UNIVERSITAT POLITÈCNICA DE VALÈNCIA

ESCOLA POLITECNICA SUPERIOR DE GANDIA

GRADO EN CIENCIAS AMBIENTALES

“Study of the dynamics of the organic matter content of soil samples of two different forests, in different plots, under three different uses of the soil”

TRABAJO FINAL DE GRADO

Autor/a:
Artur Fluvià Alba

Tutor/a:
Josep Vicent Llinares Palacios

GANDIA, 2019

Abstract

Presented thesis focuses on the dynamics of soil organic matter on sites with different silvicultural management systems.

Coppice, coppice-with-standard and high forest plots were compared in terms of soil organic matter. The study was conducted between the winter of 2016/17 and the winter of 2018/19 at the university Masaryk forest training ground Krtiny on pre-existing TARMAG research sites near Brno, Czech Republic. The samples were collected during four different calendar seasons over a full two-year period, which allowed for the evaluation of the seasonal and year-to-year dynamics of soil organic matter content.

The evaluation detected a significant effect of the type of management on the soil organic matter stock fluxes and shows that coppiced plots are the most capable of soil organic matter accumulation. However, its soil organic matter gains in topsoil are compensated by losses in deeper layers.

Keywords: Soil organic matter flux, forest management, coppice, coppice-with-standard, high forest.

Table of Contents

1 Introduction

Soil is a huge living ecosystem, home to a plethora of microorganisms, which is on the one hand affected by biotic processes of fauna and flora, and on the other hand by abiotic factors. Last, but nevertheless important is the influence of mankind. Soil belongs to non-renewable resources and, therefore, should be used with utmost responsibility. The Food and Agriculture Organization (FAO) classified soil as the most valuable natural resource as it stabilizes and affects the sustainability of life on the planet and therefore, is one of the most important parts of the ecosystem. Due to all of this, soil has to be protected and its dynamics should be monitored. Its most important role is its the participation in the cycle of matter and energy flows in nature, and the biochemical cycles of the basic components of living organisms such as nitrogen, carbon and phosphorus.

Soil organic matter (SOM) is the world's largest reservoir of carbon and energy in terrestrial ecosystems. The carbon stock of the soil is more than two fold that of the atmosphere or the plant biomass (Šantrůčková 2014).

SOM is the very foundation for healthy and productive soils. But how can organic matter, which only makes up a small percentage of most soils, be so important? The reason is that SOM positively influences, or modifies the effect of, essentially all soil properties. That is the reason it's so important to our understanding of soil health and how to manage soils better.

As a revolving nutrient fund, organic matter serves two main functions:

- As soil organic matter is derived mainly from plant residues, it contains all of the essential plant nutrients. Therefore, accumulated organic matter is a storehouse of plant nutrients.
- The stable organic fraction (humus) adsorbs and holds nutrients in a plant-available form.

According to organic matter content, soils are classified to two categories: Mineral soils and Organic soils. Mineral soils form most of the world's cultivated land and may contain from a trace up to 30% organic matter whereas Organic soils are naturally rich in organic matter mainly due to climatic and hydric reasons. Although they contain more than 30% of organic matter, it is precisely for these reasons that they are not the best cropping soils as plant need as well plenty of minerals. Soil organic matter is any material produced originally by living organisms (plants or animals) that has been returned to the soil and goes through complex decomposition and condensation (synthetic) processes. At any given time, it consists of a range of materials from the intact original tissues of plants and animals to the substantially decomposed mixture of materials known as humus.

Obviously the measurement of the volume of soil biomass and the determination of its quality and its forms are the most relevant parameters. Generally, soil quality can be evaluated for its biochemical properties related to the cycles of the elements such as carbon, phosphorus, nitrogen and sulphur that have direct influence on the amounts of nutrients available, regarding biomass we will see same later.

Total carbon is the sum of three carbon forms; organic, elemental and inorganic (usually carbonates and bicarbonates). The term total carbon is different to total organic carbon, which refers specifically to the organic carbon fraction. The terms total organic carbon, soil organic carbon and organic carbon are the same. Organic matter is commonly and incorrectly used to describe the same soil fraction as total organic carbon. Organic matter is different to total organic carbon in that it includes all the elements (hydrogen, oxygen, nitrogen, etc.) that are components of organic compounds, not just carbon. Organic matter is difficult for laboratories to measure directly, so they usually measure total organic carbon. This is probably why organic matter and organic carbon are often confused and used interchangeably.

Last but not least, it has to be mentioned that soil health and its OM content is with direct relationship with the capacity to carry out the functions needed for the wellbeing of all ecosystems components.

