% vol.)	Permanent Wilting Point (% vol.)	Available Water Capacity (% vol.)	Saturated Hydraulic Conductivity (cm/day)	Bulk Density (g/cm³)	Organic Matter (% wt.)
meAh1	51.3	38.9	15.0	23.9	25.3	1.1	7.7
meAh2	48.3	32.2	9.0	23.2	56.1	1.2	5.7
Bw	39.9	31.6	6.7	24.9	10.9	1.5	2.0
C	34.1	28.8	6.1	22.7	8.8	1.7	0.6

Douglas Fir

Table 16B: Micronutrients content

Soil horizon	P	Ca	Mg	K	CEC	BS
	mg/kg				mmol/kg	%
OH	missing					
meAh1	15	304	74	114	63.8	40.4
meAh2	16	131	46	56	54.1	27.9
Bw	79	79	43	53	27.4	45.3
C	88	124	42	66	22.4	59.8

Table 16C: Soil texture characteristics and Soil reaction

Soil horizon		Texture class	Slaking index	Battance class	pH_{water}	pH_{KCl}
meAh1		sandy loam	1.18	non battant	4.5	3.9
meAh2		loamy sand	0.96	non battant	4.6	3.8
Bw		silt loam	3.71	tres battant	4.8	4.2
C		silt loam	7.55	tres battant	5.0	4.1

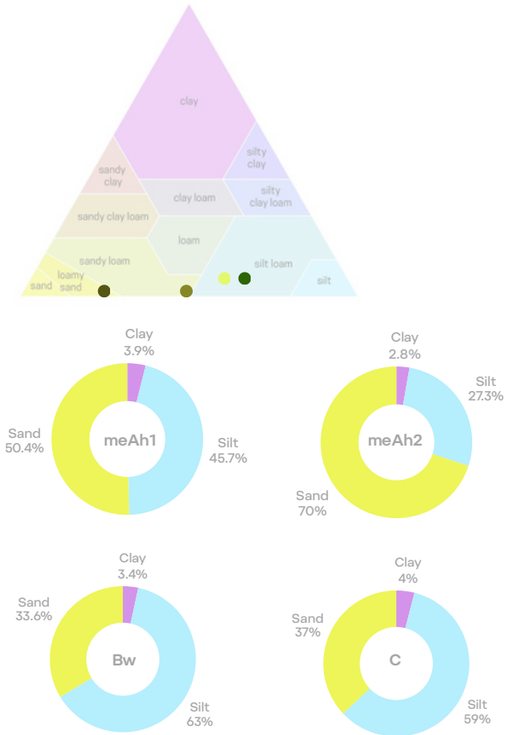


Figure 16B: Soil texture

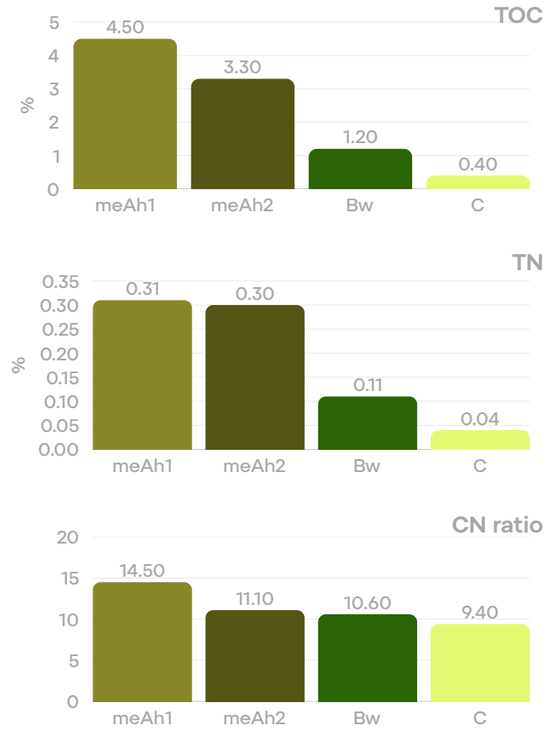


Figure 16C: Total soil carbon and nitrogen characteristics

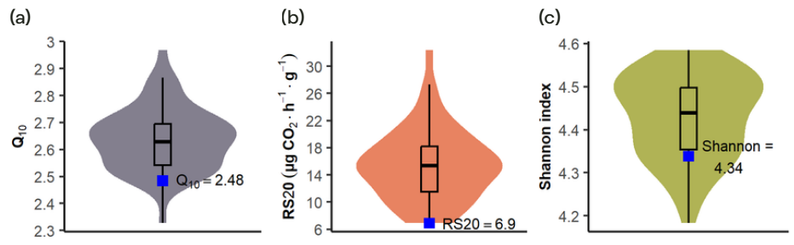
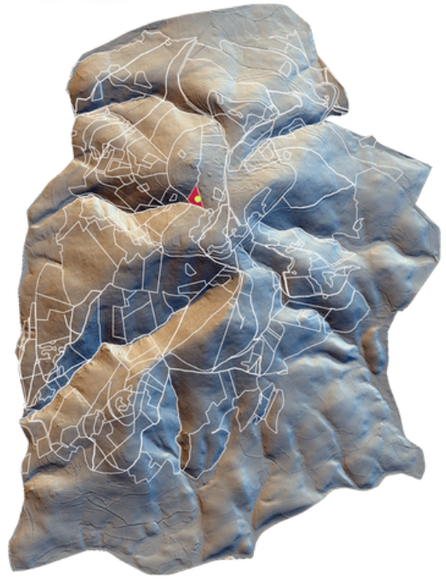


Figure 16D:
(a) Q10: the temperature sensitivity of soil respiration
(b) RS20: soil respiration value for a standardized temperature of 20 degrees
(c) Shannon: soil molecular diversity index, based on the identification of compounds from the main molecular families

site

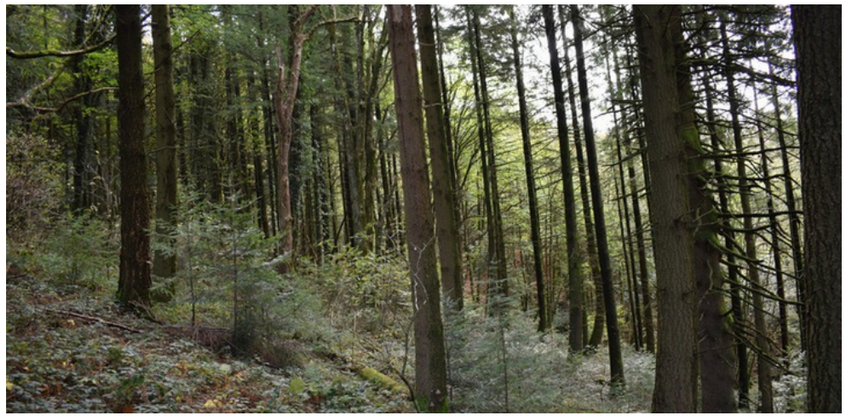
DOUGLAS FIR 17



GPS (N):	4.0325850°
GPS (E):	46.9240040°
Localization:	intramuros (2nd rampart)
Altitude:	762 m a.s.l.
Inclination:	18°
Exposure:	W

The profile is located at the break in the slope below a gently sloping plateau (inclination 18°, west exposure). The tree layer consists of douglas fir with mixture of ash. The shrub layer consists of douglas fir´s seedlings and bramble. There is no herbaceous layer, mosses are found only sporadically.





The soil surface shows relatively good resistance to erosion, whereas the silt-richer subsoil is more susceptible to disturbance. Therefore, maintaining continuous forest cover and avoiding deep skid trails are essential management principles. Ruts created by harvesting machinery and timber skidding should be promptly remediated. The soil is strongly acidic with relatively low cation exchange capacity and low to moderate base saturation, although base cation concentrations remain sufficient for forest growth. A relatively low C:N ratio indicates a potential risk of nitrogen mobilisation if mineralisation rates increase following canopy opening. Gradual stand regeneration through small canopy gaps targeted to existing regeneration patches is therefore recommended, promoting the persistence of broadleaved species. However, even slight increases in light availability may stimulate nitrophilous vegetation, particularly Rubus spp., which may require occasional manual control.

Soil Taxonomic Unit:

Endoskeletic Cambic Umbrisol (Amphisiltic, Epiloamic, Humic, Pachic, Solimovic)

Stratigraphy:

OL-OFzo-OH-meAh-meAh/Bw-Bw-BwC

Humus form:

Eumesoapmhi

OL (1 cm):	Continuous, Douglas fir needles, cones, twigs.
OFzo (1 cm):	Continuous, slightly compacted by mycelia.
OH (1 cm):	Sometimes discontinuous, loose, reddish-brown colored.



meAh1 (0-43.0 cm)

Color: 7.5YR 2.5/1 (black), texture class: sandy loam, stoniness: 30% (angular coarse gravel), structure: fine granular, bulk density: loose, moisture: slightly moist, root density: <2 mm: 100 pcs/dm^2, >2 mm: 30 pcs/dm^2. Umbric; irregular stones distribution (finer and 15% near lower boundary).

meAh/Bw (43.0-62.0 cm)

Color: 10YR 3/3 (dark brown), texture class: sandy loam, stoniness: 25-30% (angular coarse gravel), structure: fine subangular blocky, bulk density: loose, moisture: slightly moist, root density: <2 mm: 40 pcs/dm^2, >2 mm: 5 pcs/dm^2.

Bw (62.0-80.0 cm)

Color: 7.5YR 4/4 (brown), texture class: silty clay loam, stoniness: 50% (angular coarse gravel), structure: medium subangular blocky, bulk density: loose, moisture: slightly moist, root density <2 mm: 10 pcs/dm^2, >2 mm: 3 pcs/dm^2.

BwC (>80.0 cm)

Color: 10YR 4/4 (dark yellowish brown), texture class: loam, stoniness: 80% (angular coarse gravel), structure: very fine subangular blocky, bulk density: intermediate, moisture: slightly moist, root density <2 mm: 5 pcs/dm^2, >2 mm: 1 pc/dm^2. Gradual transition to soil forming substrate.

Pedon with running metamorphic processes (brunification) in initial stage. Pedoturbation by slope solifluction and direct accumulation process is in context of microdepressions within convex relief. Deep enrichment in humus corresponds with slope accumulation processes. Weathering processes of bedrock leads to reddish color tones on the background of brown Munsell color.



SOIL CHARACTERISTICS

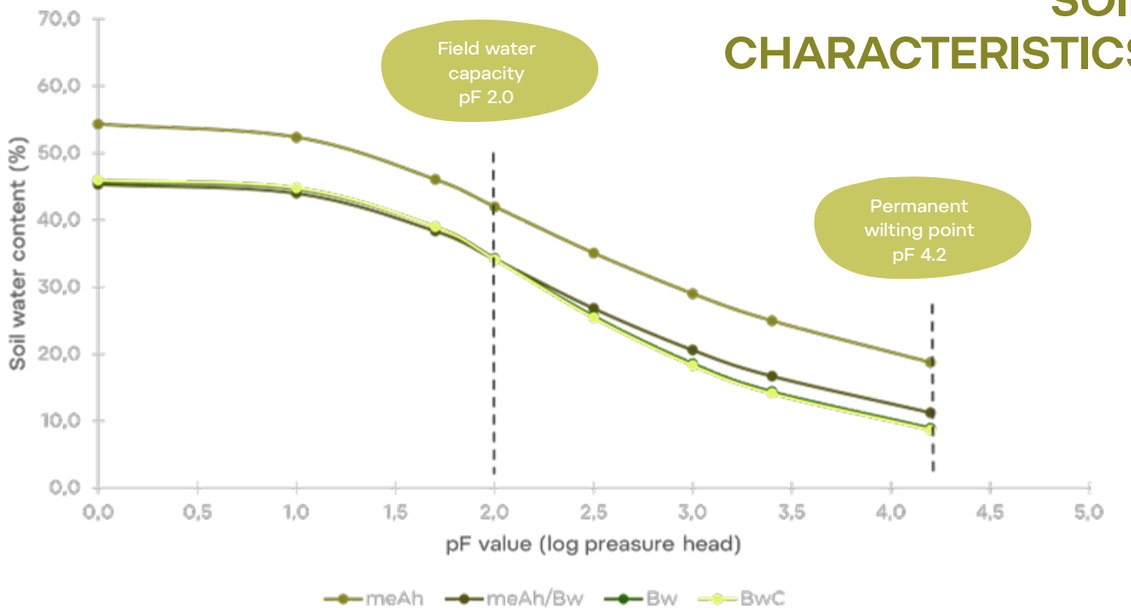


Figure 17A: Water retention curve showing the relationship between soil water content and pF value

Profile No. 17 exhibits a moderate vertical gradient, with increasing bulk density and decreasing organic matter content from the topsoil to the subsoil. The surface meAh horizon (1.0 g/cm³; 9.7% organic matter) shows relatively high maximal (54.3%) and field water capacity (42.0%). Available water capacity is 23.3% and the saturated hydraulic conductivity is medium (24.9 cm/day), indicating good retention capacity and water movement through this horizon. The transitional meAh/Bw horizon (1.3 g/cm³; 4.9% organic matter) exhibits lower maximal (45.3%) and field capacity (34.2%), with similar available water (23.0%) and slightly reduced conductivity (18.9 cm/day). In the Bw (1.3 g/cm³; 4.1% organic matter) and BwC horizons (1.3 g/cm³; 4.2% organic matter), maximal and field water capacity remain nearly constant (≈45% and 34%), while available water increases slightly to 25.4–25.5%. Saturated hydraulic conductivity is low to moderate (≈ 17 cm/day).

Table 17A: Soil properties of particular horizons - profile No. 17

Soil Horizon	Maximal Water Capacity (% vol.)	Field Water Capacity (% vol.)	Permanent Wilting Point (% vol.)	Available Water Capacity (% vol.)	Saturated Hydraulic Conductivity (cm/day)	Bulk Density (g/cm³)	Organic Matter (% wt.)
meAh	54.3	42.0	18.7	23.3	24.9	1.0	9.7
meAh/Bw	45.3	34.2	11.2	23.0	18.9	1.3	4.9
Bw	45.7	34.3	8.9	25.4	16.6	1.3	4.1
BwC	45.9	34.2	8.7	25.5	17.3	1.3	4.2

Overall, the water retention curves of meAh/Bw, Bw, and BwC converge, showing similar hydro-physical properties in the subsoil, while the upper meAh horizon remains distinct. The available water capacity remains relatively uniform throughout the profile (23.0–25.5%), ensuring a stable amount of water available to plants despite hydro-physical changes between meAh and subsoil horizons.

Table 17B: Micronutrients content

Soil horizon	P	Ca	Mg	K	CEC	BS
	mg/kg				mmol/kg	%
OH	43	507	227	176	384.2	12.6
meAh	96	84	67	50	74.6	22.3
meAh/Bw	102	83	60	34	40.1	37.7
Bw	87	84	60	33	32.6	44.8
BwC	47	78	61	32	28.3	47.0

Table 17C: Soil texture characteristics and Soil reaction

Soil horizon		Texture class	Slaking index	Battance class	pH_{water}	pH_{KCl}
OH					3.5	2.9
meAh		sandy loam	1.10	non battant	4.2	3.8
meAh/Bw		silt loam	1.59	peu battant	4.4	4.1
Bw		silt loam	2.00	tres battant	4.5	4.2
BwC		silt loam	1.92	battant	4.4	4.3



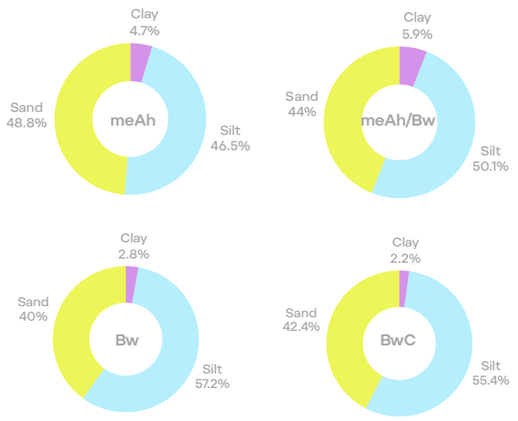


Figure 17B: Soil texture

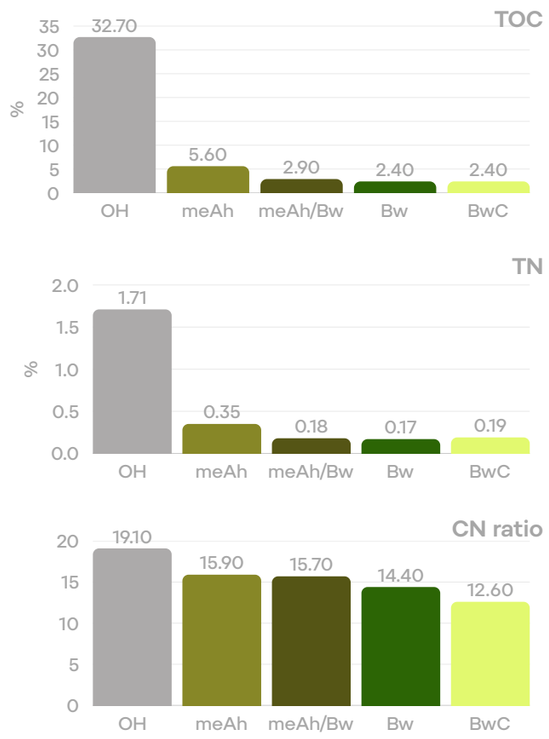


Figure 17C: Total soil carbon and nitrogen characteristics

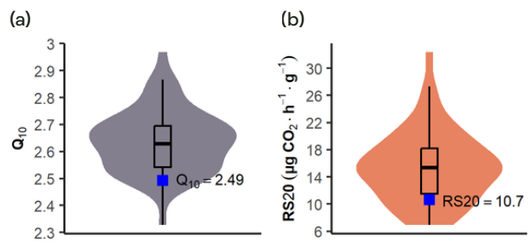


Figure 17D:
(a) Q10: the temperature sensitivity of soil respiration
(b) RS20: soil respiration value for a standardized temperature of 20 degrees
(c) Shannon: soil molecular diversity index, based on the identification of compounds from the main molecular families

Douglas Fir

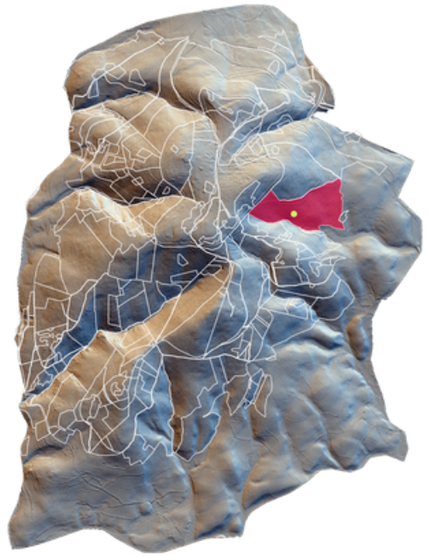
site

18

DOUGLAS FIR

Douglas Fir

GPS (N):	4.0457070°
GPS (E):	46.9219970°
Localization:	extramuros
Altitude:	647 m a.s.l.
Inclination:	20°
Exposure:	S



The profile is located in the middle of a straight slope (inclination 20°, south exposure). The tree layer consists of douglas fir (100%) without herbaceous layer, only with the occasional moss. The stand of douglas fir showing clear signs of decline. There is a permanent meteorological station.





Soil Taxonomic Unit:

Endoskeletic Dystric Solimovic Cambisol (Anosiltic, Profundihumic)

Stratigraphy:

OL-OFzo-OH-meAh-meAh/Bw-Bw-BwC-C

Humus form:

Eumesoamphi

OL (2 cm): Thick, continuous Douglas fir litter (needles, twigs, cones).

OFzo (2 cm): Continuous, loose.

OH (1.5 cm): Dark (red-brown), moderately moist, loose, weakly dense hair roots.

meAh (0–6.5 cm)

Color: 10YR 3/2 (very dark grayish brown), texture class: sandy loam, stoniness: 15% (rounded and angular medium gravel), structure: fine granular, bulk density: loose, moisture: very dry, root density: <2 mm: 80 pcs/dm^2, > 2mm: 10 pcs/dm^2. Increased admixture of gravel near/at soil surface.

meAh/Bw (6.5–19.5 cm)

Color: 7.5YR 3/3 (dark brown), texture class: loam, stoniness: 10% (angular coarse gravel), structure: fine granular, bulk density: loose, moisture: slightly moist, root density: <2 mm: 90 pcs/dm^2, >2 mm: 10 pcs/dm^2. Zooedaphon (earthworms).

Bw (19.5–48.5 cm)

Color: 10YR 5/6 (yellowish brown), texture class: silt loam, stoniness: 20% (angular medium gravel), structure: medium subangular blocky, bulk density: loose, moisture: slightly moist, root density <2 mm: 70 pcs/dm^2, >2 mm: 3 pcs/dm^2. Admixture of schist fragments.

BwC (48.5–71.5 cm)

Color: 10YR 5/6 (yellowish brown), texture class: silt loam, stoniness: 20% (angular medium gravel), structure: fine subangular blocky, bulk density: loose, moisture: slightly moist, root density <2 mm: 40 pcs/dm^2, >2 mm: 1 pc/dm^2. Wavy shape of lower boundary.

C (>71 cm)

Color: 10YR 6/6 (brownish yellow), texture class: sandy loam, stoniness: 50% (angular coarse gravel), structure: very fine massive, bulk density: loose, moisture: slightly moist, root density <2 mm: 25 pcs/dm^2, >2 mm: 1 pc/dm^2. Admixture of silt loess.



The soil profile shows a relatively uniform silty texture, which increases erosion susceptibility, particularly on such steep slope. Phosphorus contents are low both in total and plant-available forms, reflecting the Extramuros position and the absence of anthropogenic enrichment typical of Intramuros sites. In contrast, exchangeable calcium and potassium occur in relatively higher concentrations, while magnesium remains lower and may be partly limited by potassium-magnesium antagonism. Cation exchange capacity is moderate and the sorption complex shows moderate base saturation, which reduces the risk of aluminium toxicity despite strongly acidic soil conditions. Continuous douglas fir monoculture increases ecological vulnerability of the site. Regeneration should avoid soil surface disturbance and abrupt canopy opening by applying narrow regeneration strips (ca. 5–10 m wide) aligned along the slope, which reduces erosion risk and limits the development of nitrophilous vegetation. Diversification of the stand with species such as European larch, Scots pine, Northern red oak, European larch, silver birch and locally common hornbeam is recommended.

In relation to general soil evolution within the Mont Beauvray area, the pedon is typical with longer continuous pedogenesis, which leads to more pronounced pedomorphic features of metamorphic process.
Markable silt fraction admixture with features of loess loam but created in situ within cryogenic processes in Pleistocene.



SOIL CHARACTERISTICS

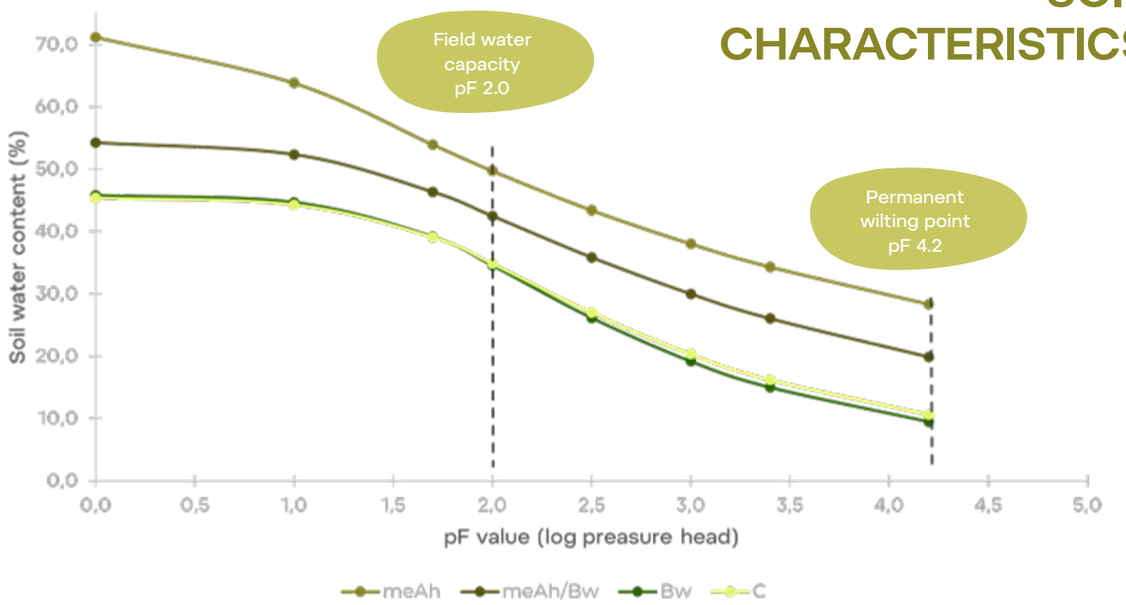


Figure 18A: Water retention curve showing the relationship between soil water content and pF value

The surface meAh horizon of profile No. 18 has very low bulk density (0.5 g/cm³, Table 27) and high organic matter content (27.5%), with maximal water content of 71.2% and field capacity of 49.7% (Fig. 18A). Available water capacity is 21.4%, and saturated hydraulic conductivity is 24.0 cm/day. The transitional meAh/Bw horizon shows increased bulk density (1.0 g/cm³) and lower organic matter (10.0%), accompanied by reductions in maximal and field water capacities (54.2% and 42.5%). Available water capacity remains but relatively stable (22.6%), and hydraulic conductivity is 20.9 cm/day.

