2025

Mendel University in Brno
Czech-Slovenian Society

# Contemplating Earth

## …Soil and Landscape

## 2024

## Conference Proceedings

Marie Balková (Ed.)

2nd–4th October 2024
Křtiny, Czech Republic

MENDELU
Faculty of Forestry and Wood Technology

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## Abstract

*Proceedings of the 'Contemplating Earth: Soil and Landscape' conference held on 2–4 October 2024 in Křtiny, Czech Republic. The conference topics are from the fields of geology, soil science, soil environment protection, soil diversity, forest and land management, nature conservation and the use of geoinformatics in these fields.*



**Keywords:** *geology, soil science, nature conservation, forest, land*

# List of Content

## Articles



## Abstracts

## Foreword

Here, for the third time, we are meeting at an Earth Day Conference that we have called 'Contemplating Earth: Soil and Landscape'. This title leads us to think that it is necessary to look at the Earth, and its soil and landscapes, from a different point of view or perspective. You may ask yourself, what other perspective? After all, we have lots of data and, based on this data, we come to specific conclusions and interpretations. While this is true, another perspective can lead us into the unknown, allowing us to think and feel everything somehow differently.

Since the founding of the Department of Geology and Soil Science 77 years ago, we, and our predecessors, have sought to understand earth as a soil-forming substrate, as a growing medium, and now as an engineered and structural substrate. In the same way, we seek to understand the processes that occur in rock, soil and vegetation, both individually and at the ecosystem level, and how these factors interact in altered cultural landscapes. The more we research, the more we know, but we also find that the true essence still eludes us. We don't know why processes are the way they are, why one substance reacts with this one and not another. This is both the beauty and the pitfall of the natural sciences. The laws and principles of nature are given by nature itself, but we humans have somehow separated ourselves from nature. And so we at least try to understand it; perhaps it would be better to "immerse" ourselves more in mother nature and let her speak for herself? We hope that she will speak to you here through the teas, honeys and gingerbreads that we had made especially for you as a limited edition in the Czech Highlands. We also believe that she will talk to you through the expert lectures and the travel stories that we have included in the programme for the first time this year and, of course, through the excursion we have prepared for you with our colleagues from the Moravian Karst Protected Landscape Area... after all, what unites us all is Nature itself.

We are truly glad to see you all again and we wish you a wonderful Earth Day – 'Contemplating Earth: Soil and Landscape'.

Valerie Vranová

# Articles

# Recultivation after the Peat Mining at Branský les I.

Josef Janoušek[1]

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**Abstract**

*The contribution describes a recultivation process after peat harvesting in the Bransky Les I. location. The recultivation of peat bogs is one way to increase the volume of water in nature. This practical experience shows how complicated it is to achieve this goal. Harvesting of peat was finished in 2018. The process of recultivation was started in 2019 and finished at the end of 2020. Nowadays, in 2024, the locality was visited to see what has happened in the last six years after the end of harvesting.*

**Keywords:** *recultivation of peat bogs, peat harvesting*

## 1 Introduction

Peatlands are a significant part of the landscape, and as such, they are protected by Act 114/1992 Coll. on Nature and Land Protection. These days, returning water to the landscape is a hotly debated topic. One of the ways to do this, especially in mountainous areas, is through the revitalization of disturbed peatlands. In most cases, this disturbance is the result of forestry work in the area and damage caused by peat extraction in the past. The primary goal of peatland restoration is a return to a naturally functioning, self-contained ecosystem (Townsend *et al,* 2003.) Peatlands are able to influence biochemical processes, and in addition to being a source of nutrients, they are a significant carbon store, and especially effective at retaining water in the landscape. They are also a habitat for numerous species of endangered plants and animals, as well as an an irreplaceable source of fresh water (Jung et. al., 2012). Peatlands are unique islands of northern nature in Central Europe. Even in the worst drought, streams originating in living bogs do not dry up.

Peats belong to the so-called wetlands, which are divided into two main groups, wetlands with humolite formation, which include peatlands covering less than 3% of the earth‘s surface (Moore *et al.*, 2017), and wetlands without humolite formation, in which we can also count hydric-affected habitats after mining, where revitalization did not take place.

The Třeboň wetlands cover an area of 2200 hectares. These are predominantly peat forests, peaty areas around ponds, spring bogs and peat meadows. The uniqueness of the area contributed to the creation of a PLA (Protected Landscape Area) in low altitudes, in which wetlands and man-made ponds are in harmony with the landscape of preexisting peatlands. At the end of the 20$^{th}$ century, it was listed as a wetland of international importance (Ramsar), where ponds and related wetland biotopes including four areas of peat bogs,

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Červené blato, Rašeliniště Mirochov, Široké Blato and Žofinka, were added in 1990, and in 1993 (Janda, 1993; Hátle, 2000; Soukupová *et al.*, 2002).

After 1754, the Imperial-Royal Patent of Forests and Timber limited the use of wood and timber as fuel on Czech lands, replacing it with coal and peat. In the Třeboň region, peat was mined more intensively only in the 19$^{th}$ century, a number of localities were partially drained and mining was carried out by hand, the so-called borking (Kučerová, 2021). Peat mining on a larger scale began in Branná near Třeboň before the Second World War and during the war period, when alternative energy sources were being sought.

In the 1950s, the Branná Plant belonging to the state-owned company Rašelina n.p. was opened, which foreshadowed intensive mining in the vicinity of Branná, from where in the 1970s mining expanded to the location Branský Forest I. In this location, mining took place on a relatively large mining site with an area of 72 ha, approx. 2 km southeast of the village of Branná near Třeboně. Prior to mining, it was a wooded area, adjacent to drainage channels that were built under the Schwarzenbergs, and the dominant tree species was Scots pine (*Pinus silvestris* L.).

In 2018, peat extraction on an area of approximately 65 ha was completed at the Branský Forest I location (five ha was reclaimed and handed over in 2005). In the following year, the reclamation plan was updated, it was approved in early 2020, then reclamation and revitalization work was underway. At the beginning of 2021, the areas were handed over to the owners, namely LČR, s.p. and the City of Třeboň. Currently, it has been approximately six years since the end of mining and three years since the handover of the areas by Rašelina a.s.

The aim of the contribution is to evaluate the reclamation and the state of the areas at the present time.

## 2 Material and methods

The site is located in forest area 15b – Třeboňská panev, on the territory of the Třeboňsko Protected Area at an altitude of around 440 m above sea level. It is located in a large area of forest vegetation at stage three and four for water habitats, with climatic area B slightly warm, average temperature 7.3 °C, average precipitation 640 mm. Geological subsoil: rH – Quaternary peats, alluvial deposits, T – Tertiary, mainly Neogene clayey and sandy sediments. In June 2019, a typological survey was carried out, from which it follows that there are modal organo-soils at the site, defined by the gley horizon of the subsoil, mosaic-like following on gleys of a predominantly Hippic character (peaty). Typologically, these are habitats defined by SLT mainly 3R and 3T.

The area of the mining site is classified as a III. PLA zone. According to the current territorial plan of Třeboň, elements of the Territorial System of Ecological Stability (ÚSES) are located on the territory of the mining site. In the territorial plan of Třeboň, this local biocenter has a functional use of „natural areas", which are supposed to ensure conditions for nature and landscape protection. The mining site is located between two sewers – U1–9 and Podřezanská, and is further bounded by a road and an intersection between forest areas 43 and 44. Before mining, the flat area now forms a depression decreasing from south to north as a result of mining. There is a main drainage channel running through the center of the area, which flows into the sewer in the northern part of the site. The groundwater level fluctuates according to the season and rainfall.

Regarding the state of the site after reclamation in 2020, in the area of interest, as part of technical reclamation, a stabilized layer of organic earth with different thicknesses of approx. 60 cm was left. A functional network of drainage channels was left, creating drainage for the given area.

According to the reclamation plan created at the request of the owners, about 55 ha were handed over in a state ready for reforestation, and about 10 ha were left ready for the creation of a “peat ecosystem” (the area north of the road crossing the mine area). In accordance with the recultivation plan, the wishes of the owners and concerned state authorities (apart from the AOPK CR), there was no significant interference with the locality’s water regime, which means there was no damming of the main drainage channel and no rise in the groundwater level. In the area designated for the creation of a „peat ecosystem,” side channels were disabled by including a five-meter section in the connection area to the main drainage channel. Eight pools with a size of approx. 400 $m^2$ were built on the territory, in the places of the original drainage channels. The areas were beginning to become massively overgrown with sedge (*Scirpus sylvaticus* L.), common dogwood (*Agrostis capillaris* L.), bush reed (*Calamagrostis epigejos* (L.) Roth), red nettle (*Juncus effusus* L.), red wormwood (*Persicaria maculosa* Gray), with the occasional occurrence of hedgehog (*Echinochloa crus-galli* (L.) P.Beauv.). Small birch saplings appeared here and there. The owners assumed that the territory would be left to spontaneous succession with a possible subsequent network or planting, while fulfilling legislative obligations.

**Fig. 1:** *Part of the site set aside for forest reclamation on the right of the road. A section set aside to create a „peat ecosystem“ to the left of the road. March 2021.*
Author: Josef Janoušek

## 3 Results and disscusion

The state of the locality in 2024. The territory has been left to spontaneous succession. The areas are overgrown with birch. Scots pine (*Pinus sylvestris* L.) is rarely found. In higher places, especially on the edges of the area, different types of willows are starting to appear, specifically the eared willow (*Salix aurita* L.) and the ash willow (*Salix cinerea* L.). The herbaceous layer is dominated by common dogwood (*Agrostis capillaris* L.), bush reed (*Calamagrostis epigejos* L.) and decomposing nettle (*Juncus effusus* L.). St. John‘s wort, St. John‘s wort (*Hypericum perforatum* L.) and spotted St. John‘s wort (*Hypericum maculatum* Crantz) are found in places. Here and there the reed-like scab (*Phalaris arundinacea* L.) appears. The red worm (*Persicaria maculosa* Gray) has almost disappeared. Pool starfish (*Callitriche stagnalis* Scop.) grows in the canals. The green grasshopper (*Pelophylax esculentus* L.) is abundant in the canals. A green layer covered most of the previously mined areas. The difference between the „peat ecosystem“ and the rest of the land can be seen in the greater concentration of decomposing nets around the side channels, which are different from the side channels in the water-filled “forest” part. However, the ground water level is also lowered here so that the peat on the surface is too dry in the summer and moisture on the surface is dependent on water coming from precipitation. Although optimal conditions have not been created for the restoration of the wetland, and probably not even the forest, here too nature shows that it can eventually take care of itself.

**Fig. 2:** *A section set aside to create a „peat ecosystem“ September 2024.*
Author: Josef Janoušek

# 4 Conclusion

The paper describes the state of the area, six years after the end of peat extraction at the Branský Forest I location. Although the reasons for the need to restore wetlands and increase water capacity in the landscape are well known, implementation in practice often encounters a number of pitfalls, leading to various compromises, as in in the case of reclamation in Branná. Despite the failure to create a wetland, the area meets all the prerequisites for the creation of a forest, which is essentially the same condition that the site had before mining.

# 5 Summary

Six years after harvesting, the peat bog is covered by birch, and the ground is mainly covered by grass. Even though measures for optimal conditions for wetland restoration were not carried out, nature shows that it is capable of doing it on its own. Conditions in the locality are conducive for the growing of trees.

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# Hard and Resistant as a Rock? Threats to Geodiversity and How to Identify and Evaluate Them

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**Abstract**

*Geodiversity is defined as the natural range (diversity) of geological (rocks, minerals, fossils), geomorphological (landforms, topography, physical processes), soil and hydrological features, including their assemblages, structures, systems and contribution to landscapes. As a whole, it represents a basis for biodiversity and it offers numerous benefits and services to human society. Currently, geodiversity is being intensively used and exploited, however, in the last decades, the geoconservation (an action of conserving and enhancing geological, geomorphological, hydrological and soil features and processes, sites and specimens) is continuously being implemented in regional, national and international nature conservation frameworks and policies. Nevertheless, despite the legislative measures, some threats and risks may still occur and endanger the sites of Earth Science interest. This contribution is focused on the main risks and threats that can endanger geodiversity and geoheritage. It also presents methodological approaches to risk assessment and evaluation of degradation risk which may contribute to the better understanding of the vulnerability and fragility of particular sites of Earth Sciences interest. Practically, the application of these assessment methods can serve as a basis for a more effective management and conservation of geodiversity and geoheritage.*

**Keywords:** *geodiversity, geoheritage, risk assessment, geoconservation; environmental education*

## 1 Introduction

In the last decades, a growing interest in geodiversity has resulted in numerous studies and projects that confirm its importance both for biodiversity, study of paleoenvironmental changes and human society (Gray, 2013; Tukiainen *et al.* 2017, 2023; Brilha *et al.*, 2018; Gordon *et al.*, 2018; Crofts *et al.*, 2020; Gray *et al.*, 2023, Migoń, 2024). The conservation of geoheritage is already seen as highly important and, although there is still an emphasis on the protection of living nature, geoconservation continuously gets more attention and recognition and it is being incorporated in some local and regional policies (van Ree *et al.*, 2017; Stewart and Gill,

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2017; Crofts *et al.*, 2020; Gray, 2021; Silva *et al.*, 2022). Despite all these efforts and also despite the facts that a site is legally protected, some threats may occur (Ruban, 2010; Wignall *et al.*, 2018; Crofts *et al.*, 2020; do Nasciemento *et al.*, 2021, Kubalíková and Balková, 2023; Kubalíková, 2024).

Given the fact that for the effective geoconservation it is essential to identify and assess the risks and threats on paticular sites, several methods for evaluating risks and threats have been developer. Usually, the classical geosite and geomorphosite assessment methods include also a degradation risk assessment as a part of overall site evaluation (e.g. Brilha, 2016), however, the works that are focused on proper identification and evaluation of the threats and risks to a geosite are still developing (García-Ortiz *et al.*, 2014; Fuertes-Guttiérez *et al.*, 2016; Ruban *et al.*, 2018, 2022; Selmi *et al.*, 2022; Kubalíková and Balková, 2023; Kubalíková, 2024).

Crofts *et al.* (2020) define several main threats to geoheritage in protected areas, but this classification can be used for any site of Earth Sciences interest: 1) Urbanisation, construction, 2) Mining and mineral extraction, 3) Changes in land use and management, 4) Coastal protection and river management and engineering, 5) Offshore activities, 6) Recreation and geotourism, 7) Climate change, 8) Sea-level rise, 9) Restoration of pits and quarries, 10) Stabilisation of rock faces, 11) Irresponsible fossil and mineral collecting and rock coring. There can occur

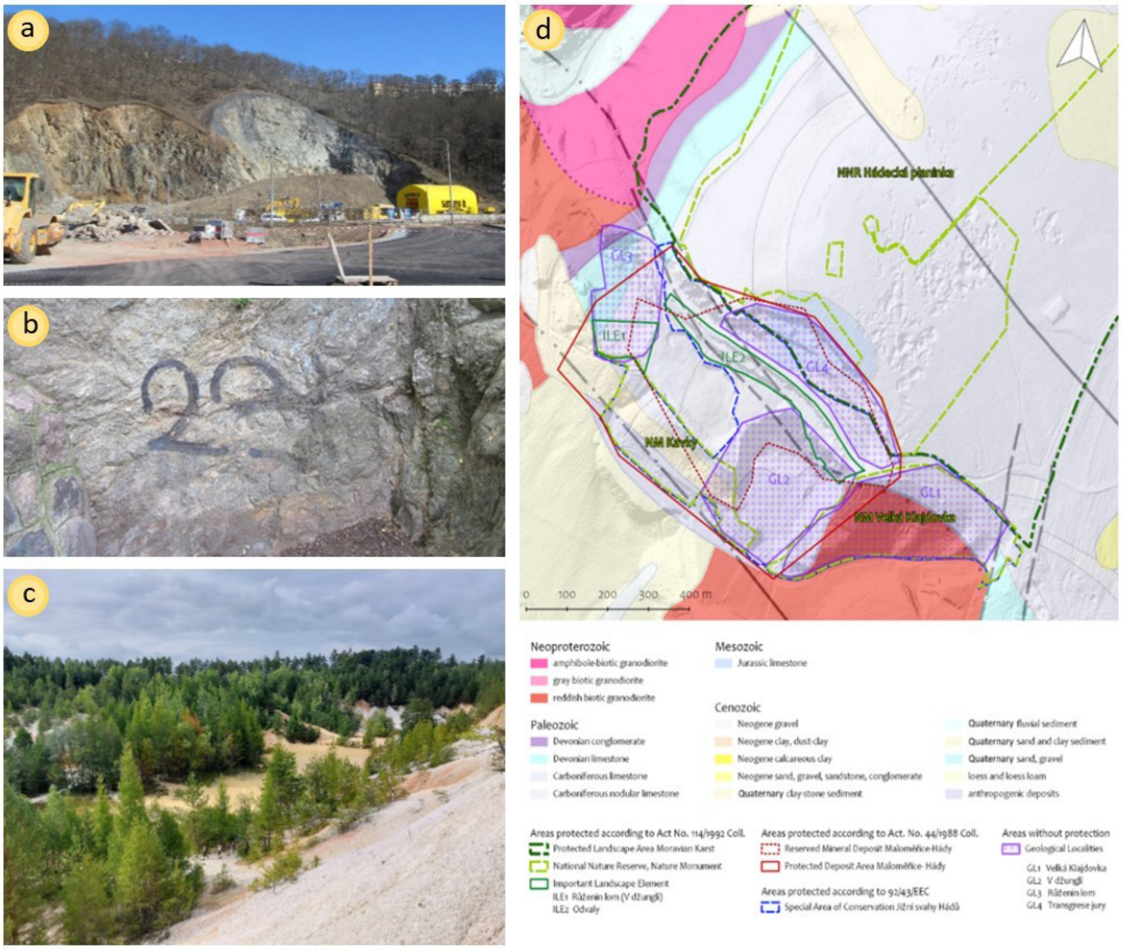


**Fig. 1:** *Threats on geoheritage and geodiversity: a) construction works (Žabovřesky tonalite quarry with river terraces); b) vandalism (Petrov metabazite outcrops); c) vegetation overgrowth (Rudice sand pit Nature Monument); d) confusion in protection measures (Hády area, Brno).*

Author: Lucie Kubalíková

other types of threats such as lack of state or regional finances for management, vandalism, vegetation overgrowth, social pressure regarding the use of the sites or confusion in protection measures (Górska-Zabielska *et al.,* 2020, Kubalíková *et al.*, 2020, Selmi *et al.*, 2022). Specific examples of some threats are displayed on Figure 1.

This contribution briefly presents a methodological approach for a complex assessment of threats and risks including their prioritization on two model sites. Based on the application of this procedure and assessment, some specific management measures are outlined and discussed.

## 2 Methods

The methodological procedure can be divided into several steps (for a more detailed description see Kubalíková and Balková 2023, Kubalíková, 2024):

(1) Description of particular site of Earth Sciences interest (geodiversity aspects of the study sites)
(2) Identification and description of threats to a particular site based on field work and literature review (Fuertes-Guttiérez *et al.*, 2016; Crofts *et al.*, 2020)
(3) Degradation risk assessment based on the geosite / geomorphosite approach. (Table 1). Every criterion is assessed within the range of 0–1 points, no weights are attributed. The maximum that a site can reach is 9 points, the limit for considering the site as threatened is established on 5 points.
(4) Assessment of the particular threats on sites by using 5 × 5 Risk Assessment Matrix (Figure 2). Risk Assessment Matrix is a simple tool often used in project planning and regional development strategies. It enables to determine the likelihood (probability) and potential effects (impact) of different types of threats, then a final degree of risk is established allowing to prioritize them (Leveson, 2011). In 5 × 5 Risk Assessment Matrix (Figure 2), the axis X represents 'impact' and axis Y represents 'probability' and their multiplication then shows the degree of particular threat.
(5) SWOT analysis as a tool which provides an overview of the assessment by highlighting strengths, weaknesses, opportunities and threats. It has been practically used in numerous studies focused on geoheritage (Carrión Mero, 2018, Sumanapala *et al.*, 2021) and it may serve as a basis for management, updating care plans or other conservation documents. Moreover, it is quite comprehensible for public and authorities. Based on this, some proposals for risk treatment, further management and monitoring can be designed.

## 3 Study area

For the purposes of this case study, two sites of Earth Sciences interest situated within the outskirts of the second largest city in Czechia (Brno, approximately 380 000 inhabitants) have been selected: Malhostovické kopečky Nature Monument and Babí lom Nature Reserve. The following description is based on the geological maps (Czech Geological Survey, 2024a), Database of Geological Localities (Czech Geological Survey, 2024b), Demek *et al.* (2015) and Care plans of the protected sites (Nature Conservation Agency, 2024).

Malhostovické kopečky Nature Monument (situated approximately 15 km north of Brno) consist of two isolated limestone outcrops called "Pecka" and "Malá skalka (Drásovský kopeček)" surrounded by intensively cultivated arable land. Geologically, the site is composed of Vilémovice limestone of the Macocha Formation (the same as limestones in nearby Moravian Karst) which contains coral fauna with stromatopors, criniods etc. This limestone

| Criterion | Scoring |
|---|---|
| Integrity | 0 – excellent conditions; 0.25 – good conditions; 0.5 – medium, average conditions; 0.75 – bad conditions, but with a possibility to recover; 1 – bad conditions, site is damaged |
| Accessibility | 0 – more than 1 km both from a parking place and stop of public transport; 0.5 – the stop and/or parking in the distance 0.2 and 1 km; 1 – the stop and/ or parking place no more than 0.2 km from the site |
| Current threats and their management | 0 – site practically not endangered; 0.25 – low anthropic and natural threats; 0.5 – potential threats, but managed well or possible to decrease; 0.75 – current anthropogenic threats but existing plans how to decrease them; 1 – existing and ongoing processes leading to the destruction of the site with no plans to recover |
| Legal protection | 0 – protected on national level; 0.25 – protected on regional level; 0.5 – protected on municipal level; 0.75 – ongoing monitoring of the site; 1 – no legal protection |
| Proximity to problematic areas | 0 – site located less than 1 km of a potential degrading area/activity; 0.5 – site located less than 0.5 km of a potential degrading area/activity; 1 – site located less than 0.2 km of a potential degrading area/activity |
| Current use | 0 – 1 activity; 0.5 – 2 different activities; 1 – 3 and more different activities |
| Visitation | 0 – low; 0.5 – medium; 1 – high |
| Number of threats | 0 – no threat; 0.25 – 1 threat; 0.5 – 2 threats; 0.75 – 3 threats; 1 – 4 and more different threats |
| Use limitations | 0 – the use is very hard due to limitations difficult to overcome (legal, permissions, safety etc.); 0.5 – the site can be used occasionally after overcoming limitations; 1 – no limitations for public use |

**Tab. 1** *Set of criteria used for Degradation Risk Assessment. The criteria are based on or have been already used in García-Ortiz et al. (2014), Fuertes-Guttierez et al. (2016), Reynard et al. (2016), Brilha (2016), Selmi et al. (2022), Kubalíková and Balková (2023), Kubalíková (2024).*

PROBABILITY

| | | | | | |
|---|---|---|---|---|---|
| Highly probable | 5 Moderate | 10 Major | 15 Major | 20 Severe | 25 Severe |
| Probable | 4 Moderate | 8 Moderate | 12 Major | 16 Major | 20 Severe |
| Possible | 3 Minor | 6 Moderate | 9 Moderate | 12 Major | 15 Major |
| Unlikely | 2 Minor | 4 Moderate | 6 Moderate | 8 Moderate | 10 Major |
| Rare | 1 Minor | 2 Minor | 3 Minor | 4 Moderate | 5 Moderate |
| | Very low | Low | Medium | High | Very high |

IMPACT

**Fig. 2:** *Risk assessment matrix (adapted from Leveson, 2011). The scoring is following: 1 to 3: minor risk (a need to plan and implement the management measures and prevent the increase of the risk, monitoring the risk), 4 to 9: moderate risk (a need to implement management measures and prevent the increase of risk, monitoring the risk), 10 to 16: major risk (a need for action and implementation of management measures), 20 to 25: severe risk (an urgent need for action and implementation of management measures).*

represent a relic of a coral reef and it was tectonically inserted into the older crystalline rocks of Brunovistulicum (granodiorites) and Boskovice Furrow permocarbon sedimentary rocks. Geomorphologically, the outcrops represent "mendips", tectonically limited elevations of resistant rocks outcropping out of the Miocene calcareous clays and Quaternary loess. Both outcrops are affected by karstification (presence of small caves and karren). On Malá skalka (Drásovský kopeček), a small rock arch can be observed (Figure 3a). Pecka is affected by quarrying (Figure 3b). Ecologically, the site is very important thanks to the presence of thermophilic steppe formations with occurrence of endangered (*Pulsatilla grandis*) (Figure 3c) and other important species (*Saxifraga tridactylites*, *Veronica prostrata*, *Muscari comosum*, *Anthericum ramosum*). Geocultural and geohistorical aspects are represented by historical limestone quarrying (especially during the 1930s and 1940s). The cultural aspect is also represented by existence of a legend about petrified wedding that refers to the specific rock outcrops on Malá skalka (Drásovský kopeček).

Currently, the site (both outcrops) is protected as Special Area of Conservation (according to the Habitats Directive 92/43/EEC) and in a category Nature Monument (according to the Act No. 114/1992 Coll. on Nature conservation). It is being intensively used as a favourite tourist destination especially during the beginning of the vegetation season when Pulsatilla grandis is blooming (Figure 3d). The site is often overcrowded and some visitors does not respect the recommendations about the movement that may contribute to the erosion of meso- and microforms. Other threat is represented by presence of litter and dump on Pecka, biking and damaging the rock landforms. Invasive species can be considered a threat as well.


**Fig. 3:** *Malhostovické kopečky Nature Monument: a) small rock arch on Malá skalka; b) Pecka outcrop affected by quarrying; c) Pulsatilla grandis in bloom; d) the site is a favourite tourist destination.*
Author: Lucie Kubalíková

However, concerning the biodiversity, the current intensity of the trampling by visitors affects the objects of protection rather positive as it keeps the steppe character of the site and enable the development of ephemeral and succulent vegetation.

Babí lom Nature Reserve consists of narrow rocky ridge – cuesta (Figure 4a) that runs north--southern direction and it is situated approximately 7 km north of Brno. Geologically it is composed of the quartzose silicified conglomerates (Figure 4b) which belong to the Devonian Basal Clastic Formation (Old Red type, possibly Lower to Middle Devonian). These conglomerates has been tectonically inserted between the metabasalts and granodiorite zone of Brno Massif. Geomorphologically, the rocky ridge represents the main landform of the study site and it is affected by frost weathering, creating distinctive mezoforms (conglomerates are nearly vertically bedded). On the surrounding slopes, the boulder fields and solifluction lobes can be observed. Ecologically, the site is important because of the presence of natural forests and other specific ecosystems: on the rocky ridge, local dwarf boreocontinental pines can be found, debris forests are situated on the slopes together with well-preserved beech forest. Some endangered species can be also found there, e.g. *Lilium martagon* or *Daphne mezereum*. The site has a high aesthetic value thanks to the presence of rocky landforms and views to the wide landscape from different parts of the ridge (Figure 4c) and thus, the site can be considered a viewpoint geosite (Migoń and Pijet-Migoń, 2017). Geohistorical value is represented by the presence of some old pathways with small sacral artefacts around them (the site is

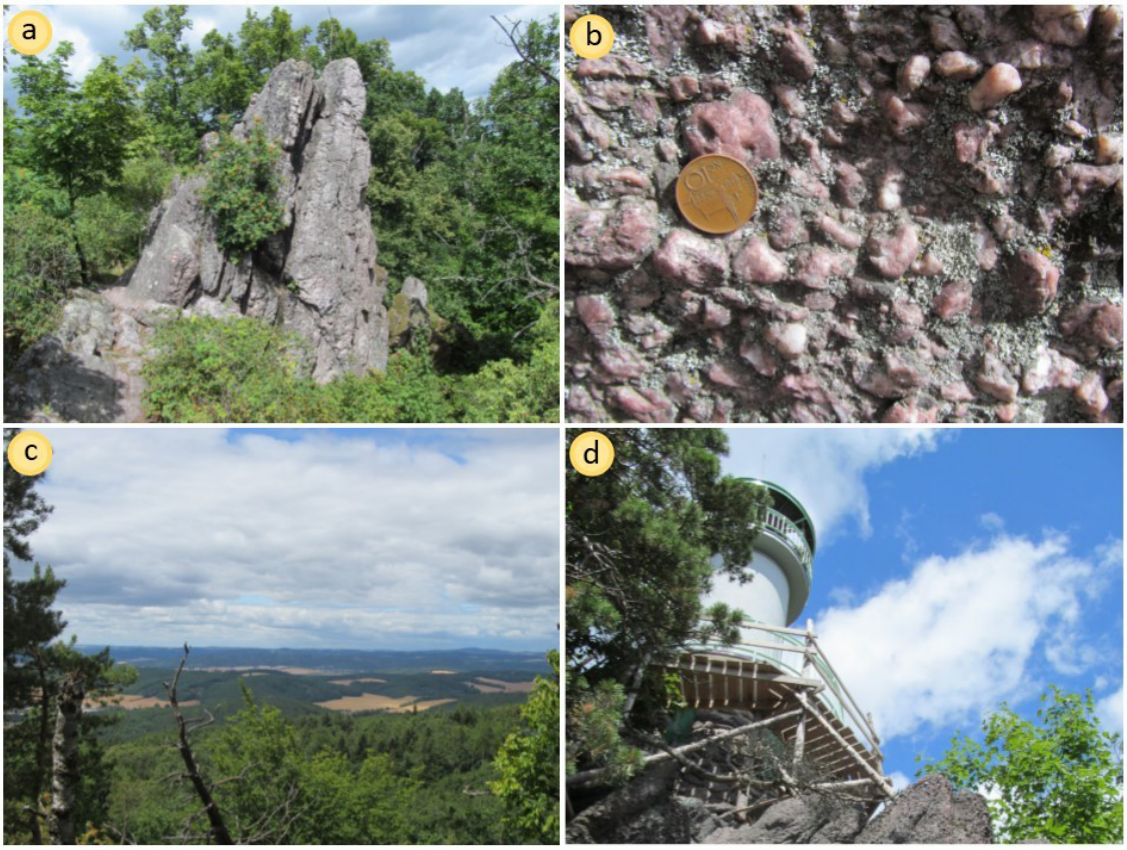


**Fig. 4:** *Babí lom Nature Reserve: a) rocky ridge represents the main landform of the site; b) red conglomerates of Devonian age; c) thanks to the wide views to the surrounding landscape (in this case towards the Bohemian-Moravian Highlands), the site can be considered a viewpoint geosite; d) a modern watchtower was constructed in 1960 and serves until present.*

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situated close to the pilgrimage church in Vranov). The tourist use of the site dates back to the first half of 19th century. Evidence of the construction of the first trigonometric point at the top of the Babí lom can be found in a painting from 1829 and it already shows tourists on the viewing platform. On the maps from 1875, Babí lom is also shown with lookout houses. Later, the site became a favourite tourist destination and the new watchtower was constructed (in 1884). In 1960, the watchtower was rebuilt and after reconstruction in 2023, it serves until now (Figure 4d).

Currently, the site is protected as Nature Reserve according to Czech legislative (Act No. 114/1992 Coll.). It is intensively used for hiking, but thanks to the difficult terrain and limited accessibility, the site is not overcrowded. Some parts of the rocky ridge are used for climbing which has a quite long tradition here. Several threats have been identified: littering, black camping, local occurrence of invasive woody plants, remains of forest monocultures. In the future, there is a risk of more intensive use of the site by specific activities such as biking which may contribute to the degradation of the site.

## 4 Results

The site has been assessed by using the Degradation Risk method and Risk assessment matrix. Table 2 and Table 3 summarize the results.

Regarding the degradation risk, the site Malhostovické kopečky Nature Monument seems to be more endangered than Babí lom Nature Reserve. It is caused by different degree of integrity (Babí lom is well preserved, while Malhostovické kopečky are already very influenced by human activities), accessibility (very good on Malhostovické kopečky – it is practically possible to park a car on a site, in contrast, Babí lom enables visits rather for well-trained tourists as the slopes are steep and on certain places, the path is not very safe). Due to the fact that Malhostovické kopečky are situated in proximity to several municipalities and active limestone quarry (less than 2 km), the scoring of "proximity to problematic areas" is higher than Babí lom Nature Reserve which is situated in forests. Both sites may be endangered by several

| Threat to geodiversity | Prob | Imp | Sum | Prob | Imp | Sum |
|---|---|---|---|---|---|---|
| | **Malhostovické kopečky** | | | **Babí lom** | | |
| Urbanisation | 3 | 5 | **15** | 1 | 5 | **5** |
| Quarrying, re-opening the quarry | 1 | 5 | **5** | 1 | 5 | **5** |
| Changes in land use management on site and in close proximity | 3 | 5 | **15** | 2 | 5 | **10** |
| Recreation, tourism (littering, breaking the rules, construction of tourist infrastructure leading to a more intensive use of the site) | 4 | 5 | **20** | 4 | 5 | **20** |
| Collecting fossils and rock specimens | 2 | 4 | **8** | 1 | 4 | **4** |
| Confusion in legal protection (different types and authorities) | 2 | 4 | **8** | 1 | 4 | **4** |
| Vegetation overgrowth incl. invasive species | 4 | 4 | **16** | 3 | 4 | **12** |
| Preferring the protection of living nature | 3 | 3 | **9** | 3 | 4 | **12** |

**Tab. 2** *Risk assessment of identified threats (using the Risk Assessment Matrix)*

threats, thus the scoring is quite high. Thanks to the fact that the terrain is more difficult in the case of Babí lom, the scoring of last criterion is better. The total score of the degradation risk assessment shows the significant difference between both sites.