2 Aims

1. SOM characterization based on determination of the % of each plots from each managements.
2. Laboratory determination of total SOM contents collected quarterly over a period of two years on experimental sessile oak dominated (*Quercus petraea)* forest stands with three different target management practices: coppice, coppice-with-standard and high forest control plots.

3. Seasonal SOM flux assessment with best potential to sequester evaluation.

3 General overview

3.1 Forest soil specifications

Forest soils differ from agricultural soils in many respects. Agricultural soils were selected because of desirable chemical and physical properties. Foresters may regard the physical properties of soils as one of the more important factors. In agricultural soils chemical properties may be most important. Historically, the better soils have been cultivated while the poorer remained under native vegetation. Certain soil properties, such as rock content, prevent or restrict agricultural activities. Forest soils tend to be shallower with more rock than agricultural soils. Since most forest soils occur on sloped terrain, they tend to be "younger" with more variability. Even so, some of these soil types can be very productive from a foresters perspective.

Fully developed forest soils are natural bodies with vertical layers. At the top is an organic surface layer or “forest floor” (O horizon) with subdivisions of fresh, undecomposed plant debris (Oi horizon, formerly called L); semi-decomposed, fragmented organic matter (Oe horizon, formerly called F) and humus; and amorphous organic matter without mineral material (Oa horizon, formerly called H). Below this surface layer is a mineral surface horizon (A); a subsurface mineral horizon often leached (E); a subsurface mineral horizon with features of accumulation (B horizon); a mineral horizon penetrable by roots (C); and locally hard bedrock (R). The E, B, C, and R horizon may be lacking, or the B horizon may be modified by groundwater or stagnant water.

Shallow and rockier soils tend to be more variable in their physical and chemical properties when compared to agricultural soils. The O horizon is usually more important in forest soil, as it is a primary source of nutrients. Agricultural soils associated with pastures and grasslands often have horizons similar to forested soils. However, if they are being cultivated, or have been in the past, they usually lack the organic (O horizon) layer. The A horizon usually has been mixed with parts of the E and even the B horizon, resulting in an artificial ploughed layer (Ap horizon). The B and/or C horizons may have been broken up by deep cultivation or ripping.

Forest soil characteristics are not only unique but their interpretation also differs from agricultural soils. Rocks, minerals, and soils are components of the lithosphere (upper part of the earth's crust). Rocks and minerals provide raw materials (parent materials) for development of most of the soils of the world. The processes of disintegration (fragmentation, splitting, and detachment) and decomposition (formation of simpler substances from complex substances) are responsible for the production of loose and unconsolidated parent materials from rocks and minerals. Only a few soils develop from organic parent materials, which are formed by deposition of residues of past vegetation, usually accumulated under wet conditions.

3.1.1 Morphology of soil profile

A floor profile is a two-dimensional section (width and depth) or vertical cut of the ground in depth. Typically, the characterization and description of a soil profile is accepted up to one meter deep or to where the mother rock is evidenced. The soil profile is divided into assumptions known as horizons, which are more or less parallel to the surface and of a defined geological origin. Capitals O, A, E, B, C and R are used to represent the main horizons of the soil.

Leaf and aboveground biomass litter in an organic forest horizon (O horizon) is a layer of relatively fresh and partially decomposed organic material that, according to the condition of the climate, the composition of the forest and the characteristics of the soil, constitutes a particular type of humus, which can be composed of one or several subhorizons (Oi, Oe, Oa). Mulch is the most distinctive feature of a forest floor, it is an important source of slow-release nutrients, an energy source for soil organisms (edaphon) and also acts as a protective physical cover for mineral soil against abiotic agents: runoff surface, erosion and extreme temperatures.

Under the O horizon the mineral horizons associated with more advanced stages of soil formation normally develop. The horizon A is a mineral horizon formed on the surface or immediately below the horizon O, where there is humified organic material (physically and chemically transformed) mixed with mineral material.

An E -eluvial horizon represents a horizon that has lost silicate clays, iron, aluminium and even organic matter, product of washing or deep migration of chemical substances, leaving a concentration of sand and silt of quartzite materials or other resistant materials. A B horizon, normally used for the diagnosis and classification of the soil, contains abundant products derived from weathering, such as silicate clays, iron, aluminium and humus, which have been relocated from the upper horizons A, E or O located at the top of the profile.