Table 18A: Soil properties of particular horizons – profile No. 18

Soil Horizon	Maximal Water Capacity (% vol.)	Field Water Capacity (% vol.)	Permanent Wilting Point (% vol.)	Available Water Capacity (% vol.)	Saturated Hydraulic Conductivity (cm/day)	Bulk Density (g/cm³)	Organic Matter (% wt.)
meAh	71.2	49.7	28.3	21.4	24.0	0.5	27.5
meAh/Bw	54.2	42.5	19.9	22.6	20.9	1.0	10.0
Bw	45.8	34.6	9.5	25.0	15.3	1.3	4.8
C	45.4	34.8	10.6	24.2	14.6	1.3	4.6

The deepest mineral horizons, Bw and C, are clearly distinct from the meAh and meAh/Bw horizon. They are denser (1.3 g/cm³) and very low in organic matter (4.8–4.6%), with substantially lower maximal (45.4–45.8%) and field water capacities (34.6–34.8%). Permanent wilting points are low, yet available water capacity remains high (24.2–25.0%). Saturated hydraulic conductivity decreases to 14.6–15.3 cm/day, reflecting compact subsoil with reduced porosity. Overall, as seen also in profiles No. 25 and 26, the soil profile shows a clear trend of decreasing increasing bulk density with depth, while available water for plants (~21–25%) remains relatively stable across all horizons.

Douglas Fir

Table 18B: Micronutrients content

Soil horizon	P	Ca	Mg	K	CEC	BS
	mg/kg				mmol/kg	%
OH	15	704	138	172	276.6	18.5
meAh	6	252	89	177	121.6	21.8
meAh/Bw	3	187	56	126	48.4	38.0
Bw	2	170	45	104	34.0	55.8
C	9	165	49	108	29.9	59.9

Table 18C: Soil texture characteristics and Soil reaction

Soil horizon		Texture class	Slaking index	Battance class	pH_{water}	pH_{KCl}
OH					3.6	3.2
meAh		silt loam	0.89	non battant	3.8	3.5
meAh/Bw		sandy loam	1.10	non battant	4.4	4.1
Bw		sandy loam	1.76	assez battant	4.4	4.2
C		sandy loam	1.83	battant	4.4	4.1

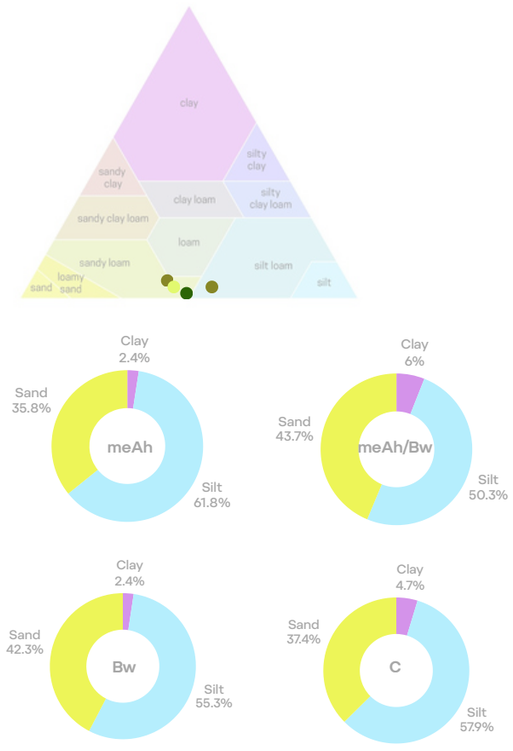


Figure 18B: Soil texture

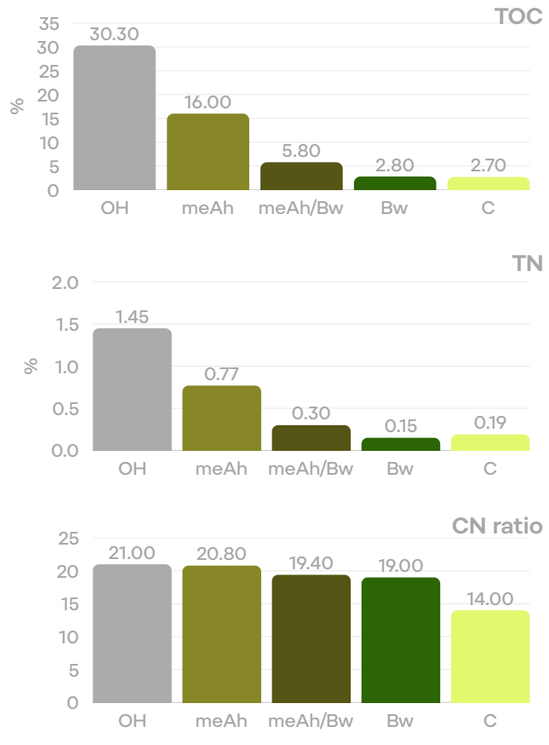
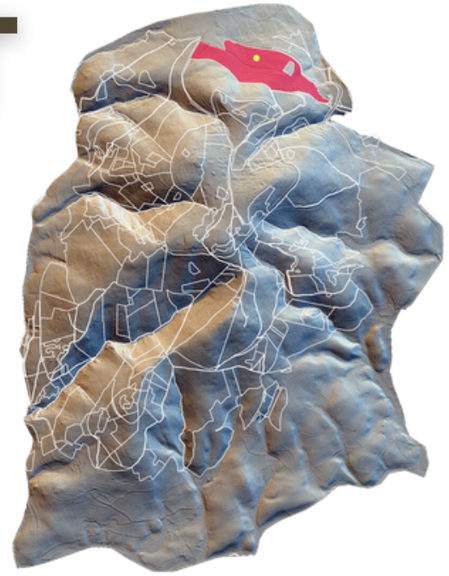


Figure 18C: Total soil carbon and nitrogen characteristics

site
19

MIXED FOREST



GPS (N):	4.0394550°
GPS (E):	46.9356010°
Localization:	extramuros
Altitude:	598 m a.s.l.
Inclination:	12°
Exposure:	N

The profile is located in the lower part of a straight slope (inclination 12°, north exposure), about 40 metres above a small stream. The tree cover consists of beech (50%), oak (40%), sweet chestnut and holly. The herbaceous layer is absent, only ocassional moss. At a depth of more than 50 cm, there is a clearly increased silt content.





The profile shows sandy loam in the upper mineral horizon grading to silt loam in deeper layers, with slightly reduced aggregate stability in the silt-rich subsoil. Weak micropodzolization is expressed by a discontinuous Bhs horizon and very strongly acidic topsoil. Cation exchange capacity is largely associated with organic matter in surface horizons and decreases markedly in mineral layers. A high Al/Bc ratio in the Bhs horizon corresponds to low base saturation, which increases with depth. The C/N ratio (≈10–14) indicates well-decomposed organic matter. Incorporation and support of spontaneously regenerating ameliorative deciduous species is recommended; at the same time, elimination of soil surface exposition is indispensable.

Mixed forest

Soil Taxonomic Unit:

Endoskeletic Cambic Umbrisol (Amphisiltic, Humic, Protospodic)

Stratigraphy:
OLn-OLv-OFzo-OH-miAh-Bhs-Au/Bws-Bws-BwsC

Humus form:
Dysmoder

OLn (2 cm):	Beech + oak, admixture of chestnut, continuous.
Olv (2 cm):	Beech + oak, admixture of chestnut, continuous.
OFzo (1 cm):	Amphigenic (mycelia and zooedaphone).
OH (2 cm):	Dark (black-brown), very abrupt lower layer boundary.

miAh (0–2.0 cm)
Color: 10YR 4/2 (dark grayish brown), texture class: sandy loam, stonine ss: 10% (angular medium gravel), structure: very fine granular, bulk density: loose, moisture: very dry, root density: <2 mm: 80 pcs/dm^2, >2 mm: 5 pcs/dm^2. Slightly leached with eluviation (micropodzolization), with white quartz grains.

Bhs (2.0–7.0 cm)
Color: 7.5YR 3/4 (dark brown), texture class: sandy loam, stoniness: 10% (angular medium gravel), structure: fine granular, bulk density: intermediate, moisture: dry, root density: <2 mm: 130 pcs/dm^2, >2 mm: 20 pcs/dm^2. Structure: combination with medium granular; slight accumulation of humus and sesquioxides (micropodzolization).

Au/Bws (7.0–38.0 cm)
Color: 10YR 4/6 (dark yellowish brown), texture class: silt loam, stoniness: 15% (angular fine gravel), structure: medium subangular blocky, bulk density: very loose, moisture: slightly moist, root density <2 mm: 40 pcs/dm^2, >2 mm: 5 pcs/dm^2. Admixture of silt; structure: 40% proportion of fine subangular blocky. Result of pedoturbation.

Bws (38.0–64.0 cm)
Color: 7.5YR 4/6 (strong brown), texture class: silt loam, stoniness: 20% (angular medium gravel), structure: medium subangular blocky, bulk density: intermediate, moisture: slightly moist, root density <2 mm: 20 pcs/dm^2, >2 mm: 3 pcs/dm^2. Loess silt admixture.

BwsC (>64.0 cm)
Color: 10YR 5/6 (yellowish brown), texture class: silt loam, stoniness: 60% (angular stones), structure: very fine subangular blocky, bulk density: intermediate, moisture: dry, root density <2 mm: 2 pcs/dm^2, >2 mm: 1 pc/dm^2.



Soil with heterogenous topsoil, affected by pedoturbation and by micropodzolization process - discontinuous but markable horizon Bhs overlying discontinuous (broken) A/B horizon.



SOIL CHARACTERISTICS

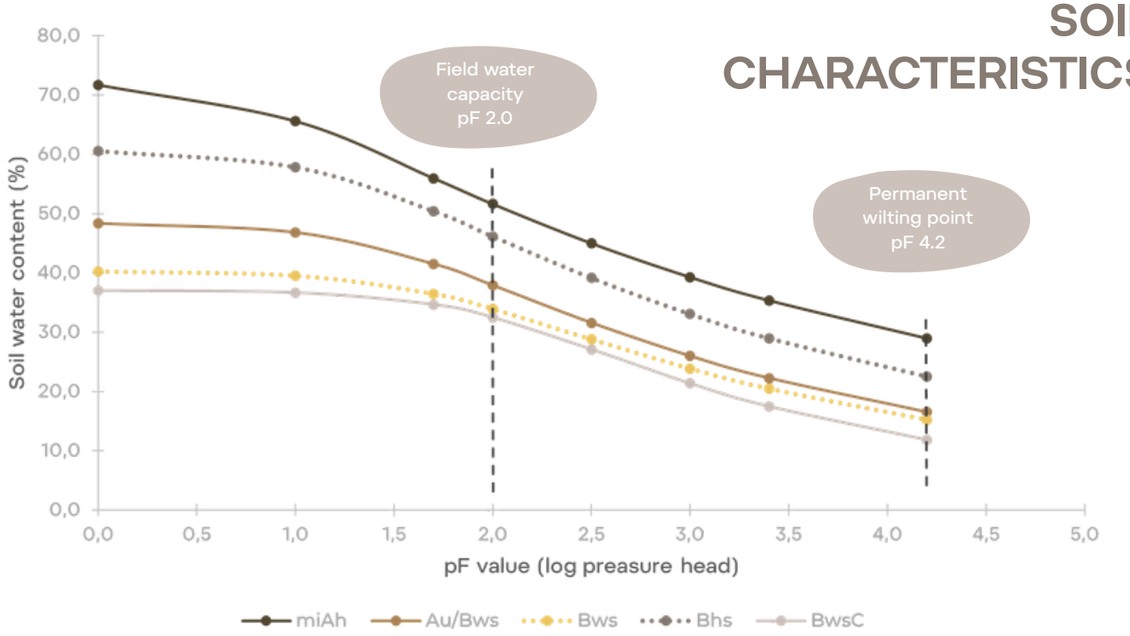


Figure 19A: Water retention curve showing the relationship between soil water content and pF value

The soil profile No. 19 exhibits strong horizontal differentiation (Fig. 19A), with properties varying markedly between organic-rich horizons and others. The topsoil miAh horizon stands out with very low bulk density (0.5 g/cm³) and extremely high organic matter content (26.11%), resulting in the highest maximal (71.7%) and field water capacity (51.6%) and high saturated hydraulic conductivity (55.8 cm/day). These features indicate highly porous, well-infiltration topsoil with efficient water retention.

In contrast, the mineral horizons immediately below (Au/Bws and Bws, Table 19A) show significantly higher bulk density (1.2-1.5 g/cm³) and sharply reduced organic matter (6.11-2.08%). Correspondingly, maximal and field water capacities drop (40.2-48.3% and 33.9-37.9%), and saturated hydraulic conductivity decreases (11.2-21.1 cm/day), reflecting compacted, less permeable layers. The Bhs horizon forms specific and distinct layer within the profile. Despite being deeper, it has relatively low bulk density (0.8 g/cm³) and high organic matter (12.80%), leading to higher water retention (maximal 60.6%, field 46.1%) and moderate hydraulic conductivity (27.0 cm/day). This contrasts sharply with the surrounding mineral horizons properties, highlighting heterogeneity of this soil profile.

Table 19A: Soil properties of particular horizons - profile No. 19

Soil Horizon	Maximal Water Capacity (% vol.)	Field Water Capacity (% vol.)	Permanent Wilting Point (% vol.)	Available Water Capacity (% vol.)	Saturated Hydraulic Conductivity (cm/day)	Bulk Density (g/cm³)	Organic Matter (% wt.)
miAh	71.7	51.6	29.0	22.7	55.8	0.5	26.1
Bhs	60.6	46.1	22.5	23.6	27.0	0.8	12.8
Au/Bws	48.3	37.9	16.5	21.4	21.1	1.2	6.1
Bws	40.2	33.9	15.2	18.7	11.2	1.5	2.1
BwsC	37.0	32.5	11.8	20.7	6.4	1.6	1.1

The deepest BwsC horizon shows maximum bulk density (1.6 g/cm³), minimal organic matter (1.14%), and the lower available water capacity (20.7%), emphasizing the contrast between compacted mineral organic-poor horizons (Bws and BwsC) and organic-rich horizons (miAh and Bhs).

Mixed forest

Table 19B: Micronutrients content

Soil horizon	P	Ca	Mg	K	CEC	BS
	mg/kg				mmol/kg	%
OH	83	341	241	480	323.8	15.7
miAh	13	233	126	286	139.5	22.6
Bhs	3	221	79	203	130.4	20.3
Au/Bws	2	216	57	110	39.9	52.3
Bws	4	205	88	105	31.9	68.7
BwsC	3	197	87	107	38.5	63.6

Table 19C: Soil texture characteristics and Soil reaction

Soil horizon		Texture class	Slaking index	Battance class	pH_{water}	pH_{KCl}
OH					3.8	3.2
miAh	●	sandy loam	0.91	non battant	3.4	2.8
Bhs	●	silt loam	1.13	non battant	3.7	3.4
Au/Bws	●	silt loam	1.47	peu battant	4.1	4.1
Bws	●	silt loam	2.37	tres battant	4.3	4.2
BwsC	●	silt loam	4.14	tres battant	4.4	4.1

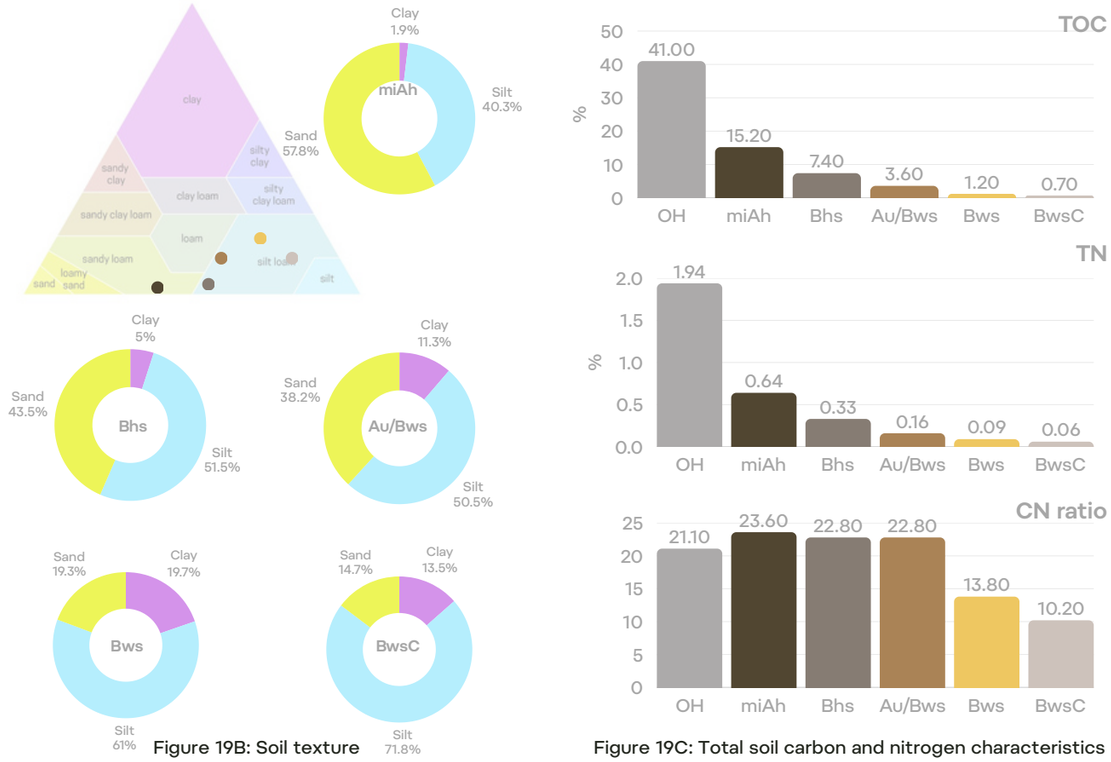


Figure 19B: Soil texture

Figure 19C: Total soil carbon and nitrogen characteristics

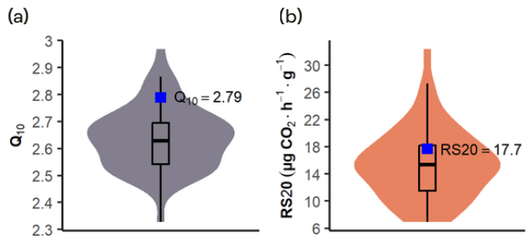
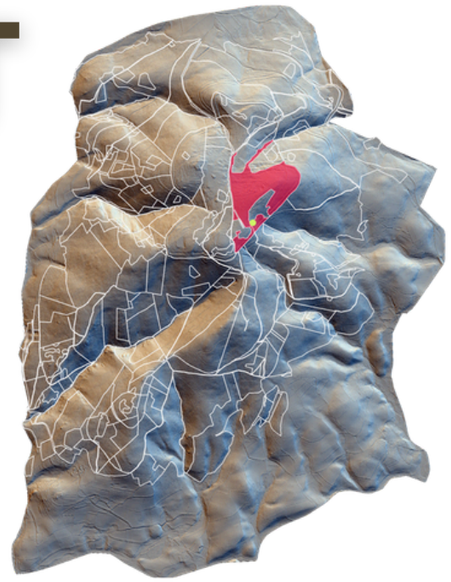


Figure 19D:
(a) Q10: the temperature sensitivity of soil respiration
(b) RS20: soil respiration value for a standardized temperature of 20 degrees
(c) Shannon: soil molecular diversity index, based on the identification of compounds from the main molecular families

site
20

MIXED FOREST



GPS (N):	4.0387170°
GPS (E):	46.9221480°
Localization:	intramuros (2nd rampart)
Altitude:	791 m a.s.l.
Inclination:	18°
Exposure:	SE

The profile is located on a slope 20 meters below the meadow plateau (inclination 18°, south-east exposure). The tree layer consists of beech and oak with mixture of sycamore, European silver fir, douglas fir and common hornbeam. The shrub layer consists of bramble and holly.





The soil profile is dominated by silt loam textures and the subsoil is therefore highly susceptible to erosion when exposed. Soil reaction is extremely to strongly acidic, with an unsaturated sorption complex in the topsoil and moderate base saturation in mineral horizons. Cation exchange capacity is largely controlled by humic substances and reaches very high values in humified horizons compared with mineral soil (very low). Calcium and magnesium contents in the parent material are very low, while potassium predominates, especially in surface layers. A pronounced TOC gradient indicates humus-rich solum sharply overlying mineral substrate. The favourable C:N ratio suggests active humus transformation but also potential rapid nitrogen release following canopy opening. Natural regeneration may be limited by rapid development of nitrophilous forest weeds. Therefore, advance underplanting with shade-tolerant species such as European silver fir, common hornbeam, sycamore, and groupwise European beech is recommended.

Soil Taxonomic Unit:

Endoskeletic Cambic Umbrisol (Humic, Organotransportic, Pantoloamic, Prototechnic, Solimovic)

Mixed forest

Stratigraphy:
OL-OFzo-OH-meAh-meAhut-Bw-C

Humus form:
Pachyamphi

OL (4 cm):	Thick, continuous litter of multispecies composition.
OFzo (5 cm):	Thick, rich in mycelia and with zooedaphone activity.
OH (7 cm):	Thick horizon of humification; rich in invertebrates; high root density (120 pcs/dm² <2 mm).



meAh (0-14.0 cm)
Color: 10YR 2/2 (very dark brown), texture class: sandy loam, stoniness: 20% (angular coarse gravel), structure: fine granular, bulk density: loose, moisture: dry, root density: <2 mm: 100 pcs/dm², >2 mm: 60 pcs/dm². Recent neoformation of organomineral horizon corresponds with current stand.

meAhut (14.0-35.0 cm)
Color: 10YR 3/2 (very dark grayish brown), texture class: sandy loam, stoniness: 30% (angular medium gravel), structure: fine granular, bulk density: loose, moisture: dry, root density: <2 mm: 70 pcs/dm², >2 mm: 20 pcs/dm². Umbric; diffuse distinctness and wavy shape of lower boundary; sparse admixture of fragments of amphoras.

Bw (35.0-84.0 cm)
Color: 10YR 4/4 (dark yellowish brown), texture class: silt loam, stoniness: 30 % (angular coarse gravel), structure: fine subangular blocky, bulk density: loose, moisture: moist, root density <2 mm: 30 pcs/dm², >2 mm: 5 pcs/dm². Diffuse distinctness and smooth-to-wavy shape of lower boundary.

C (>84.0 cm)
Color: 10YR 5/4 (yellowish brown), texture class: loam, stoniness: 60% (angular stones), structure: fine simple grain, bulk density: intermediate, moisture: moist, root density <2 mm: 5 pcs/dm², >2 mm: <1 pc/dm².

Deep humification process and partial anthropogenic accumulation of organic material at soil surface; within deep soil profile of anthropogenic accumulation and neoformation of metamorphic horizons (slight features of color and structure). Dominance of polygenic soil forming substrate (slope loam with dominance of volcanic rock in subsoil).