Based on the literature review and field work, several threats have been identified. The most important threat is represented by intensive tourist use and recreation and possible construction of accompanying tourist infrastructure (e.g. single trails in the case of Babí lom). The vegetation overgrowth and spreading the invasive and non-native species can endanger both living nature and geodiversity features (e.g. contributing to the erosion, disruption of rock massive, intensifying slope processes or simply obscuring the visibility of Earth Sciences phenomena). Also, the urbanisation and change of land-use in the case of Malhostovické kopečky Nature Monument represent a threat that needs to be taken into account when managing the site or updating the care plan.

| **Strengths** | **Weaknesses** |
|---|---|
| • Presence of important Earth Sciences phenomena<br>• High potential for education<br>• Existing legislative protection<br>• Adequate tourist infrastructure<br>• High added values (ecological, cultural) | • High visitation and tourist pressure, overcrowding in specific periods<br>• Vegetation overgrowth, invasive species<br>• Lack of integrated promotion and educational activities focused both on geodiversity and biodiversity |
| **Opportunities** | **Threats** |
| • Developing a more complex educational activities which may be more effective and enable visitors to see the links between geodiversity, biodiversity and culture<br>• Developing management measures which would involve local people and stakeholders (e.g. via discussion when updating care plans)<br>• Including these sites into the Geodiversity Action Plans for Brno and surroundings | • Construction of accompanying tourist infrastructure that may lead to a more intensive use or overexploitation of the sites and thus contributing to the degradation of the sites<br>• Lack of finances for the existing management measures (e.g. dealing with vegetation)<br>• Urbanisation and land-use changes (in the case of Malhostovické kopečky Nature Monument) Lack of interest of local stakeholders |

**Tab. 3** *SWOT analysis for both sites including the proposals for management measures*

## 5 Discussion and conclusions

Generally, the rocks are considered something stable and permanent. Indeed, this attitude has penetrated even into everyday's lives and it is reflected in numerous idioms (Kubalíková and Coratza, 2023). On the other side, like everything, the rocks are subject to permanent change and they are affected by influences of both natural and human origin. Different components of geodiversity are under pressure which should be taken into account when planning and managing natural resources (Crofts *et al.*, 2020).

The geosites situated in the proximity of large cities may suffer from higher visitation and more intensive use (Kubalíková, 2024). Very often, the visitation is accompanied by undesirable activities such as littering, vandalism, camping or construction of a more developed tourist infrastructure that contribute to a more intensive pressure on particular sites. Especially, the construction of a "more developed" tourist infrastructure in relation to looking for another possibilities of how to exploit the site (e.g. single trails, biking etc.) may be a source of future degradation of the site or overexploitation, thus it is of particular importance that these issues needs to be taken into account when revising care plans or other strategic documents.

The threat of urbanisation, changes of land-use and presence of disturbing activities in the proximity of geosite needs to be considered as relevant as well. All these aspects can be included in the development of so called Geodiversity Action Plan (Dunlop *et al.*, 2018) which may also reflect the possibilities and opportunities for a sustainable use of the sites, e.g. for environmental education which represent an important part of any geoconservation effort (Prosser, 2019). Also, making connections between different stakeholders (landowners, authorities, communities, schools, academia) is very suitable to foster the conservation of Earth Sciences phenomena (Worton and Gillard, 2013; Prosser, 2019; Kubalíková *et al.*, 2022; Bussard and Reynard, 2022).

Regarding the promotion and education, it should not be made for each phenomenon separately, but it should be mutually linked, respecting the abiotic-biotic-culture concept of geotoutrism (Dowling, 2013; Dowling and Newsome, 2018) and principles of integrated approach (Kubalíková *et al.*, 2023).

Keeping the sites legally protected or eventually foster the legal protection is also a way of how to set a more effective conservation and management, but it also depends on the cooperation of local stakeholders and state administration. Local visitors, inhabitants and municipalities should also enter the process of updating or revising care plans (e.g. via discussions) and eventually help to identify the possible threats and risks and participate on the design of management proposals.

## 6 Summary

The paper focuses on the identification and assessment of threats on specific geosites situated in the outskirts of a large city. Based on the complex assessment of risks and threats (geomorphosite method, risk assessment matrix, SWOT analysis), some specific proposals for the future management has been designed and briefly discussed.

In general, these activities may contribute to a more effective conservation of natural heritage and raise awareness of existing and possible threats to geoheritage, which is often overlooked and considered as something stable and resistant.

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# Hydric Soil Properties of Agroforestry Coffee Plantations in Peru

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**Abstract**

*Suitable hydric and aerial soil properties of the habitat are very important for its stable and sustainable development and significantly determine the state of current and future natural ecosystems. These are characteristics that can be modelled into a more desirable and favourable state through the appropriate application of management practices and overall management settings. Agroforestry systems combining the aim of balanced production while maintaining favourable microclimatic conditions appear to be a proper way of nature-friendly farming and a suitable adaptation of intensive agriculture to ongoing climate change. The aim of the research was to evaluate the soil properties in different depths of three landuse types in Peru. The research plots were in natural forest stands, pasture areas and agroforestry coffee plantations. Soil samples were collected and subsequently processed in the form of Kopecky physical cylinders for evaluation of hydrostatic soil properties. The evaluated soil hydrolimits were compared with the actual soil moisture state determined by a moisture sensor. Based on the evaluated results, the most favourable soil hydrophysical properties were found in the soil environment of natural forest ecosystems. Soil environments of pasture and agroforestry coffee plantations were comparable according to the mostly unfavourable results of the evaluated properties. Thus, the result of the conducted research clearly demonstrated the influence of landuse type on the state of hydrophysical soil properties. Similarly, the influence of landuse type on the amount of soil carbon content and its positive effect on the state of hydrophysical soil properties has been confirmed.*

**Keywords:** *soil environment, physical soil properties, landuse, agroforestry coffee plantation, pasture, forest stand, soil carbon content*

## 1 Introduction

The soil environment of natural ecosystems can be characterised as a sequence of superimposed layers of different physical and chemical properties, which is formed by a very long-term process under the influence of biotic and abiotic factors (Van Breemen, Buurman, 2002; Vavříček, Kučera, 2017). Soil properties have a very significant influence on the growing conditions of the tree species or in some cases also of other crops (Onwuka, Mang, 2018; Zanella, *et al.*, 2011). One of the soil properties that is very important for the proper development of the ecosystem grown is hydric regime, i.e. in particular the soil water content (Ritchie, 1981).

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Enough water available to the roots of a plant is necessary to cover all its physiological needs and life processes, of which the process of photosynthesis is a typical example (Porporato *et al.*, 2004; Špinlerová, 2014). The soil water content is primarily influenced by the physical and chemical properties of the soil itself, but it is possible to optimise the water content to a very high degree by appropriate cultivation interventions and methods of habitat use that are gentle and close to the natural ecosystem development processes (De Frenne *et al.*, 2021; Bonan, 2008). The overall character of the natural ecosystem, and particularly the degree of canopy cover, indicates the prevailing microclimatic conditions such as temperature, airflow, total precipitation falling on the soil surface or evapotranspiration rates (Von Arx, *et al.*, 2012; Avila, 2001).

Inside of the forest stands and agroforestry systems, it is the presence of tree cover layer and the influence of the physiological processes of the trees present that leads to the creation of a specific microclimate (Maclean, Klinges; 2021). The microclimate of these systems is typically characterized by a more favourable and balanced temperature with limited occurrence of temperature extremes, a significant reduction in evaporation or limitation and consequent total solar radiation penetrating the stand canopy (Shankar, Garkoti, 2023; Wojkowski *et al.*; 2022; Wojkowski *et al.*, 2023). These microclimatic conditions are generally perceived as ecologically more favourable for the proper functioning and development of natural ecosystems and for maintaining their ecological stability and sustainability (Devi *et al.*, 2023). On the other hand, the removal of the cover layer leads to significant changes in the microclimatic conditions of the habitat, especially in the space just above the soil surface. This change in conditions is also associated with a subsequent increase in the effect of stress factors. The consequent microclimatic conditions lead to overheating of the uppermost layers of the soil environment. These changes lead to an increase in evaporation of water from the soil and thus to a disturbance of the water balance (Kovács *et al.*, 2020). The process of humification is also negatively affected (Pirastru *et al.*, 2013).

In the case of pasture areas, the character of herbaceous vegetation is also affected. In general, species-poorer ecosystems of lower plants are created and these areas are characterised by lower cover (Alaoui *et al.*, 2011). In addition to the effect of grazing on the character of the vegetation, there is also a marked effect on the soil environment itself, where the mechanical soil compaction process occurs due to the movement of cattle over the area (Teague *et al.*, 2011).

The presence of trees on agricultural land in agroforestry systems has generally rather positive effects on soil properties (Houška, 2022). The influence of trees is mainly through an increase in organic matter and the activity of root systems. Both effects of the trees presence lead to more favourable values of the physical properties of the soil, better infiltration of water into the soil environment and also significantly eliminate soil compaction (Ghestem, *et al.*, 2011). With a balanced density of trees and their appropriate spacing, an ideal ratio between evaporation, transpiration and surface runoff is also achieved, which generally has a positive effect on soil hydric properties and the water cycle (Alkmade *et al.*, 2009).

## 2 Material and Methods

Totally nine transects of the research plots (three transects per each of three different landuse types) were located at agroforestry coffee plantations, pasture areas and nature forest stands around the town of Oxapampa, Pasco region, Peru (10.5744336S, 75.4044786W).

The climate of Oxapampa surrounding area is characterized by a warm and temperate climate. According to the Köppen and Geiger classification, this type of climate is referred to as Cfb. Average annual temperatures range from 14–15 °C. Annual rainfall often exceeds 3500 mm, the rainiest months being January and February with monthly rainfall between 450–500 mm (Aronson, 2022).

## 2.1 Soil sampling and laboratory analysing

Soil samples were taken during January and February of year 2024 in the form of 100 $cm^3$ volume Kopecky physical cylinders from depths of 0–5 cm, 5–15 cm, 15–25 cm and 25–35 cm. The evaluation of selected soil hydrolimits is based on the analysing processes presented in the literature Lesnická pedologie by Klement Rejšek (1999). During the laboratory analysing of the soil samples the values of field capacity (FC), water retention capacity (WRC), wilting point (WP), maximum capillary water retention capacity (MCR), utilisable water content (UWC) and minimum air capacity (MAC) were determined according to the above-mentioned methodology. The soil texture was determined according to the pipetting method described in the literature Analýza půd I by Jiří Zbíral (2002).

## 2.2 Data analysing

Soil retention curves were constructed for all soil samples using ROSETTA, a module of RETC version 6.0, and the SSCBD+water content at 33 kPa (TH33) module was used for evaluation. This calculation module takes as input the percentages of sand, silt and clay determined by the pipetting method. This evaluating process is based on the methodology presented in Schaap *et al.* (2001) and van Genuchten *et al.* (1991).

The amount of soil carbon was determined using a CHNS vario MACRO cube elemental analyzer. The soil sample was analyzed by the CNS module. The analysis of the total elemental abundance was carried out on the principle of "dry burning", where the soil sample is burnt at a temperature of at least 1200 °C.

Statistical evaluation of the results was performed by using Statistica analytical software, version 14.00.15, from TIBCO Software Inc, using basic statistical tests such as the Shapir-Wilk test for data normality and the Kruskal-Wallis Anova and median test. The confidence level of results was set at value of 0–0.05.

# 3 Results

In all cases of above-mentioned selected soil hydrolimits, the most favourable values were found for soil samples sampled from the soil environment of forest ecosystems at all investigated depths. Comparing the other two landuse types, comparably unfavourable values of physical soil properties were found. In some cases, the pasture areas appeared to be more favourable soil environment according to the evaluated results. Thus, in general, in most cases the soil environment of agroforestry coffee plantations was the least favourable. Generally higher values of soil hydrolimits can be inferred from the depicted soil retention curves in the soil environment of forest stands (FS) and, in some depths, also in pasture areas (P). The higher soil water holding capacity is based on the retention curve course also evident in the case of forest stand and pasture soils. These soils are still characterised by stable soil moisture values over a longer period, even at higher values of suction pressure. On the other hand, the lowest soil moisture values and the least favourable curve shape indicating low soil water holding capacity can be seen in the case of soil samples from the agroforestry coffee plantation (CP) (Figure 1).

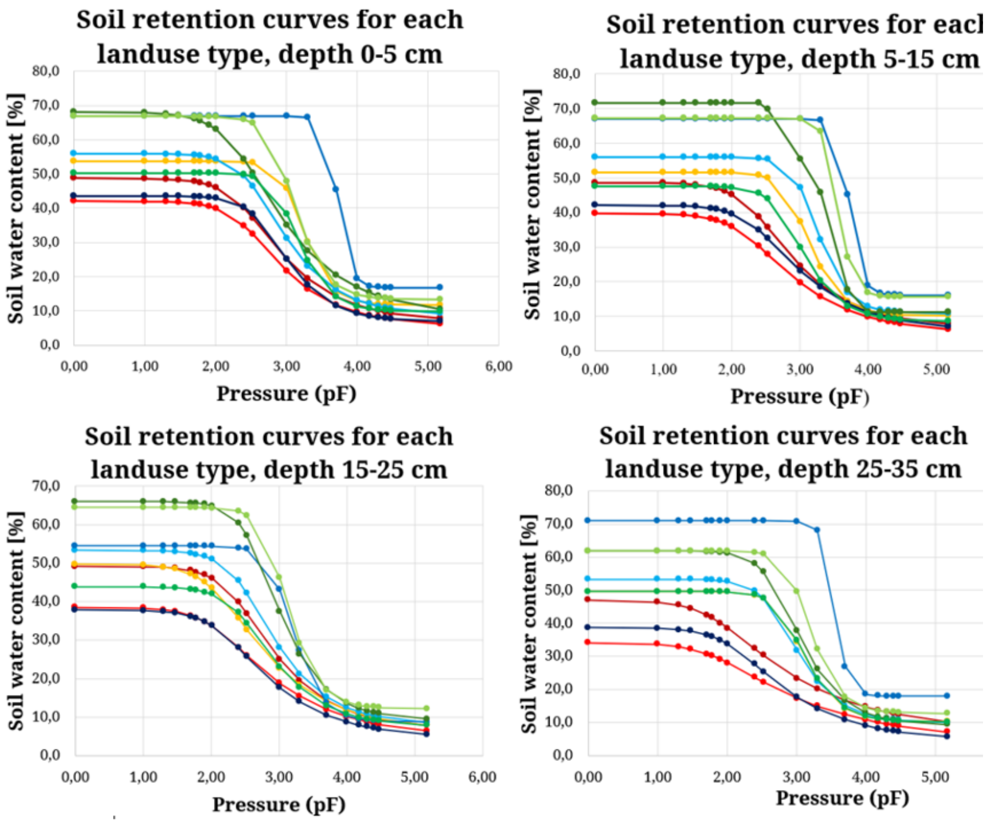


**Fig. 1:** *Soil retention curves for each landuse type and all depths*

Similar results were also found for the assessment of soil porosity. The most favourable soil porosity values at all evaluated soil profile depths were found in the natural forest stands. In contrast, the lowest soil porosity values were typical for the soil environment of agroforestry coffee plantations in all depths. The Figure 2 below shows the values of utilisable water content (UWC) at each evaluated depth.

The research also included an assessment of the total carbon content (TCC) in the soil environment of each landuse type. The carbon content values were found, then compared with the corresponding values of the other soil properties assessed and, in all cases, positive correlations were found. Thus, it is true that higher soil carbon content has a positive effect on the increase of soil physical properties values and with increasing soil carbon content, the values of the soil parameters under consideration also increase. A statistically significant relationship was found for the relationship between total carbon content and full water capacity, maximum capillary water capacity, water retention capacity and utilisable water capacity. In the case of the relationship of wilting point and minimum air capacity with total soil carbon content, a positive correlation was found, and higher carbon content also had a positive effect on the values of these soil properties. However, in these two cases the relationship was not statistically significant. According to this result, more favourable soil properties can be expected in soils with higher carbon content. During the research evaluation, higher values of TCC at all assessed depths were found in the soil environment of forest stands (Figure 3).

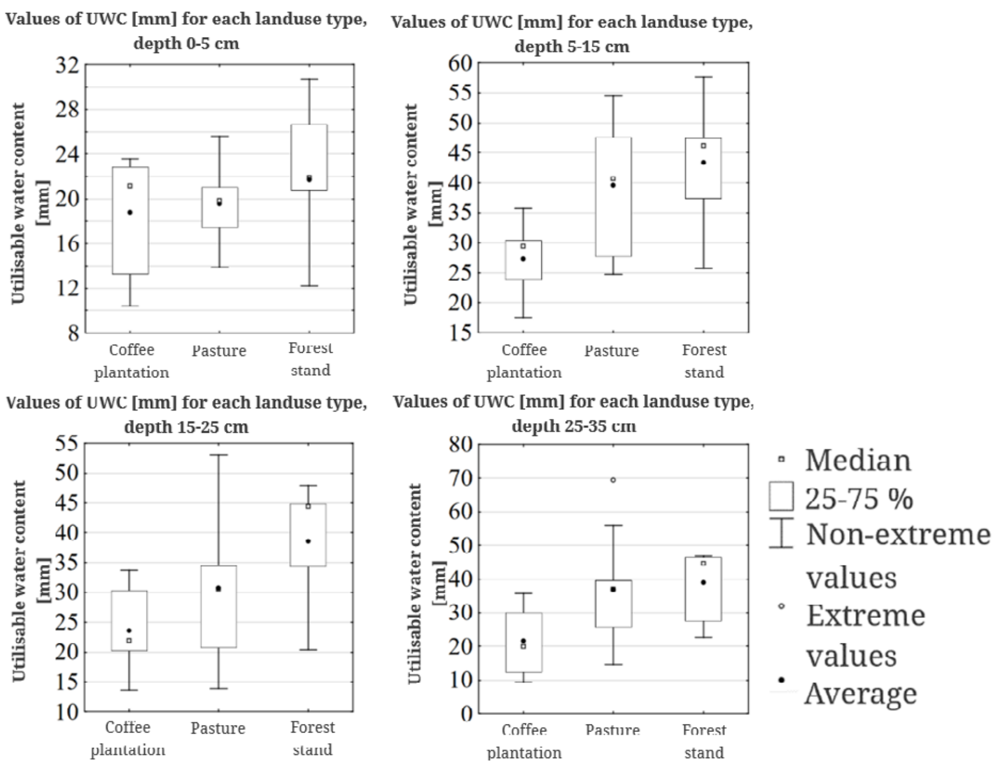


**Fig. 2:** *Values of UWC [mm] for each landuse type and all depths*

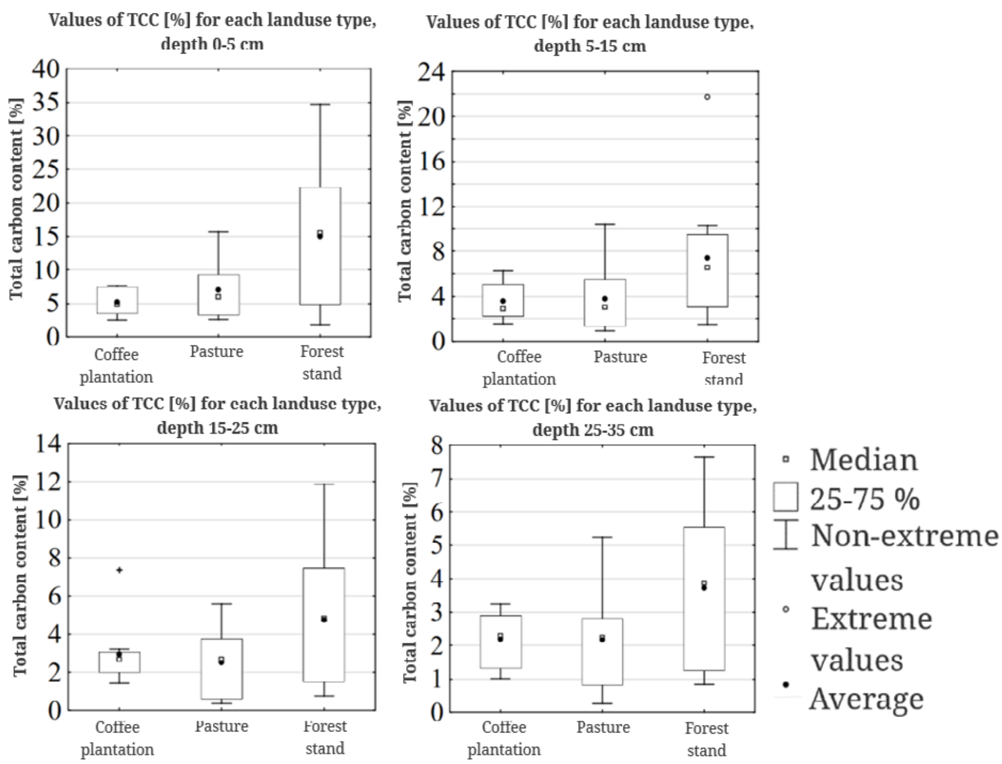


**Fig. 3:** *Values of TCC [%] for each landuse type and all depths*

# 4 Discussion

The management of natural ecosystems brings many specificities and the need for an individual approach, based mainly on the high degree of variability of natural conditions that must be dealt with. In particular, the overall topography of the terrain and the associated skeletal content or specific species and spatial composition of the habitat must be considered. All these mentioned factors also had an influence on the individual ecosystem's characteristics of the individual research plots.

Considering the topography of the terrain, the importance of slope sites is particularly evident in relation to material erosion, water runoff, and therefore the overall character of the soil environment (Fu *et al.*, 2011; Kinnell, 2000). Otherwise, the effect of soil compaction on the flat terrain of pasture areas is further enhanced by compaction caused by cattle movement (Šarapatka, Niggli, 2008).

In general, a negative influence of higher skeletal content on hydrophysical soil properties can also be confirmed (Rejšek, Vácha, 2018; Vavříček, Kučera, 2017). On the other hand, a higher skeleton content in the soil environment should result in more favourable values of soil air properties (Danalatos *et al.*, 1995), but this was not proven in the research.

From a forestry point of view, the significant influence of the tree composition of the habitat on its soil properties cannot be overlooked. Each woody species influences the conditions of the soil environment through its litterfall and its subsequent decomposition (Augusto *et al.*, 2002). In general, the litterfall of broadleaf species is perceived as more favourable (Kacálek *et al.*, 2017). In the case of the research carried out, it is possible to assess the influence of two different tree cover types on a general scale in relation to agroforestry systems, namely the influence of Pinus tecunumanii with Pinus oocarpa and then the influence of Inga edulis, which is generally known for its good ameliorative function and is often used as a shade tree in agroforestry plantations (Siles *et al.*, 2010; Cannavo *et al.*, 2011). When evaluating the surface soil layers up to a depth of 5 cm, in all cases the most favourable values of physical soil properties were evaluated in the areas of agroforestry plantations shaded by the broadleaved tree Inga edulis. Thus, the positive effect of broadleaved trees can be confirmed according to the results obtained in the soil humus layers (Wahl *et al.*, 2003; Hajnos *et al.*, 2003).

Another very important factor in the evaluation of soil environmental properties is the considerable long-term nature ecosystem forming process over which the soil environment is significantly affected (Perry *et al.*, 2008). This fact is particularly evident in physical soil properties, which change much more slowly than chemical properties (Rejšek, Vácha, 2018). This fact can also be demonstrated in a model on the example of selected research sites. The agroforestry coffee plantations were established on areas historically used for cattle grazing. The change in the management of the area occurred between 15 to 20 years ago. Since then, in the context of the long-term effects of the management type on the soil environment, this is a very short period for the current land use type to have a significant impact. In fact, the achieved results of the soil conditions of the agroforestry plantation presented in this paper, when compared to the very intensive management of pastures, which is quite different from the sustainable management of natural resources and the systematic care of the conditions of not only soil ecosystems (Tubiello *et al.*, 2007), do not show more favourable results than might be expected, and in many cases the conditions found for agroforestry sites were even less favourable than those of the pasture areas. A similar situation occurred in the case of research plots located in forest stands. Two research sites were in the old-grown natural forest of the national park. One plot was established at site previously used as a coffee plantation. Young age and different vertical and horizontal structure of this forest stand may explain the least favourable values of soil properties of this research site compared to just the sites in the national park, which are typical natural forest stands (Sellan *et al.*, 2019).

# 5 Summary

As a result of the research, it was found that the type of landuse and management applied has a significant influence on the state of physical soil properties. In general, more favourable values of soil properties were found in the soil environment of the forest ecosystem at all assessed soil depths. On the other hand, in the case of soil samples collected in agroforestry plantation and pasture areas, unfavourable values were found for all these assessed soil parameters. It is necessary to note that the unfavourable conditions of these two landuse types were very often similar in their values. In addition, a positive effect of higher carbon content on physical soil properties has also been confirmed, and since higher carbon content has generally been found in the soil environment of forest stands, a more favourable state of soil properties can be expected on forest sites. This evaluated results therefore provide very interesting information on the effect of landuse type on soil physical properties. The implication of the results should therefore clearly be, especially in the current global climate change, to strive for the conservation of forest stands and to strive for their favourable nature resources development.

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# Assessing Repeatability and Precision of Dosing Techniques in Soil Particle Size Distribution Analysis Using Laser Diffraction

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## Abstract

*This study investigates the precision and reliability of various dosing repeatability techniques for laser diffraction particle size analysis in soil samples, focusing on the impact of dosing methods on measurement reproducibility and accuracy. Three different dosing techniques (A) manual pipetting with a shaker, (B) a mash using a spatula, and (C) a dried sample using a spatula) were evaluated using a laser diffraction analyser. Soil samples representing sandy, loamy, and clayey types were analysed to assess the relative standard deviations (SD) for particle size measurements. The results were compared to traditional pipetting methods to identify discrepancies and evaluate the impact of dosing techniques on measurement precision. Significant variations in measurement precision were observed among the dosing techniques. Manual pipetting technique (A) exhibited higher relative SDs, with average values of 22.4%, indicating substantial variability and lower repeatability. In contrast, techniques B and C achieved lower relative SDs, averaging 8.1% and 7.9%, respectively. The study also confirmed that laser diffraction tends to underreport clay fractions and overreport silt fractions compared to pipetting. The results highlight the critical role of dosing technique in determining measurement precision for laser diffraction particle size analysis. Carefully optimized manual methods (such as techniques B or C) can still achieve high levels of precision, approaching those of automated dosing systems. These insights are essential for improving analytical practices and ensuring reliable soil particle size measurements in various applications.*

**Keywords:** *soil particle size sistribution (PSD), laser diffraction analysis, sample dosing techniques, repeatability assessment, standard deviation analysis*

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# 1 Introduction

Soil particle size distribution (PSD) is a crucial parameter across various disciplines, including agronomy, environmental science, and civil engineering. An accurate understanding of soil PSD is essential for determining soil texture, permeability, water retention capacity, and overall fertility. Laser diffraction is a sophisticated method for PSD analysis that provides rapid, precise, and detailed characterization of soil particles, ranging from clay to sand sizes (Eshel *et al.*, 2004; Beuselinck *et al.*, 1998).

Laser diffraction analysers operate based on the principle of light scattering. As a laser beam passes through a dispersed soil sample, particles scatter light at angles inversely proportional to their size. This scattered light is detected and analysed to generate a particle size distribution profile (Murray, 2002). This technique is favoured for its high resolution and capability to analyse a wide range of particle sizes in a single measurement. However, achieving reproducible results with laser diffraction in soil PSD analysis can be challenging. Variability in sample preparation, dispersion, and measurement conditions can lead to discrepancies between repeated measurements. Consistency in these factors is critical for reliable data, particularly when classifying soil according to the USDA soil texture triangle (Gee and Or, 2002).

A common issue in laser diffraction PSD analysis is the variability observed in repeated measurements from different aliquots of the same sample. Such variations can stem from several sources: (i) Sample Homogeneity: Soil samples may contain aggregates or unevenly distributed particles, affecting the representativeness of small aliquots (Loizeau *et al.*, 1994); (ii) Dispersion Efficiency: Inadequate dispersion can result in the presence of flocs, while over--dispersion may break down natural aggregates, both of which can lead to inconsistent results (Ryżak and Bieganowski, 2010); and (iii) Aliquot Handling: Manual pipetting or sampling can introduce variability due to differences in the amount or composition of material taken for each measurement (Konert and Vandenberghe, 1997).

Achieving reproducible results in PSD measurements using laser diffraction involves addressing these multifaceted challenges. Numerous studies have focused on identifying and mitigating sources of variability. Eshel *et al.* (2004) critically evaluated laser diffraction for PSD analysis, highlighting the importance of uniform sample preparation procedures. They found that inconsistencies in sample pre-treatment could lead to significant deviations in measured particle size distributions, underscoring the need for standardized methodologies. Proper dispersion of soil particles is essential to prevent aggregation and ensure accurate measurement of individual particle sizes (Beuselinck, *et al.*, 1998).

Manual handling of soil samples can also contribute to variability due to differences in aliquoting and mixing techniques. Automated systems for sample handling and dispersion have been developed to minimize human-induced variability. Konert and Vandenberghe (1997) compared manual and automated sample handling methods, finding that automated systems offered greater consistency and reproducibility. Loizeau *et al.* (1994) assessed a wide-range laser diffraction grain size analyzer for sediments, noting the challenges of obtaining representative aliquots from heterogeneous samples. Their findings suggest that improving aliquoting techniques is crucial for reproducible PSD measurements. Di Stefano *et al.* (2010) emphasized the importance of aliquoting techniques and proposed using automated pipetting systems to enhance reproducibility, demonstrating that automated pipetting reduces variability introduced by manual methods. Xu and Di Guida (2003), confirmed by Callesen *et al.* (2018), found that automated sample dispersion and measurement systems significantly improved repeatability. Roberson and Weltje (2014) compared various particle size analyzers, highlighting the impact of sample introduction methods on measurement accuracy. Automated dosing systems generally reduce operator-induced variability and improve repeatability, while manual methods, though flexible, can be prone to inconsistencies based on operator technique. Miller and Schaetzl (2011) observed that the coefficient of variation

(CV) for repeated measurements of the same sample ranged from 1% to 15%, depending on soil type and preparation method, emphasizing the influence of manual handling and operator variability on measurement reproducibility.

The primary objective of this paper is to assess the repeatability of soil sample dosing techniques into the wet dispersion unit of a laser diffraction analyzer. Specifically, the study aims to evaluate the consistency of three different dosing methods (hand pipette with shaker, mash using a spatula, and dried sample using a spatula) by analyzing the particle size distribution (PSD) measurements. The evaluation will be conducted using the standard deviation (SD) as a measure of variability, with the goal of identifying the dosing technique that provides the most reliable and reproducible results. This research seeks to contribute to the standardization of soil sample preparation and dosing methods in laser diffraction analysis, ultimately improving the accuracy and reliability of soil texture classification.

# 2 Material and Methods

## 2.1 Laser Diffraction Particle Size Analysis

In this study, particle size distribution (PSD) measurements were conducted using the Analysette 22 NeXT Nano laser diffraction analyser from Fritsch. This advanced instrument features a wide measuring range from 0.01 to 3800 µm, allowing for precise analysis of various particle sizes. The Analysette 22 NeXT Nano utilizes the MaS control software and supports both Fraunhofer and Mie scattering theories, providing flexibility in data analysis and interpretation. The device is equipped with a green laser with a wavelength of 520 nm and an approximate power of 1 mW, ensuring accurate and reliable measurements. (Fritsch, 2020).

The optical system of the analyser is based on a reverse Fourier design, optimizing measurement accuracy. The instrument also includes additional modules such as a wet dispersion unit and an ultrasonic box, which enhance its capability to handle different sample types and preparation methods. The suspension volume for measurements ranges from 150 to 500 ml, and the device features a radial pump with an adjustable speed of up to 3.5 l/min. Large-angle detectors and backward scattering channels contribute to the comprehensive analysis of particle size distributions. (Fritsch, 2020).