The C horizon corresponds to the deepest part of the profile, where the mineral material is partially weathering and the biological activity is low. In a soil formed in situ the weathering of the parent rock, the C horizon presents the appearance of the rock (colours, structures, textures), but this material is deeply weathered and can disintegrate with the hand. When consolidated rock is present, it is designated with the letter R, and it does not correspond to the concept of soil, but rather to the parental material that gives rise to it or that supports the soil above it.

3.1.2 Physical properties

Physical properties of forest soils develop under natural conditions by the influence of permanent vegetation cover over a long period of time. Physical properties of forest soils may be almost permanent properties unless modified by harvesting operations, shifting cultivation, and forest fires. Important physical properties of forest soils include texture, structure, porosity, density, aeration, temperature, water retention, and movement. (Osman 2013).

The physical properties of forest soils affect every aspect of soil fertility and productivity ans also determine the ease of root penetration, the availability of water and the ease of water absorption by plants, the amount of oxygen and other gases in the soil, and the degree to which water moves both laterally and vertically through the soil, also influence the natural distribution of forest tree species, growth, and forest biomass production. However, soil physical properties are largely controlled by the size, distribution, and arrangement of soil particles.

3.1.3. Chemical properties

Why Is Soil Chemistry Important? The soil quality indicator was initially developed as a tool for assessing the current status of forest soil resources and predicting potential changes in soil properties. Soil chemistry data can be used to diagnose tree vigour and document the deposition of atmospheric pollutants (e.g., acid rain).

In soil, there are inorganic and organic solids, solutes, liquids, and gases. There are larger and smaller particles, including sand, silt, and clay, and colloids—fine crystalline minerals and amorphous humus. Fine silicate clays and oxides and hydroxides of iron and aluminium, lime, gypsum, and phosphates are there along with hundreds of many other compounds, and nutrient ions. These materials are variably active and reactive; some are almost inert such as the sand grains, and some undergo continuous dynamic reactions such as the colloidal and charged clay particles.

Insoluble materials are made soluble, and soluble materials are insolubilized by diverse chemical and biochemical reactions. Important indices of the chemical behaviour of all soils, including forest soils, are pH, cation-exchange capacity, anion-exchange capacity, base saturation (BS) percentage, exchangeable sodium percentage, electrical conductivity, and redox potential. These indices characterize forest soils and affect the growth and distribution of forest tree species.

3.2 Organic matter in forest soils

Organic matter in soils is thus represented by plant debris or litter in various stages of decomposition through to humus, and includes the living organisms in soils. Above ground phytomass is generally excluded from soils, but roots may be included. It is necessary to establish a consistent terminology and the following definitions will be used:

-Organic matter: natural-C-containing-organic materials living or dead,
but excluding charcoal.
-Phytomass: materials of plant origin usually living but also includes standing plants which are dead, e.g. trees.
-Litter: dead plant (and animal) debris on the soil surface.
-Macroorganic matter: organic fragments in soils from any source.
-Light fractions: organic fragments obtained from soils by flotation on heavy liquids of densities . This fraction may be equated with macroorganic matter.
-Humus: material remaining in soils after removal of macroorganic matter. It should be noted that in some texts humus is synonymous with organic matter, and that biomass may or may not be included in humus.

The relative proportions of humus and macroorganic matter vary widely in different soils. Generally cold, acid, arid and sandy soils contain higher proportions of organic matter as plant debris than as humus because low temperature, low pH, or lack of water limit comminution of litter by fauna. Low base and nitrogen contents and high lignin contents of litter are also involved.

Humus may be further characterised chemically, physically and biologically. Chemical description is often based on extraction of organic matter by alkali to give the procedurally defined fractions known as humic acid, fulvic acid and insoluble humin.

Studies of soil organic matter using isotopes have shown clearly that the classical fractionation scheme is not well aligned with biological and biochemical processes operating during decomposition of plant materials and the formation of humus. The chemical fractions all contain recent C and other elements from both plants and microorganisms and the processes of decomposition of even simple substrates such as glucose cannot be usefully followed using this classical chemical scheme.

3.2.1 Organic matter function

Organic matter contributes to plant growth through its effect on the physical, chemical, and biological properties of the soil.
It has a:
-Nutritional function: in that it serves as a source of N, P for plant growth.

-Biological function: in that it profoundly affects the activities of microflora and microfaunal organisms.

-Physical and physico-chemical function: in that it promotes good soil structure, thereby improving tilth, aeration and retention of moisture and increasing buffering and exchange capacity of soils.

Humus also plays an indirect role in soil through its effect on the uptake of micronutrients by plants and the performance of herbicides and other agricultural chemicals. It should be emphasized that the importance of any given factor will vary from one soil to another and will depend upon such environmental conditions as climate and management history.