SOIL CHARACTERISTICS

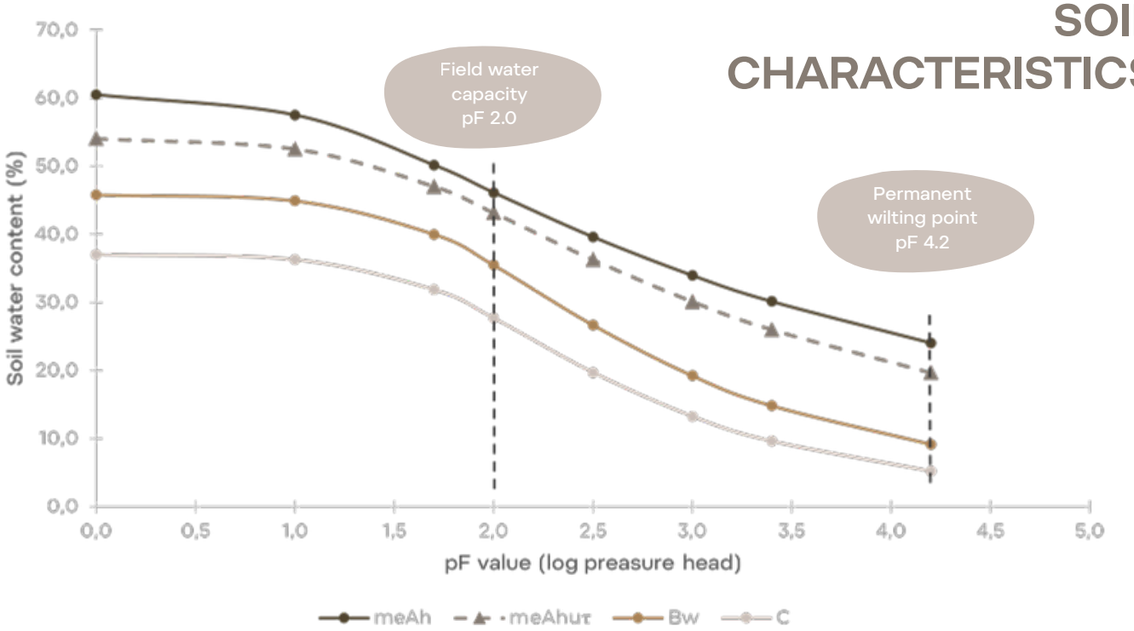


Figure 20A: Water retention curve showing the relationship between soil water content and pF value

The topsoil horizon meAh is characterized by very low bulk density (0.8 g/cm³) and high organic matter content (14.6%, Table 20), resulting in high maximal water capacity (60.5%) and field water capacity (46.1%, Fig. 20). Despite maximal water capacity, the saturated hydraulic conductivity is moderate (7.4 cm/day), indicating slower water movement compared to previously described high-permeability topsoil horizons. The next technical horizon meAhuτ shows a slightly increased bulk density (1.0 g/cm³) and a reduced organic matter content (8.5%). Maximal and field water capacities decrease moderately (54.1% and 43.1%), while available water capacity slightly increases (23.5%). Saturated hydraulic conductivity (8.8 cm/day) suggests somewhat improved pore continuity compared to the topsoil meAh. In the Bw horizon, bulk density rises to 1.3 g/cm³ and organic matter declines to 4.1%. Water retention further decreases (maximal 45.8%, field 35.5%), but available water capacity reaches the highest value within the profile (26.3%), reflecting favourable distribution of soil water storage pores. Saturated hydraulic conductivity increases to 11.7 cm/day, indicating increasing vertical movement of water in the subsoil horizons.

Table 20A: Soil properties of particular horizons - profile No. 20

Soil Horizon	Maximal Water Capacity (% vol.)	Field Water Capacity (% vol.)	Permanent Wilting Point (% vol.)	Available Water Capacity (% vol.)	Saturated Hydraulic Conductivity (cm/day)	Bulk Density (g/cm³)	Organic Matter (% wt.)
meAh	60.5	46.1	24.0	22.1	7.4	0.8	14.6
meAhuτ	54.1	43.1	19.7	23.5	8.8	1.0	8.5
Bw	45.8	35.5	9.1	26.3	11.7	1.3	4.1
C	37.0	27.7	5.2	22.5	16.2	1.6	1.1

The deepest C horizon is strongly compacted (1.6 g/cm³) with minimal organic matter content (1.1%). Maximal and field water capacities decline to 37.0% and 27.7%, respectively. However, saturated hydraulic conductivity reaches the highest value (16.2 cm/day), suggesting dominance of macropores for water flow. Maximal and field water capacities decrease moderately (54.1% and 43.1%), while available water capacity slightly increases (23.5%).

Table 20B: Micronutrients content

Soil horizon	P	Ca	Mg	K	CEC	BS
	mg/kg				mmol/kg	%
OH	32	278	118	216	330.1	8.8
meAh	20	105	48	76	62.4	19.8
meAhuτ	12	96	40	56	35.8	27.3
Bw	12	90	39	44	24.1	42.0
C	23	78	31	44	20.2	40.7

Table 20C: Soil texture characteristics and Soil reaction

Soil horizon		Texture class	Slaking index	Battance class	pH_{water}	pH_{KCl}
OH					3.7	2.9
meAh	●	silt loam	1.23	non battant	3.8	3.8
meAhuτ	●	silt loam	1.64	assez battant	3.9	4.0
Bw	●	silt loam	2.31	tres battant	3.9	4.1
C	●	silt loam	4.61	tres battant	3.9	4.0

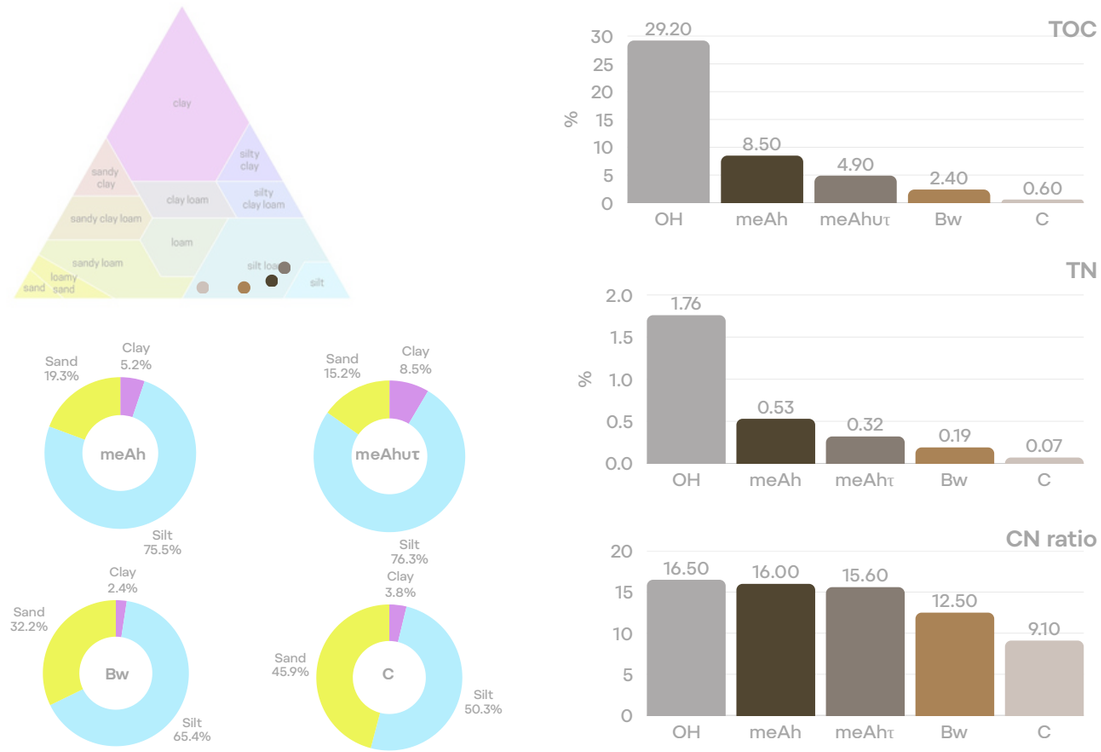


Figure 20B: Soil texture

Figure 20C: Total soil carbon and nitrogen characteristics

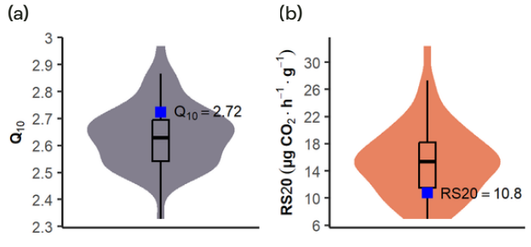


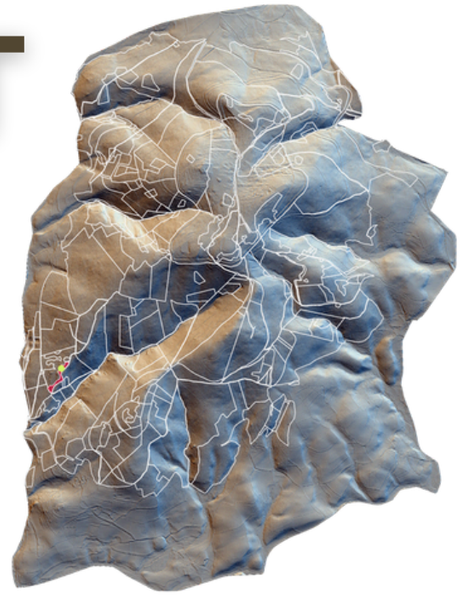
Figure 20D:
(a) Q10: the temperature sensitivity of soil respiration
(b) RS20: soil respiration value for a standardized temperature of 20 degrees
(c) Shannon: soil molecular diversity index, based on the identification of compounds from the main molecular families

Mixed forest

site
21

MIXED FOREST

GPS (N):	4.0151930°
GPS (E):	46.9109670°
Localization:	extramuros
Altitude:	490 m a.s.l.
Inclination:	15°
Exposure:	SW



The profile is located on the southwest slope (inclination 15°, south-west exposure), 10 m below the ridge. There are rock outcrops of acid vulcanites nearby. The tree layer consists of oak, sweet chestnut and hornbeam. The shrub layer consists of holly and broom. The rock outcrops are covered with moss.





Soil granulometry shows extremely low clay content throughout the profile. Dominance of silt indicates higher erosion susceptibility and low aggregate stability, while sand fractions reduce water-holding capacity. The soil is strongly acidic (pH 4.3–4.5) and poorly saturated with base cations; potassium dominates while calcium remains very low, including in the sorption complex. Such imbalance may limit plant nutrition and contribute to weaker fine-root development due to calcium–potassium antagonism. High aluminium mobility is indicated by aluminum/basic cations >1 in mineral horizons. The parent material is mineralogically poor in magnesium but relatively rich in potassium and phospohorus, although available phospohorus remains low. The relatively low C/N ratio indicates potential risk of nitrophilous vegetation after clearcutting; therefore small regeneration openings and support of natural regeneration under canopy are recommended. Maintaining mixed stands with support of sessile oak, common hornbeam and ameliorative pioneer species is advisable, while reducing holly.

Soil Taxonomic Unit:

Pantoskeletic Cambic Umbrisol (Pantosiltic, Profundihumic, Solimovic)

Stratigraphy:
OLn–OLv–OFzo–OH–miAh–Bw–C

Humus form:
Dysmoder

OL (3 cm):	Continuous litter of chestnut (+ admixture of oak, holly, hornbeam).
OFzo (1 cm):	Loose, continuous, dominance of zooedaphone.
OH (18 cm):	Very thick, very dark, grey when dry and brown when moist (character of Ahh).



miAh (0–43.0 cm)
Color: 7.5YR 3/3 (dark brown), texture class: loam, stoniness: 60% (angular coarse gravel), structure: very fine granular, bulk density: very loose, moisture: very dry, root density: <2 mm: 50 pcs/dm^2, > 2 mm: 10 pcs/dm^2. Umbric.

Bw (43.0–93.0 cm)
Color: 10YR 4/6 (dark yellowish brown), texture class: silt loam, stoniness: 45–50% (angular medium gravel), structure: very fine subangular blocky, bulk density: loose, moisture: slightly moist, root density: <2 mm: 15 pcs/dm^2, >2 mm: 1 pc/dm^2.

C (>93.0 cm)
Color: 10YR 5/6 (yellowish brown), texture class: silt loam, stoniness: 95% (angular stones), structure: fine simple grain, bulk density: loose, moisture: slightly moist, root density <2 mm: 3 pcs/dm^2, >2 mm: <1 pc/dm^2. Dominance of silt textural fraction.

Soil developed in situ with metamorphic processes (brunification) markable in mineral layers (structure and color development). Dominance of coarse fraction within soil body and markable thickness of organomineral diagnostic (umbric) horizon. Topsoil typical with high organic matter accumulation within depth of ca. 20 cm may be result of mechanical soil processing in past. Dominance of silt in soil forming substrate corresponds with periglacial weathering processes.



SOIL CHARACTERISTICS

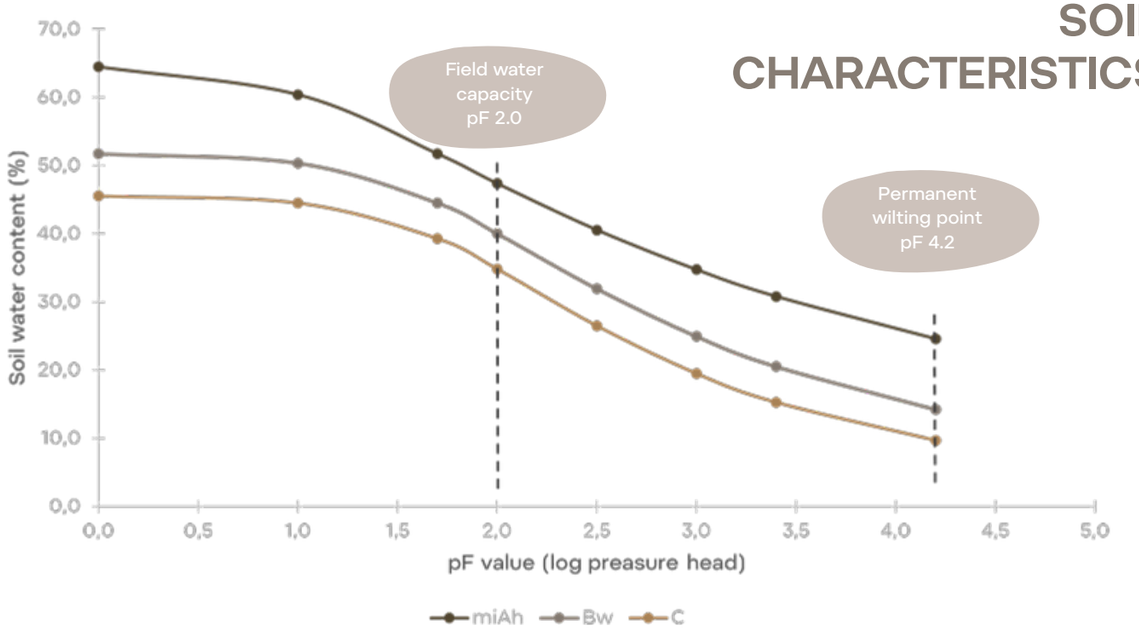


Figure 21A: Water retention curve showing the relationship between soil water content and pF value

Profile No. 21 (Fig. 21A, Table 21A) demonstrates a clear shift in soil properties with depth, with decreasing water retention, hydraulic conductivity, and organic matter, and increasing bulk density as we move down the profile. The miAh horizon has a bulk density of 0.7 g/cm³ and an organic matter content of 17.0%. It retains a relatively high amount of water (maximal 64.5%, field 47.4%) and has a moderate available water capacity of 22.8%. Saturated hydraulic conductivity is 18.3 cm/day, suggesting moderate water movement. In the Bw horizon, bulk density increases to 1.1 g/cm³, and organic matter decreases to 7.3%. Water retention is lower, with maximal capacity at 51.7% and field capacity at 40.0%, but available water capacity increases to 25.8%. The hydraulic conductivity drops to 13.5 cm/day, indicating a reduced ability for water to move through the soil compared to the miAh horizon.ss

Table 21A: Soil properties of particular horizons - profile No. 21

Soil Horizon	Maximal Water Capacity (% vol.)	Field Water Capacity (% vol.)	Permanent Wilting Point (% vol.)	Available Water Capacity (% vol.)	Saturated Hydraulic Conductivity (cm/day)	Bulk Density (g/cm³)	Organic Matter (% wt.)
miAh	64.5	47.4	24.6	22.8	18.3	0.7	17.0
Bw	51.7	40.0	14.2	25.8	13.5	1.1	7.3
C	45.5	34.8	9.7	25.1	14.4	1.3	4.0

The C horizon has the highest bulk density (1.3 g/cm³) and the lowest organic matter (4.0%). Water retention continues to decrease (maximal 45.5%, field 34.8%), while available water capacity remains at 25.1%. Hydraulic conductivity is slightly higher than in the Bw horizon, at 14.4 cm/day.

Mixed forest

Table 21B: Micronutrients content

Soil horizon	P	Ca	Mg	K	CEC	BS
	mg/kg				mmol/kg	%
OH	9	232	85	135	255.0	8.6
miAh	20	93	43	71	45.4	23.0
Bw	4	93	44	74	29.2	35.0
C	6	97	45	54	34.9	31.2

Table 21C: Soil texture characteristics and Soil reaction

Soil horizon		Texture class	Slaking index	Battance class	pH_{water}	pH_{KCl}
OH					4.0	3.5
miAh	●	silt loam	0.88	non battant	4.5	4.2
Bw	●	silt loam	1.42	peu battant	4.5	4.3
C	●	silt loam	2.08	tres battant	4.4	4.1



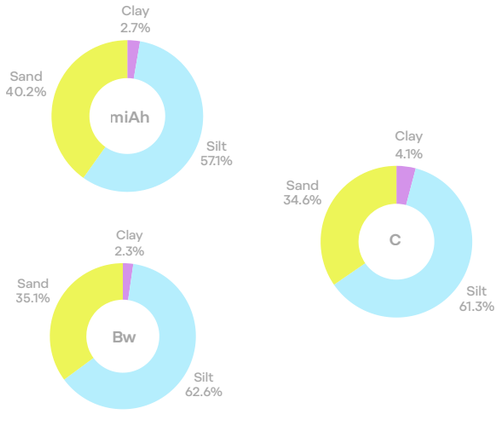


Figure 21B: Soil texture

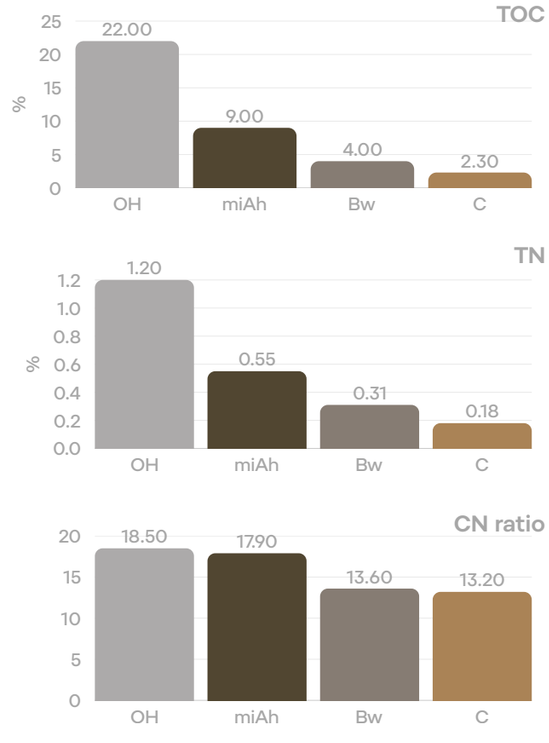


Figure 21C: Total soil carbon and nitrogen characteristics

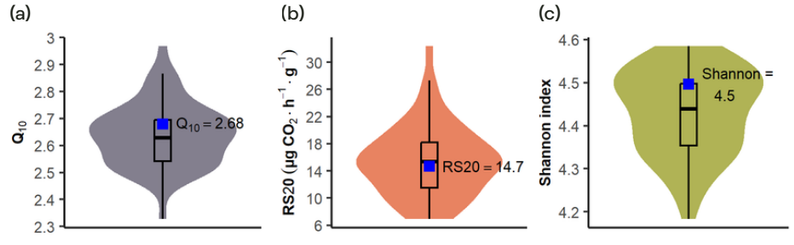
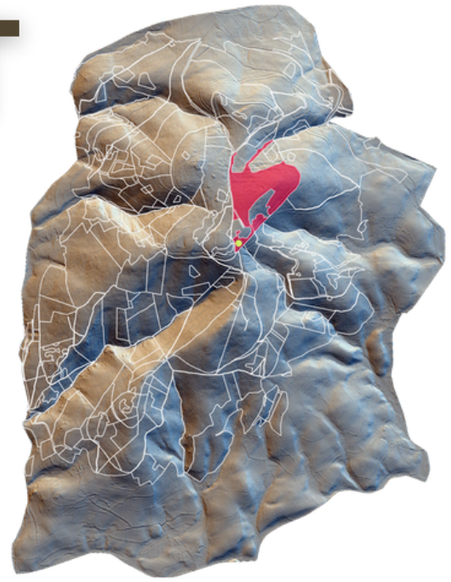


Figure 21D:
(a) Q10: the temperature sensitivity of soil respiration
(b) RS20: soil respiration value for a standardized temperature of 20 degrees
(c) Shannon: soil molecular diversity index, based on the identification of compounds from the main molecular families

site
22

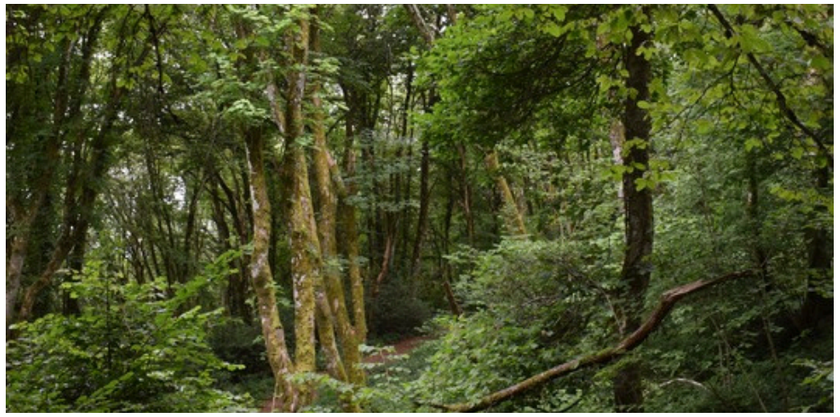
MIXED FOREST



GPS (N): 4.0369760°
GPS (E): 46.920440°
Localization: intramuros (2nd rampart)
Altitude: 794 m a.s.l.
Inclination: 15°
Exposure: SE

The profile is located on the southeast slope, about 50 meters below the summit plateau with the chapel (inclination 15°, south-east exposure). The surface relief has been heavily modified by human activity.The tree layer consists of sycamore, hornbeam, beech, oak and hazel. The shrub layer consits of holly and bramble.





Very deep soil profile with pronounced vertical distribution of soil organic carbon. The cumulative character of soil development demonstrates increased vulnerability to erosion, further supported by granulometry dominated by silt and relatively low aggregate stability. Low C/N ratios suggest rapid nitrogen mineralisation and a potential development of nitrophilous understory vegetation despite the acidic and overall nutrient-poor character of the soil. As typical for local substrates, potassium and phosphorus are relatively abundant, whereas calcium and magnesium remain low to moderate. Aluminum/basic cations ratios are slightly elevated but do not indicate aluminium toxicity or accelerated leaching of base cations. Forest management should therefore promote ameliorative species such as sycamore,European aspen and silver birch (about 20-25 %) evenly distributed within the stand. Releasing natural regeneration from the understory is recommended to enhance structural diversification of the stand.