## 2.2 Preparation of the Soil Sample

Before introducing the soil sample into the laser particle analyser, meticulous preparation is necessary. This preparation follows the methodology established by Lisá (2016) and is not standardized like the pipetting method (classic sedimentation method).

(i.) Natural Drying: The collected soil sample was left in laboratory conditions for natural drying to ensure consistent moisture content before further processing.

(ii.) Sample Grinding and Sieving: After drying, the soil was gently ground using a mortar and then sieved through a 2 mm sieve. This process was aimed at breaking down larger aggregates and standardizing the particle size for analysis.

(iii.) Chemical Treatment: Approximately 5-10 g of the sieved soil was transferred to a test tube and dispersed in a 10% potassium hydroxide (KOH) solution. This treatment was intended to remove organic materials, oxides, carbonates, and other potential contaminants.

(iv.) Boiling for Enhanced Effectiveness: The test tube containing the soil-KOH suspension was boiled in water to enhance the effectiveness of the KOH treatment and ensure the thorough removal of residual organic matter.

(v.) Centrifugation: Following boiling, the suspension was subjected to centrifugation to ensure thorough mixing and complete coating of each soil grain with the reagent.
(vi.) Finally, the KOH solution was decanted.

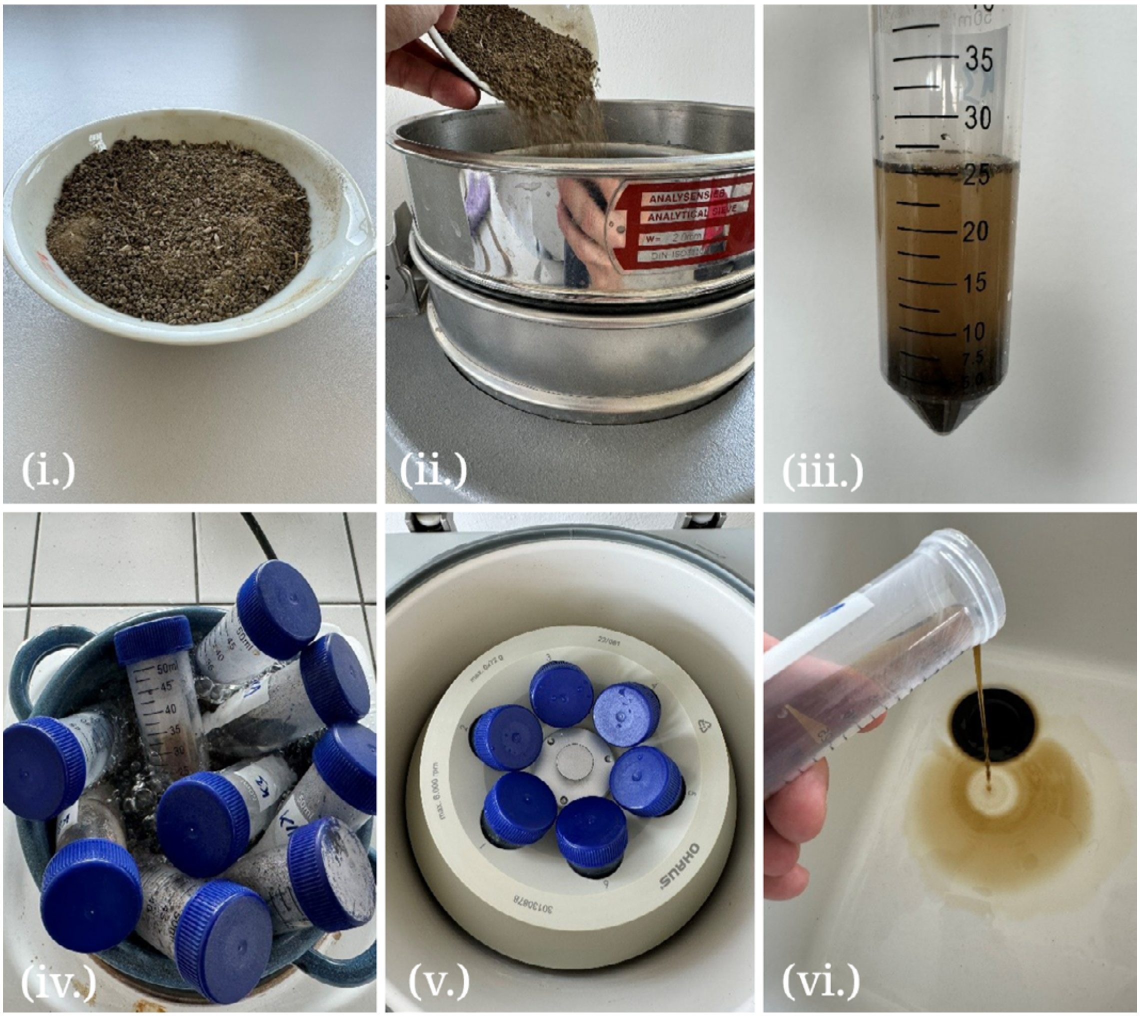


**Fig. 1:** *Soil sample preparation*

This procedure (step i-vi) is demonstrated in Figure 1. Soil samples were subsequently processed in the following three hand techniques:

- Technique A: After decantation, the suspension was replaced with distilled water. The resulting slurry was pipetted into the dispersion unit of the laser analyser, with a Vortex shaker used to achieve sample homogenization.
- Technique B: After decantation, a very small amount of distilled water was added to the soil to create a mash, which was then scooped into the dispersion unit of the laser analyser.
- echnique C: After decantation, the sample was allowed to dry before being dosed into the dispersion unit of the laser analyser.

These techniques (A-C) are demonstrated in Figure 2.

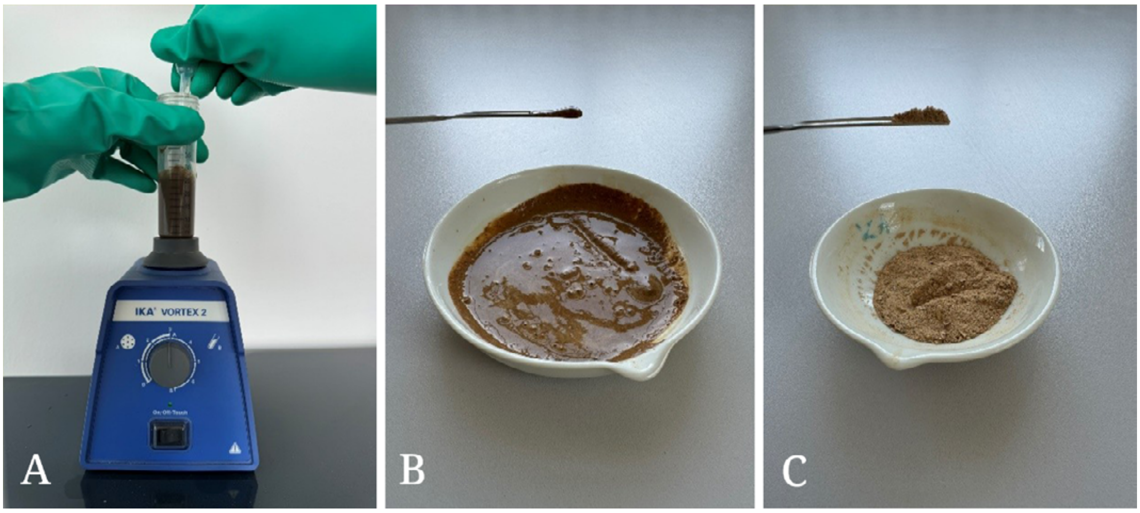


**Fig. 2:** *Schematic representation of soil sample processing and dosing techniques for laser diffraction analysis*
Author: Stanislav Paseka

## 2.3 Standard Operating Procedures

Standard Operating Procedures (SOPs) for sample measurements were established based on both practical experience and knowledge (Paseka, 2022) as well as research findings (Bieganowski *et al.*, 2018). Measurements were conducted under consistent SOP settings to ensure accuracy and reproducibility. The pump was set to operate at 80% capacity, corresponding to a flow rate of 2.8 l/min. The suspension volume was maintained at 90%, equating to 450 ml. Ultrasound power was consistently set to 50%, translating to 25 watts.

The obscuration level was controlled within the range of 15–20% to optimize signal detection and minimize measurement errors. Both the dark and background measurements were set to 10 seconds to address baseline noise and interference. The Mie scattering method was employed, with measurements lasting 25 seconds each and a total of 5 repetitions to ensure precision and statistical reliability.

For dispersion parameters, the refractive index (RI) for solid particles (silica) was set to 1.45, and for the liquid (distilled water), it was set to 1.33. The absorption coefficient (AC) was set to 0.3. These standardized settings provided a controlled environment for accurate and consistent sample analysis.

## 2.4 Soil Texture Classification and Measurement Procedures

Soil texture classifications were determined by analyzing the grain size distribution based on USDA soil taxonomy standards, with boundaries defined for sand (50–2000 µm), silt (2–50 µm), and clay (>2 µm). The grain size curve obtained from the analysis allowed for precise classification of soil textures. A total of 3 soil samples with varying textures, sandy, loamy and clayey, were tested to ensure comprehensive coverage.

Each sample was prepared uniformly and analyzed using three distinct dosing methods: Technique A) using a hand pipette with a shaker, Technique B) as a mash using a spatula, and Technique C) as a dried sample using a spatula. Each method (A-C) was tested by dispensing the sample into the dispersion unit of the laser diffractor 10 times, with each measurement repeated 5 times, resulting in a total of 450 individual measurements.

For comparative analysis, a case study was conducted using the classic sedimentation method, which involves pipetting and is based on the Stokes velocity relationship. In this case, a single measurement was performed for each soil sample.

### 2.5 Statistical Analysis

For the evaluation of the dosing methods (Techniques A, B, and C), basic statistical measures were employed to assess the repeatability and reliability of the measurements. The primary statistical tools used were the arithmetic mean and the standard deviation. These metrics were chosen for their simplicity and effectiveness in summarizing the data and identifying variability (Freedman *et al.*, 2007).

- Arithmetic Mean: The arithmetic mean, or average, is calculated by summing all the measurement values and dividing by the total number of measurements. It provides a central value (mean value denoted as E) that represents the typical measurement outcome for each dosing method.
- Standard Deviation: The standard deviation (SD) is a measure of the amount of variation or dispersion in a set of values. It is calculated by determining the average distance of each measurement from the mean. A lower standard deviation indicates that the measurements are closely clustered around the mean, suggesting high repeatability and a more reliable dosing mechanism. We analysed the data in the context of relative standard deviations and numerically in the context of ±1 SD from the mean. This approach is based on the principle that approximately 68% of the values in a normally distributed dataset lie within two standard deviations of the mean.

Assessment of Dosing Mechanisms: In this study, the repeatability of the dosing mechanisms (Techniques A, B, and C) was evaluated by comparing the standard deviations of the measurements. A smaller standard deviation indicates less variability and better repeatability, suggesting a more consistent and reliable dosing mechanism. This statistical approach ensures that the evaluation is both quantitative and objective, providing clear insights into the performance of each dosing mechanism.

## 3 Results

The data obtained from the Analysette 22 NeXT Nano laser diffraction analyzer offers a comprehensive overview of the particle size distribution (PSD) across three soil samples. The results, presented in graphs and tables, highlight key parameters such as mean particle size (E), standard deviation (SD), and the proportions of different particle size fractions (soil 1: sandy, soil 2: loamy, soil 3: clayey). This section details the findings, emphasizing the reproducibility of measurements, the impact of different dosing methods, and the implications for soil classification and analysis.

The analysis reveals significant variations in PSD depending on the dosing technique used. As illustrated in Figure 3, the highest variability in particle size distribution was observed with Technique A (manual pipetting into the laser), indicated by the broader range of values (E ± 1SD). In contrast, Techniques B and C produced more consistent results, suggesting that these methods offer more stable and reproducible measurements compared to manual pipetting.

Figure 3 shows that the laser diffraction method generally provided lower estimates for fine particles (clay fractions) compared to the traditional pipette method, particularly in Soil 3. This phenomenon carries important implications for soil classification and subsequent analyses. The differences in PSD results between laser diffraction and the pipette method could lead

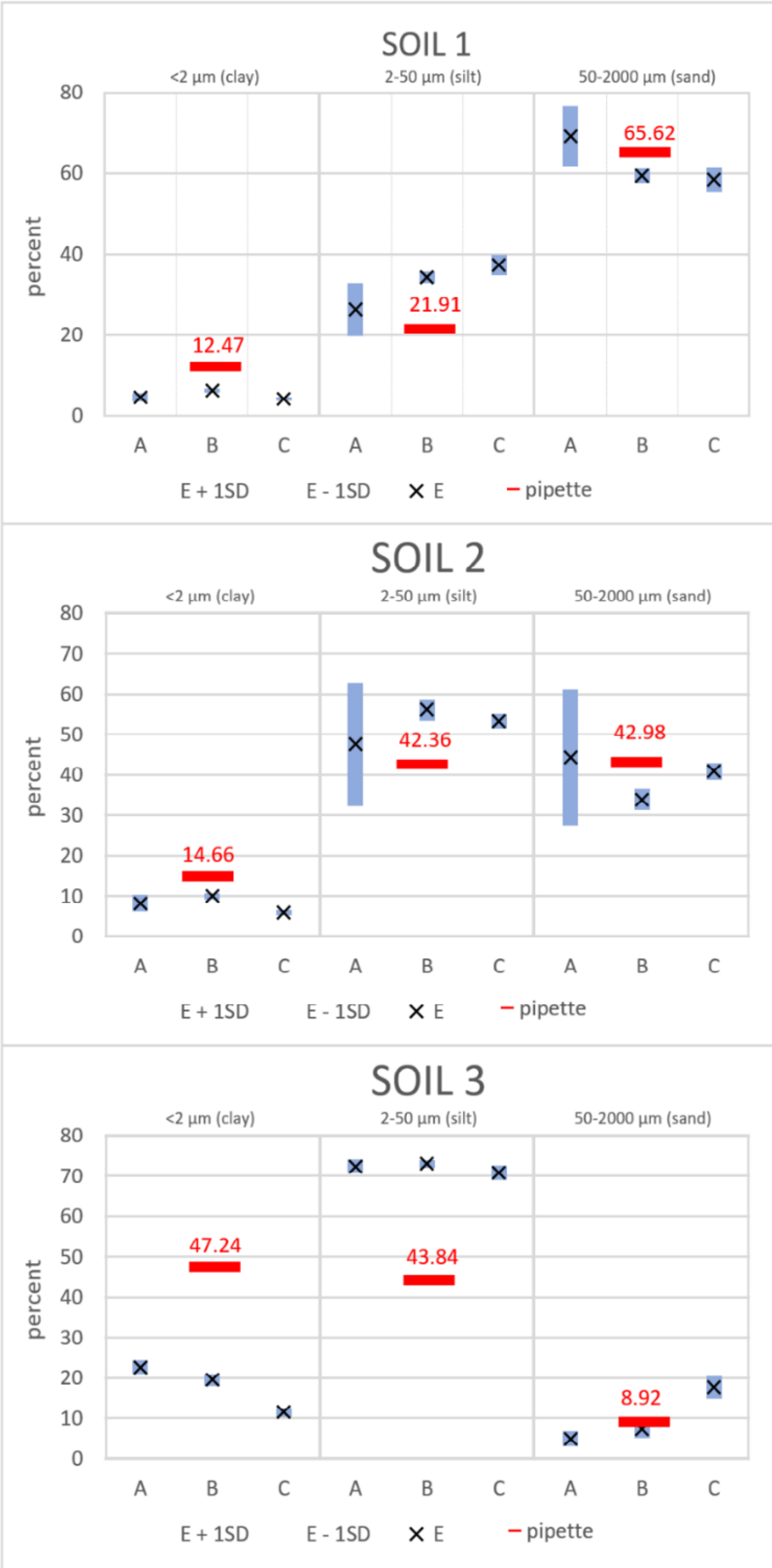


**Fig. 3:** *Evaluated results of the mean E values from the grain size curves for the cutoff values of clay, silt and nd sand including standard deviations for the 3 variants (A, B and C) of sample dosing into the laser and the measured value by the traditional pipetting method (in red in the graph)*

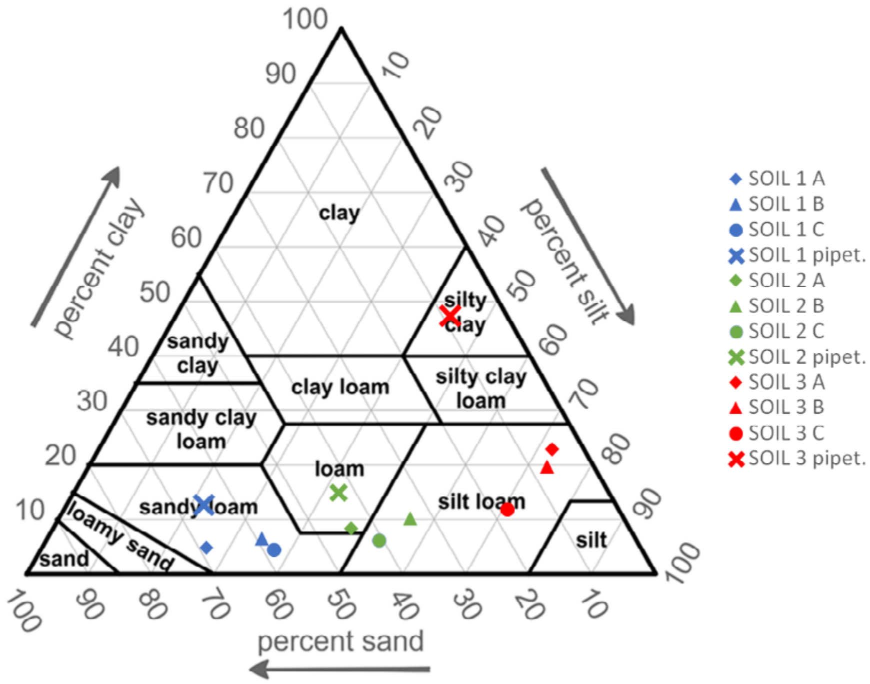


**Fig. 4:** *USDA Soil Texture Triangle Comparing Laser Diffraction and Pipette Methodologies across Different Dosing Techniques.*

to variations in soil texture classification, potentially affecting agricultural decision-making, environmental assessments, and other applications. However, this inaccuracy was not the primary focus of this study.

The analysis presented in Figure 4 illustrates the disparities in soil texture classification as determined by the USDA soil texture triangle, comparing results from three soil samples subjected to different dosing techniques into the laser diffraction analyser (Techniques A, B, and C) and the classical pipette method.

It is evident that the pipette method consistently yields higher clay content percentages compared to the laser diffraction technique, regardless of the dosing method used. This discrepancy is particularly pronounced in Sample 3, where the laser diffraction method underestimated the clay fraction by approximately 50%, leading to a significant shift in soil classification. In contrast, the sand fraction measurements obtained by the laser are relatively consistent with the pipette method, indicating that the laser method may reliably assess coarser fractions but struggles with finer particles.

While the primary aim of the study was not to compare the classical pipette method with laser diffraction but to determine the superiority of one dosing technique over another, conducting pipette measurements on the samples was essential. This allowed us to evaluate the bias introduced by each dosing technique when compared to the pipette method. The results indicate that all dosing techniques consistently diverged from the pipette method in a similar direction and to a comparable extent. Consequently, the conclusions will focus more on analysing the standard deviation (as a measure of repeatability) rather than the comparison of different techniques relative to their deviation from the pipette results. Furthermore, the limited number of soil samples tested is insufficient for drawing robust conclusions about the magnitude of this deviation.

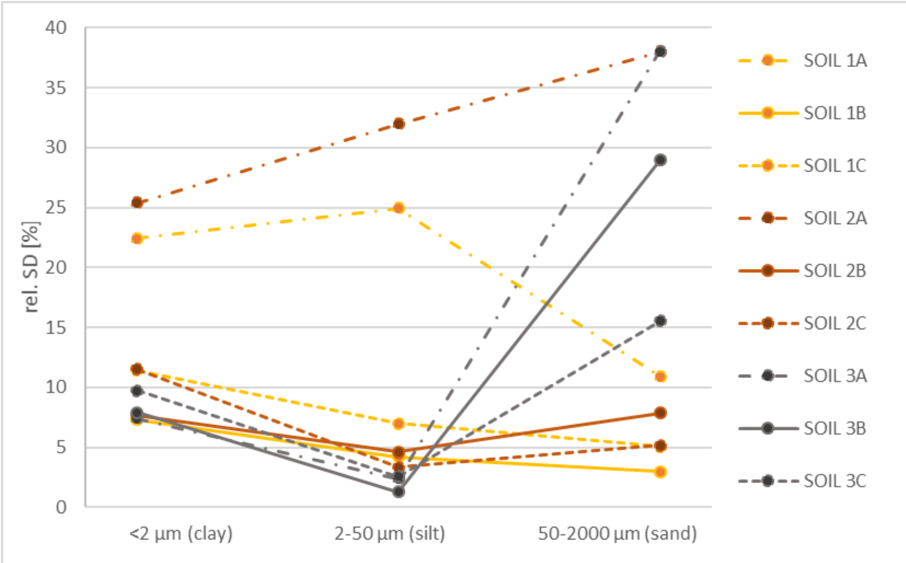


**Fig. 5:** *Relative standard deviation in percent across clay, silt, and sand fractions for three Dosing Techniques (Techniques A, B, and C)*

While the results in Figure 4 highlight the discrepancies in soil texture classification due to different dosing techniques, Figure 5 shifts the focus to evaluating the precision of these techniques. By analysing the relative standard deviations (SD) across various soil fractions, the study identifies which dosing methods yield the most consistent and reliable measurements, independent of the comparison between laser diffraction and the pipette method.

The analysis of relative standard deviation (SD) for various soil fractions (clay, silt, sand) across the three dosing techniques reveals critical insights into the precision of each method. The data indicate that Technique A consistently results in the highest relative SD, suggesting significantly greater variability and lower repeatability in measurements obtained using this method. Conversely, Techniques B and C exhibit markedly lower relative SD values, generally remaining within 10%, except for the sand fraction.

Furthermore, a substantial increase in SD is observed in the sand fraction of Soil Sample 3 (clay-rich), where variability is notably higher, particularly when using Technique A. This finding underscores the challenges of achieving consistent dosing with this method in soils with high clay content.

The results demonstrate that Techniques B and C provide more reliable and reproducible measurements, which are crucial for accurate soil texture classification and subsequent analyses. The lower variability observed with these techniques further supports their suitability for precise particle size distribution (PSD) analysis, especially in complex soil matrices such as those with high clay content. The significant differences in measurement accuracy among all three techniques also suggest that the choice of dosing method can substantially influence the outcome of soil texture classification and related applications.

Figure 6 provides a focused analysis on the precision of different techniques. By examining the relative standard deviations (SD) for each soil fraction across the three dosing methods, Figure 6 allows for a detailed comparison of the repeatability and reliability of the dosing techniques.

Figure 6 presents a column graph that clearly delineates the relative standard deviations for clay, silt, and sand fractions, as measured by the laser diffraction analyser, for each of the three dosing options (Techniques A, B, and C). The graph shows that Technique A (represented

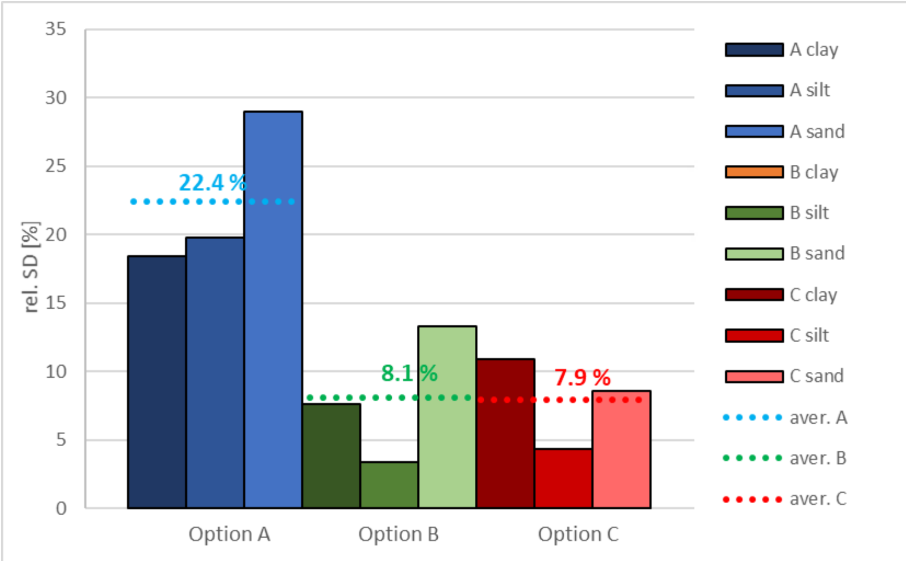


**Fig. 6:** *Relative standard deviation (%) across clay, silt, and sand fractions for three dosing techniques (Techniques A, B, and C)*

by blue columns) consistently results in the highest relative SD, with an average of 22.4%. This indicates substantial variability and lower repeatability in measurements for this technique. In contrast, Techniques B (green columns) and C (red columns) exhibit significantly lower relative SD values, averaging 8.1% and 7.8%, respectively. The lower variability for Techniques B and C underscores their superior repeatability compared to Technique A.

Among the three techniques, the silt fraction yields the lowest SD for both Techniques B and C, often falling below 5%, which highlights the effectiveness of these methods in providing consistent measurements for silt. The final data in Figure 6 reinforce the results obtained previously and highlight the superior performance of Techniques B and C in achieving reliable and reproducible measurements. This analysis is crucial for identifying the optimal dosing method for laser diffraction analysis, ensuring accurate soil texture classification and reliable particle size distribution data.

## 4 Discussion

Laser diffraction and pipetting are two commonly employed techniques for particle size analysis in soil samples, each with its own advantages and limitations. One of the major challenges associated with laser diffraction is the potential for overestimation or underestimation of specific particle fractions, particularly fine particles such as clay and silt. Svensson *et al.* (2022) reported significant discrepancies between results obtained using laser diffraction instruments, such as the Mastersizer, and traditional pipetting methods, particularly for clay and silt fractions. Their study highlights that discrepancies between these methods may arise due to suboptimal instrument settings and the selection of cutoff values between different particle fractions, such as clay and silt. According to Weiwen Qiu *et al.* (2021), laser diffraction can underreport clay fractions by up to 62% and overreport silt fractions by 23%, which aligns with earlier findings by Konert and Vandenberghe (1997) and Pieri *et al.* (2006). These differences are critical for soil texture classification as significant deviations in the measurement of clay and silt fractions can impact the final distribution of soil fractions.

The obtained results corroborate these findings, showing that laser diffraction tends to underreport the clay fraction compared to pipetting, with differences reaching up to 50% for clay fractions in this study. Additionally, the overestimation of silt fractions observed aligns with the results reported by Yang *et al.* (2015), indicating a notable percentage increase. These findings suggest that while laser diffraction offers a rapid and efficient measurement approach, its accuracy for fine particles can be influenced by various factors, including instrument settings and manufacturer specifications. It is crucial to recognize that optimizing the Standard Operating Procedures (SOPs) for laser diffraction instruments and selecting appropriate cutoff values for particle classification are essential for minimizing these discrepancies. Furthermore, different instruments may have varying characteristics and specifications that affect measurement results. This issue underscores the need for standardization of methodologies and thorough calibration of instruments to ensure the highest accuracy and reproducibility of measurements across different analytical techniques.

In this study, the evaluation of various dosing techniques for laser diffraction particle size analysis provided critical insights into their impact on measurement precision. This section focuses on the relative standard deviations (SD) of the different dosing methods and their implications for the reproducibility and reliability of soil texture measurements.

Miller and Schaetzl (2011) highlighted significant variability in the coefficient of variation (CV) based on different soil types and preparation methods. Their research demonstrated that CV for repeated measurements ranged from approximately 1% for sandy soils to up to 15% for clayey soils, indicating a substantial influence of soil texture on measurement precision. Similarly, Polakowski *et al.* (2021) examined the reproducibility of laser diffraction for soil particle size analysis and found that the CV was lowest for silt (3.44%) and highest for sand (23.28%). This variability underscores the impact of soil type on measurement outcomes. The obtained results corroborate these findings, showing significant differences in relative SD across the three tested soil samples. Specifically, for dosing Technique B, the average relative SD for clayey soil (Sample 3) was 12.7%, whereas for sandy soil (Sample 1), it was 4.9%. These results reflect the broader trend that soil texture affects measurement precision, with clayey soils exhibiting higher variability compared to sandy soils. Notably, the high SD observed in the sand fraction of clay-rich soils could influence the overall average SD, highlighting the complexities of achieving consistent measurements in heterogeneous soil matrices.

Further analysis revealed that manual dosing methods, such as those employed in techniques A, B and C, exhibited greater variability compared to automated dosing systems. Miller and Schaetzl (2011) noted that manual dosing methods generally show higher variability, with CVs typically ranging from 10% to 15%. In contrast, automated dosing systems tend to offer more consistent results, with CVs around 1–5%. This advantage of automated dosing in achieving reliable particle size distribution (PSD) measurements is evident in this study, where Techniques B and C, which involve more controlled dosing, approached the precision levels of automated methods with relative SDs of 8.1% and 7.9%, respectively.

The observed results underscore the importance of the dosing technique in influencing measurement precision. Techniques A, involving manual pipetting, displayed higher SDs due to the inherent variability in manual processes. In contrast, Techniques B and C, which provide more consistent dosing, resulted in lower relative SDs, although not as low as those typically seen with fully automated systems. This indicates that while automated dosing systems offer superior reproducibility, carefully optimized manual methods can still achieve reasonably high levels of precision.

Additionally, the precision of manual dosing methods can be affected by the operator‘s skill and the inherent variability in the dosing process. For instance, the use of a hand pipette for sample with a Vortex shaker (Technique A) was found to be particularly unsuitable, as it introduced significant variability and potential for human error. Additionally, the resulting average deviation for this technique exceeded the 10–15% range typically associated with manual dosing as reported by (Miller and Schaetzl, 2011). This highlights the need for a meticulous approach when using manual methods and suggests that automated dosing systems, which minimize human error and variability, offer a more reliable alternative for high-precision measurements.

In conclusion, while automated systems provide the highest consistency, carefully optimized manual methods can still yield reasonably high levels of precision. However, the role of the operator and the specific manual techniques used, such as pipetting from a tray, can significantly impact the results. These findings emphasize the need for selecting appropriate dosing techniques and considering operator skill to ensure accurate and reproducible measurements in soil texture analysis.

## 5 Summary

This study investigated the impact of different dosing techniques on the measurement precision of soil particle size analysis using laser diffraction. The evaluation focused on comparing the precision and repeatability of manual dosing methods, and their effects on the accuracy of soil texture classification.

The results demonstrated significant differences in measurement precision based on the manual dosing technique employed. Among the three manual dosing methods (Techniques A, B, and C), Techniques B and C achieved relatively lower relative standard deviations (SD) of 8.1% and 7.9%, respectively, indicating more consistent results. In contrast, Technique A showed higher variability, reflecting the inherent challenges associated with manual dosing processes.

Although all manual techniques offer valuable insights, Techniques B and C showed precision levels approaching those of automated systems, with relative SDs within 5% of automated benchmarks. In contrast, Technique A proved to be significantly less reliable, demonstrating excessive variability and making it less suitable for precise measurements. These findings suggest that while manual techniques B and C can achieve high levels of precision, Technique A is less effective and may be considered impractical for accurate soil particle size analysis.

The precision of particle size measurements varied notably with soil type. For instance, Technique B showed an average relative SD of 12.7% for clayey soil (Sample 3), compared to 4.9% for sandy soil (Sample 1). This finding highlights that soil texture, particularly high clay content, can significantly impact measurement variability, suggesting that soils with different textures may require tailored approaches to achieve consistent results.

The comparison between the traditional pipette method and all laser diffraction techniques revealed notable discrepancies, with the laser methods consistently showing deviations in particle size distribution. These inaccuracies were consistent across all manual dosing techniques, highlighting the inherent differences between the methods and the need for careful interpretation when comparing results from different analytical approaches.

Given that this study was conducted with only three soil samples, the findings are suggestive rather than definitive. Further research with a larger and more diverse set of soil samples is necessary to validate these results and refine dosing techniques. While manual dosing techniques can yield valuable insights into soil particle size analysis, their precision varies significantly. The study emphasizes the importance of carefully selecting dosing methods to ensure accurate and reproducible measurements.