3.2.2 Effect on soil physical condition, soil erosion and soil buffering and exchange capacity

Humus has a profound effect on the structure of many soils. The deterioration of structure that accompanies management intensity is usually less severe in soils adequately supplied with humus. When humus is lost, soils tend to become hard, compact and cloddy, and aeration, water-holding capacity and permeability are all favourably affected by humus.

The frequent addition of easily decomposable organic residues leads to the synthesis of complex organic compounds that bind soil particles into structural units called aggregates. These aggregates help to maintain a loose, open, granular condition. Water is better able to infiltrate and percolate downward through the soil profile. The roots of plants need a continual supply of O_2 in order to respire and grow. Large pores permit better exchange of gases between soil and atmosphere.

Humus usually increases the ability of the soil to resist erosion. First, it enables the soil to hold more water. Even more important is its effect in promoting soil granulation and thus maintaining large pores through which water can enter and percolate downward.

3.2.3 Effects on soil biological condition

Organic matter serves as a source of energy for both macro- and microfaunal organisms. Numbers of bacteria, actinomycetes and fungi in the soil are related in a general way to humus content. Earthworms and other faunal organisms are strongly affected by the quantity of plant residue material returned to the soil.

Organic substances in soil can have a direct physiological effect on plant growth. Some compounds, such as certain phenolic acids, have phytotoxic properties; others, such as the auxins, enhance plant growth.

It is widely known that many of the factors influencing the incidence of pathogenic organisms in soil are directly or indirectly influenced by organic matter. For example, a plentiful supply of organic matter may favour the growth of saprophytic organisms relative to parasitic ones and thereby reduce populations of the latter. Biologically active compounds in soil, such as antibiotics and certain phenolic acids, may enhance the ability of certain plants to resist attack by pathogens.

3.2.4 Types of humus in soils

Humus occurs in soils in many types, differentiates in regard to morphology and fractional composition. A type of humus is it a morphological form of naturals accumulation of humic substances in profile or on the surface of soil, conditioned by general direction of soil-forming process and humification of organic matter.

The types of humus:

- First type of humus: is characteristic for podzolic soils, grey brown soils and lateral soils under forest communities. Humic acid indicate small extent of aromatic rings condensation and they are approximate to fulvic acids. Considerable hydrophilic properties of humic acids favor to creation of chelates with polyvalent cations and ability to displacement deep into profile of soil.
- Second type of humus: is characteristic for phaeozems, rendzinas, black earths and brown soils. Extent of aromatic rings condensation is high in humic acids, which cause their hydrophobic properties and inability to creation of chelates. Humic acids are strongly connected with mineral portion of soil in this type of humus.
- Third type of humus: is characteristic for semidesertic soils. In this humus predominates fulvic acids fraction, whereas arise of humic acids is limited. Beyond this, humic acids are largely bounded with mineral portion of soil.

3.3 How to determine soil organic matter

The total organic matter content of the soil can be determined in several ways; by calcination of the soil sample, by oxidation of the sample with potassium dichromate and by oxidation with hydrogen peroxide.

3.3.1 Calcination

This method determines the total content of organic matter that the soil has (complete or in some of its fractions). It must be kept in mind that with this method higher values are obtained in the organic matter content of the soil, since with it all forms of organic carbon present in the sample are volatilized.

Dried test sample is furnace heated to constant mass at (550 ± 25) °C. The difference in the mass before and after the ignition process is used to calculate the loss on ignition (LOI). LOI is expressed as weight percentage of dry mass (DM).

3.3.2 Method of Walkley and Black

With this method, the total organic carbon content of a soil sample, complete or any of its fractions, is estimated. It is the method most used in edaphological laboratories to evaluate the organic matter of the soil.

According to the Soil Survey Laboratory (1995), this method acts on the most active forms of organic carbon in the soil and does not produce complete oxidation of these compounds, so adjustments must be made to the results obtained in the laboratory, when they want to express in terms of content of organic matter. SSL (1996) recommends using a correction factor equal to 1.724, assuming that organic matter has 58% organic carbon.

With this method, as already said, some part of the organic material of the soil may remain un oxidized, especially in its cooler and thicker fractions, so that the soil organic matter values may be underestimated, although in a fraction organic little or nothing active in it.

The oxidation reaction that occurs in this determination is violent and releases a large amount of vapors, which means that it must be done under a hood and with adequate protection.

3.3.3 Oxidation by hydrogen peroxide

Although this procedure is recommended to remove organic matter from soil samples that are being subjected to textural analysis and that present difficulties to disperse because they have a high content of it, it is also useful if you want to quantify the content of organic matter in a floor in which the content of it is low.