Soil Taxonomic Unit:

Endoskeletic Orthodystric Brunic Solimovic Regosol (Loamic, Profundihumic, Technic)

Mixed forest

Stratigraphy:
OL-OFzo-OH-meAh-miAhut-meAhut-Bt

Humus form:
Eumesoamphi

OL (4 cm): Mixed litter of sycamore (dominant), beech, holly and oak.
OFzo (3 cm): Amphigenic (mycelia and zooedaphone).
OH (0.5 cm): Discontinuous.



meAh (0-13.0 cm)
Color: 10YR 2/2 (very dark brown), texture class: loam, stoniness: 25% (angular coarse gravel), structure: medium granular, bulk density: loose, moisture: slightly moist, root density: <2 mm: 140 pcs/dm^2, >2 mm: 60 pcs/dm^2. Abrupt boundary in root density at lower boundary; rich in soil organic carbon in humified transformations.

miAhut (13.0-33.0 cm)
Color: 10YR 3/2 (very dark grayish brown), texture class: sandy loam, stoniness: 30% (angular coarse gravel), structure: fine granular, bulk density: loose, moisture: slightly moist, root density: <2 mm: 80 pcs/dm^2, >2 mm: 30 pcs/dm^2. Antrhopogenic accumulation; fragments of amphoras.

meAhut (33.0-81.0 cm)
Color: 10YR 3/3 (dark brown), texture class: sandy loam, stoniness: 35% (angular coarse gravel), structure: medium subangular blocky, bulk density: loose, moisture: slightly moist, root density <2 mm: 20 pcs/dm^2, >2 mm: 1 pc/dm^2. Anthropogenic accumulation.

Bt (>81.0 cm)
Color: 10YR 4/3 (brown), texture class: sandy loam, stoniness: 95% (angular boulders), structure: very fine subangular blocky, bulk density: loose, moisture: slightly moist, root density <2 mm: 2 pcs/dm^2, >2 mm: <1 pc/dm^2. Anthropogenic deposit.

Anthropogenical origin of whole the soil body comming from transported material. Enrichin in artefacts mainly within zone of ca. 30-40 cm. The artefacts (dominantly fragments of amphoras) do not meet criteria for Technic material. Deep soil, perspective within rooting potential, but with high water permeability.



SOIL CHARACTERISTICS

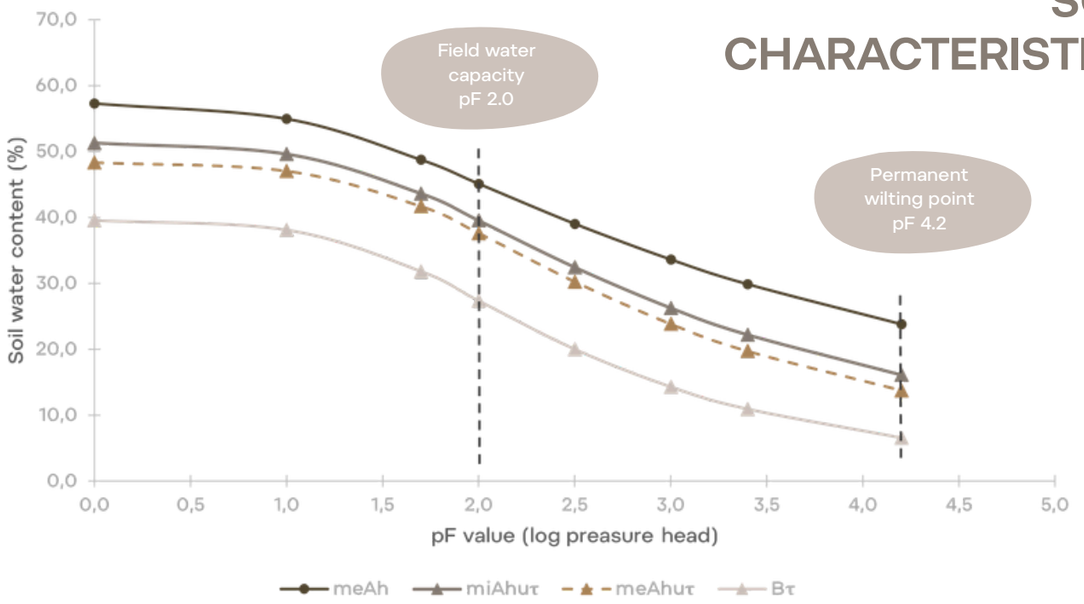


Figure 22A: Water retention curve showing the relationship between soil water content and pF value

Profile No. 22 shows a clear vertical trend of increasing bulk density and decreasing organic matter content (Table 22A), accompanied by a gradual decline in soil water retention characteristics (Fig. 22A). The topsoil meAh horizon (0.9 g/cm³; 12.3% organic matter) exhibits high maximal (57.3%) and field water capacity (45.1%). Due to a relatively high permanent wilting point (23.8%), available water capacity reaches 21.3%. Saturated hydraulic conductivity is relatively high (29.0 cm/day), indicating relatively rapid movement of rainwater through the topsoil. In the technical miAhuτ horizon, bulk density increases (1.1 g/cm³) and organic matter decreases (6.6%), resulting in lower maximal (51.3%) and field capacity (39.5%). However, a decrease in permanent wilting point (16.1%) leads to an increase in available water capacity (23.4%). Hydraulic conductivity remains moderately high (25.5 cm/day). The next technical meAhuτ horizon continues this trend, with slightly higher bulk density (1.2 g/cm³) and reduced organic matter (5.1%). Although maximal (48.4%) and field capacity (37.6%) further decline, available water capacity remains stable (23.9%) due to the lower permanent wilting point (13.8%). Hydraulic conductivity decreases to 16.5 cm/day, indicating reduced permeability.

Table 22A: Soil properties of particular horizons – profile No. 22

Soil Horizon	Maximal Water Capacity (% vol.)	Field Water Capacity (% vol.)	Permanent Wilting Point (% vol.)	Available Water Capacity (% vol.)	Saturated Hydraulic Conductivity (cm/day)	Bulk Density (g/cm³)	Organic Matter (% wt.)
meAh	57.3	45.1	23.8	21.3	29.0	0.9	12.3
miAhuτ	51.3	39.5	16.1	23.4	25.5	1.1	6.6
meAhuτ	48.4	37.6	13.8	23.9	16.5	1.2	5.1
Bτ	39.5	27.3	6.6	20.8	25.1	1.5	2.6

The deepest mineral and technical Bτ horizon shows the highest bulk density (1.5 g/cm³) and lowest organic matter content (2.6%), accompanied by the lowest maximal (39.5%) and field water capacity (27.3%). Available water capacity slightly decreases to 20.8%, while saturated hydraulic conductivity (25.1 cm/day) shows a slight increase compared to the overlying meAhuτ horizon.

Mixed forest

Table 22B: Micronutrients content

Soil horizon	P	Ca	Mg	K	CEC	BS
	mg/kg				mmol/kg	%
OH	55	1179	208	301	270.3	31.0
meAh	173	178	63	104	82.6	26.1
miAhuτ	113	113	38	52	37.1	38.1
meAhuτ	109	84	37	45	28.6	40.6
Bτ	139	94	43	48	22.7	51.5

Table 22C: Soil texture characteristics and Soil reaction

Soil horizon		Texture class	Slaking index	Battance class	pH_{water}	pH_{KCl}
OH					4.1	3.8
meAh		loam	0.94	non battant	4.3	3.8
miAhuτ		-	-	-	4.6	4.1
meAhuτ		silt loam	1.75	assez battant	4.8	4.2
Bτ		sandy loam	1.91	battant	4.8	4.1

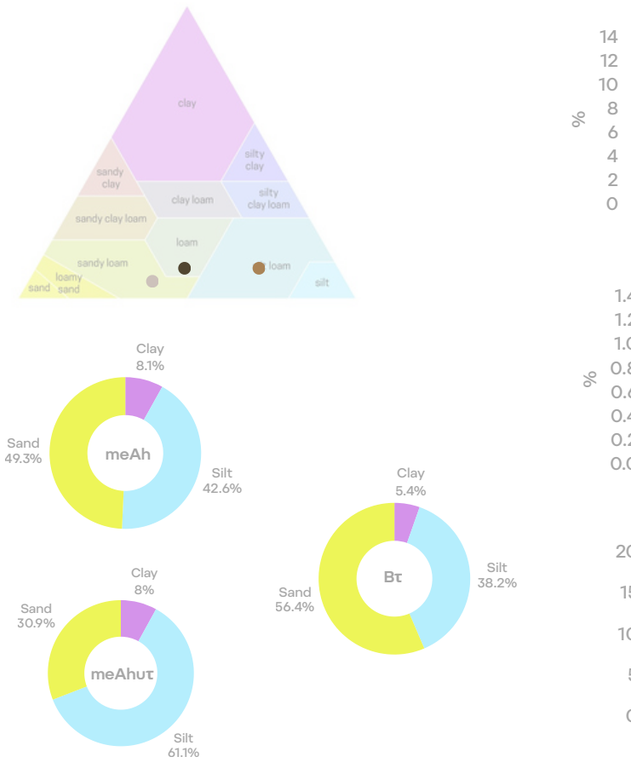


Figure 22B: Soil texture

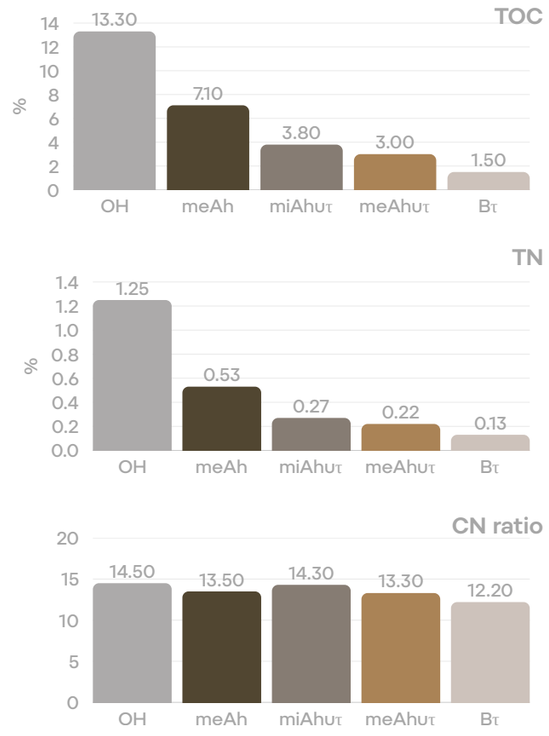
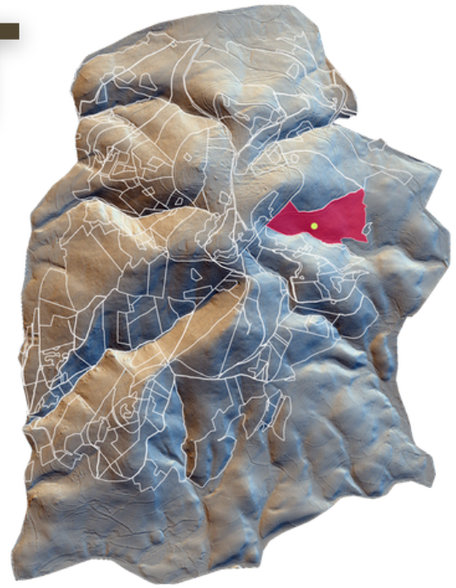


Figure 22C: Total soil carbon and nitrogen characteristics

site

23

MIXED FOREST



GPS (N):	4.0235490°
GPS (E):	46.9048950°
Localization:	extramuros
Altitude:	589 m a.s.l.
Inclination:	10°
Exposure:	SW

The profile is located on a gentle slope with slight concave curves. The slope is located about 50 meters below the forest road (inclination 10°, south-west exposure). The tree layer consists of oak (40%), horbeam (30%), beech (30%). The shrub layer is well-developed (30%) consisting of holly. Herbs are found only sporadically. The surface and topsoil contain angular stones of acidic volcanic rock (30-50%).





The soil body is characterised by increasing silt content in cambic horizons, resulting in relatively low aggregate stability and higher susceptibility to erosion. Chemical properties correspond with the regional pattern: low calcium, relatively higher magnesium, and moderate to elevated potassium and phosphorus contents. The sorption complex shows rather low cation exchange capacity and is largely controlled by soil organic matter due to the limited clay fraction, although base saturation remains moderate. The stand structure clearly demonstrates the beneficial effect of tree species diversity on soil properties: despite a uniform geological environment, ameliorative species such as European beech, sessile oak and common hornbeam enhance nutrient cycling and soil structure. holly may be selectively reduced. Additional admixture of European beech, small-leaved lime and locally wild service and sweet chestnut can further increase stand stability.

Soil Taxonomic Unit:

Katoskeletic Cambic Umbrisol (Amphisiltic, Epiloamic, Humic, Solimovic)

Stratigraphy:
OL-OFzo-OH-miAh-miAh/Bw-Bw-BwC

Humus form:
Hemimoder

OL (2 cm):	Sparsely discontinuous beech+holly+oak+hornbeam litter.
OFzo (0.5 cm):	Amphigenic, continuous, dry.
OH (0.5 cm):	Discontinuous, high fine root density.



miAh (0-35.0 cm)
Color: 10YR 3/3 (dark brown), texture class: sandy loam, stoniness: 35% (angular coarse gravel), structure: very fine granular, bulk density: very loose, moisture: dry, root density: <2 mm: 110 pcs/dm^2, >2 mm: 15 pcs/dm^2. Umbric; gradual distinctness to lower layer.

miAh/Bw (35.0-47.0 cm)
Color: 10YR 5/6 (yellowish brown), texture class: silt loam, stoniness: 40-50% (angular stones), structure: very fine subangular blocky, bulk density: very loose, moisture: dry, root density: <2 mm: 30 pcs/dm^2, >2 mm: 10 pcs/dm^2.

Bw (47.0-69.0 cm)
Color: 7.5YR 5/6 (strong brown), texture class: silt loam, stoniness: 65% (angular coarse gravel), structure: fine subangular blocky, bulk density: loose, moisture: dry, root density <2 mm: 10 pcs/dm^2, >2 mm: 3 pcs/dm^2.

Bw/C (>69.0 cm)
Color: 10YR 6/6 (brownish yellow), texture class: silty clay loam, stoniness: 85% (angular stones), structure: fine massive, bulk density: loose, moisture: dry, root density <2 mm: <1 pc/dm^2, >2 mm: <1 pc/dm^2.

Soil with accumulation of organic matter in A horizon (umbric), very loose within whole soil profile and with high stoniness in subsolum indicating high hydraulic conductivity.



SOIL CHARACTERISTICS

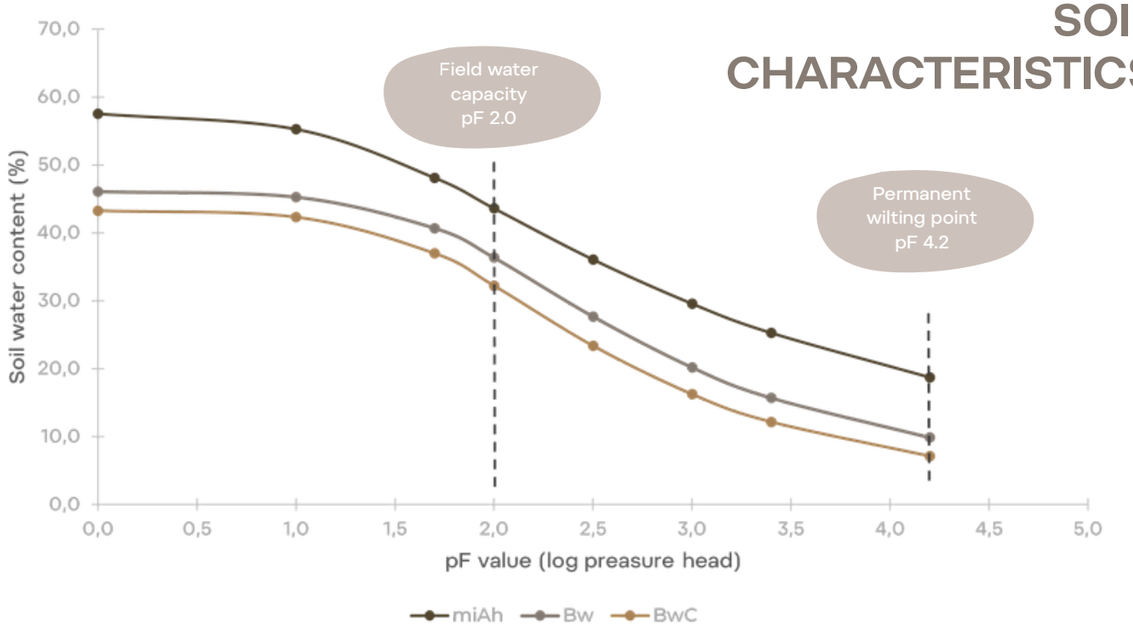


Figure 23A: Water retention curve showing the relationship between soil water content and pF value

Profile No. 23 demonstrates a clear vertical gradient in hydro-physical properties, characterized by increasing bulk density and decreasing organic matter content with depth, accompanied by changes in both soil water retention (Fig. 18) and permeability (Table 23A). The topsoil miAh horizon (0.9 g/cm³ and 10.4% organic matter) shows high maximal (57.6%) and field water capacity (43.6%). With a permanent wilting point of 18.7%, available water capacity reaches 24.9%. Very high saturated hydraulic conductivity (42.3 cm/day) indicates rapid infiltration and well-developed macropore continuity. In the Bw horizon, bulk density increases to 1.3 g/cm³ while organic matter decreases to 4.9%, resulting in lower maximal (46.1%) and field capacity (36.4%). Despite this decline, available water capacity rises to 26.5% due to a pronounced reduction in permanent wilting point (9.9%). In contrast, saturated hydraulic conductivity decreases sharply to 9.3 cm/day, suggesting reduced permeability and possible compaction of this horizon. The deepest BwC horizon (1.4 g/cm³; 3.4% organic matter) exhibits a continued decline in maximal (43.3%) and field capacity (32.2%). However, available water capacity remains relatively stable (25.1%) owing to the low permanent wilting point (7.1%). Saturated hydraulic conductivity increases moderately to 15.4 cm/day but does not reach the values observed in the topsoil miAh horizon.

Table 23A: Soil properties of particular horizons - profile No. 23

Soil Horizon	Maximal Water Capacity (% vol.)	Field Water Capacity (% vol.)	Permanent Wilting Point (% vol.)	Available Water Capacity (% vol.)	Saturated Hydraulic Conductivity (cm/day)	Bulk Density (g/cm³)	Organic Matter (% wt.)
miAh	57.6	43.6	18.7	24.9	42.3	0.9	10.4
Bw	46.1	36.4	9.9	26.5	9.3	1.3	4.9
Bw/C	43.3	32.2	7.1	25.1	15.4	1.4	3.4

Overall, while total water retention capacity decreases with depth, plant-available water (~25–26 %) remains relatively consistent throughout the profile, indicating a stable retention regime despite marked variations in hydraulic conductivity of study soil horizons.

Table 23B: Micronutrients content

Soil horizon	P	Ca	Mg	K	CEC	BS
	mg/kg				mmol/kg	%
OH	44	1213	231	262	275.0	31.4
miAh	11	107	47	63	48.9	28.4
Bw	13	110	58	37	24.8	51.6
Bw/C	11	123	66	39	25.7	57.1

Table 23C: Soil texture characteristics and Soil reaction

Soil horizon		Texture class	Slaking index	Battance class	pH_{water}	pH_{KCl}
OH					4.0	3.7
miAh	●	sandy loam	0.93	non battant	4.5	4.1
Bw	●	silt loam	1.90	battant	4.5	4.4
Bw/C	●	silt loam	2.15	tres battant	4.5	4.3



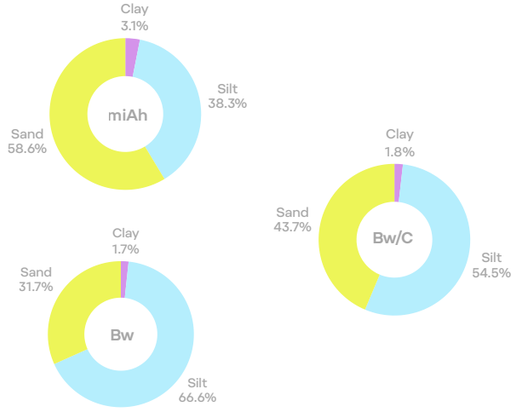


Figure 23B: Soil texture

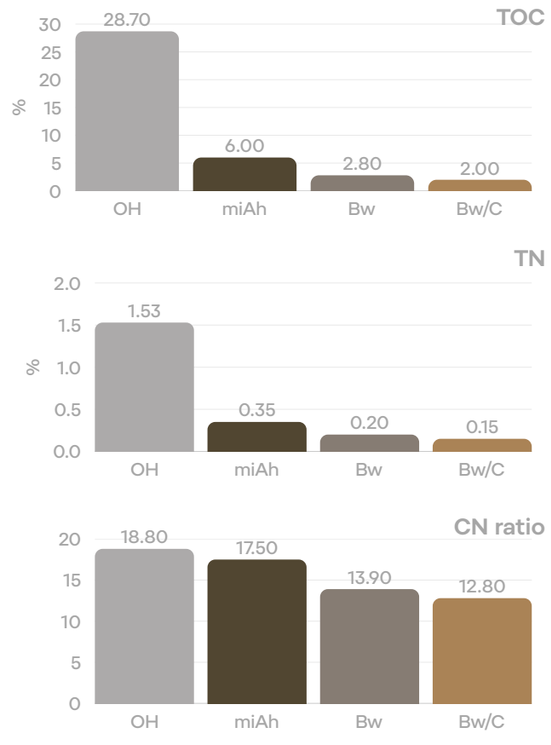


Figure 23C: Total soil carbon and nitrogen characteristics

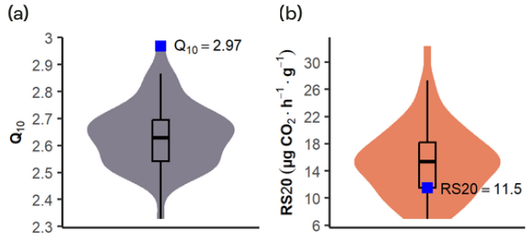


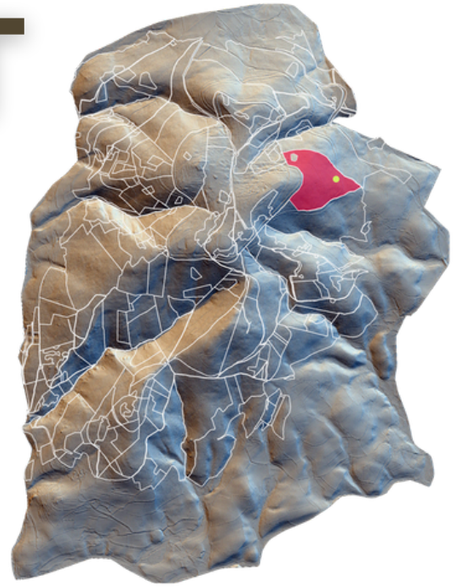
Figure 23D:
(a) Q10: the temperature sensitivity of soil respiration
(b) RS20: soil respiration value for a standardized temperature of 20 degrees
(c) Shannon: soil molecular diversity index, based on the identification of compounds from the main molecular families

Mixed forest

site
24

MIXED FOREST

GPS (N):	4.0484630°
GPS (E):	46.9257190°
Localization:	intramuros (1st rampart)
Altitude:	672 m a.s.l.
Inclination:	15°
Exposure:	SE



The profile is located in the middle of the straight slope (inclination 15°, south-east exposure). The surface and topsoil are very stony. The tree layer consists of sycamore (70%) and beech (30%). The shrub layer consists of holly and bramble. The herbaceous layer is absent, sporadically moss.





Despite the high silt content, soil aggregates remain stable due to the high organic matter content, resulting in low slaking susceptibility. Organic matter also buffers aluminium mobility despite strongly acidic conditions. The soil shows moderate cation exchange capacity, largely associated with humic substances, and relatively balanced plant-available nutrient contents. The deep humus-rich profile supports an active colloidal system and high biological activity. The site represents a typical sycamore-associated habitat, where sycamore contributes to high root density and exerts a strong ameliorative effect on soil functioning. However, the extremely high stoniness limits soil water storage. Forest management should therefore maintain a closed forest microclimate and avoid excessive canopy opening, which could increase drought stress and promote nitrophilous understory vegetation.