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# Random Forest Algorithm and Convolutional Neural Networks for the Tree Species Classification in Remote Sensing Data

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**Abstract**

*This study deals with the classification of tree species using modern methods of machine- and deep-learning applied to satellite and drone date The aim of the study is to demonstrate the ability of these methods to accurately identify and classify different tree species. The first part is focused on the use of DeepForest and Detectree2 algorithms for tree crown delineation, which allow efficient segmentation and detection of trees in complex aerial images. The work with YOLO (You Only Look Once) algorithm is presented, the purpose of which is to train a model for specific detection and classification of selected tree species from drone data. The results of this algorithm is compared to the results of Random Forest machine learning algorithm. Second part of the study is focused on tree species classification in the large area of the University Forest Area by using of the Sentinel-2 and PlanetScope data. It was used the Random Forest algorithm and permanent sample plot to train the algorithm a to create map of the main tree species.*

**Keywords:** *deep learning, machine learning, multispectral data, drone, satellite, PlanetScope, Sentinel-2, Detectree2, YOLO*

## 1 Introduction

Currently, forestry management and ecological research are increasingly turning to technologies such as unmanned aerial systems (drones), remote sensing data, and machine learning methods to more effectively map and monitor forest ecosystems. Tree species maps can then serve as supplementary outputs for forest management plans and as baseline data for clustering lidar data, enabling the application of regression models specific to the main tree species.

**https://doi.org/10.11118/978-80-7701-024-5-0047**

## 2 Material and Methods

In the first part of the study, data was acquired using the senseFly eBee Plus drone and the Parrot Sequoia multispectral camera and the S.O.D.A photogrammetric camera. The data were processed in the Agisoft Metashape software into the form of a multispectral orthophoto, vegetation indices and digital surface models. At the same time, ground truth data was collected using the Trimble R12i GNSS receiver. Object annotation was then performed using CVAT.

DeepForest and Detectree2 algorithms were used to identify crowns. The number of trees and the shape of their crowns were then compared with the inverse watershed segmentation method. Subsequently, a convolutional neural network, specifically the YOLO algorithm, was used to search for individual tree species. The results were compared with the Random Forest method.

For the creation of the main forest types, the Sentinel-2 and PlanetScope data in vegetation and non-vegetation period has been downloaded. The representation of tree species weighted by basal area was calculated for each sample plot. Sample plots containing at least 80% of the given tree species were selected as train samples. Band values and vegetation indices were calculated for these areas.

Subsequently, the Random Forest algorithm was trained in R and deployed on the entire territory of the UFE Křtiny. This created a map of the main tree species.

## 3 Results

The accuracy of tree crown mapping was determined by comparing the area of individual crowns with a standard that was created based on the manual marking of crowns. In case of use algorithm DeepForest could not perform this comparison because this algorithm it does not create precise polygons surrounding the tree crowns and thus does not allow for precise

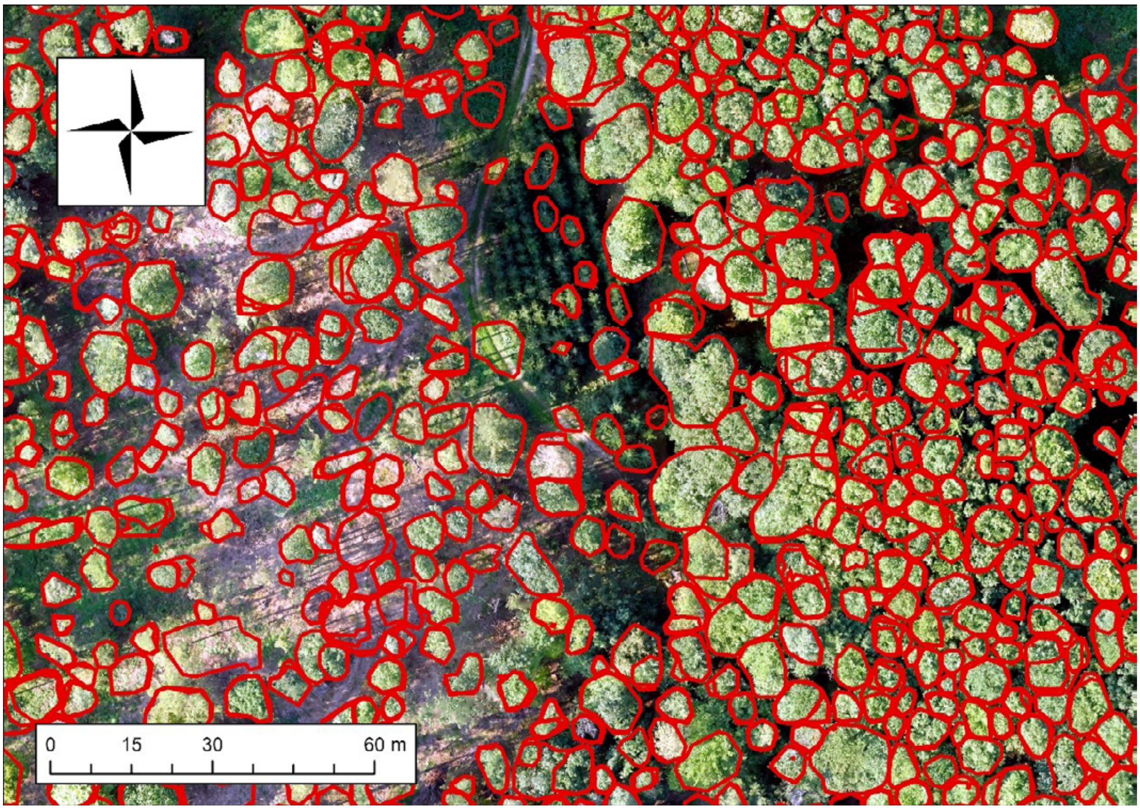


**Fig. 1:** *Identified tree crowns using Detectree2 algorithm*

| Category | F1 – score | Recall | Precision | Producer‘s Accuracy | User‘s Accuracy |
|---|---|---|---|---|---|
| Oak | 0,76 | 0,71 | 0,83 | 0,892 | 0,961 |
| Spruce | 0,76 | 0,62 | 1,0 | 0,952 | 0,833 |
| Pine | 0,6 | 0,6 | 0,6 | 0,9 | 0,818 |
| Beech | 0,62 | 0,71 | 0,55 | 0,822 | 0,948 |
| Larch | 0,82 | 1,0 | 0,7 | 0,923 | 0,827 |

**Tab. 1** *Evaluation of the classification performed by Random Forest and IWS*
Kappa Index: 0,854
Overall Accuracy: 0,885

determination their area. In contrast, the Detectree2 algorithm achieved a match of 96% between automatically calculated crown area and manual marking (with a tolerance of ±30% in area crowns). The IWS method showed an accuracy of 40%, which means that only 67 crowns of the total number had a comparable content to manually marked crowns.

Two crown delineations (IWS and Detectree2) were performed for use in the Random Forest method, as it was assumed that the quality of delineation would affect classification success. The descriptive statistics for Random Forest from IWS crowns are presented in Table 1.

The descriptive statistics for Random Forest from crowns delineated using Detectree2 are presented in Table 2. The results indicate that the impact of delineation on classification accuracy is minimal, and both outputs provide similar accuracy. The YOLO model correctly

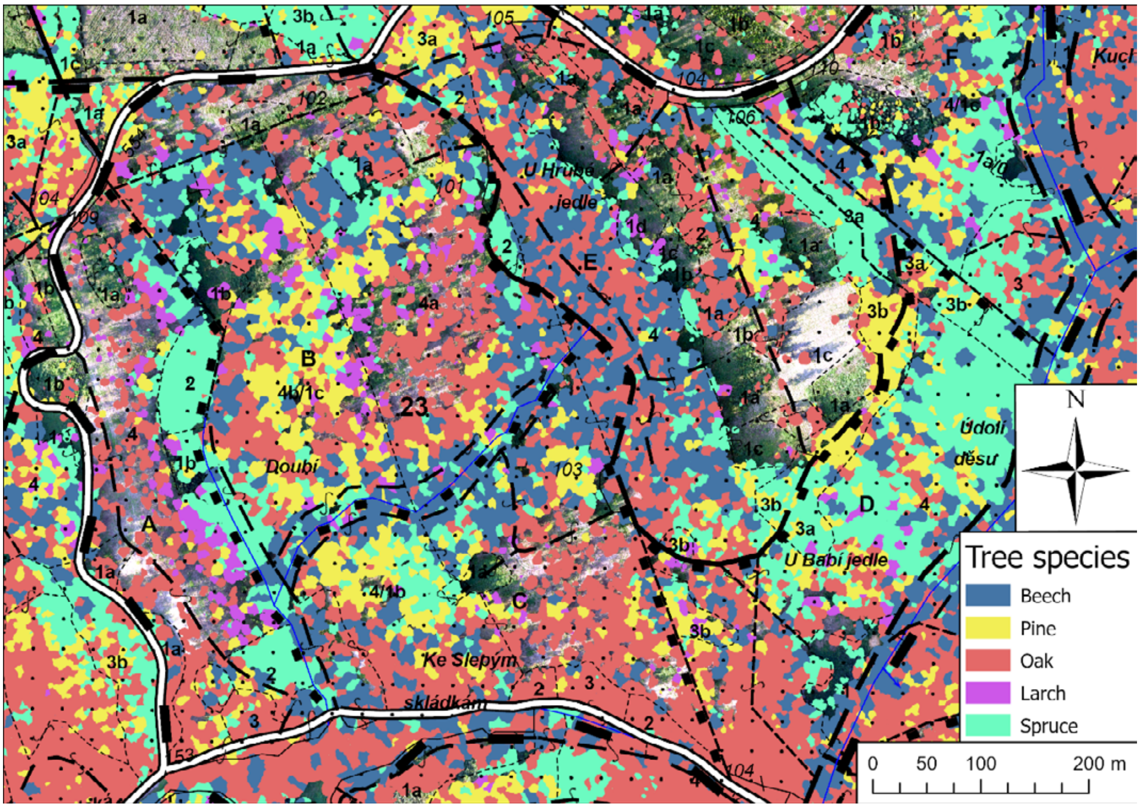


**Fig. 2:** *Map of tree species created from UAV data using inverse watershed segmentation and Random Forest algorithm*

| Category | F1- score | Recall | Precision | Producer‘s Accuracy | User‘s Accuracy |
|---|---|---|---|---|---|
| Oak | 0,6 | 0,5 | 0,75 | 0,866 | 0,962 |
| Spruce | 0,736 | 0,636 | 0,875 | 0,923 | 0,888 |
| Pine | 0,533 | 0,666 | 0,444 | 0,95 | 0,826 |
| Beech | 0,666 | 0,833 | 0,555 | 0,806 | 0,925 |
| Larch | 0,545 | 0,6 | 0,5 | 0,916 | 0,814 |

**Tab. 2** *Evaluation of the classification performed by Random Forest and Detectree2*
Kappa Index: 0,856
Overall Accuracy: 0,885

classified 70% of spruces, with minor error rates for other tree categories and the background. 69% of larches were correctly classified, but 36% were mistakenly labeled as background. Only 39% of pines were correctly classified, with 27% misclassified as deadwood and 27% as background, indicating significant classification errors. 47% of deadwood was correctly classified, while 53% was incorrectly identified as background. Background was classified very well with 61% accuracy, but errors occurred in classifying spruce (26%), larch (28%), and deadwood (9%) as background.

In case of satellite data, the overall accuracies obtained were 76.1% for Sentinel-2 and 71% for PlanetScope, with Kappa coefficients of 0.704 and 0.642 and The Average F1 score of 74.29% and 67.7%, respectively. Overall scores of predictions are 3% percent lower for Sentinel-2 and 8% lower than accuracy of their models. These results are informative when placed in the context of similar research efforts, which have utilized both similar anddiffering methodologies.

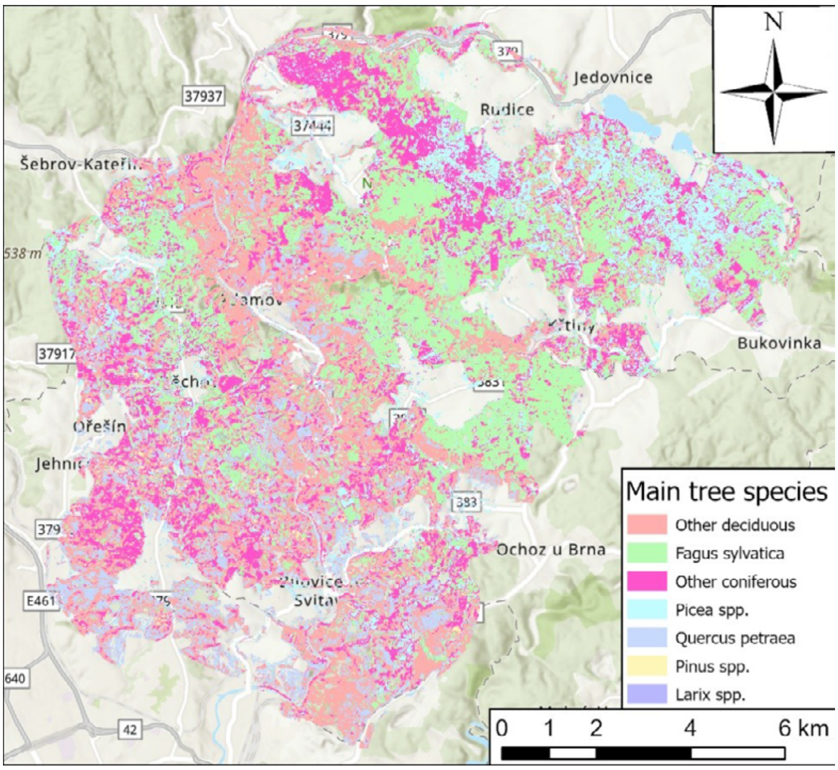


**Fig. 3:** *Main forest types (tree species) at the University Forest Enterprise Křtiny*

## 4 Discussion

The YOLO algorithm demonstrated its ability to accurately identify spruces, but the overall detection completeness was low, which could lead to certain tree species being overlooked. Despite the algorithm being trained on almost half of the area of interest, its overall completeness remained low. This result points to several potential issues. The main issue is the insufficient size of the training dataset. Studies that specifically address the size of datasets needed for training robust algorithms like YOLO highlight that the dataset should consist of thousands of images (Terven et Cordova-Esparza, 2023). Another potential problem is the use of natural data. While this presents certain challenges in deep learning, it doesn‘t necessarily lead to incorrect algorithm training. Natural data are often complex and variable, which can be challenging for models because they may contain noise, variability, and inconsistencies that are uncommon in controlled or synthetic datasets. The complexity and variability of natural data can drive algorithms to become more robust, as they must learn to extract relevant patterns and features from a challenging data environment, but this requires a sufficiently large dataset (Nat Biotechnol., 2023). The YOLO algorithm was trained only on RGB data, which put it at a disadvantage compared to Random Forest. Random Forest was trained on RGB data, multispectral data, vegetation indices, and 3D data in the form of a crown height model. Some improvement could be achieved by using a dataset that combines RGB and multispectral data. This would provide the algorithm with sufficient information, potentially enabling it to achieve results comparable to Random Forest. The results could also be improved by incorporating so-called point cloud metrics, which describe the distribution of points in the point cloud and possibly their color among the predictors. Point cloud metrics, also known as lidar metrics, are widely used in the forest inventory method called ABA (Area-based approach). The algorithm would then also work with the shape of the crowns (White *et al.*, 2013).

In case of satellite data analysys, the overall accuracy can be improved by a better set of tree sample plots. Sample plots that were used in the study were not fully precise, and it could cause higher misclassification. The Forest inventory was performed without fixation of coordinates on differential global navigation satellite system (GNSS) device but on a low accuracy level device. Incorporation of texture features (mean, variance, homogeneity, contrast, dissimilarity, entropy, second moment, and correlation of Principal components of imagery) in addition to sentinel-2 imagery and topographic features in (Ma *et al.*, 2021) study had an overall accuracy of 86.49% and a Kappa of 0.83. This suggests that integrating textural information could potentially enhance the accuracy of classifications. CHM was the most important variable in both models confirming the conclusions of other studies, where topographic features were causing significant improvements in classification. The temporal features also have a great value for classification. Spectral indices of winter images were frequently identified among the most important variables. This possibly could be due to some changes in phenological periods causing shifts in the spectral response of trees, enhancing the visibility of differences between species for machine learning classifiers. Study of (Kluczek *et al.*, 2023) suggests that spring and autumn are the best sampling periods in context of species classification.

## 5 Summary

The Random Forest model was trained using both types of crowns, first with those delineated by the IWS method and then with crowns delineated by Detectree2. Although the methods differed in crown segmentation accuracy, both approaches achieved very good overall accuracy in tree species classification, demonstrating the robustness of the Random Forest algorithm against variability in input data. The overall accuracy of over 88% is a significant achievement, highlighting the effectiveness of the combined approach in tree species classification. This result not only confirms the importance of careful selection of crown segmentation methods but also emphasizes the potential of integrating various techniques to improve classification models.

YOLO, despite its success in identifying spruce, faced gaps in overall detection completeness, indicating the need for expanded training and validation datasets to improve the model. These findings underscore the importance of sufficiently large and representative datasets for training robust models in natural data environments. Given the combination of using multiple methods for tree species detection, it can be concluded that for the area of interest, the Random Forest algorithm is more suitable, as it could work with more information about the specific tree. Issues may have arisen in connecting crowns to labeled trees, highlighting the importance of precise crown delineation for classifier training. It was found that shortcomings in the training dataset, including ambiguous crown identification from aerial imagery, may have negatively impacted model performance.

Despite not achieving the accuracy levels noted in other studies regarding the satellite data analysis, the results of this research are promising and provide valuable insights into effective strategies for enhancing classification accuracy in future. This study underscores the importance of dataset composition and demonstrates the significant potential of integrating Random Forest (RF) algorithms with Sentinel-2 imagery and Canopy Height Model for efficient tree species mapping. This method of producing high-quality tree species maps at an effective cost can significantly enhance environmental monitoring efforts and serve as a valuable tool for sustainable forest management and conservation.

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# Spectroscopic Properties of Humic Substances in Permanent Grassland Soil

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**Abstract**

*UV-VIS and infrared spectroscopy (FTIR) were used for humic substances quality evaluation. Both methods are widely applied because of their availability, sensitivity, rapidity, and affordability. The calculated spectral indexes assess the stability, hydrophobicity, and content of different functional groups in humic substances' molecules. Humic substances and humic acids were isolated from Gleyic Fluvisol (locality Jaroměřice, Czech Republic). The soil is under permanent grassland, with intensive management (4 cuts/year) and fertilisation with high-quality farmyard manure (FYM – the cattle loading 2 DJ. ha$^{-1}$). Soil samples were taken from a depth of 0–0.15 m from control and FYM variants during 2023–2024. Results were statistically evaluated (EDA, ANOVA /Tuckey's test/). UV-VIS spectra indicated a higher total humic substances content after amending soil with FYM. FTIR spectra showed more aliphatic and hydrophilic components after FYM amendments. Linear correlation was found between humic acid content and organic carbon content.*

**Keywords:** *humic substances, grassland, farmyard manure, UV-VIS and FTIR spectroscopy*

## 1 Introduction

Soil organic matter (SOM) is very heterogeneous and is defined as the mixture of organic matter remaining after the decomposition of biomass (advanced stage), which includes a variety of organic compounds (Kim *et al.*, 2023). The original material and its transformation process directly influence the chemical composition, structure and properties of SOM (Uska-Jaruga *et al.*, 2023). It represents the main carbon reservoir in the biosphere (Park and Kim, 2015). Several methods can be used to assess the quality of humic substances. These are based on different analytical principles and analytical methods (e.g. micromorphology, spectroscopy, and others). Nowadays, more advanced and non-destructive spectral methods such as UV-VIS and FTIR spectroscopy are widely applied (Michalska *et al.*, 2023). Praus *et al.* (2015) stated that both methods are used for the analysis of inorganic and organic soil components.

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Humic substances (HS) are characterized by their high absorbance in the ultraviolet and visible spectral range and the absorbance ratio A465 nm/ A665 nm (E4/E6, $Q_{4/6}$) can them well characterized. The $Q_{4/6}$ value decreases with increasing molecular weight and humification degree of humic substances. (Fasurová and Pospíšilová, 2011; Feszterová *et al.*, 2024).

FTIR spectroscopy indicates the structural composition and various functional groups content in the HS molecule. The advantage of this method is rapidity and sensitivity, and samples can be reused or archived. Calculated indexes from infrared spectral region can help to assess hydrophobicity, stability and degradability of humic substances (Demyan *et al.*, 2012; Thabit *et al.*, 2024). It is also possible to assess humic substances reactivity and content of proteins or carbohydrate (Novák *et al.*, 2017).

This research aims to give the spectral characterization (UV-VIS and FTIR) of HS in grassland soils after amending soil with farmyard manure. Besides spectral parameters and indexes, the content of humic substances, humic and fulvic acids, and the HA/FA ratio were determined. The obtained results were statistically evaluated by Statistica (EDA, ANOVA /Tuckey's test/).

## 2 Material and Methods

The studied area is in the Boskovice Furrow unit and the sub-unit Mala Haná, district Jevíčsko – Lowlands. It is formed from the Permo-Carbonate deposits (Bína and Demek, 2012). The long-term experiment is situated near Jaroměřice (Svitavy district) – see Figure 1. The precise small plot was 1.25 m × 8 m, i.e. 10 m$^2$ of harvesting area with 0.25 m (width) path. Each variant is always in four replications. The experiment was established in 2004, at an altitude of 342 m above sea level (location: 49.6282881N, 16.7317036E). The soil was classified as Gleyic Fluvisol (see Figure 1) according to Němeček *et al.* (2011). Formed from non-calcareous

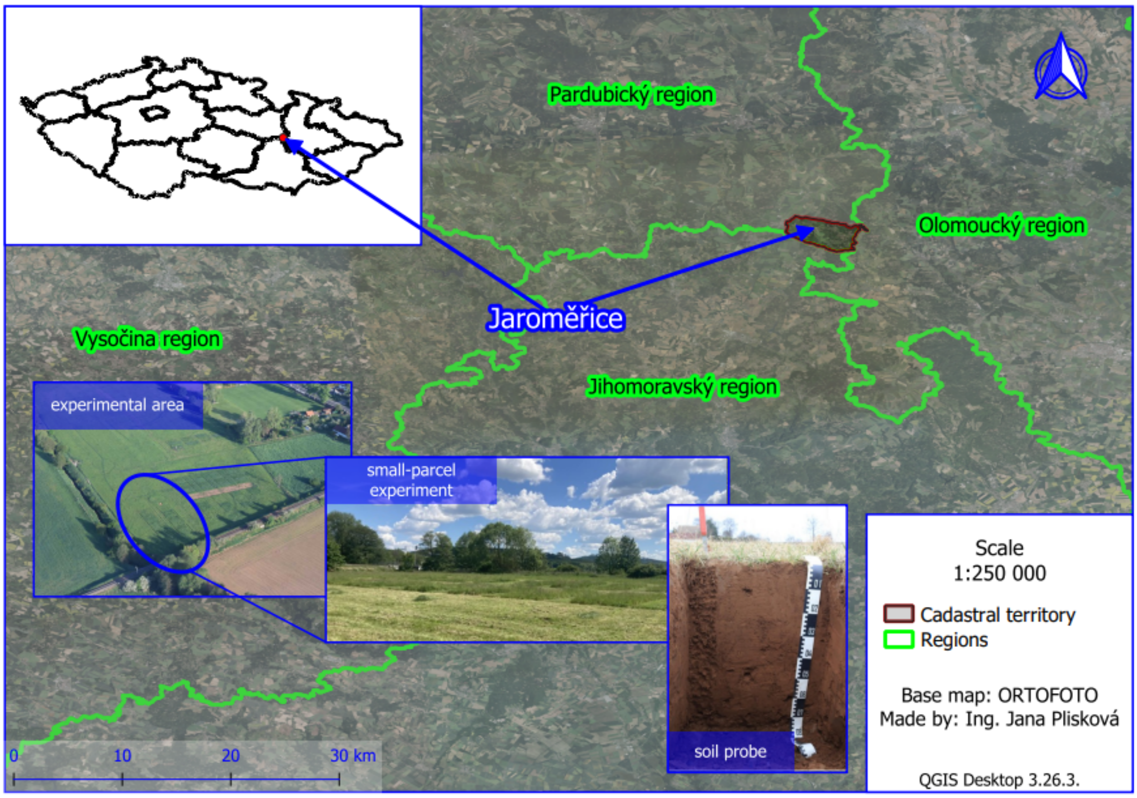


**Fig. 1:** *Studied area – locality Jaroměřice (Czech Republic)*

alluvial deposits. The basic soil properties were as follows: exchangeable soil reaction / pH/KCl / was 6.46, carbon content /Cox/ was 1.93%, and available nutrient content was: P – 37 $mg.kg^{-1}$, K – 68 $mg.kg^{-1}$, Mg – 130 $mg.kg^{-1}$). The botanical composition of grassland was mainly oatgrass (*Arrhenatherum elatius*). There was intensive management (4 cuts per year). Fertilizing followed the cattle loading (1 DJ = 60 kg $N.ha^{-1}$): intensive (4 mowings/year) = 2.0 $DJ.ha^{-1}$. The experimental variants were: /1/ control without fertiliser /Control/, /2/ farmyard manure + slurry /FYM/. The modelled experiment was designed according to the methodology of HBLFA Raumberg-Gumpenstein and VÚRV, v.v.i. (Menšík *et al.*, 2019).

Soil samples were collected from a depth of 0–0.15 m with a probe. An average sample was composed of 20–30 individual punctures. Humic substances (humic acids, fulvic acids) were extracted by a mixture solution of 0.1 M NaOH and 0.1 M Na4P2O7 (1:1, w/w). The quality of the humic substances was evaluated using the HA/FA ratio. In addition, UV-VIS and FTIR spectroscopy was applied for HS quality evaluation. UV-VIS spectrometer Varian Cary 50 probe (Varian Mulgrave, Victoria, Australia), with an optical fibre (within the range 300–700 nm) was used. A Thermo Nicolet Avatar 320 FTIR spectrometer (Nicolet, Madison, WI, USA), equipped with a Smart Diffuse Reflectance accessory (a range of 4000–500 $cm^{-1}$) was used. The colour index /$Q_{4/6}$/ ($A4_{46}/A_{665}$), humification degree and content of aromatic and aliphatic groups were determined according to Kumada (1987), Ellerbrock *et al.* (2005), Margenot et al. (2015), and Demyan *et al.* (2012). Colour index /$Q_{4/6}$/ was calculated as a absorbance ratio $A_{446}/A_{665}$ nm. The results were statistically evaluated (ANOVA /Tuckey's test/).

## 3 Results

Humic substances (HS) fractional composition showed that amending soil with FYM led to an increase in HA content. Average content of HS represents 0.79%, HA 0.45%, and FA 0.34% after FYM amendments. On the control site, the average HS content represents 0.60%, HA 0.33%, and FA 0.23%. Differences were statistically significant. Linear correlation between HA and SOC content was determined (see Figure 2). HA/FA ratio was higher than one. A positive effect of FYM amendment was documented by higher absorbance in the UV-VIS spectral range – see Figure 3. Calculated colour index /$Q_{4/6}$/ was less than 6 after amending soil with FYM and more than 6 on the control site. Humification degree was medium 20–25%. DRIFT spectroscopy identifies the increase of aliphatic hydrophilic groups after amending soil with FYM. This indicates a higher amount of humic substances – see Figure 4. FYM variant consistently demonstrated this trend throughout the entire study period 2019–2021. It was concluded that labile and degradable carbon forms were more prevalent in the FYM variant, which is increasing the available nutrients content and generally improving microbial conditions in the soil.

## 4 Discussion

The status of humic substances, and consequently soil quality, might be affected by amending soil with exogenous organic materials This enhance the microbial activity of soil biota and improve the plant growth condition. Similarly, Deru *et al.* (2023), He *et al.* (2018), and Qi et al. (2023) stated that amending grassland soil with exogenous organic and mineral materials positively affects grasslands. Mainly organic fertilizers (farmyard manure and slurry) resulted in the accumulation of HS. This was also confirmed by our study. Kidd *et al.* (2017) and Rambaut *et al.* (2022) demonstrated, that not only is nutrient status improved but also more favourable soil pH is achieved. High quality grasslands are important in the ecosystems because they fulfil important ecosystem services such as feed production, impact on water and nutrient cycles, or they can be used in a future as arable.

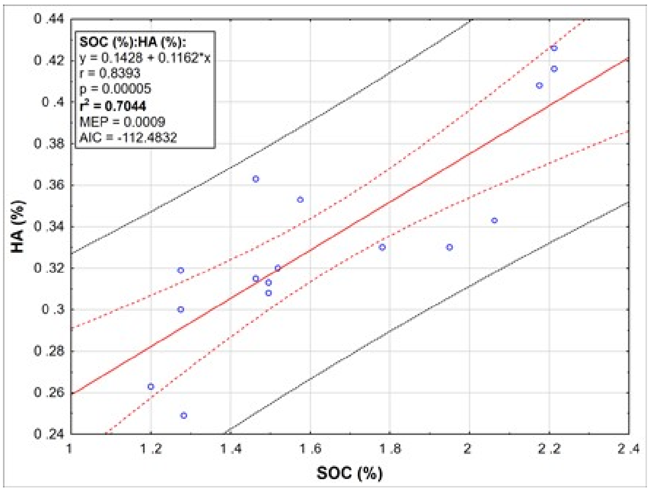


**Fig. 4:** *Linear correlation between humic acids (HA) and organic carbon content (SOC)*

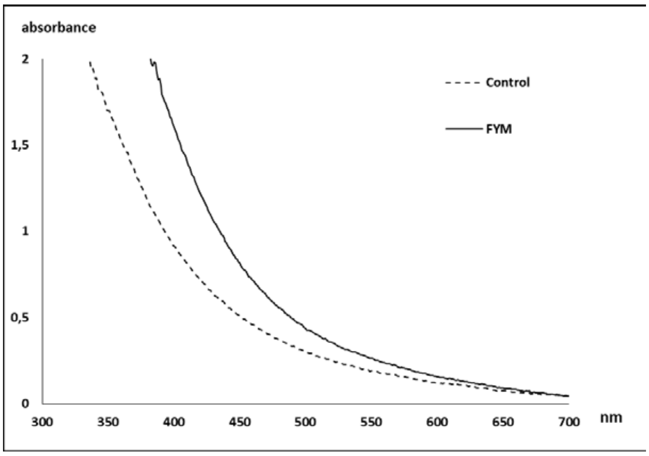


**Fig. 3:** *UV-VIS absorbance of humic substances in studied variants*

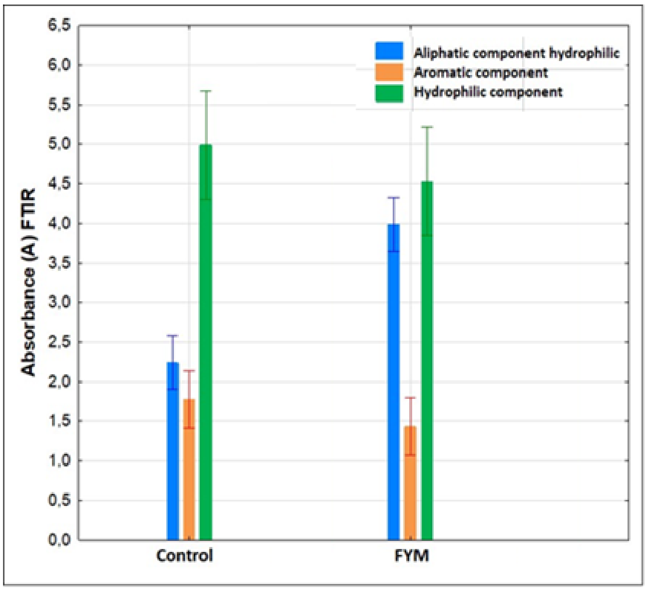


**Fig. 2:** *Composition of humic substances according to FTIR measurements*

# 5 Summary

Permanent grasslands are becoming highly topic today because they are used for feed production, as a high-quality substrate for biogas stations, or they represent the future arable soils. Attention is therefore being paid to the soil quality. Grasslands in the various types of fertilization and mowing management are widely studied. The paper aims to assess the results of a field experiment at the locality Jaroměřice (Malá Haná region, Czech Republic). The soil is under intensive management (4 cuts/year) and farmyard manure and slurry (FYM) were applied. The quantity and quality of humic substances were evaluated using a multicriteria ANOVA test. It was confirmed that the application of farmyard manure (FYM) significantly improved SOM content and quality. A linear correlation humic acids and organic carbon content was found. The UV-VIS spectra showed increasing in humic substances absorbance after amending soil with FYM. A higher proportion of aliphatic hydrophilic groups in the manure variant compared to the control was documented by FTIR spectroscopy..