In this determination, great care must be taken when making the additions of hydrogen peroxide since the reaction can be very violent and can cause burns to the operator, as well as loss of material from the sample, invalidating the determination.

4. Soil quality

Soil is one of the most important resources for life on the planet, since it is the fundamental basis for agricultural and forestry production. (Martin and Adad, 2006).

According to the concept of Atlas and Bartha (2002) and Nannipieri et al. (2003), "Soil is a structured system, heterogeneous and discontinuous, fundamental and irreplaceable, developed from a mixture of organic matter, minerals and nutrients capable of sustaining the growth of organisms and microorganisms."

Its formation is a complex process that involves physical, chemical and biological changes of the original rock. Physicists involve the reduction of the size of the particles without any alteration in their composition, and are caused by cycles of ice-thaw, rain and other environmental effects. Chemicals are caused by the separation of mineral particles from rocks; its alteration or destruction and the resynthesis to stable solid compounds are mainly due to the action of water, oxygen, carbon dioxide and organic compounds (Budhu, 2007).

On the other hand, the biological changes are made by the community that lives in the soil: flora, macrofauna, mesofauna (arthropods, annelids, nematodes and molluscs), microfauna (protozoa and some nematodes) and microbiota (bacteria, actinomycetes, fungi and algae), and 80-90% of the processes are reactions mediated by the microbiota (Nannipieri et al., 2003; Porta et al., 2003).

These biological changes are: the degradation and the contribution of organic matter, the production of CO2 in respiration, the intervention in the mobility of the biogeochemical cycles of the elements and the mechanical effects of animals and plants, as well as the fractionation of the rocks by the roots, among others (Porta et al., 2003).

4.1 Measurement of soil quality

Taking into account that the soil is an ecosystem where multiple factors interact and it is not possible for a single indicator to provide complete information, it is necessary to rely on physical, chemical, biological, productive and social indicators to determine the quality and / or health of soil (Doran and Parkin, 1994, Ramírez, 2004).

Larson and Pierce (1991), Doran and Parkin (1994) and Seybold et al. (1997) established a minimum group of soil properties to be used as indicators, since there were many and not all were sufficiently accurate and important; among them are the physical, chemical and biological indicators.

4.1.1 Physical indicators

The physical characteristics of the soil are a necessary part in the evaluation of the quality of this resource, since they cannot be easily improved (Singer and Ewing, 2000). The physical quality of the soil is associated with the efficient use of water, nutrients and pesticides, (Navarro et al., 2008), (Lal, 1998). This quality cannot be measured directly, but is inferred through the quality indicators (static or dynamic) and the measurement of the attributes that are influenced by the use and management practices (Carter, 2002; Sánchez-Maranon et al., 2002; Dexter, 2004).

The structure, apparent density, aggregate stability, infiltration, surface soil depth, water storage capacity and saturated hydraulic conductivity are the physical characteristics of the soil that have been proposed as indicators of its quality.

4.1.2 Chemical indicators

The chemical indicators refer to the conditions of this type that affect the soil-plant relationships, the water quality, the buffer capacity of the soil, and the availability of water and nutrients for plants and microorganisms (SQI, 1996). These include nutrient availability, total organic carbon, labile organic carbon, pH, electrical conductivity, phosphate absorption capacity, cation exchange capacity, changes in organic matter, total nitrogen and the mineralizable nitrogen.

4.1.3 Biological indicators

Biological indicators integrate a large number of factors that affect soil quality, such as abundance and byproducts of macroinvertebrates (Karlen et al., 1997). These break, transport and mix the soil when building galleries, nests, feeding sites, turrículos or compartments (Villani et al., 1999); Processes directly affect the incorporation and redistribution of various materials or indirect formation of microbial communities, transport of propagules, antibiosis or selective reduction of viability, etc. (Wolters, 2000); they include functions such as respiration rate, ergosterol and other by-products of fungi, decomposition rates of plant residues, and N and C of microbial biomass (SQI, 1996, Karlen et al., 1997). Other biological indicators are respiration rate, various enzymatic activities and functional diversity of microbial community.

Since the microbial biomass is much more sensitive to change than the total C, the microbial C: soil organic C ratio has been proposed to detect early changes in the dynamics of organic matter (Sparling, 1997).

5. Coppice, Coppice With Standard and High Forest Stands

5.1 Coppice

Coppicing has been traced back to Neolithic times by archaeologists who have excavated wooden tracks over boggy ground made entirely of coppiced material.