Soil Taxonomic Unit:

Katoskeletic Cambic Umbrisol (Amphisiltic, Epiloamic, Humic, Solimovic)

Stratigraphy:
OL-OFzo-OH-meAh-Bw-BwC

Humus form:
Hemimoder

OLn (3.5 cm):	Recent leaves of sycamore, beech and oak.
OLv (1.5 cm)	Continuous, thick litter, dominance of beech leaves.
OFzo (2.0 cm):	Amphigenic (mycelia and zooedaphone).
OH (0.5 cm):	Discontinuous, dark (brown to brown-black).



meAh (0.0–47.0 cm)
Color: 7.5YR 2.5/2 (very dark brown), texture class: sandy loam, stoniness: 40% (angular stones), structure: medium granular, bulk density: very loose, moisture: slightly moist, root density: <2 mm: 220 pcs/dm^2, >2 mm: 30 pcs/dm^2. Umbric, humus-rich; gradual distinctness and wavy shape of lower boundary.

Bw (47.0–72.0 cm)
Color: 10YR 3/3.5 (dark-to-dark yellowish brown), texture class: silty clay loam, stoniness: 70% (angular boulders), structure: fine subangular blocky, bulk density: very loose, moisture: slightly moist, root density: <2 mm: 10 pcs/dm^2, >2 mm: 1 pc/dm^2. Fasciculate roots and organic matter accumulations in isolated enclaves.

Bw/C (>72.0 cm)
Color: 10YR 4/4 (dark yellowish brown), texture class: silty clay loam, stoniness: 85% (angular boulders), structure: very fine subangular blocky, bulk density: loose, moisture: dry, root density <2 mm: 2 pcs/dm^2, >2 mm: 1 pc/dm^2. Fasciculate roots and organic matter accumulations in isolated enclaves.

Soil developed in context of scree-slope accumulation with high stoniness; very high root density; sycamore distribution corresponds with the scree enclave where humification processes and humus accumulation dominate. Below metamorphic properties are running.



SOIL CHARACTERISTICS

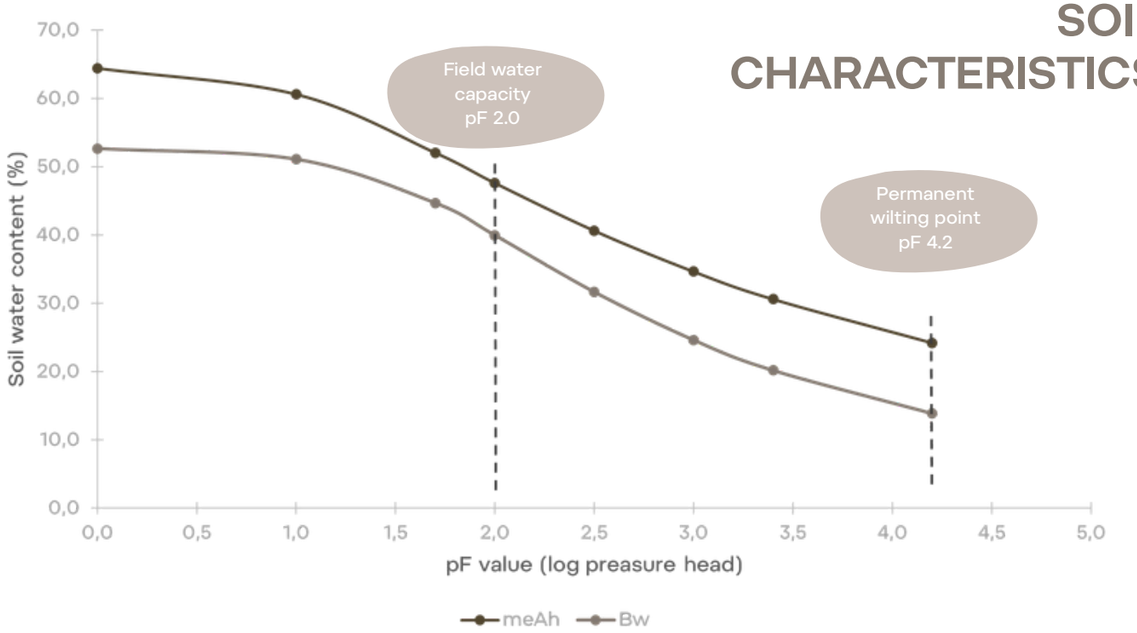


Figure 24A: Water retention curve showing the relationship between soil water content and pF value

This profile No. 24 shows a relatively simple two-horizontal layering with a clear gradient of hydrophysical properties from the organic-rich topsoil to the mineral subsoil. The meAh horizon has low bulk density (0.7 g/cm³) and relatively high organic matter content (16.4%), which supports high maximal (64.4%) and field water capacities (47.6%). Saturated hydraulic conductivity is moderately high (30.1 cm/day), allowing efficient water movement through the upper horizon. Available water capacity is 23.4%, indicating good water availability for plants. The mineral Bw horizon shows an increase in bulk density (1.1 g/cm³) and a decrease in organic matter content (7.6%), which corresponds to lower maximal (52.6%) and field water capacities (40.0%). Despite this reduction, the available water capacity increases slightly to 26.1%, while the saturated hydraulic conductivity decreases to 18.8 cm/day, reflecting slower but steady water movement probably through the mesopores and micropores.

Table 24A: Soil properties of particular horizons – profile No. 24

Soil Horizon	Maximal Water Capacity (% vol.)	Field Water Capacity (% vol.)	Permanent Wilting Point (% vol.)	Available Water Capacity (% vol.)	Saturated Hydraulic Conductivity (cm/day)	Bulk Density (g/cm³)	Organic Matter (% wt.)
meAh	64.4	47.6	24.2	23.4	30.1	0.7	16.4
Bw	52.6	40.0	13.9	26.1	18.8	1.1	7.6

Overall, this profile maintains a balanced water retention capacity across both horizons (~23–26% available water), suggesting consistent water availability for plant throughout the profile, even as soil compaction increases with depth.

Table 24B: Micronutrients content

Soil horizon	P	Ca	Mg	K	CEC	BS
	mg/kg				mmol/kg	%
OH	51	585	258	248	373.8	15.2
meAh	9	173	70	77	87.6	24.6
Bw/C	11	162	61	42	40.0	47.5

Table 24C: Soil texture characteristics and Soil reaction

Soil horizon		Texture class	Slaking index	Battance class	pH_{water}	pH_{KCl}
OH					3.5	3.0
meAh	●	sandy loam	0.96	non battant	3.8	3.9
Bw/C	●	silt loam	1.37	no battant	3.8	4.2



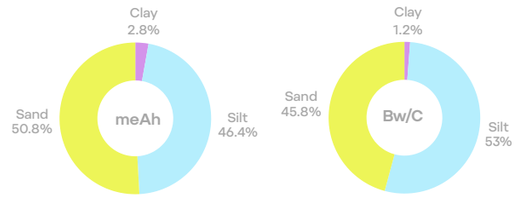


Figure 24B: Soil texture

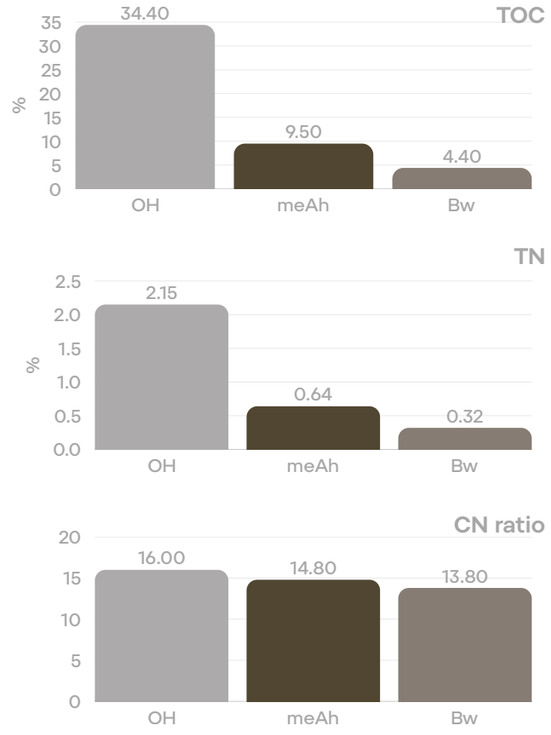


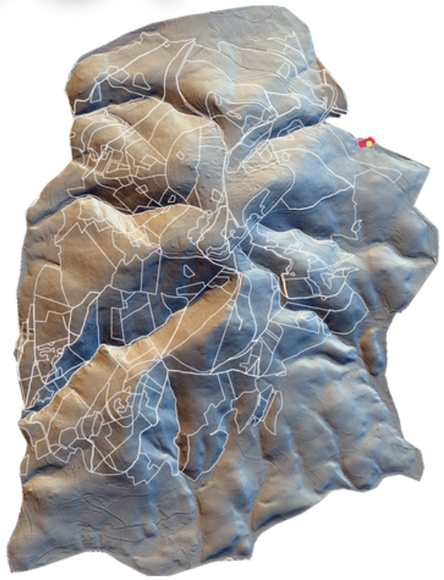
Figure 24C: Total soil carbon and nitrogen characteristics

Mixed forest

site

CLEARCUT 25

GPS (N):	4.0536130°
GPS (E):	46.9285000°
Localization:	extramuros
Altitude:	542 m a.s.l.
Inclination:	5°
Exposure:	SE



The profile is located in the floodplain at the bottom of a wide valley, 25 m north of a small stream (inclination max 5°, south-east exposure). The parent material consists of mixture offluvial and colluvial sedimets. This is a spruce´s clearcut area with crushing and mulching. The vegetation cover consists of rush, ramble, and red-berried elder.





Soil Taxonomic Unit:

Amphiskeletic Fluvic Stagnic Umbrisol (Endoloamic, Episiltic, Solimovic)

Stratigraphy:
OL-OFzo-OHg-miAhg-meAhg-Bgτ

Humus form:
Eumesoamphi

OL (2 cm):	Crushed post-harvest debris with dominance of Norway spruce.
OFzo (3 cm):	Thick, continuous, refflecting post-harvest management and organic matter transformations.
OH (1.5 cm):	Dark, moist, continuous.



miAhg (0-32 cm)

Color: 10YR 4/2 (dark grayish brown), texture class: clay loam, stoniness: 40% (angular boulders), structure: very fine angular blocky, bulk density: intermediate, moisture: moist, root density: <2 mm: 20 pcs/dm^2, >2 mm: 5 pcs/dm^2. Umbric, accumulated, structure partially massive (approx. 20-30%) with weak odour of anaerobic organic matter transformations.

meAhg (32-54 cm)

Color: 10YR 7/1 (light gray), texture class: sandy clay loam, stoniness: 65% (angular stones), structure: fine angular blocky, bulk density: intermediate, moisture: moist, root density: <2 mm: 1 pcs/dm^2, >2 mm: <1 pc/dm^2. Bright color due to low organic matter content in slightly reduced colluvial material. Structure partially massive (approx. 20-30%). Does not fulfill criteria for gleyc properties.

Bgτ (>54 cm)

Color: 7.5YR 5/8 (strong brown) + Gley1 7/10Y (light greenish gray; 35-40% of mottles), texture class: sandy clay loam, stoniness: 70-85% (angular boulders), structure: coarse angular blocky, bulk density: firm, moisture: wet, root density: <2 mm: <1 pc/dm^2, >2 mm: 0 pcs/dm^2. Alteration of reduction/oxydation processes.

The soil is located at the valley bottom within fluvial-colluvial accumulation. Texture is dominated by silt and coarse sand with low clay content (<10 %), resulting in silt loam to sandy loam and reflecting erodible material. The soil is strongly acidic with low to moderate ECEC, except in the organic-rich topsoil. Base saturation is moderate, with relatively high magnesium proportions. Mineralogy of the soil-forming substrate is generally poor, except for high phosphorus content. Elevated nitrogen and low C/N favour nitrophilous and invasive species; therefore, systematic control of forest weeds is essential. Regeneration should be carried out primarily under the shelter of the maternal stand. Considering soil moisture, depth and nitrogen status, sycamore, alders, common ash, European silver fir and small-leaved lime are recommended.

Stagnic properties in subsoil layers, overlayed with colluvial material of recent accumulation; pedoturbation in topsoil (mulching/crushing).
Site contitions represent accumulation base in a bootom of wide valley.
Combination of pedogenic processes (colluvial/fluvial materials accumulation, oxydation/reduction, all under slightly running metamorphic processes.



SOIL CHARACTERISTICS

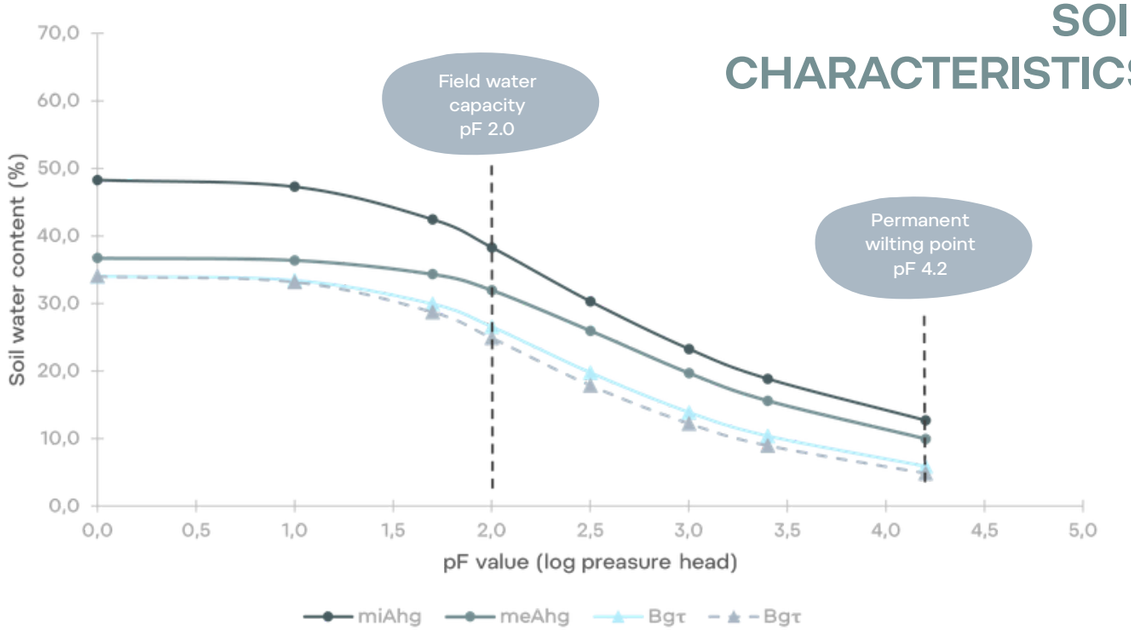


Figure 25A: Water retention curve showing the relationship between soil water content and pF value

This profile No. 25 is characterized by progressive compaction and decreasing organic matter with depth (Table 25A, Fig. 25A). The surface horizon retains moderate water, while the deeper horizons are less retentive, although plant-available water remains relatively consistent. The surface miAhg horizon has moderate bulk density (1.2 g/cm³) and relatively low organic matter (5.0%), resulting in maximal water capacity of 48.2% and field water capacity of 38.3%. Saturated hydraulic conductivity is low (9.7 cm/day), reflecting limited infiltration and moderate pore connectivity in this topsoil horizon. The next underlying meAhg horizon exhibits higher bulk density (1.6 g/cm³) and lower organic matter (1.7%), with reduced maximal water capacity (36.7%) and field water capacity (32.0%). Saturated hydraulic conductivity decreases further to 6.2 cm/day, indicating increasing compaction and restricted water movement in this layer.

Both deeper anthropogenic Bgτ horizons are highly compacted (bulk density 1.7 g/cm³) with very low organic matter (0.6–0.7%). Maximal water capacity is lowest in the profile (34.0%), and available water capacity ranges from 24.9% to 26.5%. Saturated hydraulic conductivity varies slightly (14.0–18.0 cm/day), suggesting limited but uneven macropore development.

Table 25A: Soil properties of particular horizons – profile No. 25

Soil Horizon	Maximal Water Capacity (% vol.)	Field Water Capacity (% vol.)	Permanent Wilting Point (% vol.)	Available Water Capacity (% vol.)	Saturated Hydraulic Conductivity (cm/day)	Bulk Density (g/cm³)	Organic Matter (% wt.)
miAhg	48.2	38.3	12.7	25.6	9.7	1.2	2.5
meAhg	36.7	32.0	9.9	22.0	6.2	1.6	1.7
Bgτ	34.0	26.5	5.9	20.6	14.0	1.7	0.7
Bgτ	34.0	24.9	4.9	20.0	18.0	1.7	0.6

Overall, available water capacity remains relatively stable across all horizons (20.0–25.6%), indicating that despite low total retention, a considerable proportion of water is still plant-available. This profile demonstrates lower water retention and permeability compared to all described catalogue profiles, likely due to the combined effects of high bulk density and low organic matter.

Table 25B: Micronutrients content

Soil horizon	P	Ca	Mg	K	CEC	BS
	mg/kg				mmol/kg	%
OH	67	1425	300	191	352.4	28.7
miAhg	13	159	54	75	55.1	32.9
meAhg	6	149	52	61	41.1	41.6
Bgτ	1	147	53	62	44.5	50.5
Bgτ	2	176	78	74	46.2	48.1

Table 25C: Soil texture characteristics and Soil reaction

Soil horizon		Texture class	Slaking index	Battance class	pH_{water}	pH_{KCl}
OH					3.8	3.4
miAhg		silt loam	2.15	tres battant	3.8	3.5
meAhg		sandy loam	3.97	tres battant	4.0	3.7
Bgτ		silt loam	4.96	tres battant	4.1	3.7
Bgτ		sandy loam	5.25	tres battant	4.3	3.7



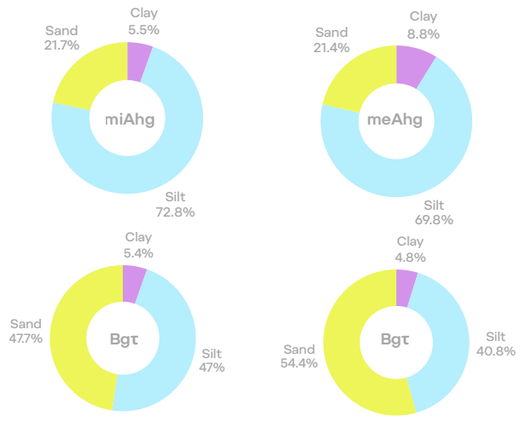
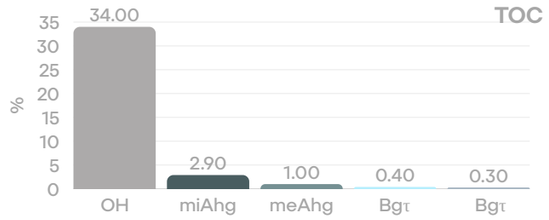
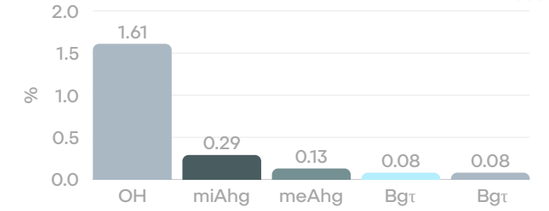


Figure 25B: Soil texture





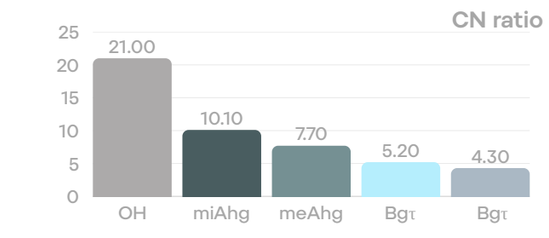


Figure 25C: Total soil carbon and nitrogen characteristics

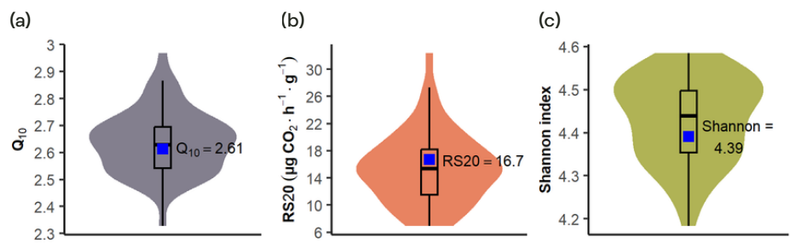


Figure 25D:
(a) Q10: the temperature sensitivity of soil respiration
(b) RS20: soil respiration value for a standardized temperature of 20 degrees
(c) Shannon: soil molecular diversity index, based on the identification of compounds from the main molecular families

Clearcut

site

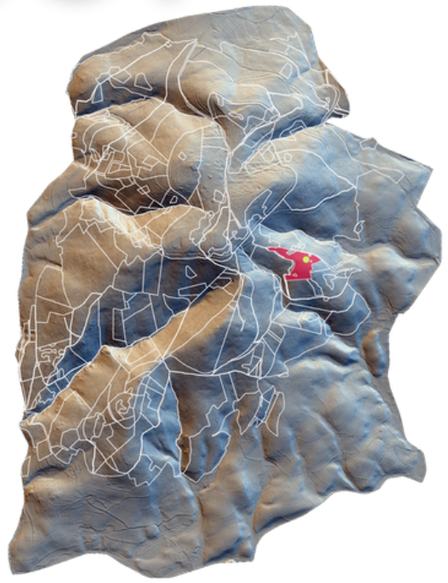
CLEARCUT 26

Soil Taxonomic Unit:

Endoskeletic Cambic Umbrisol (Humic, Katosiltic, Solimovic)

Clearcut

GPS (N):	4.0239200°
GPS (E):	46.9266930°
Localization:	extramuros
Altitude:	628 m a.s.l.
Inclination:	22°
Exposure:	NW



The profile is located in the lower part of a slope (inclination 22°, nortwest exposure). This is a clearcut of douglas fir and spruce with solitary trees of sweet chestnut, hazel and sycamore. The whole area is overgrown (bramble and broom).





Steep slope site with increased erosion risk, particularly in deeper horizons dominated by silt loam with low aggregate stability. The soil is strongly acidic throughout the profile and characterised by low ECEC, with low base saturation in the topsoil and moderately higher values in deeper mineral layers. Potassium availability is relatively sufficient, whereas magnesium and calcium occur in lower concentrations, indicating a potential risk of magnesium limitation under stress conditions. Elevated potassium and phosphorus contents correspond to the mineral composition of the parent material. Following clearcutting, rapid mineralisation of humus-rich surface layers promotes competitive nitrophilous species such as common hazel, common broom and bramble. Successful establishment of target species—especially sessile oak, European beech, hornbeam and European silver fir in lower slope positions)—requires systematic multi-year control of competing vegetation. An admixture (approx. 15-25%) of ameliorative pioneer species such as silver birch and European aspen is recommended in either uniform or group-wise mixtures.

Stratigraphy:
OL-OFzo-OH-meAh1-miAh2-miAh/Bw-Bw-BwC

Humus form:
Eumesoamphi

OL (4 cm):	Thick, loose, continuous mixed litter (dominantly bramble + chestnut, hazel).
OFzo (2 cm):	Thick, continuous.
OH (0.5 cm):	Fast mineralization process within open plot of aged clearcut.

meAh1 (0–11 cm)
Color: 10YR 2/2 (very dark brown), texture class: sandy loam, stoniness: 30% (angular coarse gravel), structure: fine granular, bulk density: very loose, moisture: very dry, root density: <2 mm: 130 pcs/dm^2, >2 mm: 45 pcs/dm^2.

meAh2 (11–38 cm)
Color: 10YR 3/3 (dark brown), texture class: sandy loam, stoniness: 40% (angular coarse gravel), structure: fine granular, bulk density: loose, moisture: dry, root density: <2 mm: 130 pcs/dm^2, >2 mm: 40 pcs/dm^2. Umbric.

miAh/Bw (38–63 cm)
Color: 10YR 3/4 (dark yellowish brown), texture class: sandy loam, stoniness: 40% (angular boulders), structure: fine subangular blocky, bulk density: loose, moisture: slightly moist, root density <2 mm: 70 pcs/dm^2, >2 mm: 10 pcs/dm^2.

Bw (63–102 cm)
Color: 10YR 5/8 (yellowish brown), texture class: silt loam, stoniness: 75% (angular large boulders), structure: medium subangular blocky, bulk density: loose, moisture: slightly moist, root density <2 mm: 15 pcs/dm^2, >2 mm: 2 pcs/dm^2.