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# Palaeogeographical Changes in Sedimentary Environment Extents on Area of the Czech Republic

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**Abstract**

*Palaeogeographical changes in geological environments, represented by extrusions and sedimentation, were assessed among vector models from the Czech Republic (CR) covering Bohemian Massif and Outer Western Carpathians. The vector models contained reconstructions of sedimentation extensions during culminant marine transgressions or regressions since Permian (299 Ma), Jurassic (152 Ma), Cretaceous (93.9 Ma), Eocene (56 Ma), Lower (23 Ma) and Upper Miocene (11.6 Ma) to Upper Pleistocene (18 ka). The assessment was carried out through comparison among changes of the sedimentary environment extension size between sequential layers and with present distribution of the selected stratas. Terrestrial surface during marine regressions extended 70% of the CR. The most spread marine transgression relinquished < 30% of the dry land. The terrestrial surface covered permanently 14.8% of the CR since existence of the Bohemian Massif. Pleistocene was characteristic by terrestrial environment diversification after conclusive sea regression. Permanent land occurrence suggested conditions for long-time ecosystem adaptation to environmental changes in contrast to mobile zones.*

**Keywords:** *palinspatic modelling, vectorisation, environmental changes, (semi)water ecosystem*

## 1 Introduction

Palaeogeography occupies distribution of lands and oceans on Earth' surface in geological past. It focuses on interpretation of Earth surface development consequences for present geological environment and spreading of living forms (Cox and Moore, 2005). The geological environment development initiates far-reaching environmental changes, during which reproductive-isolation barriers form to support endemism or equilibrium disturbance between natural conditions and ecosystems enhancing evolution of life systems (Eldredge and Gould, 1972). The assessment of relationships between palaeogeographical conditions and living form occurrences is carried out through ecosystem classification. The ecosystem classification suggests relation between geological environment and life community functions connected with bioproduction, species richment and also with adaptation ability to environmental changes (Hamilton, 1988).

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Classification of palaeogeographical conditions are individual or typological as with the fundamental physical geography. While present-time ecosystem classifications are based on direct indication of natural conditions through composition of living forms, the ecosystem structure in geological past is derived through suitable geodata interpretation. Geological data are either factic or interpretative (Kukal *et al.*, 2014). Subsequently, palaeogeographical reconstruction of ancient natural conditions uses presumptions about natural condition uniformity and about plate tectonics (Kalvoda *et al.*, 1998). The natural process uniformity assumes that processes of rock origination, transformation and disruption were same in geological past as in present-time. The lithospherical plate tectonics theory observes movements of land and ocean crust on more dense and hot mantle from origination to destruction of supercontinents (Burke and Wilson, 1976). Reconstruction of natural conditions begins through using of petrographical factic maps, which show present distribution of rocks. The petrographical data are generalised to regionally-geological maps integrating rocks to units with similar development (Davis *et al.*, 2012). Rock unit original extent is subsequently estimated through observations of palaeomagnetism, isotopes and similarities among sediments (including facial analysis) (Kalvoda *et al.*, 1998) (Fig. 1).

Reconstruction process for rock occurrence at origination time is divided with respect to original sedimentation basin preservation rate. Preserved sedimentation basins without tectonical deformations are reconstructed synoptically. The residues from originally larger basin are reconstructed palinspaticly through balance between tectonic move velocity forming rocks and erosion intensity (Pešek *et al.*, 1998). The balance equation is defined either magnetostratigraphically or through gravitional anomalies mapping. Magnetostratigraphical mapping focuses on the best correlation detection between palaeomagnetical anomalies at oceanic crust and equally old igneous rocks on dry land (Ziegler, 1999). The mapping of gravitional anomalies shows differences at Earth crust density, which follow interfaces between sedimentary and crystallic bodies (Yegrorova and Starostenko, 2002). Palaeomagnetism commonly with environmental indicators in sediments suggest climatical conditions in specific period of geological past. Especially, fossils bound to strait climatic zones or minerals forming strictly under favorable climate are environmental indicators suggesting climatic conditions (Barker and Elderfield, 2002).

Tectonical movements keep substance cycling between Earth surface and lithosphere. These cyclings include cycles of rock origination and disruption, uplifts and declenations of lithospherical plates to supercontinental rise and destruction. The lithospherical plate movements are driven (i) by energy from radioactive Earth core, which causes convective heat moves at mantle, (ii) by water presence, which decreases attrition between plates, and (iii) by gravity (Kearey and Frederick, 1996). The movements become evident along interfaces between particular plates, where geodynamical environments form. Geodynamical environments are distinctible along move course as subduct, where one plate replaces under the other, as obduct, where one plate displace over the other, as collisional followed by counter uplifts and as translational followed by skids along the contact axis (Zonenšajn *et al.*, 1976). The supercontinent developmental cycle consists of many geotectonical cycles, which period prolonges according to destruction intensity of united plates. Each geotectonical cycle contains endogenous and exogenous compounds. Endogenous orogenic cycle is a series of mountain-forming processes, when wrinkled mountain systems have change effectivity of atmospherical circulation. Wrinkle-conditioned climate-sedimentation cycles are distinguished to sedimentary environments either along spread of platform area submersion by sea or after sea regression. Exogenous effects of climate-sedimentation cycles are based in sea transgression that enhances climate warming (Levin, 1994).

Lands have formed around cratons (blocks) from less dense crystallic rocks over more heavy indigenous ocean crust. Tendency toward first craton forming rose during setting of hot young Earth surface. As first, the setting surface was covered by sliding crust islands, which

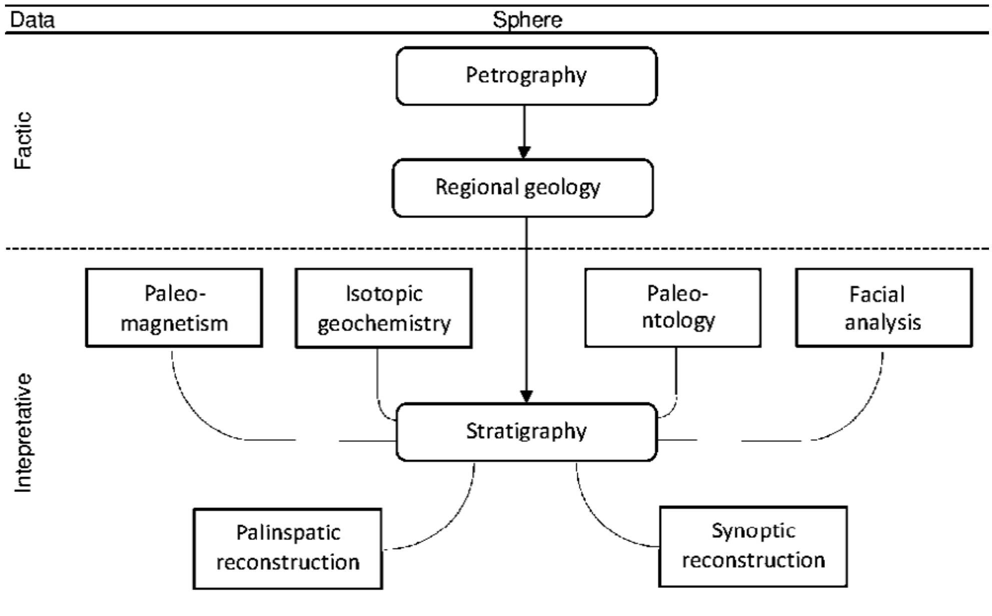


**Fig. 1:** *Processing flow toward palaeogeographical reconstruction of sedimentary environments*

were ancestral before ocean plates. Convective magma flows left less dense elements close to Earth surface, where they penetrated through forming ocean crust during gravitional differentiation to crystallise as bases for continental crust (Nicoli *et al.*, 2018). Howerer, Earth body gravitional differentiation was markedly enhanced during large impacts at 4.1–3.8 Ga. Impacts periodically tended to melt crust to more effective separation of less dense elements from more heavy, which fell to core. The power after impacts deviated convectional flows at Earth mantle to new magma springs, which warmed crust from below with same differentiation effect. Upto 65% from continental crust has been formed during 3.8–2.5 Ga after least nine large impacts of cosmic bodies with diameter 20–50 km, which caused craters with diameter around 500 km (Simpson, 2010).

Earth' geological past was divided to eons of Precambrian (4.6–0.54 Ga) and Phanerozoic (periods younger than 0.54 Ga). The Earth crust cooled coherently before 3.8 Ga, when it enabled occurrence of surface waters (Nutman *et al.*, 2007). Tectonic movements of lithospherical plates formed protogeological cycles at first, which were followed gradually by development of two praecontinents Protogea and Vaalbara. Precambrian eon was finished by surfacing of Rodinia supercontinent, which covered south hemisphere predominantly before 1.3–0.7 Ga (Pesonen *et al.*, 2021). Destruction of Rodinia contributed to cores for construction of all present continental plates through crystallic rock associations. The construction of major land crust for North and South Americas, Antarctis and Australia was based around separated Precambrian blocks. Africa was composed from three West-African, Kalaharian and Kongo blocks (Begg *et al.*, 2009). In contrast, Eurasia was formed after connection of several originally far lands from north and also from south hemisphere.

The presented study focused on comparison between geological environment changes in mobile Europe during Phanerozoic. Europe was formed through unique way from several microcontinents, which joined to Baltic block from edge of south Gondwana land (Kalvoda et al., 2002). The join caused large wrinkles, but also sediment development division between consolidated platforms and mobile zones (Ziegler, 1999). Alternating geological environments separated variable conditions from stable, where life communities long-timely develop adaptation ways to overcome loads (Cox and Moore, 2005).

## 2 Material and Methods

Changes at geological environments were assessed in the Czech Republic through vectorised palinspatic reconstructions of periods from Late Paleozoic to Quaternary. The Czech Republic (78,866 km$^2$; 48.569–51.021N; 12.102–18.863E) covers Bohemian Massif (84.6%) and penetrating West Carpathians (15.4%). Sedimentary basins during individual geological periods were combined into terrestrial, freshwater and marine environments (Kalvoda *et al.*, 1998). Transient wetland (moorland) as well as (peri)glacial ecosystems were assigned to the terrestrial environments. The rock dating was estimated relatively according to Gradstein and Ogg (2012). Sedimentary environment occurrence was vectorised for periods of transient Carboniferous-Permian (299 Ma), Upper Jurassic (152 Ma), Upper Cretaceous (93.9 Ma), Lower Eocene (56 Ma), transient Oligocene-Miocene (23 Ma), Upper Miocene (11.6 Ma) and Upper Pleistocene (18 Ka).

Lower Permian was selected as first period, when the Bohemian Massif was cratonised conclusively after variscan wrinkling to compact area from Moldanubic, Saxothuringian, Rhenohercynian and Brunovistulic lands (Chlupáč *et al.*, 2002). Following Mezozoic to transient period between Paleogene and Neogene (Oligocene-Miocene) were selected due to marine transgressions with intensive sedimentation, while Upper Miocene was characteristic by

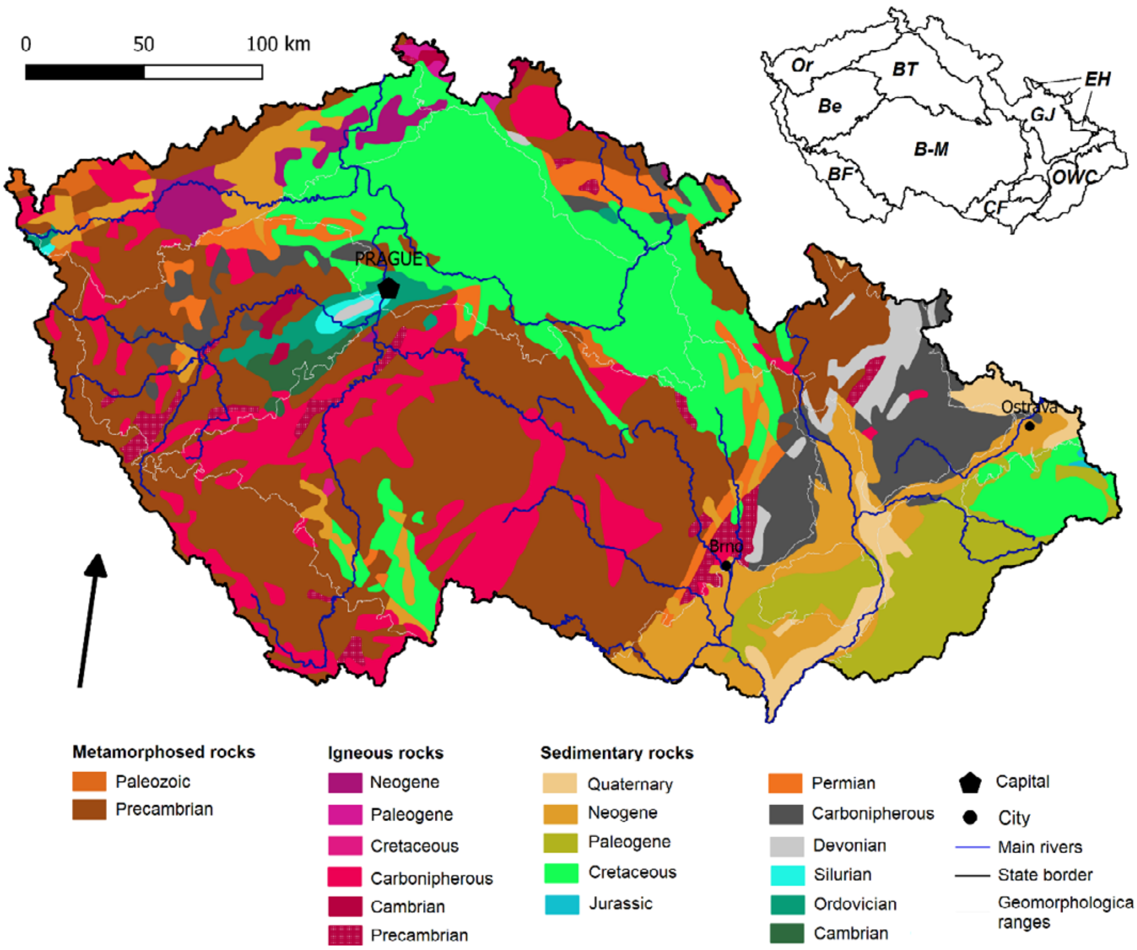


**Fig. 2:** *Figure 2: Lithostratigraphical division (data according to Pawlewicz et al. 2003) compared with geomorphological units of the Czech Republic (according to Kukal et al. 2014). Or – Ore Mts.; Be – Berounian; BT – Bohemian table; B-M – Bohemian-Moravian; BF – Bohemian Forest; GJ – Giant-Jeseniky Mts.; EH – Epi-Hercynian; CF – Carpathian Foredeep; OWC – Outer Western Carpathians.*

marine sedimentation decline and by global cooling (Zachos *et al.*, 2001). Upper Pleistocene was vectorised from bases covering Late Glacial, after which a gradual development of warming geological present has begun (Robets, 1998).

The assessment of changes in sedimentary environment extents was divided into recognition on changes of palaeogeographical sediment distribution and into recognition of differences between past extents and present distribution. Recognition of sediment distribution changes included combination of vector models, validation and overlays between timely related models. Recognition of the differences with present sedimentary occurrence consisted of overlay analysis and map algebra. The Permian model was vectorised according to Opluštil and Pešek (1998), the Jurassic model according to Adámek (2005), the Cretaceous model according to Čech (2011) and the Eocene model according to reconstructed marine environments (Rögl, 1998) and freshwater sedimentation (Kvaček *et al.*, 2014). The Lower Miocene was reconstructed according to Pálenský and Budil (2009), while the Upper Miocene was composed from models of marine sedimentation (Kováč *et al.*, 2007) and of riverine pattern development (Ložek *et al.*, 2004). The Quaternary model was created through overlay between regional division of Quaternary sedimentation (Růžička a Budil, 2009) and Quaternary rock types occurrences (Culek *et al.*, 2005). Validation was carried out through European rock stratigraphy map (Pawlewicz *et al.*, 2003) and through bedrock structure of the CR (Culek a Grulich, 2009) (Fig. 2–4). Map algebra focused on separation between stable and variable sedimentary environments.

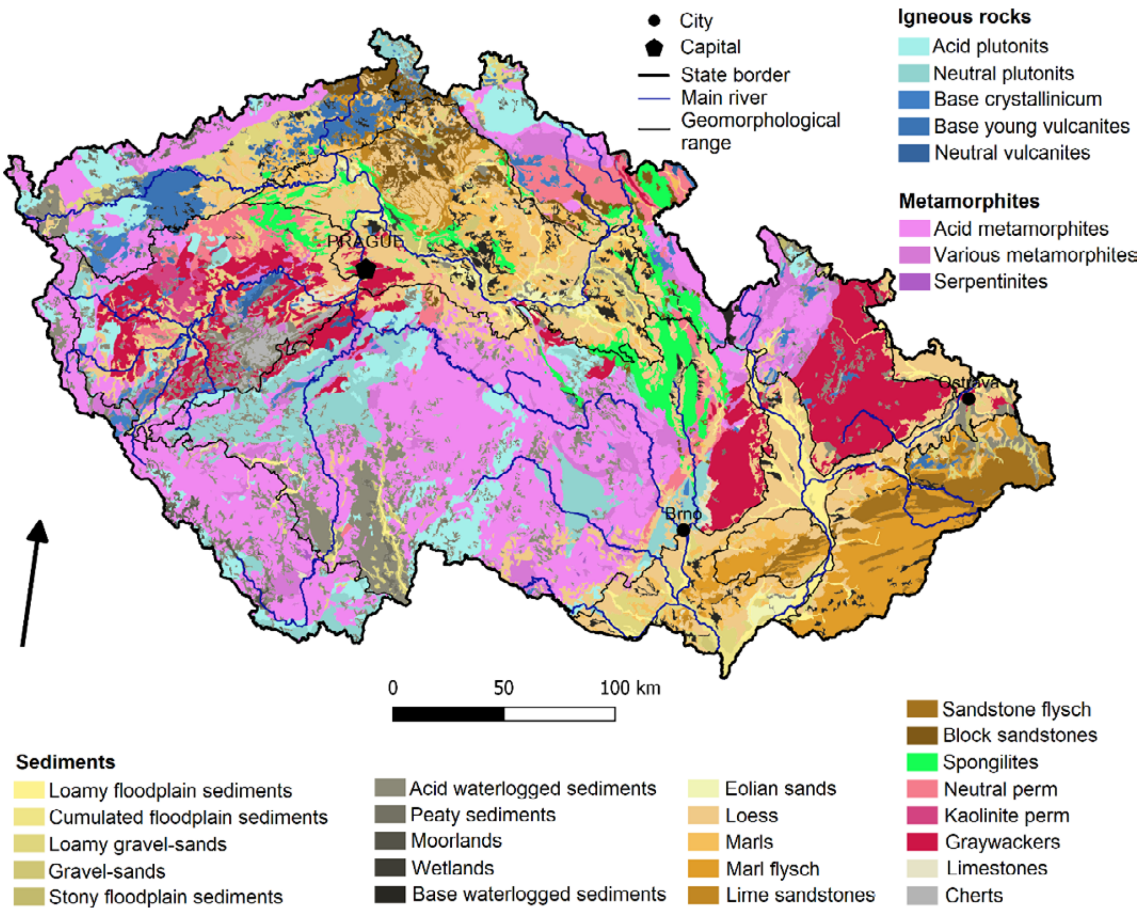


**Fig. 3:** *Figure 3: Bedrock structure of the Czech Republic (data according to Culek and Grulich 2009).*

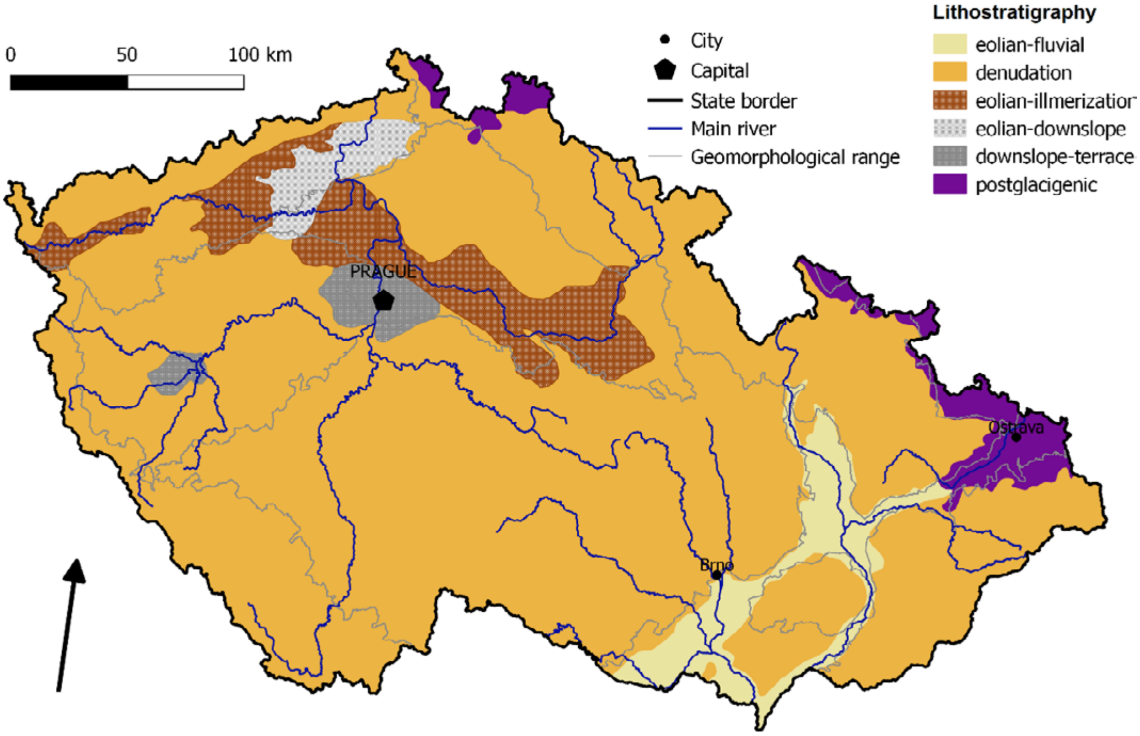


**Fig. 4:** *Lithostratigraphical division of Quaternary cover in the Czech Republic (data accoding to Růžička and Budil 2009).*

## 3 Results and discussion

Transitions among sedimentary environments divided ecosystem development between areas with permanent dry land since Late Paleozoic to present-time covering fewer than 14.8% of the CR and variable areas covering 85.2%. This divided sedimentary development suggested gross extents in main differences among adaptations of living forms to global changes. On the other hand, the accuracy of these estimates was limited by input geodata various quality and by discontinuos landscape development between selected periods with large marine transgressions or regressions.

The development of sedimentary environment extents followed plate tectonics global processes, which correspond with relation between geotectonical cycle dating and dominanting rock bodies. The CR is predominantly formed by rocks from Upper Precambrian (almost 36%), when kadomian orogenesis was in progress (Kalvoda *et al.*, 2002), from Carboniferous (19.6%), when variscan orogenesis has proceeded (Opluštil and Pešek, 1998), from Upper Cretaceous (17.2%), when the Pangea desintegration during opening of Atlantic ocean caused mediterranean orogenesis with the largest marine transgression in Phanerozoic era (Levin, 1994), and from Neogene (10.5%), when alpine wrinkling has culminated (Rögl, 1998). In contrast, the Silurian (0.29%) and Jurassic rocks (0.05%) cover CR at least, while the Triassic is almost missing completely (Pešek *et al.*, 1998).

Majority from evident geological periods was mostly represented by sediments. Metamorphic rocks dominate markedly at Precambrian bodies, while igneous rocks preponderated during Carboniferous period. The metamorphic rock occurrence was in the CR limited since Upper Precambrian to Ordivician age, while important igneous bodies rose intermittently since Upper Precambrian to Carboniferous age and continually since the end of Mezozoic era to

| Period | Metamorphosed | Igneous | Sedimentary | Total |
|---|---|---|---|---|
| Quaternary | - | - | 100.00 | 2.29 |
| Neogene | - | 18.00 | 82.00 | 10.47 |
| Paleogene | - | 4.25 | 95.75 | 6.22 |
| Cretaceous | - | 0.21 | 99.79 | 19.58 |
| Jurassic | - | - | 100.00 | 0.05 |
| Triassic | - | - | - | 0.00 |
| Permian | - | - | 100.00 | 3.13 |
| Carboniferous | - | 64.93 | 35.07 | 17.15 |
| Devonian | - | - | 100.00 | 1.65 |
| Silurian | - | - | 100.00 | 0.29 |
| Ordovician | 32.73 | - | 67.27 | 2.04 |
| Cambrian | 3.49 | 36.14 | 60.37 | 1.21 |
| Precambrian | 94.38 | 5.62 | - | 35.92 |

**Tab. 1** *Proportion of the sedimentary environments in individual geological periods of the Czech Republic (%)*

| Environ-ment | Sedimenta-tion | Permi-an | Juras-sic | Creta-ceous | Eoce-ne | Lower Mioce-ne | Upper Mioce-ne | Upper Pleis-tocene |
|---|---|---|---|---|---|---|---|---|
| terrestrial | volcanic | 0.35 | - | - | - | 0.97 | 1.94 | 0.04 |
| | denudation | 70.47 | 64.70 | 29.25 | 66.03 | 65.94 | 56.34 | 77.20 |
| | aeolian | - | - | - | - | - | - | 13.74 |
| | freeze | - | - | - | - | - | - | 2.19 |
| freshwater | cirques | - | - | - | - | - | - | 0.02 |
| | moorland | - | - | - | - | - | - | 1.03 |
| | postglacigenic | - | - | - | - | - | - | 1.76 |
| | lacustrine | 18.29 | - | - | 13.11 | 12.92 | 7.34 | 0.52 |
| | floodplain | 10.89 | - | - | 4.65 | 6.43 | 9.69 | 4.01 |
| | brackish | - | 1.57 | - | - | - | - | - |
| marine | marine | - | 33.73 | 70.75 | 16.20 | 13.74 | 24.69 | - |

**Tab. 2** *Proportion of the sedimentary environments in individual geological periods of the Czech Republic (%)*

Neogene. Sediments predominated altogether in Silurian and Devonian, Permian, Jurassic and Cretaceous and since beginning of the Cenozoic era (Tab. 1). Present surface of the CR is formed the most by acid metamophites (20.6%), greywackes (8.7%), acid waterlogged sediments (7.9%) and loess or loess-loams (13.7%).

Majority from evident geological periods was mostly represented by sediments. Metamorphic rocks dominate markedly at Precambian bodies, while igneous rocks preponderated during Carboniferous period. The metamorphic rock occurrence was in the CR limited since Upper Precambrian to Ordivician age, while important igneous bodies rose intermittently since Upper Precambrian to Carboniferous age and continually since the end of Mezozoic era to Neogene. Sediments predominated altogether in Silurian and Devonian, Permian, Jurassic and Cretaceous and since beginning of the Cenozoic era (Tab. 1). Present surface of the CR is formed the most by acid metamophites (20.6%), greywackes (8.7%), acid waterlogged sediments (7.9%) and loess or loess-loams (13.7%).

The development of sedimentary environments was in the CR influenced by marine transgressions or regressions alternately. Marine transgression spread the most in Cretaceous and in Upper Miocene. Initial as well as final periods, such as Lower Permian and Quaternary, were characteristic by complete sea regression, when denudated environments have exceeded 70% from the country area. In contrast, land proportion decreased the most to 29.3% during Cretaceous and subsequently in Upper Miocene to 56.3%. Upper Jurassic and also Paleogene were followed by terrestrial environment preservation on more than 60% of the CR area (Tab. 2). Marine regression after culmination of variascan wrinkling was followed by Mezozoic transgressions (Fig. 5). Jurassic trangression covered 33.7 of the CR by sea, while Cretaceous 79% in total. Paleogene was followed by slight sea retreat, while Upper Miocene was characteristic by last trangression (Fig. 6). Subsequent permanent sea regression from European mobile zones took continentalisation of the sedimentary conditions.

| Environment | Sedimentation | Permian | Jurassic | Cretaceous | Eocene | Lower Miocene | Upper Miocene | Upper Pleistocene |
|---|---|---|---|---|---|---|---|---|
| terrestrial | volcanic | 0.00 | - | - | - | 90.26 | 2.19 | 16.62 |
| | denudation | 0.16 | 0.00 | 0.03 | 0.00 | 9.99 | 11.70 | 16.14 |
| | aeolian | - | - | - | - | - | - | 100.00 |
| | freeze | - | - | - | - | - | - | 0.00 |
| freshwater | cirques | - | - | - | - | - | - | 0.00 |
| | moorland | - | - | - | - | - | - | 63.03 |
| | postglacigenic | - | - | - | - | - | - | 0.00 |
| | lacustrine | 0.03 | - | - | 0.00 | 6.86 | 0.09 | 100.00 |
| | floodplain | 4.26 | - | - | 0.49 | 0.78 | 81.50 | 21.16 |
| | brackish | - | 0.00 | - | - | - | - | - |
| marine | marine | - | 0.05 | 14.39 | 20.66 | 6.87 | 3.62 | - |

**Tab. 3** *Ratio of ancestral sedimentary environment extents at present-time residues in the Czech Republic (%)*

Alpine orogenesis spread terrestrial sedimentation the most from Phanerozoic geotectonical cycles due to wrinkling of pan-American mountains and of Alpian-Himalayan arc (Zachos et al., 2001). Culminating laramian phase caused sea retreat in Eocene around 54.6% from the CR area, while terrestrial environment proportion expanded about 49.9%. Terrestrial environments spread about 36.8% and remnant expansion about 13.1% contained lakes. Transition between Oligocene and Miocene was followed by penetration of volcanic environments about 1% and of floodplains about 1.8%. The Miocene transgression expanded sea over 11% and floodplains over 3%, while lakes decreased around 5.6%. Late alpine wrinkling has supported Quarternary diversification of terrestral environments in relation with climate differentation during ice ages and also with volcanic aktivity reload (Růžička and Budil, 2009). Upper Pleistocene was followed by the largest loess sedimentation spreading, frost weathering and also by (mountain) glacier activities in the CR (Samec, 2014). The aeolian sediments covered upto 14% of the CR, glaciers around 1.8% and moorlands 1%, while lakes and floodplains decreased about more than 12% in comparison with Neogene (Tab. 3).

Development of typified sedimentation extents has confirmed that the CR majority was elevated from sea or big river reach during mountain-forming processes. Totally 81.2% of the CR was after elevation dried, but at least 4% of the area was flooded by freshwaters during Quaternary period again. Remnant disseminated areas from the Praděd mountain range in Hrubý Jeseník Mts., Králický Sněžník, Rychleby Mts. to west Giant Mts., core of the Karlovarská Highland, west foothill of Plzeň Upland, Central-Bohemian Upand, Modrava, Boletice and Javořice Highland seem as permanent dry land since Lower Permian (Fig. 7). Nevertheless, the distinction between permanently denudated areas and variable sedimentation basins was loaded by inaccuracies at input data and discontinuity among periods compared.