It can provide a constant supply of material for a wide variety of uses. The material is of a size which is easily handled. This was very important before machinery was developed for cutting and transporting large timber, when anything more than 20 miles from a large river could only be used locally. Through the 18th and 19th centuries, coppiced woodlands provided industrial charcoal for the smelting of iron, and bark from which tanning liquors were prepared.

However, by the mid-twentieth century coppicing was in rapid decline and many coppice woods were replanted with conifers, or simply neglected.

In terms of physiology coppicing occurs when a tree is felled and sprouts arise from the cut stump (known as a stool). This process can be carried out over and over again and is sustainable over several hundred years at least, the stool getting ever larger in diameter. The shoots arise from dormant buds on the side of the stool or from adventitious buds developing in the cambial layer below the bark. Root buds can produce coppice shoots when close to the stump, especially in birch and hazel. The development of the buds is initiated by a change in plant hormone levels following removal of the crown or stem.

All broadleaves coppice but some are stronger than others. The strongest are ash, hazel, oak, sweet chestnut and lime whilst the weakest include beech, wild cherry and poplar. Most conifers do not coppice.

The number of shoots per stool depends on the species, its age and size. A large number emerge in the first year – up to 150 in some cases, but these quickly die off in following years as self thinning takes place. By mid rotation 5-15 are left. The final number depends on the rotation length and species. Sweet chestnut coppice cut in its 16th year has about 5,000 stems/ha.

Oak, hazel and lime commonly grow a metre in their first year; ash and willow can grow much more and in the second year growth is generally greater. From the third year, growth slows dramatically.

A sloping cut is traditional as it was thought to shed water and prevent fungal decay. However, there is no evidence that a sloping cut minimises fungal attack. A low cut maximises the yield and encourages shoots to develop their own roots; it is also safer to work when stumps are cut low. The bark below the cut should not be damaged.

Work traditionally takes place during the winter – October to the end of March. There is no silvicultural reason for this but coppice, which is cut during July, August and September, will produce shoots, which are not frost hardy. Coppicing during the spring will disturb nesting and trample the ground flora. Coppice material cut in the winter works better and lasts longer than that cut when the sap levels are higher.

Figure 1: Coppice trees.

5.2 Coppice with standards

Coppicing with standards or maiden trees (trees which are not coppiced) was a common woodland management practice in the midlands. It gives a sustainable timber crop for construction and furniture making, whilst at the same time providing a range of locally coppiced products and firewood.

The standards could be one species or multiple species. For instance it could be Oak standards over Hazel, Sweet Chestnut or Lime or a mixed understorey.

The rotation period could be over 20 years with some standards being left to mature for up to 6 rotations. In any one compartment there would be a number of standards at various ages. Up to 40% of the canopy can be occupied by standards. Too many standards will result in poor coppice re-growth due to insufficient light reaching the ground . Standards should be retained at a density of about 30-100 per hectare a 10-18m spacing.

Figure 2: Coppice with standards.

5.3 High Forest Stands

A high forest is a type of forest originated from seed or from planted seedlings. In contrast to a low forest (also known as a coppice forest), a high forest usually consists of large, tall mature trees with a closed canopy. High forests can occur naturally or they can be created and/or maintained by human management. Trees in a high forest can be of one, a few or many species. A high forest can be even-aged or uneven-aged. Even-aged forests contain trees of one, or two successional age classes (generations). Uneven-aged forests have three or more age classes represented.

High forests have relatively high genetic diversity compared with coppice forests, which develop from vegetative reproduction. A high forest can have one or more canopy layers. The understory of a high forest can be open (parklike, easy to see and walk through), or it can be dense. A high forest's understory can have high or low vegetation species diversity.

Figure 3: High forest stands

6. Geomorphology, Geology, Soils And Topography

The site is located within the Brno Massif in terms of geology where the parent materials are mainly amphibolic granodiorites, diorites and sometimes even old matabazites (diabases). The massif is tectonically deformed and differs from the Variscan massifs lying to the west. Devonian conglomerates and grained siliciclastic sedimentary claystones significantly protrude in this area west to the edge of the Moravian Karst. Aeolian blankets are typical for the whole of Brno area and their effective thickness can be of very significant drift depth. Fairly widespread are sandy clay loam deluvial slope sediments. Alluvial sand and gravel drifts are of lesser importance (Culek et al. 2005).