BwC (>102 cm)
Color: 7.5YR 5/8 (strong brown) + Gley1 7/10Y (light greenish gray; 35–40% of mottles), texture class: sandy clay loam, stoniness: 70–85% (angular boulders), structure: coarse angular blocky, bulk density: firm, moisture: wet, root density: <2 mm: <1 pc/dm^2, >2 mm: 0 pcs/dm^2. Alteration of reduction/oxydation processes.



Deep soil with developed cambic metamorphic horizon and with deep humus accumulation (announcing umbric properties).



SOIL CHARACTERISTICS

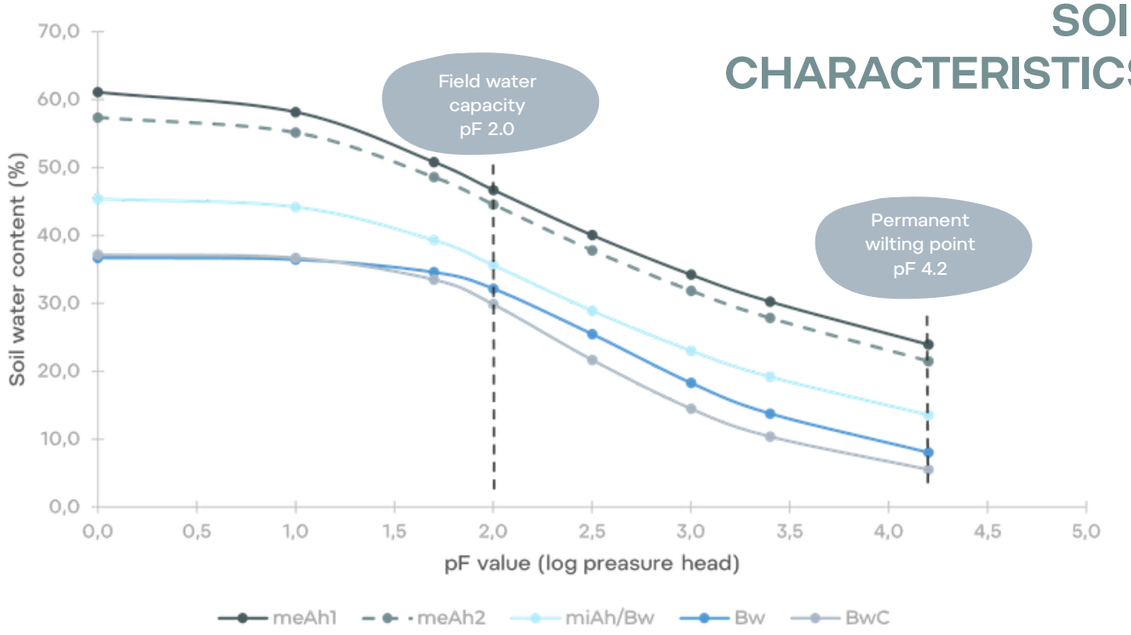


Figure 26A: Water retention curve showing the relationship between soil water content and pF value

This profile No. 26 illustrates the interaction of texture and bulk density in controlling water storage and movement along the natural soil development profile. Both topsoil horizons, meAh1 and meAh2, have low bulk density (0.8–0.9 g/cm³) and high organic matter content (15.2–11.0%), resulting in high maximal water capacity (57.3–61.1%) and field water capacity (44.5–46.7%). Saturated hydraulic conductivity is also relatively high (25.2–25.8 cm/day), indicating good pore connectivity and efficient water infiltration into underlying mineral horizons. The transitional miAh/Bw horizon shows increased bulk density (1.3 g/cm³) and reduced organic matter (4.9%), with lower water retention (maximal 45.4%, field 35.6%) and decreased hydraulic conductivity (15.4 cm/day), reflecting the shift toward more compact mineral subsoil.

Deeper horizons, Bw and BwC, are strongly compacted (1.6 g/cm³) with minimal organic matter (1.1–1.6%). Maximal and field water capacities decrease (36.7–37.1% and 29.9–32.2%), and saturated hydraulic conductivity varies between 5.6 and 10.8 cm/day, indicating limited vertical water movement in profile.

Table 26A: Soil properties of particular horizons – profile No. 26

Soil Horizon	Maximal Water Capacity (% vol.)	Field Water Capacity (% vol.)	Permanent Wilting Point (% vol.)	Available Water Capacity (% vol.)	Saturated Hydraulic Conductivity (cm/day)	Bulk Density (g/cm³)	Organic Matter (% wt.)
meAh1	61.1	46.7	23.9	22.7	25.2	0.8	15.2
meAh2	57.3	44.5	21.5	23.1	25.8	0.9	11.0
miAh/Bw	45.4	35.6	13.6	22.0	15.4	1.3	4.9
Bw	36.7	32.2	8.0	24.1	5.6	1.6	1.6
BwC	37.1	29.9	5.5	24.3	10.8	1.6	1.1

Available water capacity remains relatively high across all horizons (22.0–24.3%), suggesting that despite increasing compaction, the whole profile can still supply water to plants.

Table 26B: Micronutrients content

Soil horizon	P	Ca	Mg	K	CEC	BS
	mg/kg				mmol/kg	%
OH	32	977	235	272	292.8	26.4
meAh1	9	137	63	169	83.1	23.0
meAh2	8	91	43	124	64.0	21.8
miAh/Bw	9	80	34	67	35.6	26.9
Bw	16	98	43	51	27.0	40.8
BwC	27	103	43	58	19.6	59.2

Table 26C: Soil texture characteristics and Soil reaction

Soil horizon		Texture class	Slaking index	Battance class	pH_{water}	pH_{KCl}
OH					4.3	3.6
meAh1		sandy loam	1.02	non battant	3.6	3.7
meAh2		silt loam	1.19	non battant	3.6	3.8
miAh/Bw		silt loam	1.79	assez battent	3.7	3.9
Bw		silt loam	4.66	tres battant	3.8	4.0
BwC		silt loam	5.19	tres battant	3.9	4.2

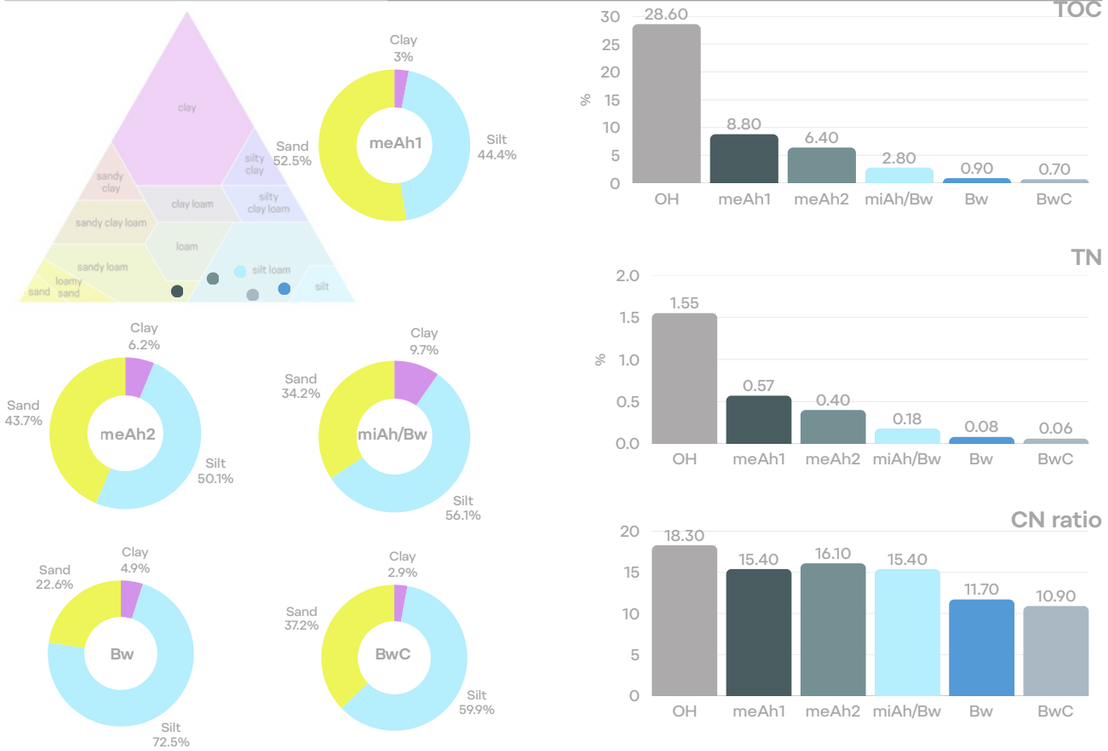


Figure 26B: Soil texture

Figure 26C: Total soil carbon and nitrogen characteristics

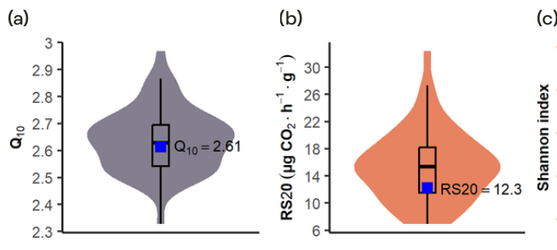
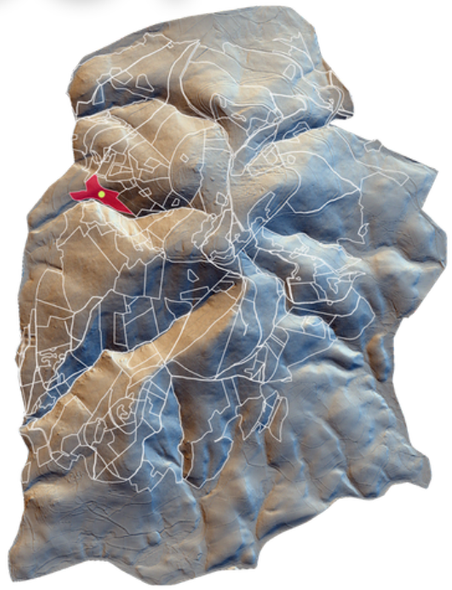


Figure 26D:
(a) Q10: the temperature sensitivity of soil respiration
(b) RS20: soil respiration value for a standardized temperature of 20 degrees
(c) Shannon: soil molecular diversity index, based on the identification of compounds from the main molecular families

Clearcut

site

CLEARCUT 27



GPS (N):	4.0208100°
GPS (E):	46.9248930°
Localization:	extramuros
Altitude:	517 m a.s.l.
Inclination:	24°
Exposure:	SSW

The profile is located in the middle section of a straight slope (inclination 24°, south-southwest exposure). It is a clearcut area more than five years old with solitaire sweet chestnut trees, covered by forest weed (bramble and broom) and fern. The profile is dominated by a silty texture.





Surface horizons show sandy loam texture, whereas mineral horizons are silt loam, reflecting decreasing TOC with depth. Exposed subsoil is prone to aggregate destabilisation. Soil reaction is strongly acidic; CEC is low in mineral horizons but high near the surface due to humic substances. The sorption complex is moderately to slightly unsaturated, with potassium dominating base cations and comparatively low calcium and magnesium. Elevated subsoil potassium is mainly related to sorption on iron and aluminum oxides and partly to associations with labile organic carbon. Dense nitrophilous vegetation, especially bramble, restricts regeneration. Recommended species include sessile oak, European beech and common hornbeam, with European silver fir on fresher lower slopes. Pioneer admixture of silver birch and European aspen is suitable; service tree may serve as an economically and ecologically promising admixture species.

Soil Taxonomic Unit:

Amphiskeletic Cambic Umbrisol (Amphisiltic, Epiloamic, Solimovic)

Stratigraphy:
OL-OFzo-OH-miAh-meAh-miAh/Bw-Bw-BwC

Humus form:
Eumesoamphi

OL (3 cm):	Dry, thick, spruce needles and twigs; blackbarry leaves.
OFzo (1 cm):	Dry, thick.
OH (1 cm):	Continuous, dry, thick, with high hair root density.

miAh (0–5 cm)

Color: 10YR 3/2 (very dark grayish brown), texture class: loamy sand, stoniness: 15% (angular medium gravel), structure: fine granular, bulk density: very loose, moisture: very dry, root density: <2 mm: 110 pcs/dm^2, >2 mm: 30 pcs/dm^2.

meAh (5–30 cm)

Color: 10YR 3/3 (dark brown), texture class: sandy loam, stoniness: 25–30% (angular stones), structure: medium granular, bulk density: loose, moisture: dry, root density: <2 mm: 130 pcs/dm^2, >2 mm: 20 pcs/dm^2. Umbric, darkness gradient from dark to bright, low to moderate SOM concentration; silt loam admixture.

miAh/Bw (30–44 cm)

Color: 10YR 4/4 (dark yellowish brown), texture class: sandy loam, stoniness: 60% (angular stones), structure: medium subangular blocky, bulk density: loose, moisture: dry, root density <2 mm: 50 pcs/dm^2, >2 mm: 3 pcs/dm^2. Silt loam admixture; fine granular structure proportion (30%); gradual discontinuous (broken) shape of lower layer boundary.

Bw (44–64 cm)

Color: 10YR 4/6 (dark yellowish brown), texture class: silt loam, stoniness: 30% (angular stones), structure: fine subangular blocky, bulk density: loose, moisture: slightly moist, root density <2 mm: 25 pcs/dm^2, >2 mm: 1 pc/dm^2. Gradual smooth-to-wavy lower boundary.

BwC (>64 cm)

Color: 10YR 5/6 (yellowish brown), texture class: silt loam, stoniness: 65% (angular stones), structure: very fine subangular blocky, bulk density: intermediate, moisture: slightly moist, root density <2 mm: 5 pcs/dm^2, >2 mm: 2 pcs/dm^2. Week soil aggregates stability.

Moderately deep umbrisol with accumulation of organic matter at or near soil surface; 100% vegetation cover on aged clearcut plot products woody + bush + herb debris. Difuse boundary in organomineral-mineral transition zone with broken shape probably result from solifluction.





SOIL CHARACTERISTICS

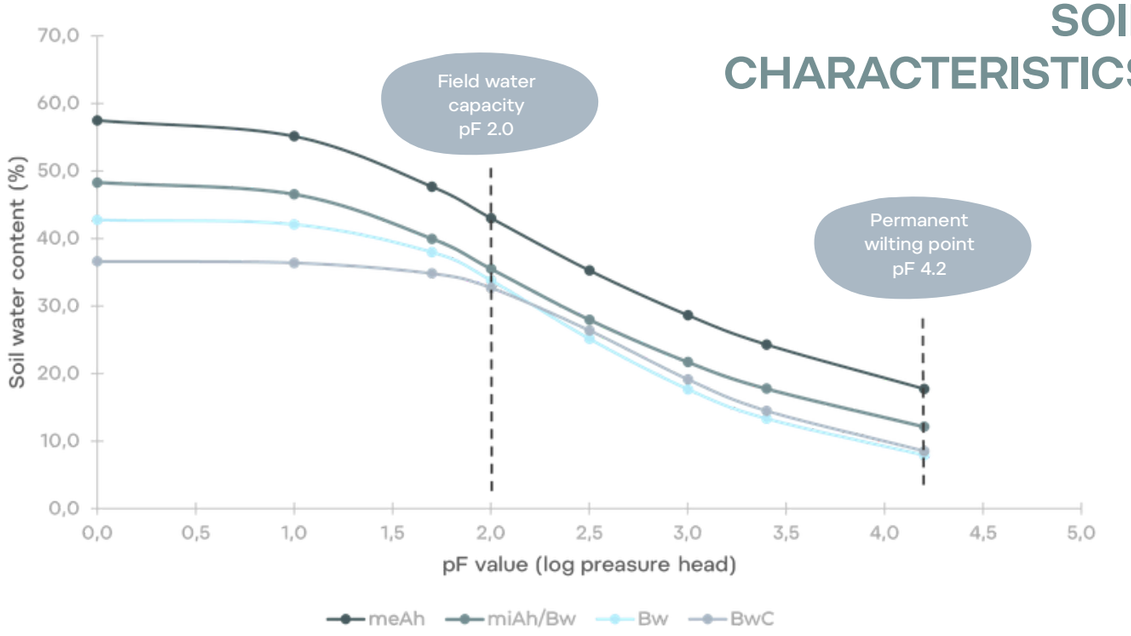


Figure 27A: Water retention curve showing the relationship between soil water content and pF value

Soil profile No. 27 exhibits vertical differentiation of the studied soil properties, like the previously described naturally developed profile No. 26, though it shows notable differences in water retention and hydraulic conductivity. Similar to profile No. 26 (Fig. 26A, Table 26A), the surface meAh horizon of profile No. 27 (Fig. 27A, Table 27A) exhibits a low bulk density (0.9 g/cm³) and relatively high organic matter content (10.2%), resulting in high maximum water capacity (57.5%) and field water capacity (43.0%). Saturated hydraulic conductivity is very high (59.2 cm/day), even exceeding that of the meAh1 horizon in profile No. 26 (≈34 cm/day), indicating exceptionally rapid water movement under these conditions of profile No. 27.

The transitional miAh/Bw horizon shows increased bulk density (1.2 g/cm³) and decreased organic matter (6.1%), with reduced water retention (maximal 48.3%, field 35.5%) and moderate hydraulic conductivity (28.6 cm/day). This pattern also mirrors the transitional horizon behaviour of Ah/Bw horizon, which was also observed in previously described profiles No. 1, 19 and 26.

Table 27A: Soil properties of particular horizons – profile No. 27

Soil Horizon	Maximal Water Capacity (% vol.)	Field Water Capacity (% vol.)	Permanent Wilting Point (% vol.)	Available Water Capacity (% vol.)	Saturated Hydraulic Conductivity (cm/day)	Bulk Density (g/cm³)	Organic Matter (% wt.)
meAh	57.5	43.0	17.7	25.3	59.2	0.9	10.2
miAh/Bw	48.3	35.5	12.1	23.3	28.6	1.2	6.1
Bw	42.8	33.8	7.9	25.9	10.1	1.4	3.0
BwC	36.6	32.7	8.5	24.2	4.5	1.6	1.8

Deeper horizons, Bw and BwC, are strongly compacted (1.4–1.6 g/cm³) and low in organic matter (1.8–3.0%). Maximal and field water capacities decline further (36.6–42.8% and 32.7–33.8%), and saturated hydraulic conductivity decreases sharply (10.1–4.5 cm/day). Compared to profile No. 26, the subsoil in profile No. 5 shows lower conductivity in the deepest horizon, indicating more restricted vertical water movement on this soil conditions.

Table 27B: Micronutrients content

Soil horizon	P	Ca	Mg	K	CEC	BS
	mg/kg				mmol/kg	%
OH	25	718	264	212	261.0	28.2
meAh	7	207	37	144	70.4	27.6
miAh/Bw	3	206	38	123	46.8	40.1
Bw	5	239	45	122	35.3	60.3
BwC	5	194	37	121	29.0	62.1

Table 27C: Soil texture characteristics and Soil reaction

Soil horizon		Texture class	Slaking index	Battance class	pH_{water}	pH_{KCl}
OH					3.8	3.4
meAh		sandy loam	0.87	non battant	4.3	3.9
miAh/Bw		sandy loam	1.22	non battant	4.5	4.1
Bw		silt loam	2.79	tres battant	4.5	4.2
BwC		silt loam	4.35	tres battant	4.4	4.1



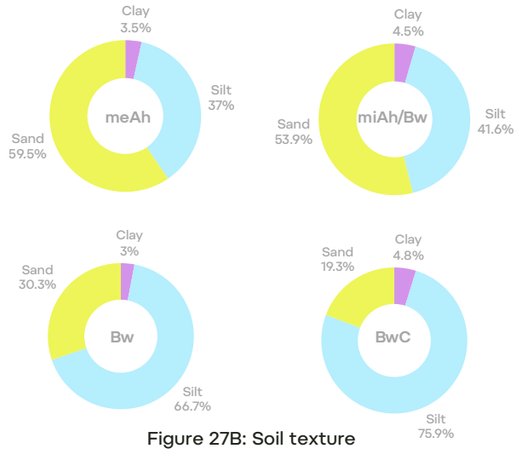
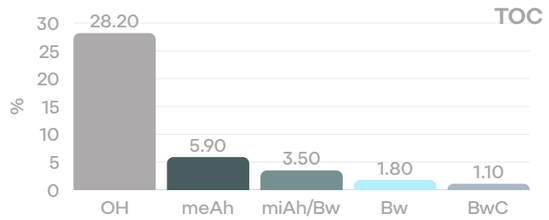


Figure 27B: Soil texture



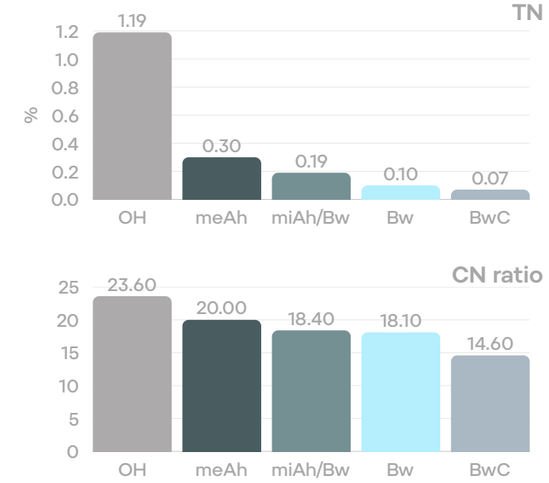


Figure 27C: Total soil carbon and nitrogen characteristics

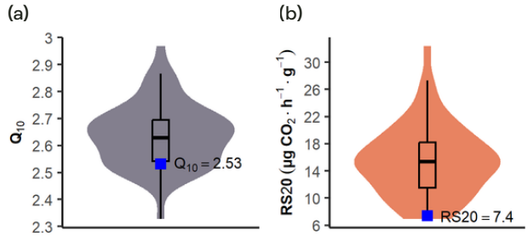


Figure 27D:
(a) Q10: the temperature sensitivity of soil respiration
(b) RS20: soil respiration value for a standardized temperature of 20 degrees
(c) Shannon: soil molecular diversity index, based on the identification of compounds from the main molecular families

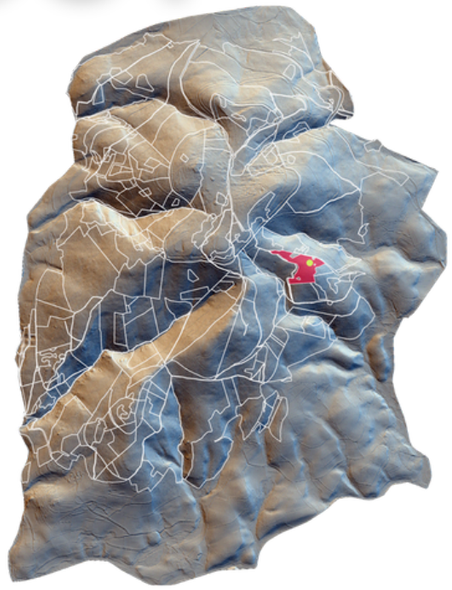
Clearcut

site

CLEARCUT 28

Clearcut

GPS (N):	4.0455130°
GPS (E):	46.9190690°
Localization:	extramuros
Altitude:	688 m a.s.l.
Inclination:	17°
Exposure:	NNE



The profile is located on a straight slope, about 40 meters below the ridge (inclination 17°, north-northeast exposure). This is a clearcut planted by oak, douglas fir, pine and silver fir. Although the entire profile is highly stoniness, it does not apply for the soil surface. There is a permanent meteorological station.





Grain-size distribution is dominated by silt and fine sand, resulting in siltic to arenic textures with moderate aggregate stability partly supported by organic matter, as reflected by the low slaking index (battance). Base saturation is low to moderate and the sorption complex is dominated by acidic cations. Although magnesium prevails among base cations, its concentrations remain low and nutrient balance is constrained by aluminum. The soil profile shows deep TOC distribution and considerable nitrogen fixation in organic matter, with C:N ratios of about 16–25 indicating variable transformation intensity. Total phosphorus is relatively high due to mineral sources, whereas plant-available phosphorus remains low because of fixation by iron and aluminum compounds. In clearcut areas, regeneration should support diverse species including common hornbeam, silver birch, European aspen and service tree. Despite its allochthonous origin, Northern red oak may also be included due to its drought tolerance.