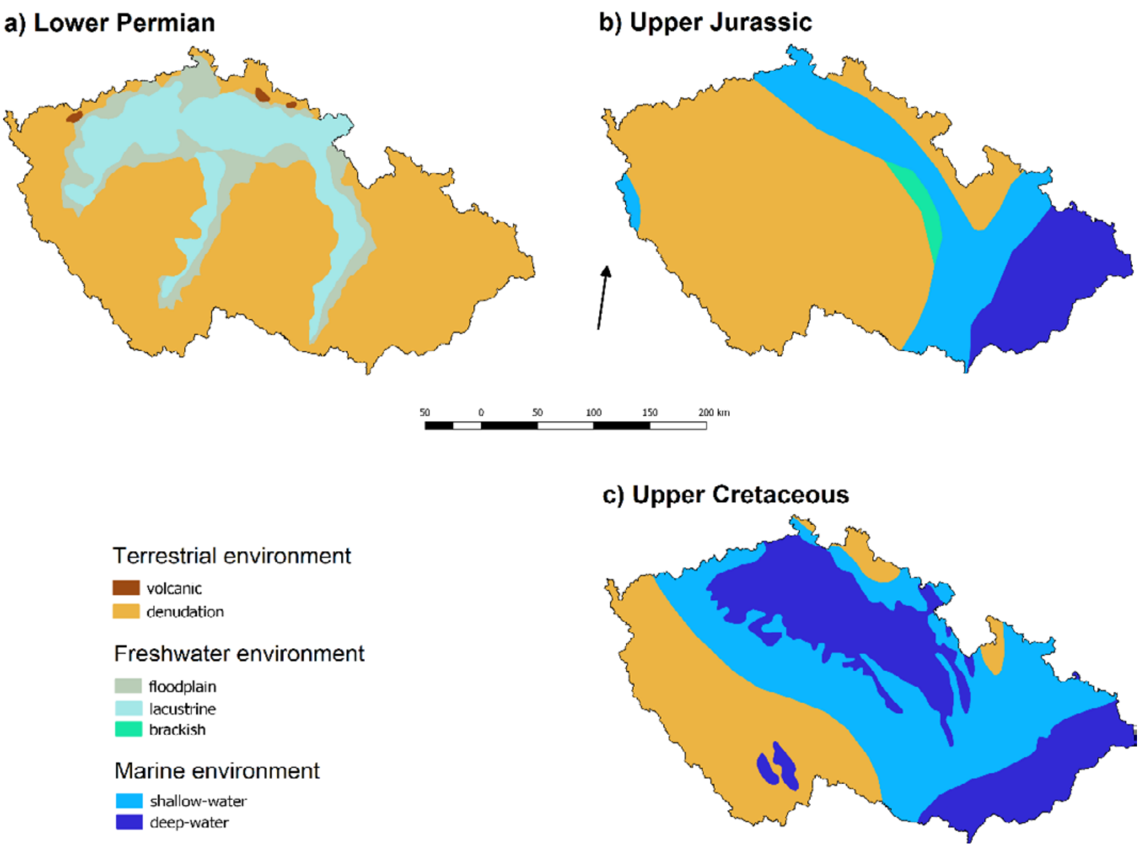


**Fig. 5:** *Simplified sedimentary environment extents from Upper Paleozoic to Mezozoic in the Czech Republic.*

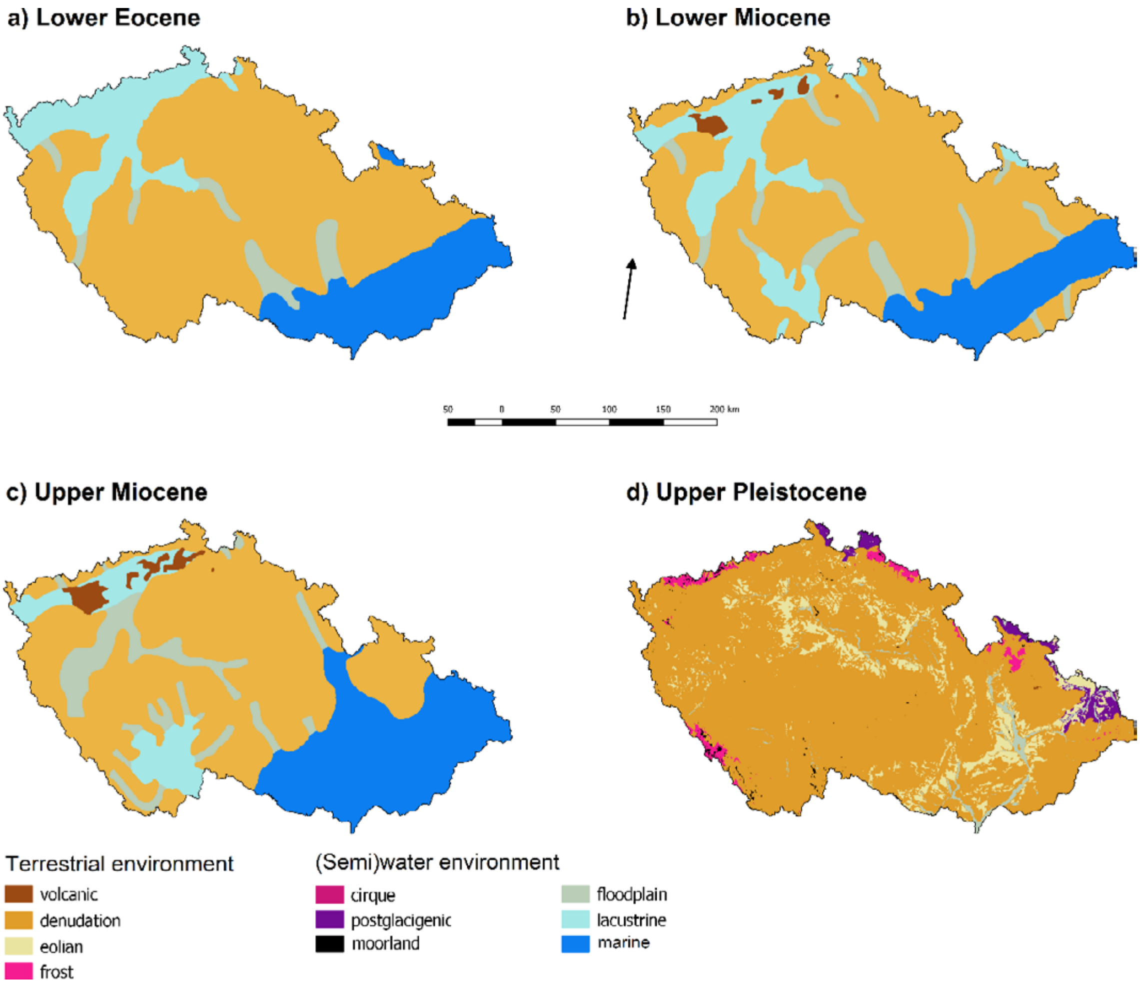


**Fig. 6:** *Simplified sedimentary environment extents during Cenozoic era in the Czech Republic*

The accuracy in input geodata depended both on well-obtained rock occurrence, and on various definitions about sedimentary environments. Variously detail maps and scatterly occured rocks from observed periods have caused uncertainies at interpolated transitions among particular sedimentary types (Yegorova and Starostenko, 2002). The most significant differences appeared among maps showing rock distribution between Upper Paleozoic and Mezozoic and between Neogene and Quaternary. While Lower Carboniferous was mapped during detail survey, the Upper Carboniferous to Mezozoic era were mapped through surface outcrops, irregular boreholes and geophysical measurements. Although Lower Carboniferous was mapped in detail, its rocks were sampled by small borehole number, so primary rock thickness forming indigenous relief cannot be derived credibly. Despite lower survey accuracy, the Upper-Carboniferous deposits were mapped mostly synoptically except Ostrava and Upper-Silesian basins (Pešek *et al.*, 1998). The least precise was map of Upper Jurassic due to small sediment proportion concentrated into bar zone in the Outer Western Carpathians, which conditioned layer scale 1:10,000,000 (Chlupáč *et al.*, 2002).

In contrast, Quaternary sediments were mapped in most detail, although its polygons were connected through different way than older sedimentary types. Different way for the Quaternary model composition was based on connections among variously mapped bodies. While denudated or (post)glacigenic conditions were delimited at scale 1:500,000, another Quaternary sediment types were clarified at scale 1:50,000 (Culek *et al.*, 2005). The different approach toward the Quaternary sediment modelling was affected by different rock definitions. Quaternary rocks

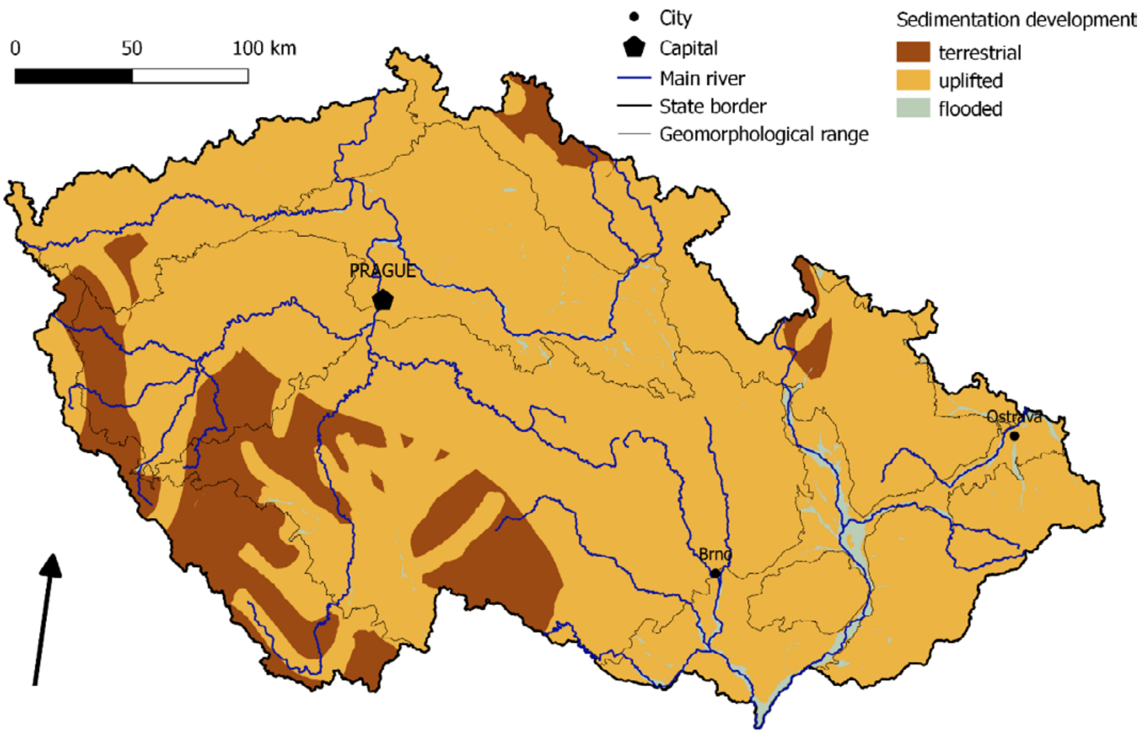


**Fig. 7:** *Distribution of stable terrestrial environments and mobile zones in the Czech Republic*

are unconsolidated and forming surface bodies under direct vegetation effects in contrast to older periods. Connections between rocks and vegetation liken Quaternary sediment definitions to soils formed due to reactions between living and lifeless matter. Simultaneously, they suggest that similar relationships between environment and vegetation affected sediment forming also in geological past (Cox and Moore, 2005). From this point of view, consolidated pre-Quaternary sediments demonstrate residual soils predominantly, where intensive reactions with life communities had passed.

When we could compare Quaternary sediments with previous periods, then extent of denudation conditions should be redefined. The application of denudation characteristics has used mapping of hillwashes presented allochthonously on older bedrock with different composition. If denudated cover includes also parautothonous rock residues on compact subsoil with same composition, the ratio between present and Pleistocene occurrence of slope environments could suggest preservation about 81.6% from Pleistocene hillwashes under present-time conditions.

The redefinition of relationships between sediments and soils was based on continual transition between Upper Pleistocene and geological present in Holocene. Similar redefinition in older periods was unable by discontinuity at geological time. The discontinuity caused uncertainties at accuracies of variability estimates on particular sedimentary environment extents. On the other hand, the observation on continual sedimentary environment development was limited by data amount and quality got for individual periods. Small borehole number impeded macrorelief development estimates, while data missing between Pleistocene and Holocene was displaceable by indications with different spatial resolution.

# 4 Summary

Palaeogeographical changes in sedimentary environment extents were assessed through comparison among vector models including periods with culminating marine transgressions or regressions since rise of the Bohemian Massif at Upper Paleozoic to Upper Pleistocene. Rock dominance in the Czech Republic is directly proportional to estimated age of its formation. The CR is predominantly formed by Precambrian, Carboniferous, Cretaceous and Neogene rocks. The Precambrian rocks are mostly metamorphosed, while Carboniferous rocks are predominantly igneous. The other geological periods were predominantly formed by sediments.

Dry land between Upper Paleozoic and geological present covered permanently upto 15% from the CR area. The land area during marine regressions exceeded 70% of Czechia. Maximum marine transgression forsook less than 30% of dry land. Quaternary period was contrarily characterised by diversification in terrestrial environments due to climatic changes and volcanic reactivation. The Pleistocene denudation environments remained in Holocene as preserved on 16.14% of slopes with allothonous hillwashes and on 65.5% of slopes with parachthonous hillwashes.

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# Current and Potential Phytopathological Problems of Silver Fir

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**Abstract**

*In recent years, forest species with a small percentage of distribution are used more often than ever. Climate change and some serious biotic agents (especially bark beetles) are main reason why we can observe this phenomenon. The silver fir (Abies alba Mill.) is among the most valuable conifers in Europe for ecological and economic reasons. It has the largest distribution area of all the European species of fir. A lot of careful consideration and strategic adaptation within management practices of fir forests is necessary for succesfull establishment. It's quite common that fir stands are affected by the competitive pressure of beech. This may be due to climate change, as well as biotic factors such as plant diseases. Most important diseases are wood decay fungi like Armillaria spp. and Heterebasidion spp., needle cast Herpotrichia needle browning or Lirula nervisequia and needle rust especially Pucciniastrum epilobii. For some pathogens like Herpotrichia needle browning seems it's typical to be triggered by a complex disease resulting from synergistic interaction of several fungal pathogens. Climate change is intricately linked to the heightened prevalence of forest pathogens with significant damage potential in Europe.*

**Keywords:** *fir, forest pathogens, needle cast, forest protection, drought*

## 1 Introduction

In recent years, tree species with a smaller percentage of distribution in forest stands have increasingly come to the foreground in forestry. One of the most commonly used species, especially in the so-called Hercynian mix, is the silver fir (*Abies alba*). However, cultivation can be impacted by several serious issues (Zúbrik *et al.*, 2017; Jarzyna, 2021). Drought-weakened stands are particularly susceptible to infestation by *Armillaria* spp. or mistletoe, while denser stands are more susceptible to infestation by agents of diseases of the needles like needle cast or rust. The most important pathogens affecting fir trees are listed below.

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## 2 Fungal Pathogens (Biology, Symptoms, Protection)

It is possible to encounter a number of pathogens limiting the cultivation of fir tree in Europe and especially in the Czech Republic. The most important category are wood-decay fungi. The most important representatives are *Armillaria* spp. and *Heterobasidion* spp., which pose a risk especially to former agricultural land (Jankovský, 2002; Soukup, 2005; Bledý *et al.*, 2024). *Stereum sanguinolentum* is often found as a wound parasite in areas of high wildlife pressure or after unsustainable logging. Other representatives are the *Phellinus hartigii* or the banded *Fomitopsis pinicola*. Canker is caused by fungi of the genus *Cytospora*, especially *C. pinastri* (syn. *C. pini, C. abietis*, anamorph *Valsa abietis*). The most common fungi on fir are the so-called Cytospora canker. Needle cast category are most often represented by *Herpotrichia* needle browning and *Lirula nervisequa* (syn. *Hypodermella nervisequa*), as well as *Lophodermium piceae* and *Rhizosphaera* spp. The most important rusts are fir broom rust (*Melampsorella caryophyllacearum*) and fir fireweed rust (*Pucciniastrum epilobii*), which require two hosts for a successful life cycle. For nurseries and forest restoration the greatest risk is posed by the agents of seedling drop and root rots, especially *Phytophthora* root rot (*Phytophthora cactorum*) and fungi of the genera *Pythium, Fusarium, Cylindrocarpon, Verticilium*. Other causal agents of seedling and seedling diseases are *Allantophomopsis lycopodina*, *Leptosphaeria* spp., *Phialocephala fortinii*, *Pseudaegerita* spp., *Scirrhia aspidiorum*, *Sydowia polyspora*, *Peyronellaea* spp., *Phomopsis* spp., *Varicosporium elodeae*, *Gyoerffyella rotula*. Last but not least parasite of silver fir in recent years is white mistletoe (*Viscum album*) which has been spreading throught Europe (Noetzli *et al.*, 2003).

## 3 Biology, Symptoms And Protection

*Armillaria* spp. are the most important pathogen of all coniferous trees. It is widespread and phytopathologically most important species of silver fir. Most known representatives of the genus is *A. ostoyae*, most commonly on spruce, but also on fir, and the *A. cepistipes* with the *A. gallica* infecting conifers rarely. *A. borealis* can occur on both conifers and deciduous trees but does not cause significant damage. They produce cap-shaped fruiting bodies with scales that emerge in autumn. The biggest damage is caused by the *Armillaria* in non-native stands on nutrient-rich habitats and newly afforested agricultural land (Jankovský, 2002; 2003). Symptoms of infestation include the focal nature of the infestation, resin eruption in infested individuals, white wood rot occurring most often in the roots and lower part of the trunk, bottle-shaped thickened bases of trunks, presence of fruiting bodies in the vicinity of infested trees, white blanched syrrocium under the bark and brown to black rope-like rhizomorphs on and around the roots (Soukup, 2005). Mature trees can live with developing blight for up to decades, whereas seedlings often die within the first year of infestation. The importance of *Armillaria* increases with high temperatures and low rainfall during the growing season. *Heterobasidion annosum sensu lato* includes several species, three of which are commonly found in Europe including the Czech Republic: *H. annosum sensu stricto* on conifers and deciduous trees, *H. parviporum* mainly on spruce and other conifers and more rarely on deciduous trees, and *H. abietinum* exclusively on conifers (Niemela et Korhonen, 1998; Klavina *et al.*, 2021). First representative is the most common species in the Czech Republic and causes significant damage mainly in forest stands on former agricultural land. The main symptoms of *Heterebasidion* spp. are root rot progressing to the trunk and subsequent thinning of the tree crown (Soukup, 2011). Trees in the stand are infested in clumps and are prone to breakage and uprooting. Fruiting bodies of *Heterobasidion* grow on stumps, roots, and dead trunks and are cork to woody, splayed to cap-shaped. *Stereum sanguinolentum* mainly attacks spruce and other conifers including fir, rarely also deciduous trees (live or dead).

It causes white rot of wood. Infection occurs at sites where whitewood is injured (e.g. by the bite of wildlife or mechanization). The growth of fruiting bodies on living trees occurs several years after infection, on dead wood earlier (Soukup, 2008). The fruiting bodies are relatively hard and have a smooth to bumpy spore coat (hymenium). Spore coat of *Stereum* turns blood red when injured. *Phellinus hartigii* causes white rot, typically spreading through the stem from the point of fruiting body growth. In the advanced stages of rot, trunk breakage may occur (usually in strong winds). The fruiting bodies on the trunk are perennial, rusty brown to brown. Young fruits are cup-shaped and typically hemispherical, hoof-shaped to obovate with a cracked surface when old. The wood in the last stage of infection is ochre-yellow in colour and quite brittle, soft and fibrous (Bledý *et al.*, 2024). Unlike all the previous species, *Fomitopsis pinicola* causes brown rot (blocky decay of the wood). In the advanced stage of rot, the trunk may also break. The fruiting bodies grow on the host trunk, are perennial, hemispherical to hoof-shaped, with hard bark. The flesh of the fruiting bodies is white to yellowish, the tubes ochre to yellowish, brown in age.

Some fungi of the genus *Cytospora* cause canker. *Cytospora* fungi overwinter in necrotic bark. Spores are spread mainly by water, but also by wind, insects and human activity. Infection usually occurs during spring (Jacobi, 2013). The main symptoms of infestation are colour changes and premature needle or leaf drop, branch dieback (usually progressing from the lower branches upwards), necrosis on stems and branches (often elongated, slightly sunken and different in colour from the surrounding healthy tissue) and severe resin rot, but trees rarely die (Trush *et al.* 2021). On or near necrotic trunks and branches, the pathogen forms entire clusters of fungal filaments which develop in the cambium of the host. The tips of the filaments later penetrate the bark surface and appear as black, grey, yellow-brown or white dots. It may contain both pycnidia and perithecia. The pycnidia of *Cytospora* fungi are characterised by conspicuous orange 'pentacles'. *Cytospora pinastri* forms asexual stage fruiting bodies (pycnidia) on fir needles that resemble bumps. In the pycnidia, they form tiny hyaline horn-like spores (conidiospores) that infect the youngest, newly emerging fir needles at the time of germination. Two-year-old and older needles and the unwounded bark of the branches are resistant to infestation. If infection has occurred, the mycelium spreads up to the trunk of the tree through the mycelium, but the infection does not spread to the trunk. Under the surface of the bark of freshly dead fir branches, sexual stage fruiting bodies (perithecia) form and burrow to the surface. Already weakened trees are particularly susceptible, most often due to drought, but also e.g. waterlogging, late frosts, heatstroke, mechanisation, improper use of pesticides, other pathogens or insects (especially insects).

According to the current knowledge, the browning of fir needles or *Herpotrichia* needle browning is caused by the co-action of several fungal pathogens, mainly of needle cast character (Pusz *et al.,* 2020). The pathogens pose a risk, especially for stands with high air humidity on poor soils. Infected needles turn grey-green to straw-brown, then fall off and show white tufts of mycelium. The shoot ends of heavily infected branches die. Needles and branches die mainly at the base of the crowns. Reduction of the aesthetic value of the trees is common, but mortality is rare. *Lirula nervisequa* is the causal agent of needle cast, closely related to the *L. mascorpora* which infects spruce trees (Čermák *et al.,* 2014). Both of these cankers cause browning and subsequent needle drop. On the reverse of the needles, longitudinal black fruiting bodies (hysterothecia) containing vesicles with sexual spores (ascospores) form around the main nerve. The disease mainly affects the lower branches. Confusion with other species causing needle drop cannot be ruled out in the early stages of infection.

*Melampsorella caryophyllacearum* as a two-host rust, attacks fir trees and herbs of the family *Caryophyllaceae* like *Cerastium* spp., *Stellaria* spp., *Arenaria* spp. and *Malachium* spp. This rust infects the cambium of fir trees through the bark of young branches. Infected fir trees form cancerous nodule or bump-shaped tumors that take up to several years to develop. When the tree is infected, the quality of the wood is degraded and resistance to wood-decay fungi (especially *Phellinus hartigii*) is weakened. When the buds are infected, the buds form witch hazels, which have shortened and yellowish needles from which rust fruits (aecie) grow. The needles fall off in autumn. For its development, which is often conditioned by a 'wet' spring, the fir rust prefers stands at lower altitudes, close to water sources and in stands with more shrubs. *Pucciniastrum epilobii* attacks fir and willow herb *Epilobium* spp.. Infection of fir trees occurs in spring by basidiospores. During the summer, yellow fruiting bodies (aethecia) covered with a white tubular elongated blanks grow on the reverse of the youngest needles (Kunca *et al.,* 2020). Symptoms are typical during the period of aecia formation, outside this period confusion with other pathogens (e.g. *Rhizosphaera, Cytospora*) is possible. Infected needles curl, gradually turn yellow and brown and fall off the same year. Fir fireweed rust is an increased risk in nurseries and christmas tree plantations.

*Phytophthora* root rot damages mainly the root collar and is a major contributor to seedling dieback which occurs on almost all tree species. Pale spots appear on the hypocotyl and womb leaves during May–June, which later turn brown to black and grow into whitish like-spidery mycelium. Infestations are usually focal. Severely infested seedlings die. Annual seedlings are most at risk. Confusion is possible with other species involved in seedling drop from the genera *Pythium, Fusarium, Cylindrocarpon, Verticilium* (Pešková, 2005). These fungi are commonly found in the soil and on the surface of the seeds. Their spread occurs through the soil and growing medium. They can cause death of germinating seeds, rotting and smothering of roots and corms. The typical symptom is softening of the root collar, bending and falling to the ground. If the seedling becomes woody, the disease is manifested by root rot, where the seedlings remain standing after death.

White mistletoe is an evergreen branching semi-parasitic plant growing on the trunks and branches of trees, from which it draws water, inorganic and organic substances. Mistletoe usually flowers during February–April for 3–4 weeks. Pollination of the flowers is by insects, more rarely by wind (Baltazár, 2016; Cristini, 2018). The fruit is a sessile, white, false berry, ripening in November–January. The seeds with sticky pericarp are spread by birds (mainly *Turdidae*) on the surface of their bodies and through the digestive tract. The seeds begin to germinate at temperatures of 8–10 °C, and light is essential for germination. Vegetative spread of mistletoe rarely occurs. In the Czech Republic, fir trees are attacked by a subspecies of silver fir mistletoe (*Viscum album* subsp. *abietis*) with broad green leaves. Symptoms of mistletoe infestation include swollen trunks and branches, dieback of parts of the branches or the top above the infestation site, tubular corridors in the wood caused by root action and reduced growth. If parasitisation is very severe, mortality may occur. Mistletoe is particularly problematic in the dry season, as water drainage increases the hydric stress of the host and reduces resistance to attack by other biotic agents. In the Czech Republic, white mistletoe occurs mainly at lower and middle elevations and on older trees with a larger trunk diameter. In recent years, there has been a marked increase in the occurrence of all mistletoe subspecies in the Czech Republic, probably due to drought and high temperatures.

## 4 Prevention And Control

Typical control against wood-decay fungi include changing the species composition, removing infected material (especially trees with fresh symptoms) and practical changes in cuting. Biopreparations based on the fungi of the genus *Trichoderma* can be used against *Armillaria* spp. (Percival *et al.*, 2011), and *Phlebiopsis gigantea* (syn. *Phlebia gigantea*) against *Heterobasidon* spp. Water treatment on charred and intermittently waterlogged soils and loosening of the planting to reduce stumps (stumps are a source of infection) are also suitable against *Heterobasidion*. Prevention of infestations primarily based on avoiding injury to trees is most important control against *Stereum* spp. and *Phelinus* spp. It is necessary protect roots, root flares and the bases of tree trunks with branches in exposed areas, harvesting and approaching timber during the dormant season, and treat wounds with a protective coating. At the same time, it is necessary to remove from stands fir trees with stem cankers caused by fir broom rust, which are often infected with *Phellinus hartigii*.

The key to controlling *Cytospora* spp. is avoid stress to trees: planting site-appropriate woody plants, pruning for air circulation (in dry weather to prevent the spread of spores and as close to the trunk as possible without damaging the collar), avoiding soil compaction and damage to trees, fertilising and watering adequately if there is a lack of nutrients in the soil (watering mature trees especially in summer and late autumn before the soil freezes). Control of planting material is also important. Larger wounds should be treated with an appropriate fungicide. Infested and dead parts of trees (including bark) should be removed and burned. It is not recommended to apply any coatings to wounds after removal of infected parts (only treat with fungicide) and allow the tissue to dry. Adherence to protective and defensive conrol against other pathogens will reduce the risk of combined tree stress. No effective chemical or biological defenses currently exist.

Defence against needle cast consists of thinning stands (reducing air humidity), avoiding long-term waterlogged sites and frost basins or removing heavily damaged individuals from the stand. Chemical intervention is appropriate in the case of heavier infestations in the previous season. It is carried out as a preventive control during the infection period (from the time of budburst to the end of bud growth) in nurseries and christmas tree plantations but is not necessary in forest stands.

Protection against fir broom rust consists of eliminating the second host and removing infested branches or heavily infested fir trees from the stand. To control fir fireweed rust, a second host is removed near nurseries, plantations and mature crop. In nurseries (and possibly also planting), preventive fungicides are carried out 3–4 times at intervals of 10–14 days from the beginning of May in the event of a stronger incidence of fir fireweed rust in the previous year. Spraying by fungicide must ensure perfect coverage of the treated trees, must be carried out on a dry surface and must not get wet before drying.

Prevention of seedling drop consists of deep and repeated loosening of the flower beds, ensuring sufficient air flow, avoiding waterlogging, disinfecting the substrate before sowing and pickling the seed. Fungicides are applied by watering at the first sign of infestation.

Prevention against white mistletoe involves growing ecotypes or cultivars more resistant to mistletoe infestation, high temperatures and drought, or trees on which mistletoe is virtually absent (e.g. beech, elms, oaks, larch). Due to the higher level of mistletoe infestation in older stands, a reduction in the practical cutting period may be considered. Removing mistletoe by cutting together with part of the host branch is only suitable for trees with a low degree of infestation, as pruning leads to weakening of the host and the mistletoe can regenerate (Lorenc, 2020; Lorenc et Véle, 2022). In stands, removal of infested trees is recommended, but felling will lighten the stand, creating favourable conditions for mistletoe development. Growth regulators can only be used on deciduous deciduous trees during dormancy, when they have no side effects on the host.

The current list of authorised products and other plant protection products can be found on the Plant Health Portal (ÚKZÚZ, 2014-2024), there is also a list for suitable products to forest protection (Zahradník et Zahradníková, 2024).

## 5 Summary

Silver fir has the potential to play a crucial role in the future composition of Central european forests. With ongoing climate change it is necessary to focus on abiotic and biotic factors more than ever. *Armillaria* spp. like the most important pathogen of all coniferous trees is widespread and phytopathologically most important species of silver fir. Wood-decay fungi is often accompanied by other fungal pathogens like *Heterobasidion* and needle cast or rusts. It's really important to use every part of preventive control of biotic agents and focus on IPM (integrated pest management). If we can find a right way how to cultivate silver fir at current weather condition and under phytopathological pressure, it's possible to fulfill both productive and non-productive functions in mountainous forests and water-influenced habitats at lowe altitudes. Adaptive management, which supports the establishment of mixed stands with silver fir, is essential for enhancing the stability and biodiversity of these ecosystems. The use of small-scale clear-cutting and selection-cutting methods that mimic natural processes is key to promoting structural differentiation within forest stands.

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# Removing Soil Compaction by Deep Grouting

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## Abstract

*Soil compaction causes many serious problems in agriculture and the environment. Mainly improper intensive farming, heavy machinery, and reduced organic fertilizer supplements increase soil ocompaction. It results in the compression of pores and impedes root growth, disturbing water and air transport, and yield decreases. The issue of soil quality and health cannot be solved without the determination of the soil's physical parameters and penetration resistance. The study aims at the reduction of soil compaction using three technologies of deep grouting: (1) the control site; (2) the Vogt Geo Injector; (3) the Vogt Geo Injector enriched Diatomaceous earth; (4) the tractor with air injector. The soil injection was done with high-pressure air at 8,5 bar (123psi) and penetration resistance was registered by the electronic penetrologger Eijkelkamp 06.15.SA with GPS localization. The distances from the drilling point were: 0.10 m, 0.40 m, 0.70 m and 1 m. It was supposed, that after amending soil with Diatomaceous earth, voids were filled with low decomposable material, which improves the effectivity of injections. The obtained results showed that using the Vogt Geo Injector enriched with Diatomaceous earth gave the lowest values of soil penetration resistance. In both variants, the Vogt Geo injector decompaction area was about 1 m$^2$ from the drilling point to a depth of 1 m. In both variants, the Vogt Geo injector decompaction area was about 1 m$^2$ from the drilling point. The drilling depth was 0.80 m and the maximum effect of grouting was approximately 0.40 m.*

**Keywords:** *soil compaction, high-pressure injection, penetration resistance*

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# 1 Introduction

Soils are exposed to a wide range of exogenous factors, which can have a positive or negative effect on their properties. One of the negative factors is soil compaction, which means that the density of the soil increases when it is compressed. Globally, around 68 million ha of agricultural land has been compacted (Flowers and Lal, 1998). In other words, the soil becomes denser, when the pores are compressed (Smith *et al.*,1997; Bedrna, 2002). Soil compaction is a natural process (e.g. heavy textured soils), which can be accelerated by farming systems, agrotechnical measures, cropping and tillage systems. These are critical factors for soil compaction (Javůrek and Vach, 2008). A direct correlation between soil compaction and texture was reported by Byrd and Cassel (1980). Soil compaction can be easily and rapidly measured and the penetration resistance is registered. The relationships between soil compaction levels and penetration resistance have been described in many studies (e.g. Grunwald *et al.*, 2001; Ferrero *et al.*, 2005; Dexter *et al.*, 2007; Usowicz and Lipiec, 2009; Liu *et al.*, 2022). Furthermore, the penetration resistance was the essential variable in developing water, air and heat pedotransfer functions (Usowicz *et al.*, 2006; Usowicz and Lipiec, 2009). Besides agriculture, penetration resistance is important in civil engineering for assessing the accessibility of construction sites. A high level of soil resistance to penetration can prove to be essential for the foundation of buildings. According to Hakansson *et al.* (1988) and Whalley *et al.* (1995), soil compaction affects nearly all the soil properties and functions of the soil. Therefore, the identification of factors affecting soil compaction is important for evaluating soil quality, rooting depth, trafficability, and timing of tillage operations. Compaction increases the mechanical resistance of the soil by pressing soil particles more closely together resulting in root growth being restricted. On the other hand, decreases in the number and size of large pores (macropores) disturb both air and water soil regimes. As a result, there are fewer pores with a diameter larger than roots in which the roots can grow freely, without mechanical resistance. To avoid soil compaction, it is important to employ remedial measures including drainage, supplying organic materials, improving soil structure, liming, keeping the soil covered with vegetation, and other agrotechnical measures. The most important consideration is to avoid tillage when the soil is too wet. A dry soil has greater bearing capacity for loads, while a wet soil is compressed under a similar pressure. Having a large contact area with the help of broad tyres or dual wheels results in a lower wheel load and it is also connected with higher financial costs of soil cultivation and the soil vulnerability to erosion increases as well (Batey, 2009; Keller et al., 2019; Polcar *et al.*, 2021).

The preliminary study aims at the evaluation of soil compaction and reduction of penetration resistance using three technologies of deep grouting: (1) the control site; (2) the Vogt Geo Injector; (3) the Vogt Geo Injector enriched Diatomaceous earth; (4) the tractor with air injector.