The World Reference Base system of soil classification updated in 2006 by the Food and Agriculture Organization is to be used to describe the soils of the target area: Haplic Luvisols to Chernozems on loess drifts in depressions can be found in the Soběšice region as well as Cambisols and Albeluvisols on slopes and foothills. Rocky valleys and steep slopes of the area are overlaid by a number of soils. These soils are strongly influenced by its parental substrate and can range from lithic Leptosols to Leptosols or rendzic limestone Leptosols. Areas with limestone outcrops, especially on slopes, can feature browned (decalcified fine earth soil segment) rendzic Leptosols crossing over to Cambisols. Haplic Luvisols on loess and loess clay are an important aspect on upland platforms. Relict karst soils such as Terra Fusca and Terra Rossa are good representatives of places where the limestone base is not overlaid with loess (Culek et al. 2005). The overall declination of the region is from north to south, most slopes are, therefore, south facing. The topography is formed by ridge faults and fault-line gaps, while numerous rocky valleys developed across the fault-line gaps. The deepest river valley is cut out by the Svitava flow, where the elevation difference averages about 300 meters.

Other rivers valleys are from 100 m to 200 m deep. Strong valley phenomenon has developed on the Svitava and Svratka watercourses and that, together with diverse geological base and heterogeneous topography, leads to the overall increase in biodiversity of the region. The relief of the region has a character of flat highlands with altitudinal differences of 150 m to 200 m. Some deep cut fault-lines near tall ridges exhibit the nature of rugged highlands with altitudinal segmentation of 200 m to 300 m (Culek et al. 2005).

7. Methods

7.1 Studied Areas

The TARMAG research plots are located in close vicinity of Brno (Figure 4) in the Masaryk forest enterprise training ground Křtiny (TFE), which is an organizational part of Mendelu. The plots were founded at the turn of 2008 and 2009 and initially served to simulate the effect of coppice and coppice-with-standards (c-w-s) forests on biodiversity.

Collected data contributed to the project of Ministry of the Environment of the Czech Republic’s (MoE CZ) called ‘Biodiversity and Target Management of Endangered and Protected Species in Coppices and Coppices-with-Standards Included in the System of NATURA 2000 (Kadavý et al. 2011).The TARMAG site work-named Hády is located about 2 km north-east of Brno (Figure 5) and TARMAG II site called Soběšice (Figure 6) is located about 1 km north of Brno.

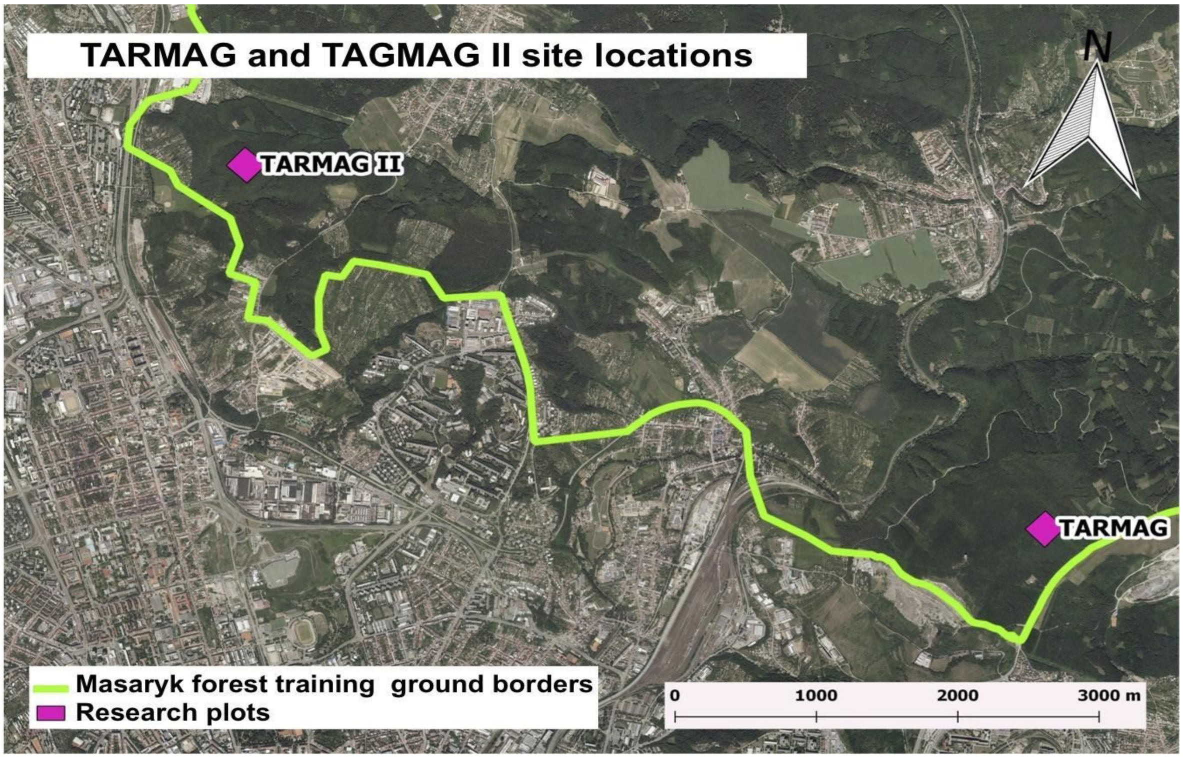


Figure 4: Location of Masaryk forest and research plots.