Soil Taxonomic Unit:

Katoskeletic Cambic Umbrisol (Hyperdystric, Hyperhumic, Endoloamic, Episiltic, Pachic, Solimovic)

Stratigraphy:
OL-OFzo-OH-meAh-miAh/Bw-Bw

Humus form:
Eumesoamphi

OL (0.5 cm):	Discontinuous.
OFzo (0.5 cm):	Discontinuous.
OH (2 cm):	Continuous, dry, thick, dark.



meAh (0–51 cm)

Color: 10YR 2/2 (very dark brown), texture class: sandy loam, stoniness: 30–60% (angular coarse gravel), structure: fine granular, bulk density: very loose, moisture: slightly moist, root density: <2 mm: 120 pcs/dm^2, >2 mm: 30 pcs/dm^2. Umbric, humus-rich, gradient in stoniness (30% in 0–15 cm; lower 60%).

miAh/Bw (51–66 cm)

Color: 7.5YR 4/4 (brown), texture class: sandy loam, stoniness: 65% (angular stones), structure: very fine granular, bulk density: very loose, moisture: slightly moist, root density: <2 mm: 30 pcs/dm^2, >2 mm: 3 pcs/dm^2. Gradual, wavy transition zone to Bw.

Bw (>66 cm)

Color: 7.5YR 4/6 (strong brown), texture class: sandy loam, stoniness: 75% (angular stones), structure: medium subangular blocky, bulk density: very loose, moisture: slightly moist, root density <2 mm: 110 pcs/dm^2, >2 mm: 10 pcs/dm^2. Gradual, broken layer boundary with enclaves of organic matter.

Soil with high stoniness of volcanic rock fragments; without coarse surface fragments.



SOIL CHARACTERISTICS

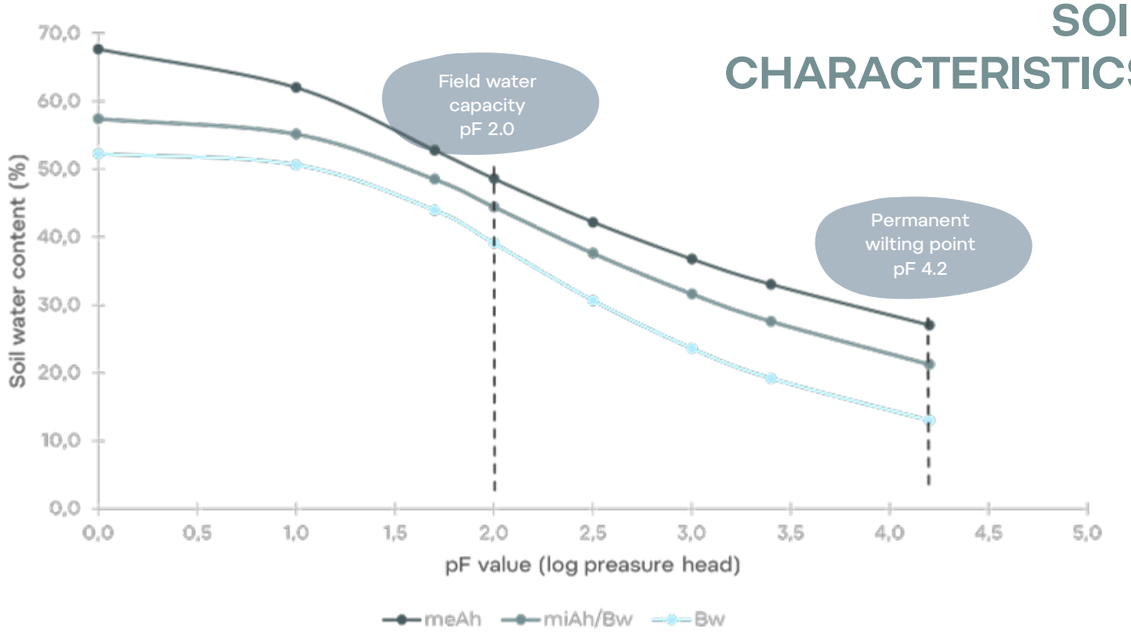


Figure 28A: Water retention curve showing the relationship between soil water content and pF value

Profile No. 28 exhibits a relatively homogeneous distribution of hydro-physical properties across all horizons, with gradual, rather than abrupt, changes in water retention, hydraulic conductivity, and bulk density. The meAh horizon is characterized by very low bulk density (0.6 g/cm³) and high organic matter content (20.1%), resulting in the highest maximal (67.7%) and field water capacities (48.6%). Saturated hydraulic conductivity is moderate (25.9 cm/day), ensuring efficient but not rapid water movement. In the transitional miAh/Bw horizon, bulk density increases slightly to 0.9 g/cm³, and organic matter decreases to 11.6%, but maximal water capacity (57.4%) and field water capacity (44.5%) remain relatively high. Available water capacity (23.2%) also stays consistent, with hydraulic conductivity remaining stable at 24.9 cm/day, suggesting good but moderate water movement.

The deepest Bw horizon, with further increases in bulk density (1.1 g/cm³) and a decrease in organic matter (6.9%), shows a small reduction in maximal (52.3%) and field water capacity (39.1%). However, available water capacity increases to 26.1%, and hydraulic conductivity slightly drops to 24.4 cm/day, reflecting a minor but consistent shift toward more compacted, less permeable soil.

Table 28A: Soil properties of particular horizons – profile No. 28

Soil Horizon	Maximal Water Capacity (% vol.)	Field Water Capacity (% vol.)	Permanent Wilting Point (% vol.)	Available Water Capacity (% vol.)	Saturated Hydraulic Conductivity (cm/day)	Bulk Density (g/cm³)	Organic Matter (% wt.)
meAh	67.7	48.6	27.0	21.6	25.9	0.6	20.1
miAh/Bw	57.4	44.5	21.3	23.2	24.9	0.9	11.6
Bw	52.3	39.1	13.0	26.1	24.4	1.1	6.9

Despite these changes, the profile remains remarkably homogeneous in its ability to retain soil water, with available water capacity remaining steady across all horizons (~22-26 %). This indicates a well-balanced distribution of soil water retention properties, ensuring potential stable plant water availability throughout the profile.

Table 28B: Micronutrients content

Soil horizon	P	Ca	Mg	K	CEC	BS
	mg/kg				mmol/kg	%
OH	31	576	179	158	288.5	16.9
meAh	6	94	49	71	67.7	17.2
miAh/B	4	91	45	51	40.8	26.5
Bw	4	101	53	43	30.1	40.1

Table 28C: Soil texture characteristics and Soil reaction

Soil horizon		Texture class	Slaking index	Battance class	pH_{water}	pH_{KCl}
OH					3.6	3.1
meAh	●	silt loam	0.88	non battant	4.2	4.1
miAh/Bw	●	sandy loam	1.04	non battant	4.2	4.3
Bw	●	sandy loam	1.33	non battant	4.1	4.4

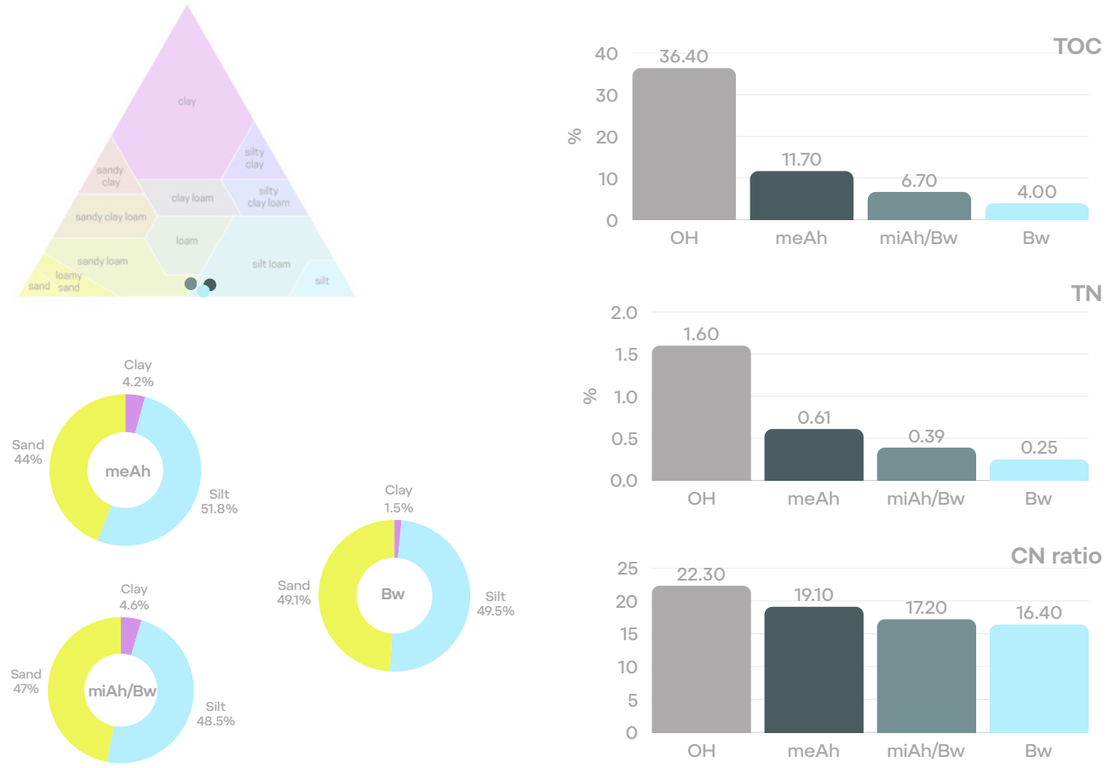


Figure 28B: Soil texture

Figure 28C: Total soil carbon and nitrogen characteristics

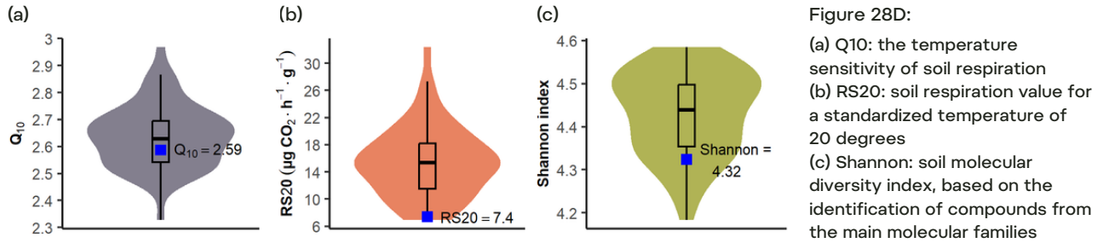


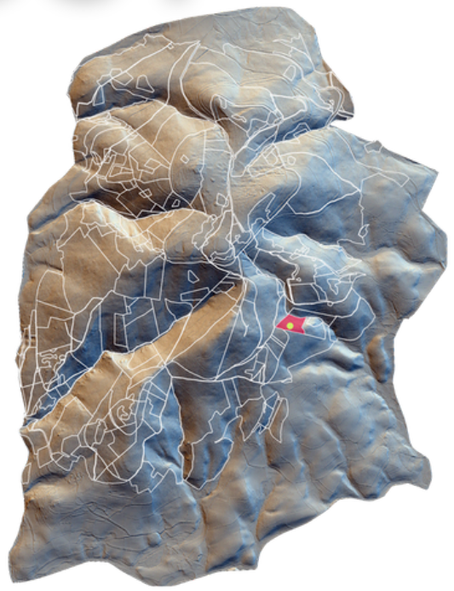
Figure 28D:
(a) Q10: the temperature sensitivity of soil respiration
(b) RS20: soil respiration value for a standardized temperature of 20 degrees
(c) Shannon: soil molecular diversity index, based on the identification of compounds from the main molecular families

Clearcut

site

CLEARCUT 29

GPS (N):	4.0430360°
GPS (E):	46.9140210°
Localization:	extramuros
Altitude:	634 m a.s.l.
Inclination:	10°
Exposure:	NE



The profile is located on a straight slope, 20 meters below the ridge (inclination 10°, north-east exposure). This is a spruce´s clearcut with solitary trees of sweet chestnut. New trees were planted here. The area is overgrown (broom and foxglove).





The soil shows extremely low clay content (<2 %), therefore the sorption complex is largely controlled by humic substances. TOC is moderate to high in the upper horizons. The soil is strongly acidic with generally low base saturation. Temporary nutrient enrichment may occur following accelerated mineralization of organic matter after clearcutting. However, high Al/Bc ratios indicate a potential limitation of nutrient uptake and increased risk of nutrient leaching, particularly in such permeable soils. Available phosphorus is extremely low throughout the profile. Large-scale clearcutting may therefore promote rapid development of nitrophilous and invasive vegetation. Regeneration should be supported by gradual stand diversification and regular mechanical vegetation control, while cut biomass can remain on the soil surface as mulch improving soil moisture and temperature conditions. Support of naturally regenerated woody species is advisable during forest regeneration in terms of support of biodiversity.

Soil Taxonomic Unit:

Katoskeletic Hyperdystric Cambic Umbrisol (Amphisiltic, Epiloamic, Hyperhumic, Protospodic, Solimovic)

Stratigraphy:
OL-OFzo-OH-meAh1-meAh2-Bw1-Bw2-BwC

Humus form:
Eumesoamphi

OL (3 cm):	Thick layer of mixed chestnut and Norway spruce litter (leaves, needles, twigs, cones, fruits).
OFzo (1.5 cm):	Thick, partially humified with abrupt transition in lower boundary.
OH (0.5 cm):	Discontinuous, admixture of medium gravel.

meAh1 (0–4 cm)
Color: 10YR 3/2 (very dark grayish brown), texture class: sandy loam, stoniness: 25% (angular coarse gravel), structure: medium granular, bulk density: very loose, moisture: very dry, root density: < 2 mm: 120 pcs/dm^2, > 2 mm: 30 pcs/dm^2. Thin, bright, slightly eluviated within micropodzolization.

meAh2 (4–22 cm)
Color: 7.5YR 3/3 (dark brown), texture class: sandy loam, stoniness: 30% (angular coarse gravel), structure: medium granular, bulk density: very loose, moisture: dry, root density: < 2 mm: 120 pcs/dm^2, > 2 mm: 20 pcs/dm^2. Umbric; with irregular accumulations of organic matter (lined with fascuculate root concentration) near lower boundary.

Bw1 (22–42 cm)
Color: 7.5YR 4/4 (brown), texture class: clay loam, stoniness: 45% (angular coarse gravel), structure: medium subangular blocky, bulk density: very loose, moisture: slightly moist, root density < 2 mm: 70 pcs/dm^2, > 2 mm: 10 pcs/dm^2.

Bw2 (42–71 cm)
Color: 7.5YR 4/6 (strong brown), texture class: clay loam, stoniness: 65% (angular boulders), structure: fine polyhedral, bulk density: loose, moisture: moist, root density < 2 mm: 10 pcs/dm^2, > 2 mm: 2 pcs/dm^2.

BwC (>71 cm)
Color: 10YR 4/6 (dark yellowish brown), texture class: silty clay loam, stoniness: 90% (angular boulders), structure: very fine polyhedral, bulk density: intermediate, moisture: moist, root density < 2 mm: 1 pc/dm^2, > 2 mm: 1 pc/dm^2.



Deep soil with moderate stoniness in cambic horizon; no markable microdepressions within soil surface and accelerated mineralization especially of chestnut litter.



SOIL CHARACTERISTICS

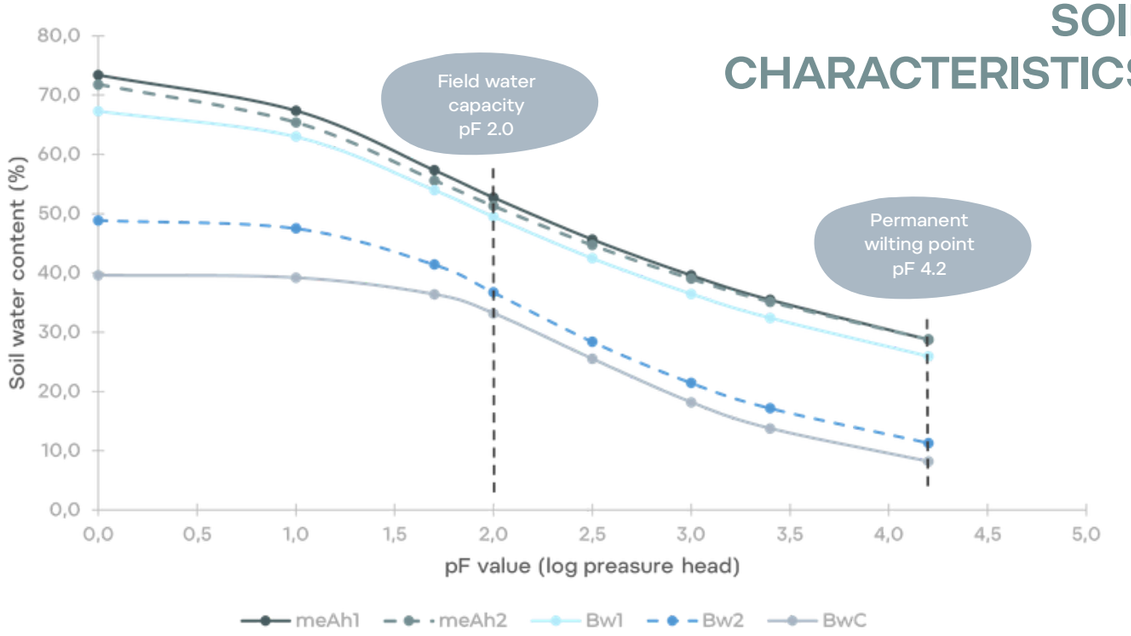


Figure 29A: Water retention curve showing the relationship between soil water content and pF value

Profile No. 29 shows a clear trend of decreasing water retention, hydraulic conductivity, and organic matter with depth, while bulk density increases, reflecting a shift from organic-rich, permeable topsoil to more compacted subsoil. The meAh horizons (meAh1 and meAh2, Table 29A) have low bulk density (0.4–0.5 g/cm³) and relatively high organic matter (39.1% and 29.8%). Maximal water capacity is high (73.4% and 71.8%), with field water capacity around 52%. Saturated hydraulic conductivity decreases slightly from 63.7 cm/day in meAh1 to 45.7 cm/day in meAh2, showing a slight reduction in permeability.The Bw1 horizon is more like the meAh horizons in terms of water retention, with a maximal capacity of 67.3% and field capacity of 49.5%. It has a bulk density of 0.7 g/cm³ and organic matter content of 19.1%. However, hydraulic conductivity drops significantly to 18.2 cm/day, indicating reduced permeability compared to the meAh horizons.

Table 29A: Soil properties of particular horizons – profile No. 29

Soil Horizon	Maximal Water Capacity (% vol.)	Field Water Capacity (% vol.)	Permanent Wilting Point (% vol.)	Available Water Capacity (% vol.)	Saturated Hydraulic Conductivity (cm/day)	Bulk Density (g/cm³)	Organic Matter (% wt.)
meAh1	73.4	52.7	28.7	24.0	63.7	0.4	39.1
meAh2	71.8	51.3	28.8	22.5	45.7	0.5	29.8
Bw1	67.3	49.5	26.0	23.5	18.2	0.7	19.1
Bw2	48.9	36.7	11.3	25.4	18.6	1.2	5.9
BwC	39.6	33.2	8.2	25.0	6.9	1.5	2.5

In the deeper horizons, bulk density increases (from 1.2 g/cm³ in Bw2 to 1.5 g/cm³ in BwC), and organic matter decreases (5.9% in Bw2 to 2.5% in BwC). Water retention declines significantly, with maximal capacities dropping from 48.9% in Bw2 to 39.6% in BwC. Field capacities fall from 36.7% to 33.2%. Available water capacity remains stable at around 25.4% in Bw2 and 25.0% in BwC. Hydraulic conductivity decreases sharply, from 18.6 cm/day in Bw2 to 6.9 cm/day in BwC, reflecting increased compaction and reduced permeability.

Table 29B: Micronutrients content

Soil horizon	P	Ca	Mg	K	CEC	BS
	mg/kg				mmol/kg	%
OH	12	829	261	180	356.4	18.9
meAh1	4	181	111	181	179.8	14.9
meAh2	3	112	80	112	125.2	15.3
Bw1	1	104	69	104	56.3	32.5
Bw2	1	100	65	100	36.5	45.1
BwC	1	101	65	101	39.5	41.8

Table 29C: Soil texture characteristics and Soil reaction

Soil horizon		Texture class	Slaking index	Battance class	pH_{water}	pH_{KCl}
OH					3.6	3.3
meAh1		sandy loam	0.71	non battant	4.0	3.5
meAh2		sandy loam	0.73	non battant	4.3	3.9
Bw1		silt loam	0.80	non battant	4.4	4.2
Bw2		silt loam	1.48	peu battant	4.5	4.2
BwC		silt loam	3.38	tres battant	4.3	4.0

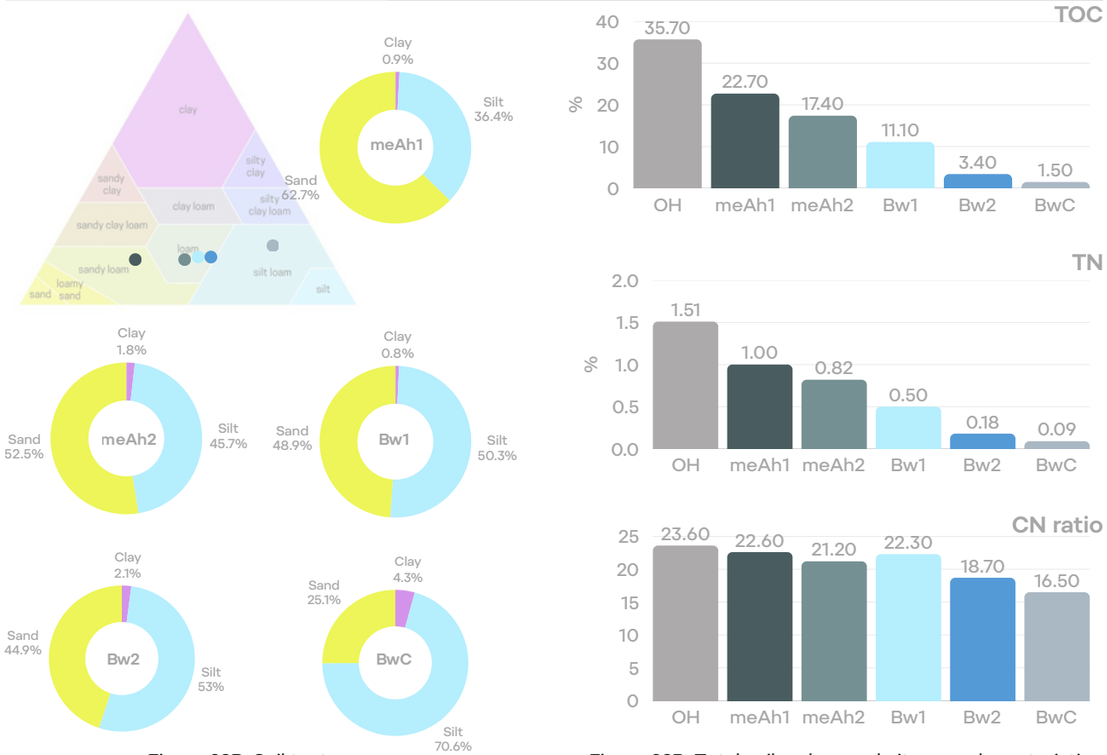


Figure 29B: Soil texture

Figure 29B: Total soil carbon and nitrogen characteristics

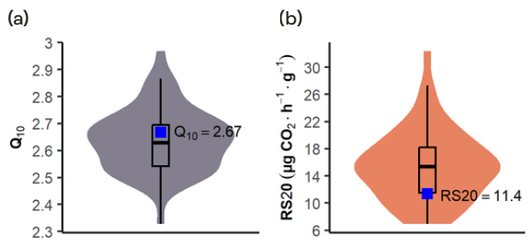


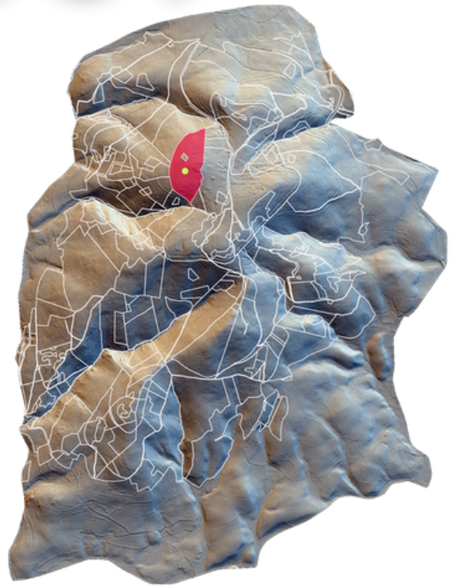
Figure 29D:
(a) Q10: the temperature sensitivity of soil respiration
(b) RS20: soil respiration value for a standardized temperature of 20 degrees
(c) Shannon: soil molecular diversity index, based on the identification of compounds from the main molecular families

Clearcut

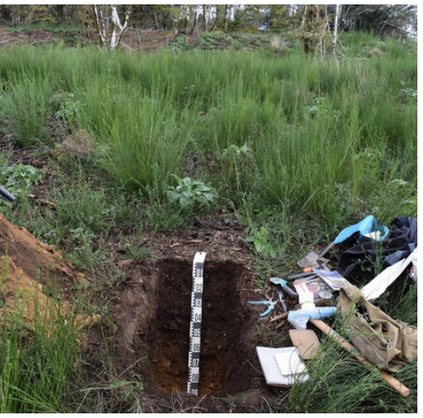
site

CLEARCUT 30

GPS (N):	4.0307630°
GPS (E):	46.9266210°
Localization:	intramuros (2nd rampart)
Altitude:	781 m a.s.l.
Inclination:	7°
Exposure:	W



The profile is located on a gentle slope between anthropogenic terraces (inclination 7°, west exposure). This is a clearcut area covered with a layer of wood chips, currently overgrown, mixture of bramble, broom, and foxglove).