# 2 Material and methods

A field experiment with various treatments of deep grouting was carried out on a Haplic Luvisol near the village of Zbýšov, southern Moravia (Czech Republic). The soil was clayic textured (clay 58%; silt 37%; sand 5%), with low organic matter content 1.42% (w/w). The research area has rather uniform soils to genesis and textural composition, with gradual increasing of clay content is a depth – see Tab 1. The other basic properties of the study soil are given in Tab. 1. The experiment was done in May 2024 on the plot used as arable soil for crop cultivation with localisation at N: 49.14523; E:16.35890, and altitude 348 m a.s.l. Soil samples were collected from a depth of 0–0.20 m; 0.20–0.40 m; and 0.40–0.60 m with a probe. An average sample was composed of 5–10 individual punctures. Standard analytical methods were used to determine total carbon content, texture, moisture, and soil pH (Pospíšilová *et al.*, 2016).

| **Depth (m)** | **pH/KCl** | **TOC (%)** | **Clay (<2µm) (%)** | **Silt (50-2 µm) (%)** | **Sand (2000-50 µm) (%)** | **Moisture (weight %)** |
|---|---|---|---|---|---|---|
| 0–0.20 | 7.01 | 1.42 | 58 | 37 | 5 | 23.7 |
| 0.20–0.40 | 6.84 | < 1 | 66 | 29 | 5 | 20.7 |
| 0.40–0.60 | 7.01 | < 0.5 | 60 | 33 | 7 | 17.2 |

**Tab. 1** *Basic soil properties – average values*

The resistance to penetration was registered by the electronic penetrologger Eijkelkamp 06.15. SA (Royal Eijkelkamp, the Netherlands). Penetrologger parameters were as follows: the cone base area 2 $cm^2$; angle 60 deg.; and penetration speed 2 cm/sec. The following technologies of deep grouting were studied: (1) the control site; (2) the Vogt Geo Injector; (3) the Vogt Geo Injector enriched Diatomaceous earth; (4) the tractor with air injector The measurements distances from the drilling point were as follows: 0.10 m, 0.40 m, 0.70 m. The drilling depth was 0.80 m. The number of replicate measurements depends on the accuracy required and on the natural variability of the soil. Campbell and O'Sullivan (1991) recommend 10 measurements per plot. The distance between the plots is minimally 50–60 cm given possible soil deformation resulting from the insertion of the cone. In our case, 16 replications per plot were taken in the north-easterly direction (8 replications) and south-westerly direction (8 replications).

## 3 Results

Results of the soil penetration resistance (PR) in studied variants are documented in Fig. 1 and Fig. 2. The character of PR curves is very similar and can be described as linear till the depth of 0.40 m. Generally, the measured PR values varied between 1.036 and 3.149 MPa within the soil profile. The lowest PR values were after the application of the Vogt Geo Injector enriched Diatomaceous earth. In the upper horizon (0–0.20 m) the measured PR value is less than 1.50 MPa. These findings can be interpreted as the favourable conditions for uninterrupted root growth. PR values at about 2 MPa and higher were registered at 0.30–0.40 m depth. According to Sáňka *et al.* (2008), these conditions are unfavourable for root growth. Measured

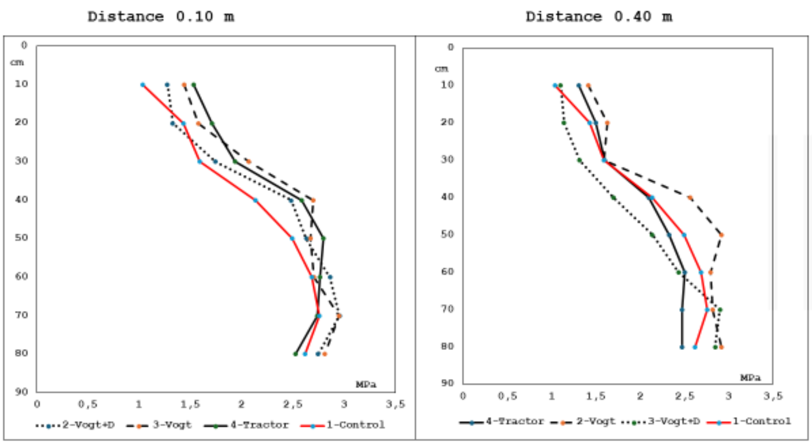


**Fig. 1:** *Penetrogram at 0.10 m and 0.40 m from a drilling point*

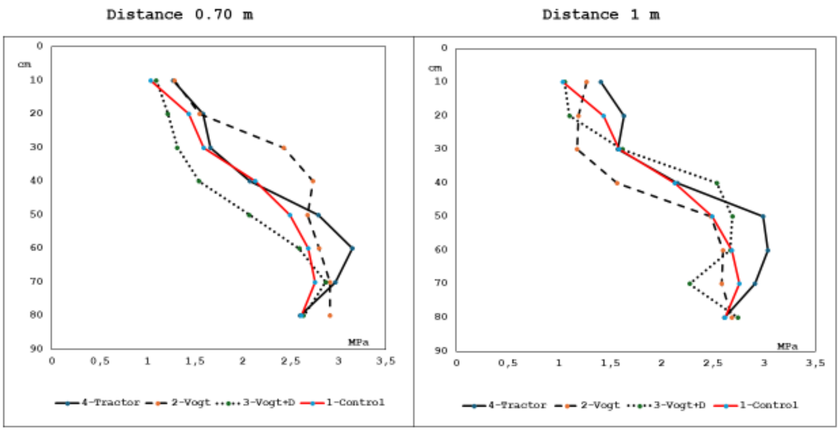


**Fig. 2:** *Penetrogram at 0.70 m and 1 m from a drilling point*

PR values were evaluated as high. Approximately 3 MPa can be regarded as the upper limit for uninterrupted root growth. This value was registered in a depth of more than 0.50 m. The obtained results are preliminary, and the research will continue. However, the decreasing tendency of PR after deep grouting is evident. Especially, the variant with Diatomaceous earth enrichment showed promising results at all studied distances from a drilling point. Further research is necessary to study the effect of aeration on PR values and the measurements before, during and after vegetation periods are recommended

## 4 Discussion

Knowledge of the spatial distribution of the penetration resistance after deep grouting can help identify zones with soil compaction (strength) problems and develop management options that minimize crop production risks and the harmful impact of traffic on the environment. As quoted by Usowicz and Lipiec (2009) and Liu *et al.* (2022) soil penetration resistance data are valuable mainly in precision agriculture to establish adequate management measures. The obtained results indicated that PR values are too high, and this level of soil resistance may cause many problems in the studied locality. A depth of about 0.20 m is insufficient for the root growth and the yield will be negatively affected. Interrupted root growth leads to reduced water and nutrient absorption, and ultimately to reduced crop production. Similarly, Locher & De Bakker (1990) stated that PR less than 1.5 MPa in the upper horizon (0–0.30 m) is desirable. Too much compaction may hinder the rootage of crops or the supply of oxygen for soil biota and roots. Too low PR level, on the other hand, renders insufficient bearing capacity to carry the weight of heavy machinery or other agricultural implements. In this study, a value of 3 MPa was registered at a depth of 0.60 m. This study represents preliminary results and further research is necessary to understand the effect of aeration on PR values.

# 5 Summary

Improper intensive farming, heavy machinery, and reduced organic fertilizer supplements increase soil compaction. It results in the compression of pores and impedes root growth, disturbing water and air transport, and yield decreases. Soil compaction causes many serious problems in agriculture and the environment. In this study, various treatments of deep grouting were performed on a Haplic Luvisol to reduce compaction, improve porosity, water, and air regime. The soil was clayic textured, with low organic matter conten 1.42% (w/w). The research area has rather uniform soils concerning genesis and textural composition. Three technologies of deep grouting were studied: (1) the control site; (2) the Vogt Geo Injector; (3) the Vogt Geo Injector enriched Diatomaceous earth; (4) the tractor with air injector. The soil injection was done with high-pressure air at 8,5 bar (123psi) and penetration resistance was registered by the electronic penetrologger Eijkelkamp 06.15.SA with GPS localization. The distances from the drilling point were: 0.10 m, 0.40 m, 0.70 m and 1 m. Measurements were done in May 2024 on the plot used as arable soil for crop cultivation with localization at N: 49.14523; E:16.35890, and altitude 348 m a.s.l. Soil samples were collected from a depth of 0–0.20 m; 0.20–0.40 m; and 0.40–0.60 m with a probe. An average sample was composed of 5–10 individual punctures. Standard analytical methods were used to determine total carbon content, texture, moisture, and soil pH. The obtained results showed that using the Vogt Geo Injector enriched with Diatomaceous earth gave the lowest values of soil penetration resistance. In both variants, the Vogt Geo injector decompaction area was about 1 $m^2$ from the drilling point. The drilling depth was 0.80 m and the maximum effect of grouting was approximately 0.40 m.

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# Silver Fir (*Abies alba* Mill.), a Raising Queen of the Woods: a Brief Overview of Fir's Ecology, and Impact on Soil and Silviculture

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**Abstract**

*Ongoing climate change is the main of many factors driving huge changes in forestry all over Europe. On one hand the rising temperatures allow higher volume increments of many tree species but on the other hand forest evapotranspiration is less and less often compensated by enough precipitation leading to stressing of trees. Huge dieback of allochthonous Norway spruce (Picea abies (L.) H. Karst.) stands in central Europe is an example of insufficient soil water availability through recent growing seasons. Autochthonous stands show both better resistance and resilience and so do mixed stands. Silver fir (Abies alba Mill.) is one of Europe's most important woody species both in ecological and economical aspect. It has gone through a significant change in its representation in Czech forests through last two centuries though, starting at around 20% and currently moving around 1,2%. Fir can effectively stabilize forest stands thanks to its deep root system and it can also lift water from deeper soil levels into topsoil making it available for itself and other trees even of different species. The roots can also improve the soil's physical conditions and connect to many mycorrhizal fungi species. Fir can grow in mixture with many other commercial tree species (i.e. Fagus sylvatica L., Picea abies (L.) H. Karst.), positively affecting their seeds' germination or volume increment. It is not yet known for sure what is the meliorative effect of fir as most science work focused on topsoil without studying mineral soil layer. As for topsoil, the fir creates significantly less litter but of very similar chemical and physical properties.*

**Keywords:** *climate change, melioration, mixed forests, Norway spruce, roots, stabilization*

## 1 Introduction

All over the world the average annual temperature is rising but the amount of precipitation is staying the same with difference in its distribution (IPCC, 2021). The climate extremes caused by climate change (Gulev *et al.,* 2021) are more and more intense and frequent (Begović *et al.,* 2020; Popa *et al.,* 2024). The rising temperatures cause higher trees' volume increments on one

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**Fig. 1:** *Silver fir monospecific stand showing die back in central France*

hand but higher evapotranspiration (Rahmati *et al.,* 2023) on the other hand, often causing insufficient soil water availability during growing seasons making them vulnerable to pathogens (Cienciala and Melichar, 2024). The forest ecosystems can be stressed by lack of available water showing different symptoms from loss of vitality, through embolism, to premature defoliation (Schuldt *et al.,* 2020; Frei *et al.,* 2022). Silver fir has gone through a period of dieback in the second half of last century caused by synergic effect of many factors from which $SO_2$ gaseous emissions seem to be the strongest, even stronger than climate (Elling *et al.* 2009; Diaci, 2011). Fir hasn't been specifically supported in our forests for around 200 years (Filipiak *et al.,* 2023) in synergy with unfavorable conditions caused by mentioned pollution, forest management and game population increment (Vrška *et al.*, 2009), leading to its significant forest representation reduction from around 23% (Málek, 1983) to actual 1.2% (MZe, 2023).

## 2 Regeneration

As a shade strongly tolerant climax species (Filipiak *et al.,* 2021; Novák and Dušek, 2021), silver fir can grow under canopy for many years, even decades without losing its vitality (Úradníček, 2010). Fir is sensitive to sudden canopy removal as it takes the trees a few years to acclimate making fir sensitive to rapid and strong direct light intensity increment (Čater and Diaci, 2017). Considering artificial regeneration, it is possible to affect the young trees' direct sunlight acclimatization via previous cultivation methods (Robakowski *et al.,* 2021). Fir's regeneration is generally problematic because of ungulates as they repeatedly damage the trees making it impossible for them to grow into canopy (Häsler and Senn, 2012; Frei *et al.,* 2024).

**Fig. 2:** *Fir natural regeneration on a stump*

On the other hand, fir shows great resistance to fungi after being mechanically damaged by game (Kohnle and Kändler, 2007). Another limiting factor of regeneration can be before mentioned insufficient water availability caused by too little precipitation as a much more important climatic factor than temperature (Subotić *et al.,* 2005). Silver fir on the other hand seems to be more drought tolerant than Norway spruce showing ability to acclimate to drier conditions (Piedallu *et al.,* 2023).

## 3 Mixed forests as an effective adaptation too

Fir is one of fundamental European tree species in terms of mixed forest stands (Caudullo *et al.,* 2016; Dobrowolska *et al.,* 2017; Hilmers *et al.,* 2019). It has been proven that spruce mixed stands increase their resistance and resilience meaning they could be a tool for supporting Norway spruce showing dieback all over Europe (Jactel *et al.,* 2017; Honkaniemi *et al.,* 2020). Norway spruce has been highly planted throughout whole Czech Republic without respecting its ecological conditions from 2$^{nd}$ half of 18$^{th}$ century creating monospecific even-aged stands leading to large area spruce stands dieback during last 10 years especially on their allochthonous sites (Bednář, 2016; Erber, 2019) while spruce shows better adaptation ability on its autochthonous sites, generally in mountainous forests (Hartl *et al.,* 2014). Most often used management connected to even-aged stands was clear-cut system which creates unsuitable conditions for many species' natural regeneration, especially of shade tolerant species, for example silver fir (Dobrowolska *et al.,* 2017). An advantage of mixed stands is that different species may occupy different niches (Uhl *et al.,* 2013) and can help each other for example by lifting water from deeper soil layers up to topsoil like silver fir does (Magh *et al.,* 2018) or by bringing more water to the soil surface during precipitation thanks to smooth bark like European beech does (*Fagus sylvatica* L.). Mixed stands even show better

**Fig. 3:** *Rich structured european beech and silver fir forest in western Croatia*

volume increment and lesser radial growth variability when managed correctly (Remeš, 2006; Schütz, 2002; Vacek *et al.,* 2021; Ray *et al.,* 2023). It has been also shown that both silver fir and Norway spruce represent better seed germination under each other in mixed stands (Hofmeister *et al.,* 2008).

## 4 Silviculture and growth

Fir's radial increment has increased significantly since late 20th century with reduction in $NO_3$ and $SO_2$ emissions and increase in temperatures as most probable factors (Bošeľa *et al.,* 2014). Declining trees presenting lower foliar nutrients concentrations show stronger relations between climate and growth and lower oxygen isotopes concentrations than non-declining trees (González de Andrés *et al.,* 2022). Čavlović *et al.* (2015) found that un-even aged forest structure promotes silver fir stands regeneration after stress. Fir also shows better diameter increments in stands with lesser stand density and basal area of overtopping trees, while tree diameter seems to be most important variable for fir's radial growth (Bončina *et al.,* 2023). Thanks to its high shade tolerance fir can naturally regenerate and prosper even in small stand gaps where other species can't even survive (Muscolo *et al.,* 2017). It also prefers un-even

**Fig. 4:** *Rich structured mixed forest of silver fir and deciduous trees*

aged rich structured forests suitable for its regeneration and growth (Ficko *et al.,* 2016; Dujka and Kusbach, 2020). In terms of height fir seems to grow until around 80 years with maximum between 50 and 60 years and then it accumulates significant diameter increments (Tudoran *et al.,* 2021). In the past fir's radial growth represented significant variability caused probably by nitrogen availability in soils (Pinto *et al.,* 2007) which is not actual anymore as there's nitrogen exposition (Carvalheiro *et al.,* 2019) showing positive effect on fir's radial growth (Bis and Dobrowolska, 2012).

## 5 Forest stabilization, melioration

Silver fir grows relatively deep root system starting as a tap root and then changing to heart-shaped able to penetrate also hard soils (Fér and Pokorný, 1993; Úradníček *et al.,* 2009; Třeštík amd Podrázský, 2017). Thanks to its deepest rooting out of our native coniferous species (Novotný *et al.,* 2010), fir is affected by windthrow rarely (Třeštík and Podrázský, 2017). It is a fundamental species for stabilization of hard soils and gleysols (Šindelář *et al.,* 2005). Silver fir is also an important species for maintaining resilience and stability of many mountainous stands in Europe (Frei *et al.,* 2024) as well as a prevention of avalanches and soil erosion (Tinner *et al.,* 2013; Vitasse *et al.,* 2019).

Silver fir's stand stabilization effect is indisputable but its effect on soil is still in question. It has been referred to as meliorating species but lately it has been found that fir's litter has similar chemical composition and create similar humus conditions as Norway spruce (Podrázský *et al.,* 2022) with slightly better nutrient availability (Podrázský *et al.,* 2024).

**Fig. 5:** *Mountainous European beech and silver fir forest in Snežnik, Slovenia*

Significant difference with Norway spruce is that silver fir creates significantly less litter in mature stands (62 vs 81 t/ha) (Podrázský *et al.*, 2022). Fir could also positively affect soil by its deep and wide root system by growing through soil and improving its physical conditions (Šindelář *et al.,* 2005; Kacálek *et al.,* 2017; Dušek *et al.,* 2020). A higher polysaccharide of both plant and microbial origin has been found in fir's rhizosphere (Bartoli *et al.,* 1993).

## 6 Mycorrhizal associations

Mycelium works as a network connecting trees and fungi (Teste *et al.*, 2009) transmitting nutrients and water (Teste *et al.,* 2010). Silver fir has a big potential for ectomycorrhizal fungi biodiversity support as it connects to at least a few dozen fungi species (Mrak *et al.,* 2020). Fir shows association with more fungi species on newly occupied agricultural land than Scotch pine (*Pinus sylvestris* L.) does (Waźny, 2014). Connection between fir and fungi is relatively fast as ectomycorrhizal associations are made within one generation (Comandini *et al.,* 1998) showing differences along fir's phonologic phases (Unuk *et al.,* 2019).

## 7 Conclusions

Silver fir is a very important species of whole Europe except its northern in terms of both ecology and economy. It grows in mixtures with many deciduous and coniferous species and creates mycorrhizal associations with dozens of fungi species. Mixed forests show better resistance and resilience to climate change supporting existing secondary spruce stands. Firs also positively affect forest stands by stabilizing them and creating un-even structures which are then suitable for their regeneration and growth thanks to their high shade tolerance.

**Fig. 6:** *Silver fir natural regeneration next to a Russula sp.*

They can naturally regenerate and prosper even in small forest gaps that are unsuitable for other species' survival. A danger for fir regeneration are ungulates who commonly mechanically damage fir terminal buds and insufficient precipitations. In the past, fir has gone through a significant reduction of its forest representation because of synergy of factors most probably lead by $SO_2$ emissions.

Silver fir creates significantly less litter than Norway spruce, but their chemical conditions are similar. Silver for on the other hand positively affects the stands by its deep root system improving soil's physical conditions and allowing fir to lift water from deeper soil layers into topsoil. Because of its stabile root system, it is a fundamental species on many mountainous or heavy soil sites and can also prevent avalanches. Firs seem to be able to both occupy new sites thanks to mycorrhizal associations and grow as a climax species thanks to their shade tolerance. They show a big potential for adaptations against climate change in terms of growing mixed species that often show both higher volume increment and vitality.

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# Abstracts

# Latent Obstacles of Microbially-Explicit Soil Biogeochemical Models

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## Abstract

*In the last decade, the advance of microbially-explicit soil biogeochemical models (MEM) offered an alternative to classical multicomponent soil organic carbon quality models, which are based on first-order decay kinetic. Because soil microbial biomass and extracellular enzymes are explicitly represented in these models, the fluxes between the pools are nonlinear and bi-directional. This fact has been shown to cause problems with identifiability of model parameters. The potential inaccuracy of parameterisation brings long-term predictions of MEM, which are often quantitatively different from predictions of classical models (e.g., $CO_2$ fertilisation effect), into question. The only solution to identifiability problem is to perform model calibration against several different data products. However, our research suggests that this is not always vital due to uncertainties associated with available data. All data essential to MEM calibration, such as soil microbial biomass, its chemical composition, and extracellular enzyme activities, are obtained indirectly from measured proxy-parameters. The relationship between the proxy-parameters and the data assimilable by the MEM is not always straightforward. To calibrate MEM against the available data, a greater level of detail regarding microbial physiology and enzyme activity must be explicitly included. Even though such a procedure unavoidably increases the complexity of MEM on the one hand, it could reduce the number of parameters that requires calibration on the other hand. As we show on example of fermentation products dynamic in soil, sufficient level of detail allows to apply fixed physiological parameters derived for pure cultures without losing model performance, because these parameters are hard-wired in central metabolism and thus, almost invariable among different microbial species.*

**Keywords:** *microbially-explicit soil biogeochemical models, soil microbial biomass, enzyme activities, fermentation products, ecological stoichiometry*

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# Soil Respiration Response to the Harvest of the Norway Spruce Forest

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## Abstract

*Clear-cutting is still the most common method of wood logging in the Czech Republic. Moreover, recent dry periods and bark beetle attacks have increased the number of areas with removed forest stands. Such areas shift from being carbon sinks to being carbon sources. In our study, we focused on the effect of clear-cutting on $CO_2$ emissions from soil in a mid-altitude Norway spruce stand. The stand is a part of the experimental station Rájec-Němčice in Drahanská vrhovina. We measured soil $CO_2$ efflux several times per year for two years before and two years after the harvest of the old stand. Additionally, soil temperature, as one of the main factors driving soil processes, was continuously monitored during this period. Soil $CO_2$ efflux and soil temperature were also measured in a neighboring undisturbed mature Norway spruce forest as a reference. The harvested stand is a part of the ILTER and the Ecosystem station belonging to the CzeCOS infrastructure and is also equipped with meteorological sensors and an eddy covariance system measuring the $CO_2$ budget of the ecosystem.*

*Soil $CO_2$ efflux in the old forest before harvest reached a maximum of around 4.5 µmol $m^{-2}s^{-1}$ and was consistently lower than in the reference stand. Soil temperatures were comparable between the two stands. After the old spruce forest was harvested, soil $CO_2$ efflux substantially increased and exceeded that in the reference stand, especially during the first half of the growing season. The increase in soil $CO_2$ efflux can be attributed mainly to the increase in soil temperature. Daily mean temperatures in the harvested area were up to 4 °C higher than in the reference stand, with the differences being greater during the first half of the growing season. The phenology of the herbal cover and bushes can contribute to these seasonal differences. According to the eddy covariance measurements, the ecosystem respiration increased after the harvest and the ecosystem changed from the carbon sink to the carbon source.*

**Keywords:** *Picea abies, soil $CO_2$ efflux, soil temperature, clear-cut*

## Acknowledgement

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# Effect of Different Agricultural Management on Soil Properties

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## Abstract

*The aim of this contribution is to present the results of soil properties obtained during the project SoilX. The SoilX Project as a part of EJP SOIL addresses 3 main research questions: 1. How exactly did soil management alter soil hydraulic properties in long-term field experiments across Europe? 2. To what extent can soil structural improvements enhance the resilience of cropping systems to future precipitation extremes? 3. Which socio-economic factors enable soil management improvements? Contrasting soil management treatments in 12 long-term agricultural field experiments (LTE) To fulfil the objectives of the project from the Czech side, the field measurements and sampling were carried out in the spring of 2023 after sowing at two locations, Čáslav (Luvisol) and Lukavec (Cambisol). Two variants were investigated at both sites: control (no fertilizers and other enrichments) (MIN), and manure and N2PK fertilized soil (FYM). In the field, a penetration resistance, soil $CO_2$ efflux, field soil water content (SWC), earthworms' abundance, and unsaturated hydraulic conductivity were measured. Grab soil samples were taken to evaluate basic soil properties (soil pH, soil organic carbon content (SOC), texture) and stability of aggregates (WSA index). Undisturbed samples were taken to measure the soil water retention curves (SWRC) and total porosity (P). Data obtained within this project and data gained before during LTE will be used as inputs into selected biophysical models to estimate the benefits of soil structural improvements for mitigating the impacts of increasing precipitation.*

**Keywords:** *long-term experiments, soil management, soil structure, fertilisation, SoilX*

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# Soil Heterogeneity in the Forest-Tundra Ecotone of the Putorana Plateau, Siberia

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## Abstract

*Soil heterogeneity along elevational gradients was studied in a less accessible and explored forest-tundra ecotone in the NW part of Central Siberia. Data on soil physical and chemical properties were collected along three horizontal transects at an elevation of 100–420 m asl at two sites with different slope angles. At each transect, five soil pits were excavated to a 0.3–0.4 m depth. Soil samples were collected at the depths of 0–0.1 m, 0.1–0.2 m, and 0.2–0.3 m. The results showed a pronounced effect of slope angle on the pattern of soil properties along the elevational gradient. At a gentle slope site, soils had 2.5 times greater thickness of the surface organic layer, higher pH, Na+ content, and lower C, N, Ald, and Fed concentrations, indicating slower pedogenic processes on this site. On the other hand, at the site with a steeper slope, soil properties were better differentiated between transects located along the elevation gradient, especially at the depths of 0.1–0.2 and 0.2–0.3 m. However, a clear positive or negative trend with the elevation was observed only for some soil properties, e.g., thickness of the surface organic layer, C, N, or Ald concentrations on the Lama site.*

*Our study, performed in the forest-tundra ecotone of the Putorana Plateau, did not confirm a general trend of the changes in soil properties along the altitudinal gradient that occurs at lower latitudes for most of the soil properties measured. The results indicate that slope angle and accumulation of surface organic layer play an important role in the differentiation of soil properties and soil development. In addition, the frequent thermal inversion situations in the lake valleys, reported in the literature, may counteract some of the expected trends. In general, soils on the steeper slope with a thinner surface organic layer exhibited a higher degree of weathering than those on the gentle slope, and soil properties were better differentiated along the elevational gradient there, especially at depths below 0.1 m.*

**Keywords:** *surface organic layer, soil properties, forest-tundra ecotone, altitude, basalts*

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# The Effect of Differently Structured Forest Stands on Soil Environment

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## Abstract

*As the climate continues to change, it becomes necessary to ask how forestry cultivation methods should adapt. This project investigates what impact these cultivation practices have on the forest soil environment and on individual tree species, focussing on even-aged and uneven-aged (height-differentiated) mixed stands of the main economic tree species planted as monocultures (oak, pine, spruce, beech) from lower (Hradec Králové, Polánky), middle (University Forest Enterpise Masaryk Forest in Křtiny) and higher (Beskydy, Šumava) elevations. To date, results have been obtained for humus horizons at 0–50 cm at six study sites, with analysis of further soil samples still ongoing. Preliminary results indicate significant differences in the amount of microbial carbon in the humus of oak, pine, spruce and beech monocultures and between mixed and differentiated stands, but no significant difference between mixed and differentiated stands. Differences were less clear for ammonia nitrogen (NH4-N), with significant differences between pine monoculture and mixed even-aged stands. Results for POXC (active carbon) were similar, with a significant difference between spruce monoculture, oak monoculture and mixed stands.*

**Keywords:** *microbial carbon, mixed forest, mineral nitrogen, permaganate oxidable carbon, humus horizon*

## Acknowledgement

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# Soil Water Storage Determined by the Resistivity Tomography Under Different Forest Management

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## Abstract

*In the paper, we evaluate the impact of forest management system on the dynamics of soil water reserves. Electrical resistivity tomography (ERT) provides anon-destructive method of detecting soil water and another soil properties. The measurements were carried out in the core zone of the Dobroč primaeval forest (plots Dobroč 1, Dobroč 2, Dobroč 3), in the buffer zone of the Dobroč primaeval forest with a predominance of European beech (Beech forest) and in the spruce monoculture near the buffer zone (Spruce forest). Measurements were performed using the time-lapse ERT method using a Wenner-Schlumberger electrode arrangement. We performed ERT measurements at monthly intervals during the growing season, the measured soil resistivity was calibrated to the volumetric soil moisture. To determining the volumetric water content, we used the time domain reflectometry (TDR) method. The location of the TDR probes was above the investigated plots, at a depth of 10 to 80 cm with a step of 10 cm. The measurement was carried out continuously at hourly intervals during the growing season. By evaluating the relationship between TDR and ERT using calibration equations, we determined the amount of soil water within the measured plots. The results showed that the spruce monoculture is the most threatened due to climate change and uneven rainfall. The decrease in the soil water supply was the fastest in the managed spruce forest. At the same time, it also reached the lowest soil water reserves. The results showed that the lowest soil water storage was on the spruce stand plot (53.31±9.55 $dm^3.m^{-3}$), on the contrary, the highest was on the Dobroč 2 plot (133.14±5.37 $dm^3.m^{-3}$). The forest ecosystem of the Dobroč primaeval forest appears to be the most resistant with respect to the soil water supply. Here, the trend of soil water supply in the growing season was more balanced than in areas outside the primeval forest. At the same time, the average soil water reserves reached higher values on these areas.*

**Keywords:** *resistivity tomography, soil water storage, slope deposits, water movement*

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# Ectomycorrhizal Fungi and Soil Nitrogen Losses in Spruce Forests With Alleviated Nitrogen Limitation

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## Abstract

*Ectomycorrhizal fungi (EMF) are tree symbionts that participate in multiple ecosystem functions including nutrient cycling. Spruce forest soils are usually rich in organic matter, but limited by availability of nutrients, especially nitrogen (N). In such conditions, EMF community is prevailed by nitrophobic species, which form extensive mycelia and are able to mine nutrients from soil organic matter. They form a substantial part of microbial biomass important for maintaining of low N losses. However, when N limitation is relieved, EMF community becomes enriched in nitrophilic species, which lack ability to form extensive mycelia and their decomposition capabilities are often weak. This may slow down decomposition and lead to increased soil carbon and N sequestration. However, on the other hand, the reduction of the EMF biomass may decrease soil N retention.*

*We aimed to relate the shifts in the EMF community due to elevated N input to changes in ecosystem N retention at three Norway spruce forest sites with different historical atmospheric N deposition and ongoing long-term N fertilisation experiments with different setup. In all cases, elevated N input reduced EMF abundance and lead to retreat of nitrophobic species. However, we did not observe any dramatic increase of N leaching and we conclude that when the dose of N is not extreme, the ecosystem is able to keep up the N retention capacity and low N losses despite a retreat of (nitrophobic) EMF.*

Keywords*: Norway spruce forests, ectomycorrhizal fungi, soil nitrogen losses, elevated nitrogen inputs*

## Acknowledgement

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# Soil Moisture and Temperature in the Forest and Agricultural Landscape at the Amálie Location – Selected Results from Early-stage Monitoring

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## Abstract

*Soil is a key water reservoir, which is now strongly affected by climate change and human activities. Overheating of the landscape occurs more frequently. The aim of this contribution is to present selected results from unique soil moisture and temperature monitoring situated in drought-prone area of Central Bohemia, where the Amálie Smart Landscape project of the Czech University of Life Sciences is being realized (CVPK CZU, 2018). Soil moisture is here actually measured by almost 300 TMS TOMST microclimatic stations in different spatial scales and depths. Monitoring networks were established in the realized measures, namely in silvoarable agroforestry and regulated drainage systems in the agricultural part, and under different tree species in the forested part. Moreover, soil moisture is also measured along five transects passing through the entire Amálie area with the purpose of comparing agricultural and forest landscapes and local microclimate.*

*Early-stage data from the agroforestry system show the ability of the forested part to prevent landscape overheating. Tree alleys also exhibited more intensive soil moisture depletion and more effective recharge mechanisms than arable land. In regulated drainage, we observed an increase in soil moisture in the locations with low slopes and in the deeper soil layers in comparison with unregulated control. For the forested part of Amálie, results of different tree species monitoring show that during early spring, the soil under evergreen spruce is drier than for larch or beech; mechanisms are partly described by Kuželková et al. (2024). A comparison of agricultural and forest landscapes shows the ability of the forest to mitigate soil and surface temperature extremes during hot periods. Overall, the monitoring provides valuable data about the concrete effects of realized measures and helps to clarify the role of the forest. The presented findings can help with effective adaptation to climate change and the related occurrence of hydroclimatic extremes.*

**Keywords:** *soil moisture and temperature, unique monitoring network, climate change adaptation, mitigation measures, forest versus arable land*

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# How Rewilding by Large Herbivores Influences Grassland Functioning