The soil is relatively resistant to erosion due to favourable mineralogical composition and gentle topography. Soil reaction is very strongly acidic and the sorption complex, despite moderate cation exchange capacity, is poorly saturated with base cations, while exchangeable aluminium dominates and may pose a risk of toxicity. Nevertheless, the soil-forming substrate provides sufficient nutrient reserves of potassium, magnesium, calcium and phosphorus. Following clearcutting, the site is prone to colonisation by pioneer species such as common broom, typical of acidic and nutrient-poor soils. This nitrogen-fixing shrub shows high vitality, rapidly covers open ground and may suppress tree regeneration. Therefore, early control of its expansion, including occasional manual removal, may be necessary to secure successful establishment of the next forest generation. sessile oak (and/or Northern red oak) and Scots pine are recommended as target species, with Eouropean larch as an admixture. Pioneer species such as European aspen and silver birch may facilitate early stand development.

Soil Taxonomic Unit:

Terric Anthrosol (Cabonic, Hyperdystric, Katoskeletic, Solimovic, Technic)

Stratigraphy:
OL-OFzo-OH-meAh-meAhτ-Ahτu-Ahτu/Cτ-Cτ

Humus form:
Lignoamphi

OL (1 cm):	Mixed; coarse woody fragments, spruce needles, twigs and cones.
OFzo (0.5 cm):	Young, recently mineralized; fine gravel admixture.
OH (1.5 cm):	Hr, recent; advanced humification near lower boundary, fine gravel admixture.

meAh (0–4 cm)
Color: 7.5YR 2.5/2 (very dark brown), texture class: loam, stoniness: 10% (angular fine gravel), structure: medium granular, bulk density: very loose, moisture: slightly moist, root density: < 2 mm: 60 pcs/dm^2, > 2 mm: 10 pcs/dm^2. Pedoturbed (mechanization).

meAhτ (4–24 cm)
Color: 10YR 2/2 (very dark brown), texture class: loam, stoniness: 15% (angular coarse gravel), structure: medium granular, bulk density: very loose, moisture: dry, root density: < 2 mm: 15 pcs/dm^2, > 2 mm: 15 pcs/dm^2. Abrupt lower boundary.

Ahτ (24–52 cm)
Color: 10YR 3/2 (very dark grayish brown), texture class: loam, stoniness: 60% (angular coarse gravel), structure: fine granular, bulk density: very loose, moisture: slightly moist, root density < 2 mm: 10 pcs/dm^2, > 2 mm: 7 pcs/dm^2. Artefacts (dominantly amphoras fragments), admixture of volcanic rocks; mechanically transported; result of human intensive activity.

Ahτ/Cτ (22–72 cm)
Color: 10YR 4/4 (dark yellowish brown), texture class: sandy loam, stoniness: 40% (angular stones), structure: fine subangular blocky, bulk density: intermediate, moisture: slightly moist, root density < 2 mm: 5 pcs/dm^2, > 2 mm: 5 pcs/dm^2. Color gradation with depth; accumulation of boulders at lower boundary (in transition to C).

Cτ (>72 cm)
Color: 10YR 5/6 (yellowish brown), texture class: loamy sand, stoniness: 70% (angular coarse gravel), structure: very fine massive, bulk density: loose, moisture: slightly moist, root density < 2 mm: 1 pc/dm^2, > 2 mm: < 1 pc/dm^2. Accumulation of stones at upper boundary; lower continues transition zone to bedrock.

Anthropogenic soil accumulated on in-situ weathered bedrock (acid neovolcanite with admixture of fine-grain shale. Anthropogenic sediment with markable thickness (80 cm) defines site conditions for stand. Initial humification at surface corresponds with actual forest generation and at the same time reflects applied forest management (post-harvest crushing, mulching).





SOIL CHARACTERISTICS

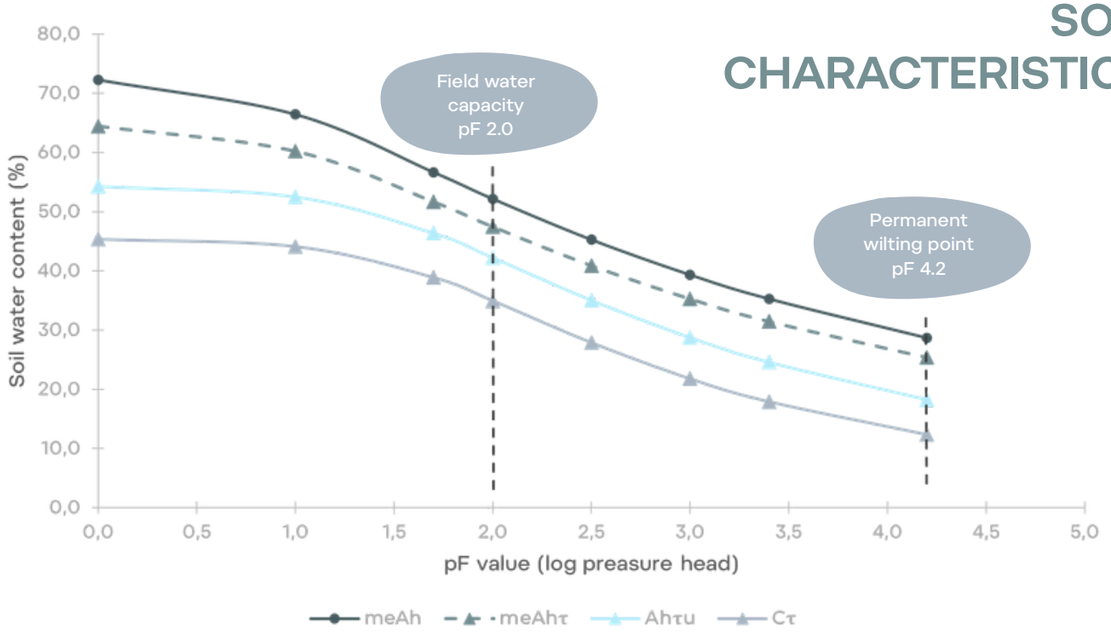


Figure 30A: Water retention curve showing the relationship between soil water content and pF value

Profile No. 30 shows pronounced vertical differentiation, with increasing bulk density and decreasing organic matter content from the surface to the deepest mineral horizons. The topsoil meAh horizon (0.5 g/cm³; 27.4% organic matter) is markedly distinct from the underlying layers. It exhibits the highest maximal (72.3%) and field water capacity (52.2%), high available water (23.5%), and an exceptionally high saturated hydraulic conductivity (69.4 cm/day), reflecting a very macroporous, organic-rich soil layer. In contrast, the technical meAhτ horizon (0.7 g/cm³; 17.9% organic matter) shows reduced maximal (64.4%) and field capacity (47.4%), slightly lower available water (22.1%), and a sharp drop in hydraulic conductivity to 14.3 cm/day. The following Ahτu horizon (1.0 g/cm³; 8.9% organic matter) continues the trend of decreasing total retention (maximal 54.3%, field 42.2%) while maintaining available water (24.0%) and moderate conductivity (18.5 cm/day). The deepest Cτ horizon (1.3 g/cm³; 4.8% organic matter) exhibits the lowest total retention (maximal 45.4%, field 34.9%) but preserves available water (22.6%) with moderate hydraulic conductivity (16.8 cm/day).

Table 30A: Soil properties of particular horizons - profile No. 30

Soil Horizon	Maximal Water Capacity (% vol.)	Field Water Capacity (% vol.)	Permanent Wilting Point (% vol.)	Available Water Capacity (% vol.)	Saturated Hydraulic Conductivity (cm/day)	Bulk Density (g/cm³)	Organic Matter (% wt.)
meAh	72.3	52.2	28.7	23.5	69.4	0.5	27.4
meAhτ	64.4	47.4	25.4	22.1	14.3	0.7	17.9
Ahτu	54.3	42.2	18.2	24.0	18.5	1.0	8.9
Cτ	45.4	34.9	12.3	22.6	16.8	1.3	4.8

Overall, the horizons exhibit very good level of available water capacity, which remains relatively stable throughout the profile (~22-24%) despite decreasing organic matter and the transition from porous topsoil to denser, more compact mineral subsoil.

Table 30B: Micronutrients content

Soil horizon	P	Ca	Mg	K	CEC	BS
	mg/kg				mmol/kg	%
OH	23	250	100	134	331.0	7.3
meAh	39	138	66	147	172.2	123
meAhτ	19	141	57	97	115.5	16.0
Ahτu	87	143	49	40	48.6	34.2
Cτ	150	152	54	36	36.8	45.6

Table 30C: Soil texture characteristics and Soil reaction

Soil horizon		Texture class	Slaking index	Battance class	pH_{water}	pH_{KCl}
OH					3.2	2.7
meAh		sandy loam	0.40	non battant	3.2	2.7
meAhτ		silt loam	1.03	non battant	3.8	3.6
Ahτu		silt loam	1.33	non battant	4.0	4.0
Cτ		silt loam	1.80	battant	3.9	4.0

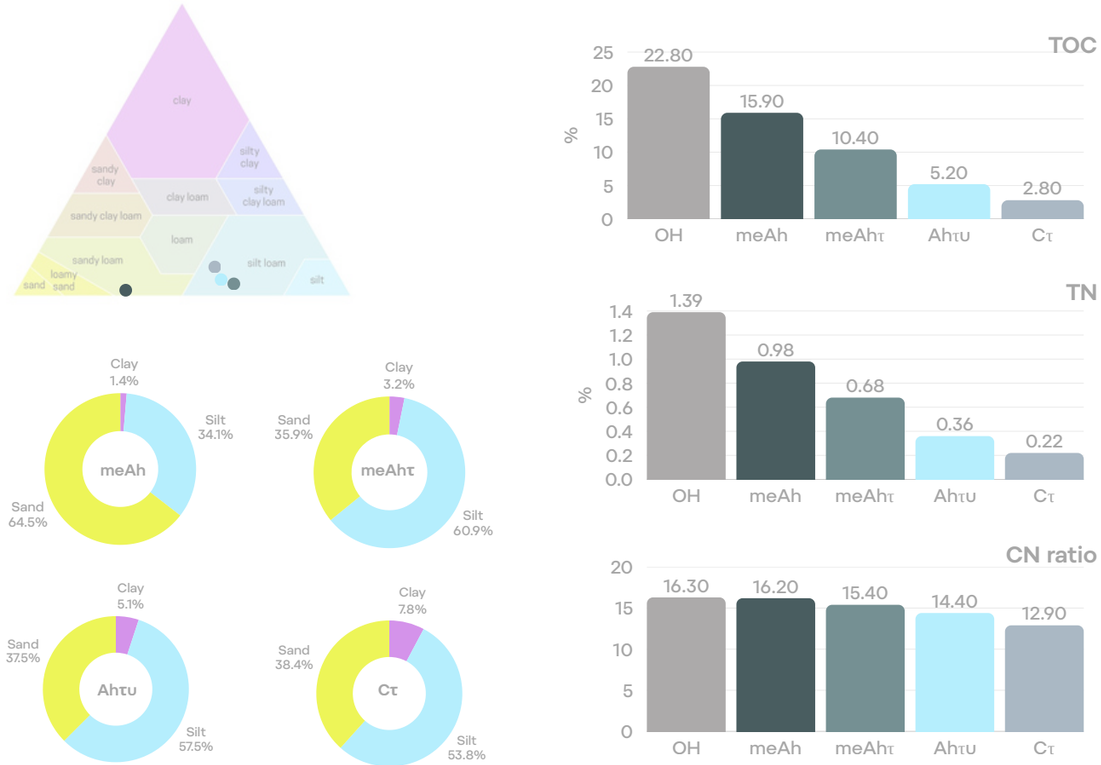


Figure 30B: Soil texture

Figure 30C: Total soil carbon and nitrogen characteristics

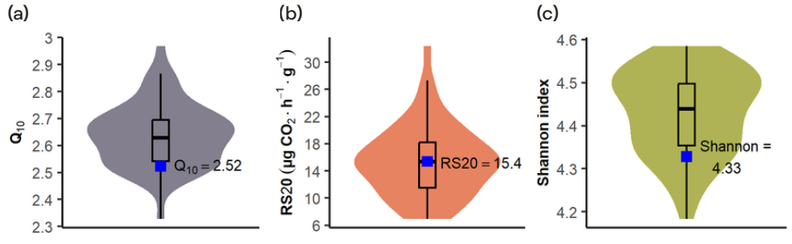


Figure 30D:
(a) Q10: the temperature sensitivity of soil respiration
(b) RS20: soil respiration value for a standardized temperature of 20 degrees
(c) Shannon: soil molecular diversity index, based on the identification of compounds from the main molecular families

Clearcut



General site conditions and related forestry recommendations

Most sites at the Mont Beuvray Bibracte have soils corresponding to Cambic Umbrisols and Dystric Cambisols that have developed on acidic silicate substrates. Both soil characteristics and their development have been strongly influenced by long-term accumulation processes in the landscape, closely linked to historical settlement and associated economic and cultural land use. In particular, past deforestation has had markedly negative consequences, resulting in pronounced water erosion and the formation of deep colluvial deposits on lower slopes. In upper slope positions, accumulation processes are often directly associated with former settlement activities and with technogenic/anthropogenic soil materials.

These processes have led to considerable enrichment with organic matter, which represents the main cause of stratification in the soil body. Organic matter contributes to aggregate stability and resistance to erosion, whilst simultaneously forming a substantial nitrogen pool bound within organic compounds.

From a mineralogical perspective, as the soils have developed on strongly acidic rocks, they are poor in several essential elements, particularly calcium and, to a lesser extent, magnesium. In contrast, potassium occurs at relatively high concentrations, which may lead to imbalances among base cations, especially through antagonistic interactions with calcium and magnesium. Total phosphorus levels are similarly elevated, an enrichment that most likely originates from historical anthropogenic activity; its redistribution within the deeper parts of the soil profile is probably related to binding with organic matter and to sorption processes involving iron and aluminium hydroxides and oxyhydroxides. The soils at these sites also represent a significant reservoir of organic carbon at various stages of transformation. The mineral component of the soil body is, however, mineralogically and sorptively weak. Clay mineral content is extremely low and the texture is typically dominated by silt fractions. This granulometric composition substantially increases soil erodibility and reduces the natural sorption capacity of the mineral soil.

Our findings suggest that future forest management should focus primarily on protection of the soil surface. This is essential not only for erosion control but also to prevent accelerated mineralisation of organic matter following canopy disturbance, which may lead to the proliferation of nitrophilous and often invasive plant species.

The present tree species composition reflects historical forestry practices, particularly the widespread promotion of Douglas fir (Pseudotsuga menziesii) and sweet chestnut (Castanea sativa), often resulting in stands with relatively low species diversity. Regeneration of such stands is frequently problematic, especially where ageing Douglas-fir stands occur on exposed sites. Ideally, stand regeneration should avoid large-scale clear-cutting and instead employ smaller regeneration elements such as group openings, narrow regeneration strips, or strip fellings aligned along the slope. These approaches allow for a gradual structural diversification of the stand. Shelterwood systems and regeneration under partial canopy cover represent suitable complementary approaches, as does the release of naturally established advance regeneration.

From the perspective of species composition, it is advisable to combine economically valuable tree species with pioneer species possessing ameliorative effects on soil properties. Such mixtures contribute to soil protection, improve the condition of upper soil horizons and support the successful establishment of the next forest generation.

For acidic and nutrient-poor sites, often with local accumulations of organic matter, the following tree species are considered particularly suitable:

Sessile oak *(Quercus petraea)*
Tolerant of nutrient-poor and relatively dry soils. Best grown at higher stocking density to promote straight stem formation.

European beech *(Fagus sylvatica)*
Suitable for underplanting beneath the shelter of the parent stand; dense spacing is recommended to support crown shaping.

Silver birch *(Betula pendula)*, mountain ash *(Sorbus aucuparia)*, European aspen *(Populus tremula)*
Typical pioneer species with a strong ameliorative effect on soil properties. Suitable as admixture species in target stand composition and particularly valuable as preparatory species during the early stages of stand development.

Common hornbeam *(Carpinus betulus)*
An ameliorative accompanying species capable of tolerating relatively dry conditions.

Sycamore *(Acer pseudoplatanus)*
A species with dense rooting systems suitable for fresh colluvial or deeply humic sites; southern exposures should preferably be avoided.

Small-leaved lime *(Tilia cordata)*, wild cherry *(Prunus avium)*
Suitable for accumulation positions of slope colluvium with favourable moisture conditions; less suitable for drought-prone sites.

European silver fir *(Abies alba)*
Well suited to deeper soils with sufficient water availability; among conifers it exhibits a pronounced ameliorative effect on soil conditions.

European larch *(Larix decidua)*
Within the local environmental context, potential soil acidification effects are of secondary importance. In mixtures, larch plays a strong structural stabilising role. As a light-demanding species it should be introduced early, preferably in strips or narrow regeneration openings, where it can develop in a dominant canopy position.

Northern red oak *(Quercus rubra)*
An introduced species, but highly tolerant of drought conditions.

Wild service *(Sorbus torminalis)*
Suitable as an admixture species on sites with sufficient soil moisture, particularly in lower slope positions; an economically promising species.

Douglas fir *(Pseudotsuga menziesii)*, sweet chestnut *(Castanea sativa)*
Both species may still be considered in stand composition, although not as dominant components but rather as structural elements within mixed stands. Douglas fir may be retained in the upper canopy layer, provided that complete canopy closure is avoided, as it tends to produce very shaded understoreys.

Scots pine *(Pinus sylvestris)*
Considered a strongly light-demanding species, yet tolerant of partial shade. Equally tolerant of a wide range of soil water regimes, from waterlogged to severely drought-prone conditions. Exhibits high ecovalence with respect to soil nutrient content; well adapted to nutrient-poor, dry and acidic soils. A highly plastic species with a pioneer character, functional as a preparatory and structural component on exposed sandy or skeletal soils, while also capable of forming ecologically stable, continuous monocultures.

General silvicultural model based on site conditions

The traditional clear-cut system should be gradually abandoned as it inevitably reduces the soil-protective function of forests and diminishes related ecosystem services during generational stand replacement.

The recommended management concept may be described as a shelterwood-transformation system with a pioneer nurse layer and a permanent light-bearing overstorey, representing a gradual transformation of existing stands towards a continuous-cover forest model supporting species, spatial, age and vertical structural diversity.

During timber harvesting operations, any disturbance to the soil surface should be mitigated promptly. On particularly sensitive sites sites defined by steep long slopes, the usecable extraction systems should be considered as a means of minimising soil damage.



Summary

This publication provides a comprehensive overview of environmental conditions on the Mont Beuvray massif, with particular emphasis on the soil environment and forestry management of this exceptional ecological and historic landscape. The main aim has been to document the area's natural conditions, focusing on the ecological stability of forest stands, environmental constraints of the tree species represented and the prospects for sustainable stand regeneration. This information is of fundamental importance given the historical context of the site. Forest stands must be understood not only as ecological units but also as a vital means of preserving the cultural and archaeological heritage of this exceptional locality.

The book is conceived as the catalogue and is a multidisciplinary work that integrates the fields of climatology, geology, soil science, soil biology, ecology and forestry. At each of thirty survey sites, evenly distributed across a forested area of approximately 1112 ha (71% of the whole massif area), soil genesis was characterised according to the World Reference Base for Soil Resources (WRB 2022), taking into account the site's topographic, geological and biological context. Most soils corresponded to Cambic Umbrisols and Dystric Cambisols, which develop on strongly acidic silicate substrates that are inherently poor in essential base cations, particularly calcium and magnesium. The mineralogical poverty of the parent material represents a fundamental constraint on both soil fertility and long-term stand productivity.

Soil properties are strongly influenced by long-term landscape accumulation processes that are closely linked to historical settlement and land use. Umbrisols, which dominate the soil cover, largely owe their development to colluvial accumulation driven by slope erosion and direct anthropogenic accumulation within the fortress walls (intra muros) on the massif summit, where a notable increase in artefact finds, including ceramics, brick fragments and charcoal, testifies to intensive past human activity.

These processes have resulted in stratified soil bodies enriched in organic matter and phosphorus. However, they have also rendered the mineral soil fraction mineralogically and sorptively weak, with extremely low clay contents and silt-dominated textures, both of which substantially increase erodibility.

Soil biological activity across the massif is characterised by the high molecular diversity of organic matter, which is generally associated with low decomposition rates and biological stability under undisturbed conditions. However, microbial CO_2 emission fluxes and the pronounced temperature sensitivity of soil respiration indicate that this stability could be quickly compromised by rising temperatures or canopy disturbance, triggering accelerated mineralisation of organic matter and significant carbon losses. These findings further emphasise the importance of maintaining continuous forest cover for long-term soil carbon conservation.

From a forestry perspective, these soil conditions have direct and urgent management implications. The historically promoted dominance of Douglas fir and sweet chestnut has resulted in stands of low species diversity, problematic natural regeneration and accelerated soil acidification. Any disturbance to the canopy, particularly large-scale clear-cutting, risks triggering accelerated mineralisation of organic matter, leaching of nutrients from an already base-poor system, proliferation of nitrophilous and invasive plant species and irreversible loss of topsoil through erosion. Therefore, forest management must prioritise continuous soil surface protection as a non-negotiable principle. Regeneration should rely on small-scale interventions, such as group openings, strip felling and shelterwood systems, combined with the deliberate introduction of ameliorative pioneer species, to gradually restore soil conditions and structural diversity. The long-term goal must be to transition to a continuous-cover forest model that will simultaneously safeguard the ecological integrity of the site and the irreplaceable cultural heritage preserved beneath its soils.

The Soil Environment at Mont Beuvray, Bibracte

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This publication presents a distinctive and comprehensive assessment of soil conditions within the forest ecosystems of the Mont Beuvray-Bibracte region. It integrates detailed descriptions of soil profiles and analytical results with well-founded recommendations for forest management. The added value and originality of the work are further reinforced by extensive, high-quality photographic documentation and precise hydrophysical measurements—components that are frequently absent in comparable publications. Overall, the book constitutes a significant contribution to the fields of soil science, forestry, and ecology. It provides a reliable and practically oriented resource for exprts, as well as for readers with a broader interest in the functioning and sustainable management of forest ecosystems.

Technical University in Zvolen, Faculty of Forestry
Research field: forest soils, soil microorganisms, forest ecology

Assoc. Prof. Dušan Vavříček

A further strength of the catalogue is its inclusion of recommendations for target management practices at each soil-typologically defined site. The monograph has broad applicability and can serve as a model for similar studies of other landscape components. It is an exceptionally valuable work, offering thorough and well-developed information of relevance both to the region itself and to multidisciplinary research more widely.

Czech Forestry Institute, Brandýs nad Labem
Research field: forest soils, forest ecology, plant nutrition, regeneration

Mendel University in Brno