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## Abstract

*Trophic rewilding is a restoration approach that aims to promote self-regulating complex ecosystems by restoring natural ecological processes through introduced animal species, mostly large ungulates (especially megafauna with individual weights exceeding 45 kg), while reducing human control and inputs. The main expectations are to increase the spatial heterogeneity in the structure and composition of the vegetation through selective grazing, to support the productivity of the system by stimulating rhizosphere processes and returning part of the nutrients in available forms to the soil, and to support the distribution of plant seeds. This should be accompanied by an increase in the diversity of other organisms – insects, birds, decomposers and others. Changes in ecophysiological processes in plants, together with an increase in nutrient availability, should then lead to a large accumulation of stable organic matter in the soil and an improvement in its water-holding capacity. Our ideas about the positive effects of reforestation with large grazers as a nature-based solution for landscape management are mainly based on historical and currently documented changes in ecosystem functioning after the great Pleistocene extinction and the still ongoing significant reduction of large grazers. Additional knowledge comes from hundreds of studies of the effects of grazing by cattle or other domesticated grazers on vegetation and soil properties. Most of the results of current studies point to context-dependent outcomes of plant-herbivore interactions, namely their dependence on climatic and edaphic factors, but also on the size and diversity of herbivores and their diets. In fact, there are very few data directly assessing the effects of trophic rewilding where it has been applied in the last two decades.*

*In response to a call for data-driven experimental rewilding projects focused on national contexts, we collected unique data on the effects of large herbivore rewilding on soil and vegetation properties from seven sites in the Czech Republic. These sites include the xeric steppe-woody biotopes of Milovice-Traviny (MTR) and Milovice-Pod Benátským vrchem (MBV, both grazed since 2015), the xeric to mesic steppe-shrub sites of Dobřany (DOB), Mašovice (MAS), Havraníky (HAV), the alluvial meadows of Josefovské louky (JOS), and the mesic steppe woodland of Hradec Králové (HRK, all grazed since 2018), with Exmoor ponies, European bison, and backbred Bos primigenius cattle (singly or in combination) present on areas ranging from ≈30 to ≈250 ha. Despite the relatively short duration of rewilding actions and considerable variability in the response rate of soil properties to grazing, our results indicate improved nutrient availability, as evidenced in the soil by higher nitrification rate or soluble nitrogen concentration and by systematically higher N levels in aboveground plant biomass, and accelerated ecosystem metabolism, as evidenced by higher soil microbial biomass and dissolved carbon content. Aboveground plant biomass also contained relatively more water, indicating a reduction in water loss by evapotranspiration from the system. Belowground biomass was not affected, enabling a regrow after grazing and providing a sufficient input of organic residues to the soil. In support of this, on longer grazed pastures, rewilding contributed to soil carbon sequestration associated with increased water holding* *capacity and improved soil structure. Other characteristics, such as reduced dissolved P concentration or total P content in soils and increased N/P ratio in leaves of grazed vegetation, suggest P limitation in grazed plots.*

*In summary, grazing has led to closer interactions between grazed vegetation and soil processes mediated by soil microorganisms, resulting in faster N recycling and better N supply to growing plants after grazing. At the same time, water loss from the system was reduced and its content in plants increased through several mechanisms involving lower aboveground biomass, probably a shift in plant traits and increased water holding capacity of soils enriched in soil organic matter. We suggest that the closer relationship between vegetation and soil organism activity induced by grazing of large herbivores, which reduces the risk of water and N scarcity limiting plant production, allows the system to respond more rapidly to environmental changes and gives it a better potential for regulation and adaptation to new conditions. This appears to be a major advantage in a rapidly changing climate with frequent extremes compared to systems actively managed by humans to maintain and protect their current state. A potential risk to sustainable productivity and system functioning may then be a deepening of P limitation, which can be partially mitigated by leaving herbivore carcasses in the field.*

**Keywords:** *rewilding, large herbivores, soil C sequestration, plant biomass, nutrients*

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# The Use of Computed Tomography and Image Analysis to Study the Effect of Fertilization on Soil Structure During a Long-term Experiment

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## Abstract

*The aim of this contribution is to present the results of soil properties (porosity) obtained in the Czech Republic as part of the SoilX project. The main research question of the SoilX project is: How exactly has soil management altered soil hydraulic properties in long-term field experiments across Europe? Contrasting soil management treatments in 12 long-term agricultural field experiments (LTE) across Europe are investigated. In order to fulfil the objectives of the project from the Czech side, field measurements and sampling were carried out in spring 2023 at two locations, Čáslav (Luvisol) and Lukavec (Cambisol). Two contrasting variants were studied at both sites: control (no fertiliser and other amendments) (MIN) and fertilised with manure and H+N3PK (FYM). Plastic columns with a diameter of 7 cm and a height of 12 cm were collected at a depth of 1–13 cm (Ap horizons) and 30–42 cm (Bw and Bt horizons in Lukavec and Čáslav, respectively). These samples were used for porosity measurements using computed tomography (CT) NIKON XTH 225 ST. In addition, set of three 100 cm$^{-3}$ undisturbed soils samples were taken from each horizon to measure porosity and soil hydraulic properties using standard methods.*

*The results from the Lukavec site show that the porosity determined from the plastic column samples obtained by CT is higher in the Ap horizon in the control than that in the fertilized variant, while no effect of fertilization is observed in the Bw horizon. Whereas at the Čáslav site, the effect of fertilisation is evident. The fertilised variant showed higher porosity in the Ap horizon and lower porosity in the Bt horizon compared to the control. The results obtained on the 100 cm$^{-3}$ correspond to the CT observations.*

**Keywords:** *computed tomography, porosity, soil structure, image analysis, long-term experiments*

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# Grassing of Zone I in the Moravian Karst Area

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## Abstract

*Moravian karst is the most important karst area in the Czech Republic. Administration of Moravian Karst PLA is responsible for protection of the karst area. New zonation of nature protection was established in 2019 and brought positive changes in management of agriculture land to protect not only karst phenomena but also underground water.*

*Farmers had to change 114 ha arable land to grassland in the first zone of nature protection. The Nature Conservation Agency of the Czech Republic contributed to the purchase of a regional and species-enriched grass mixture to increase biodiversity in agriculture landscape. The levels of pesticides in drip water under arable land regularly exceeded the permitted limit for groundwater. Concentrations of some individual pesticides and their metabolites exceeded the permitted limits several times. The average arable land sample in 2018 and 2019 contained 27 and for drip water 29 detectable pesticides and their metabolites. The change in management was significantly reflected in the reduction of concentrations of some pesticides and their metabolites and also gradual decreasing of nitrates concentrations (dropping under the public health limit for drinking water is estimated for more than 20 years).*

*Grassing above the caves and around the sinkholes has contributed not only to the protection of the karst underground and water from pollution, but also to differentiation in the agricultural landscape. Green islands on arable land have thus become home to many animals and various species of plants, including rare and endangered weed plants, which have been irretrievably disappearing from farmland.*

**Keywords:** *karst, grassing, pesticide, caves, sinkholes, wate, soil*

## Acknowledgement

Grassing of zone I of the Moravian Karst PLA would not be possible without the great cooperation from farmers in the Moravian Karst PLA, support from colleagues at the Moravian Karst PLA Administration, NCA CR South Moravia Regional Office and NCA CR's Headquarters, cooperation with the Moravian Karst PLA rangers, Institute of Plant Production, Public Research Institution, ALS Czech Republic Certified Laboratories Ltd., State Land Office in Blansko, Central Institute for Supervising and Testing in Agriculture Brno, State Agricultural Intervention Fund Blansko, Agrostis trávníky Ltd., and all the others who have helped us to implement this great change in the agricultural landscape within the Landscape Protection Programme.

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# Patterns of Spring Soil Moisture Regimes under the Canopy of Beech, Spruce and Larch Trees

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## Abstract

*Presented contribution follows the results of established soil moisture and temperature monitoring of Czech University of Life Sciences located at experimental site Amálie. It further broadens the insights into climate-change adaptation management of drought-prone forested areas, considering different effects of deciduous and evergreen species on landscape water management.*

*The findings revealed substantial differences in soil moisture regimes between deciduous (beech – Fagus sylvatica, larch – Larix decidua) and evergreen (spruce – Picea abies) species (Kuželková et al., 2024). These differences are most pronounced during the spring months due to the canopy interception and early transpiration of evergreen spruce. In contrast, the interception and transpiration losses of deciduous trees are significantly reduced until foliage emergence in early May. From March to May, the soil moisture under spruce repeatedly drops below the limit of easily available water, while beech and larch retain significantly higher soil moisture levels, keeping the soil water resource for the warmest months.*

*The repeating spring patterns of depleted soil moisture under the canopy of evergreen spruce, suggests the importance of respecting the species-specific adaptation to lower altitudes with limited precipitation and increased temperatures. With the actual rise in extreme meteorological events due to climate changes, the prioritizing of native habitat – adapted species over the abundant mountain – adapted species like spruce is becoming highly relevant.*

**Keywords:** *soil moisture patterns, deciduous and evergreen trees, forest hydrology, climate change adaptation*

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# Needle Optical Properties of Silver Fir (Abies alba Mill.) Related to the Stand Light Microclimate

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## Abstract

*After the massive bark beetle outbreak and large-scale emergency logging of Norway spruce monoculture stands across the Czech Republic, silver fir (Abies alba Mill.) is a candidate tree species in the process of forest transformation. Thanks to its better growth in conditions of mild drought, silver fir appears very promising. However, as a very shade tolerant species, silver fir may be prone to various abiotic stressors in more open stands. The present pilot study explores the variability in needle-level optical properties in relation to the stand light microclimate in purpose to use needle reflectance for evaluation of young stands physiological status.*

*Needle optical properties are determined by biochemical and structural needle traits, such as photosynthetic pigments, water and dry matter content. These needle traits change with tree physiological status, and they are sensitive to light availability. The study was conducted on young fir stands with gradual light microclimatic conditions, which were represented by different types of forest regeneration: a shelter-wood cut (the highest degree of shading by mature trees), a natural regeneration under sparse canopy, a gap cut and small clear cut (all three representing a moderate degree of shading) and a clear cut (the lowest degree of shading). The stands were at the age of 10–17 years and ten individuals were evaluated at each stand. The current and previous-year needles from the upper part of the canopy were samples and needle reflectance between 350 and 2500 nm was measured by the contact probe.*

*Our results showed that the needle optical properties of the needles are sensitive to different light microclimates, especially for extreme situations (shelter-wood cut and clear cut). However, the sensitivity of the indicators used was limited for clearly distinguishing among stands with a moderate degree of shading. Differences in the leaf-level reflectance are promising for remote sensing (e.g. UAV-based) evaluation of silver fir physiological status for reforestation.*

**Keywords:** *needle reflectance, tree physiological status, reforestation*

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# Phytomanagement of Petroleum-polluted Soils with Industrial Crop *Miscanthus x giganteus*

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## Abstract

*Petroleum hydrocarbons are one of the most abundant sources of environmental pollution. A series of experiments, both pot and field, were carried out in Northern Bohemia (Czech Republic) to assess the potential of industrial crop Miscanthus x giganteus to grow on petroleum contaminated soils and contribute to their remediation and test the quality of biomass in terms of its potential energetic valorization.*

*As expected, despite high survival rate of plants, higher hydrocarbons concentrations exhibited toxic effects on plant biomass and physiological parameters, however the toxicity was higher in soils from real long-term polluted sites compared to diesel-spiked soils indicating significant toxicity synergy of other pollutants, salinity or soil parameters. In soil contaminated with diesel only, miscanthus proved ability to grow in high concentrations up to 50 g/kg. Different plant characteristics (biomass yield, height, number of sprouts, physiological parameters and others) responded to hydrocarbons toxicity with different sensitivity. Actually, at lower diesel concentrations significant hormesis (temporal increase) was found for some photosynthetic indicators.*

*Degradation of diesel during first two vegetation seasons followed dominantly the first-order kinetics suggesting ongoing biodegradation. In planted soils the degradation was enhanced, however the enhancement was proportional to plant development. So, it was negligible at higher concentrations with the highest toxicity. Since no uptake of petroleum hydrocarbons from soil to above-ground plant parts was detected, it indicates that the most likely mechanisms is the support of biodegrading soil microorganisms by plants, i.e. rhizodegradation. This conclusion is also supported by increased relative abundance of some petroleum degrading bacterial genera in miscanthus rhizosphere in soil from real contaminated site. On the other hand, no increase in abundance of genes for several enzymes involved in the biodegradation of petroleum compounds (AlkB, pahGP) was detected in diesel contaminated soil after two cultivation seasons, so the phytoremediation mechanism is still unclear. However, the changes in composition of soil microbial communities, content of organic carbon and production of root exudates were confirmed in several experiments.*

*Some practical biomass parameters (such as heating value or composition of pyrolytic products) were slightly affected in diesel contaminated soil, nevertheless the applicability of biomass for energetic purposes was preserved.*

*Overall, these results indicate feasibility of M. x giganteus for phytomanagement of petroleum contaminated sites, however the task is not simple but it is very site-specific.*

**Keywords:** *phytomanagement, miscanthus, petroleum, soil pollution, biomass, soil microorganisms*

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# Evaluating the Physiological Status of European Beech Across Ecological Gradients

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## Abstract

*European beech (Fagus sylvatica L.) is a dominant and keystone species in European forests, crucial for ecosystem functioning. Climate change is altering the environmental conditions across its current distribution, causing stress and making forest health monitoring more urgent in the Czech Republic and other European regions. Early detection tools for physiological stress in beech forests are essential for effective management and conservation.*

*This study evaluates the applicability and sensitivity of selected physiological indicators of European beech under varying environmental conditions (temperature, precipitation) within its ecological valence. Four beech stands, representing a gradient of ecological conditions, were observed during the peak of one vegetation season: Stand Kocanda represented the microclimatic and ecological optimum; stand Hradecko was at the lower altitudinal margin with limited water availability; stand Deštné was at the upper altitudinal margin with low temperatures; and stand Znětínek was exposed to extreme direct sunlight. Among the candidate indicators, specific leaf area and the chlorophyll fluorescence parameter Fv/Fm (derived from the OJIP test) were the most sensitive to the ecological gradient. These indicators effectively reflected the physiological status of European beech across different environmental conditions. Other tested indicators showed ambiguous responses or lacked sensitivity to the ecological gradient.*

*The evaluated indicators can reflect multiple plant stresses caused by various environmental factors. Future research should focus on identifying unambiguous, effectively measurable indicators to improve early detection and monitoring of forest health.*

**Keywords:** *stress indicators, chlorophyll fluorescence, leaf reflectance, specific leaf area*

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# The Use of Scaling Factors for the Interpretation of Spatial Variability of Soil Hydraulic Properties of Colluvic Soils

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## Abstract

*The soil structure and, consequently, soil hydraulic properties of tilled soil vary in space and time. The spatial variability of soil properties within the sloping area may be enhanced by water erosion processes (i.e., soil material loss at steep parts and its accumulation at concave and bottom parts), which may even lead to soil type diversification. In addition, colluvial soils and deposits, occupying concave slope elements, are formed by many layers of different ages and characteristics. When interpreting the water regime using the HYDRUS programs, it is then necessary to enter a number of materials with different properties. However, the variability of the soil properties can also be entered using the reference soil hydraulic properties and scaling factor. Therefore, this study aimed to test this alternative method to characterize the variability of soil hydraulic properties and the soil-water regime. The study was performed on the morphologically diverse study site in a loess region of Southern Moravia, Czech Republic. The original soil type Haplic Chernozem, resulting from erosion, was changed to regosol (steep parts) and colluvial soils (base slope and the tributary valley). At this location, the spatial and temporal variability of topsoil hydraulic properties within a representative transect was previously evaluated using the scaling factor and HYDRUS-2D (Nikodem et al., 2021). In 2021, new research focused mainly on colluvium took place on the site (Zádorová et al., 2023). Two colluvial profiles in two representative terrain positions (toe-slope and side valley) were excavated down to the expected in-situ material not affected by the colluvial process. Two reference soil profiles representing the main parts of the catena were examined – a fully developed soil in the upper flat part and a truncated profile in the highly exposed steep part. Soil hydraulic properties, θ(h) and K(h), were measured on 100-cm3 undisturbed soil samples using the multistep outflow experiment and numerical inversion with HYDRUS-1D. Next, the reference soil hydraulic properties, θ*(h*) and K*(h*), and scaling factors (αh, αK, and αθ) were evaluated to describe spatial and temporal variability of the soil hydraulic properties. Finally, the HYDRUS-1D program was used to simulate water flow within the soil profiles, in which spatial variability of soil properties was interpreted in the usual way (i.e., specified by different soil hydraulic properties) or using the hydraulic properties and scaling factors that were either defined for each layer or linearly interpolated.*

**Keywords:** *soil diversification, soil hydraulic properties, mathematical modeling, HYDRUS program*

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# Comprehensive Evaluation of the Dyje River Basin (From a Landscape Architect's Perspective)

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**Abstract**

*Climate change is leading to more frequent hydrological extremes that impact all aspects of human life. Periods of drought are alternating with flood events, and this issue resonates not only within professional circles but also among the general public. Addressing these extremes requires a comprehensive and integrated approach that combines technical, environmental, social, and economic measures.*

*One of the key points for mitigating the impacts of climate change is adaptation measures. However, designing these measures encounters fundamental issues such as the location of measures, resolving property rights, scaling to specific values, and financing implementation. The reason for these challenges is the conflicts between technical and ecological (nature-based) measures in the landscape, arising from different approaches to the issue. Technical measures can often negatively affect the environment, and extensive interventions and projects can lead to the degradation of natural ecosystems and loss of biodiversity. Technical solutions are often aimed at quick and efficient fixes, which may not always consider long-term sustainability, while ecological measures require time and a systematic approach. Additionally, technical measures may be less flexible and adaptable, frequently leading only to increased levels of safety protection. Due to their complexity, nature-based measures are often suppressed and can be financially demanding in the long term. Balancing these technical and ecological measures in the landscape requires a comprehensive approach, dialogue between experts and stakeholders, and an assessment of the overall impacts on the environment and society.*

*In evaluating adaptation measures, a multicriteria analysis was used, focusing both on the area of interest within the Dyje River basin (in the Czech Republic) and on assessing some indicators at the national level to calibrate individual values. It was found that, according to vectorized data from the Agricultural Water Management Administration, 3,000 km of watercourses have been modified in the area of interest, representing nearly a quarter of the total length of all watercourses. According to this data, almost 12% of the total area of the Dyje River basin has been drained. Looking at the timeline of land drainage, we can see that the oldest recorded drainage dates back to 1900, and the most drainage constructions were realized around 1930 and 1970. Current land use is also very intensive; nearly 53% of the total area is used as standard arable land, which is most susceptible to erosion, both water and wind erosion.*

*The aim of the paper is to summarize how significantly the landscape in the Czech Republic has been changed and to highlight problematic areas where adaptation measures should be effectively directed, based on the evaluation of key indicators. These indicators include land drainage, modification of watercourses, historical changes in the landscape, and current land use.*

**Keywords:** *adaptation measures, erosion, historical changes in land use, river modifications*

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To all the remarkable individuals who have impacted my life.

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# Particle Size Analysis Measured Using the Improved Integral Suspension Pressure Method Compared with the Standard Hydrometer Method

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**Abstract**

*Soil texture is a fundamental soil characteristic. Due to the influence of soil particle distribution on almost all physical and chemical soil properties, it can be used to estimate other important soil characteristics such as hydraulic conductivity, water retention characteristics, parameters of retention curves and many others. Particle size analyses are performed using standard methods such as the pipette or hydrometer method. Currently, standard methods are being replaced by innovative automated methods, which may include automatic measurement of pressure changes in the suspension or laser analysis. The main objective of this study was to compare the standard hydrometer method with the automated improved integral suspension pressure method (ISP+) (Durner et Iden, 2021), which is based on the same physical principle (Stoke´s law).*

*The measurements were performed on eight types of soil samples, namely two samples of sandy soil, four samples of silty soil, and two experimental mixtures – the first one prepared by mixing foundry sand ($d_{50}$ = 0.14 mm) and micro-milled sand ($d_{50}$ = 0.027 mm) in a 1:1 ratio, the second one was represented by pure kaolin clay. For each sample type 8 particle size analyses were performed – 4 by hydrometer method and 4 by ISP+. Therefore, overall, 64 particle size analyses were performed. The sample pretreatment for both methods was identical. The control reference density was calculated using the constant density based on the mass of the dissolved dispersant and the variable density of water as a function of temperature.*

*The study results showed a good agreement between the ISP+ method and the hydrometer method, both in determining the clay fraction (R2 = 0,98; RMSE = 2,32%) and in determining the sand (R2 = 0,99; RMSE = 2,75%) and silt fraction (R2 = 0,98; RMSE = 2,89%).*

**Keywords:** *soil texture, sedimentation methods, hydrometer, ISP+, soil particle size*

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# Rewilding: Carbon Sequestration and Biodiversity Change in Spontaneously Regrowing Abandoned Landscape

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## Abstract

*In January 2024, the solution of the 4-year pan-European Horizon-WILDCARD project was launched. The project involves 16 scientific institutions from 9 European countries. Project focuses on the quantification of carbon changes (storage or release) in the ecosystem, as well as changes in biodiversity after management has ended and the ecosystem re-grows spontaneously. The volume of organic carbon and biodiversity are evaluated in the above-ground and below-ground components of the ecosystem. Chronosequence approach is interconnected with research on permanent plots. The topic is closely connected with the declaration of the highest authorities of the European Union towards the commitment of achieving carbon neutrality till 2050. In the contribution, based on an extensive overview of pan-European literature, a current overview of knowledge about trajectories of organic carbon sequestration in soils and microbiome changes, as well as existing science gaps, will be presented. The teams will also be offered participation in the solution of the project and publication of its results.*

**Keywords:** *forest management, agriculture, secondary succession, environmental DNA, organic carbon, ecological gradients, multitaxonomic biodiversity, ecoregion, Europe*

## Acknowledgement

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# Assessment of the Young Silver Fir Physiological Status Using Functional Leaf Traits

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## Abstract

*Silver fir (Abies alba Mill.) is a candidate tree species in the process of species conversion of monocultural Norway spruce (Picea Abies (L.) H. Karst.) stands, which are currently subject to the negative effects of bark beetle and adverse climatic changes. In mixed stands, silver fir could be more resistant to moderate drought compared to Norway spruce. However, as a shade-tolerant species, silver fir may be more susceptible to various abiotic stressors in more open forest canopies. For these reasons, it is necessary to study its ecological requirements within the site conditions for effective application in forest management.*

*In a pilot study, the physiological status of young trees of silver fir was studied under different light microclimatic conditions with varying forest regeneration methods – shelter-wood cut, gap cut, clear cut and natural regeneration. The physiological condition was assessed using anatomical and biochemical indicators (content of photosynthetic pigments and phenolic compounds, specific leaf mass per area and water content) along with temperature and humidity evaluations at the habitat.*

*We concluded that silver fir thrives better in sites with high to moderate shading compared to clear-cut areas with full sunlight exposure, as evidenced by the increased carotenoid to chlorophyll ratio in the needles. However, although silver fir is considered a shade-tolerant species, it can adapt to full sunlight conditions and achieve a very good physiological state. The selected biophysical and physiological parameters were sensitive to the degree of sunlight exposure but not enough to clearly distinguish sites representing a moderate level of shading.*

**Keywords:** *biophysical parameters of needles, chlorophyll, soluble phenolics, forest recovery type, site microclimatice, light conditions – shading*

## Acknowledgement

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# Nitrogen Losses in Forest Catchments: Insights from Functional Genes

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## Abstract

*Nitrogen inputs can alleviate N limitation and potentially impose N losses in forests ('opened N cycle'), which is indicated by enrichment of soils in $^{15}N$ over the $^{14}N$. However, the complex N cycle hinders accurate quantification of N fluxes. At the same time, soil biologists are striving to find meaningful indicators to characterise the "openness" of the N cycle. Nitrification and denitrification are the main biotic pathways through which N escapes from forest soils. Losses of nitrate, the leachable end-product of nitrification, can be measured in the drainage from the catchment. In contrast, gaseous N losses, associated mainly with denitrification, are difficult to extrapolate from point measurement owing to spatiotemporal variability. Estimates of denitrification rates include also mass budget and modelling approaches based on $^{15}N$ enrichment in the ecosystem. An additional possibility is quantifying the abundance of microbial genes encoding enzymes catalysing denitrification steps and linking these to estimates of actual N losses. This works well at the level of particular processes. However, the next step is to link gene potential to soil $\delta^{15}N$ in ecosystems, as it integrates a wide range of N transformations, including inputs and losses.*

*We linked the soil $\delta^{15}N$ signature to ecosystem N losses and the gene potential of the soil microbiome in 14 Czech forest catchments. We show that N losses are associated with the soil $\delta^{15}N$ and that $\delta^{15}N$ scales with the abundance of soil bacteria. The abundance of the archaeal amoA gene, representing the first step in nitrification, followed by the abundance of narG and napA genes, associated with the first step in denitrification, explained most of the variability in soil $\delta^{15}N$. These genes were more informative than the denitrification genes nirS and nirK, which are directly linked to $N_2O$ production. Thus, nitrite formation appears to be the critical step in N losses. We emphasise the role of ammonia oxidizing Archaea as the main mediator of nitrification in forest soils, which besides the nitrite production also generate $N_2O$ as a by-product. We provide evidence that the genetic potential for ammonia oxidation and nitrate reduction is representative of forest soil $^{15}N$ enrichment and thus indicative of ecosystem N losses.*

**Keywords:** *gene marker, N loss, $d^{15}N$, denitrification, nitrate, forest soil*

## Acknowledgement

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# Microbial Communities of the Hedgerows of the Central Bohemia Uplands

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## Abstract

*Central Bohemian Uplands is a region localized in the north-west of the Czech Republic. Due to its volcanic origin it is characterized by dominantly solitaire steep hills peaking around 400–800 metres above see level. Majority of the area is protected under the Czech Act 114/1992. Due to hill steepness landslides are common in the area. Due to this the hedgerows were constructed here since the middle ages. Especially in meadows and agriculture fields these hedgerows present significant centres of biodiversity of plants and animals as well as migration routes.*

*Microbial communities of 10 hedgerows on agriculture land (meadows and arable soil, not forest) in southern part of Central Bohemia Uplands were selected for sampling. Samples were taken between the stones on the hedgerow, directly on the mounds and surrounding fields. Sampling was carried out twice (spring, autumn) to cover seasonal changes. Samples were analysed by phospholipid fatty acid analyses (PLFA) to reveal living microbial biomass and rough structure of the microbial community.*

*As expected, higher biomass was found in the autumn sampling compared to spring. Biomass of all determined microbial groups was increased suggesting the input of fresh nutrients from shrubs was the key driving factor without any discrimination between microorganisms. Microbial biomass on hedgerows was significantly higher compared to the mounds and surroundings. Absolute values ranged between 30 mg/kg dwt and 186 mg/kg dwt, i.e. values were several times higher compared to common agriculture soils in the Central Europe. Also stress indicators trans/cis as well as cy/pre were significantly lower on the hedgerows compared to mounds and surrounding soil, suggesting higher well-being of microbes on the hedgerows.*

*Overall the results show that hedgerows present, together with plant and animal communities, significant centres of microbial biodiversity which should be protected for future.*

**Keywords:** *hedgerows, microbial communities, phospholipid fatty acids, microbial biomass*

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# Soil Nutrient Stocks as a Function of Forest Stand Type

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## Abstract

*Forest soils are an important reservoir of organic matter. It accumulates not only carbon but also other elements (N, P, K, Ca, Mg, etc.) necessary for the functioning of forest ecosystems. The accumulation or, conversely, the rate of decomposition of organic material and the associated nutrient uptake or release depend on the composition of the organic matter itself as well as on external conditions such as climate, topography or the permeability of the soil and soil-forming substrate. This work focuses on the assessment of organic matter and nutrient stocks in selected forest stands at the site of long-term experiments in the Amálie locality. Field soil sampling was carried out in six stands dominated by monocultures of spruce, larch and beech. The analyses performed included the determination of organic carbon content, soil bulk density, active and exchangeable pH, as well as cation exchange capacity and element contents in sorption complex (Ca, Mg, K). The study shows that spruce stands have the highest carbon stocks in the soil profile, while beech stands have the highest stocks of exchangeable elements. The type of stand directly influences soil chemistry through litterfall, with beech stands exhibiting more favourable values of soil pH and saturation of the cation exchange capacity than coniferous stands. The likely influence of water distribution on soil chemistry appears to be less significant than litter composition and root depth.*

**Keywords:** *forest soil, surface organic horizons, nutrient supply, forest cover*

## Acknowledgement

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# Pedotransfer Function Expressing the Relationship Between Total Organic Carbon and Bulk Density in Forest Soils in the Czech Republic

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## Abstract

*Owing to its role in mitigating $CO_2$ in the atmosphere, the total organic carbon (TOC) stock in soil, a key component of the terrestrial carbon cycle, is of significant interest in as regards climate change. To determine TOC stock, it is first necessary to determine the soil's bulk density (BD), determined through intact soil sampling; however, in forest soils, it can be difficult to determine BD due to high levels of stoniness and/or tree root coverage. Furthermore, the method is time consuming and labour intensive, making it impractical for studies over large areas. In such cases, BD can be determined using a pedotransfer function (PTF) expressing the relationship between forest soil TOC and BD. The aim of this work, therefore, was to determine a forest soil PTF using actual data obtained from 777 soil pits dug as part of the Czech Republic's National Forest Inventory (NFI). Within the NFI, BD is assessed from undisturbed core samples, while TOC is assessed from mixed sample, from the same soil genetic horizons. Both generalised linear (GLM) and generalised linear mixed effects (GLMER) models were used, with the final GLMER model best expressing the relationship for individual natural forest areas within the NFI dataset. The GLMER-based PTF described in this study can be widely applied to accurately estimate soil BD via TOC concentration, at temperate forest sites where stoniness and/or root cover previously made it technically impossible to take undisturbed samples.*

**Keywords:** *carbon stock, climate change, soil properties, czech natural forest areas, Czech National Forest Inventory, soil stoniness*

## Acknowledgement

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# The Influence of Mechanical Site Preparation on the Soil Properties at the Záhorská Lowland

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## Abstract

*The area of eolitic sands formed mainly from dunes represents approximately 600 km$^2$ of the area of Slovakia (1.2%). The traditional way of managing the stands in this area has consisted of clear-cutting, removal of logging residues with a bulldozer and ploughing. An alternative method of management is the incorporation of logging residues into the upper soil layer by soil cutter. The aim of the study was to compare the effect of these soil preparation methods on the physico-chemical and microbial properties in the first 30 cm of soil profile in intensively managed forest sandy soils 30 years after the treatment.*

*The results showed the differences of the soil physico-chemical properties between the monitored preparation techniques. Specifically, soil moisture, C and N content showed a significant increase after incorporation of logging residues to the topsoil, while the levels of pH and P content showed a significant decrease and no significant differences in the amount of Ca, Mg and K were observed between site preparation techniques. The decomposition and mineralization of organic matter were influenced by the post-harvesting management of logging residues, indicating that these processes are related to alterations in C supply, which influences the microbial population and its activity. We found that the incorporation of logging residues significantly increased microbial biomass carbon, N-mineralization and catalase activity, which resulted in in changes of N dynamics. On the other hand, significant decrease in functional diversity index of microorganisms and no significant differences in basal respiration and functional group richness were observed between plots with different site preparation. An analysis of the microbial functional group composition according to MicroRespTM assay and Biolog assay showed significant increase in utilisation of Malic acid, Glutamine, α-Ketoglutaric acid, Arginine, α-Ketobutyric acid and α-Cyclodextrin in case of logging residues incorporation into the topsoil. As a consequence of these processes, harvesting does not necessary lead to losses of N via leaching, even when decomposition of logging residues is enhanced by their incorporation. This site preparation technique also decreases soil reaction and therefore phosphorus can be immobilized in insoluble compounds.*

**Keywords:** *logging residues, soil preparation, soil properties, microbial properties, Pinus sylvestris (L.)*

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## THE DEPARTMENT OF GEOLOGY AND SOIL SCIENCE

The Department of Geology and Soil Science (ÚGP), part of the Faculty of Forestry and Wood Technology (LDF) at Mendel University in Brno, applies geological and pedological concepts in the development of forestry, landscape management and arboriculture studies. Studies at the ÚGP are built upon by including courses in related basic or specialised sciences from within the LDF, such as biology, biochemistry, micromorphology, hydrogeology, hydropedology, geoarchaeology, geodiversity and remote sensing. These disciplines are interpreted with an environmental perspective and the knowledge gained through the combination of disciplines used to promote sustainable use of Central European cultural landscapes, with a particular emphasis on forestry and landscaping.

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## CZECH-SLOVENIAN SOCIETY

The company, Česko-slovinská společnost, z.s. [Czech-Slovenian Society]' was founded in Brno in 2002. Its main mission is to develop and expand long-standing cultural and economic relations between the Czech Republic and Slovenia, especially in the fields of education, culture, sport and mutual understanding; to promote preservation of the national, linguistic and cultural identity of Slovenians living in the Czech Republic and Czechs living in Slovenia; and to strengthen mutual values and understanding between the two countries. We organise guest visits by representatives of Czech and Slovenian culture, prepare professional excursions for interest groups, and arrange travelling exhibitions highlighting personalities and important features of both countries to the Czech and Slovenian public. We also organise annual meetings and tourist events for Slovenians living in the Czech Republic and for all friends of Slovenia.

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