Both plots are 4 ha in size and are subdivided into 16 cells of 4 different intervention intensities (each logging intensity is replicated four times over within the studied area).

The aim of this project was to pinpoint and evaluate only the differences between two 'extreme logging intensities' of the current design. That being the subplots with maximal logging intensity (100%) coppice stands (clearcuts) and the subplots with minimal logging intensity, or else as described by the authors of the design as plots with medium high felling intensity (65 – 79%), simulating c-w-s forest sites.

Two representatives of each class in each plot were chosen based on the topology of the site (topologically most homogenous sites, with similar orientation and the least amount of sloping). Two new control-sampling sites replaced the existing control plots, again, mainly because of site similarity and vicinity. These new high forest control plots are located about 50 m off the current site design in the northeastern direction and are intentionally placed further into the neighboring forest stand (not directly adjacent to the TARMAG II site) in order to eliminate the possible edge effect and to offer the closest possible analogy of the pre-intervention state.

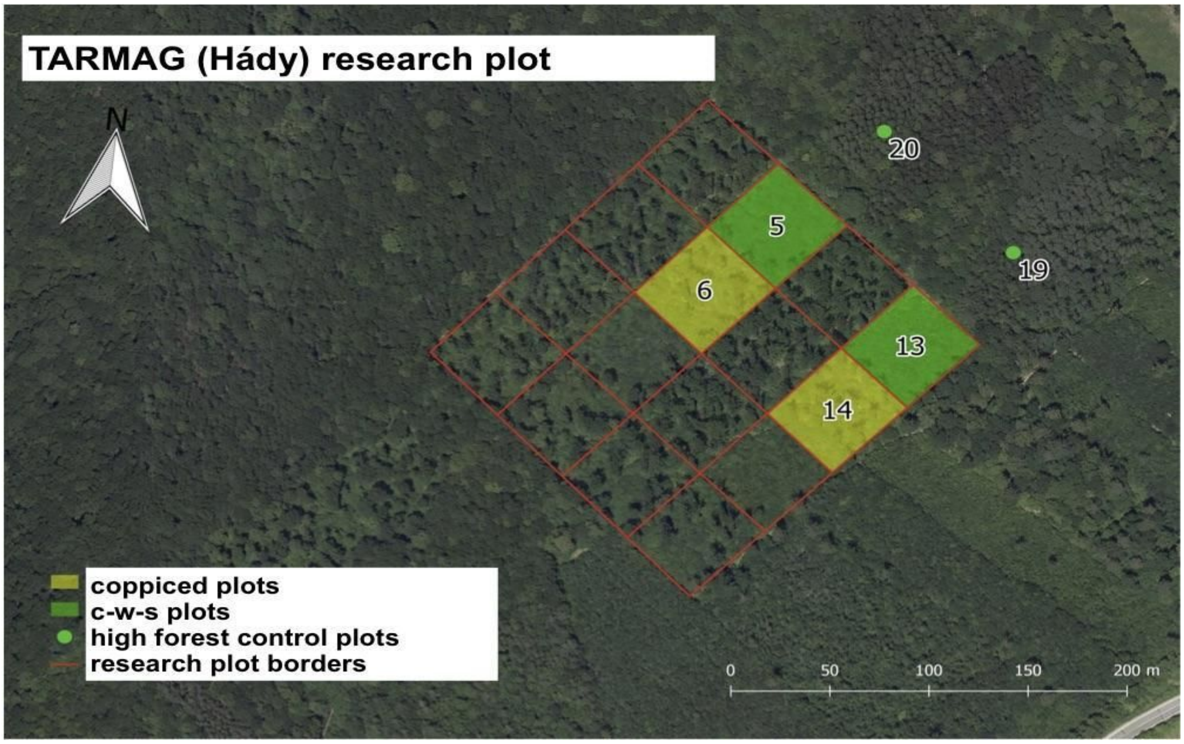


Figure 5: Location of coppiced, c-w-s and high forest control plots of Hády.

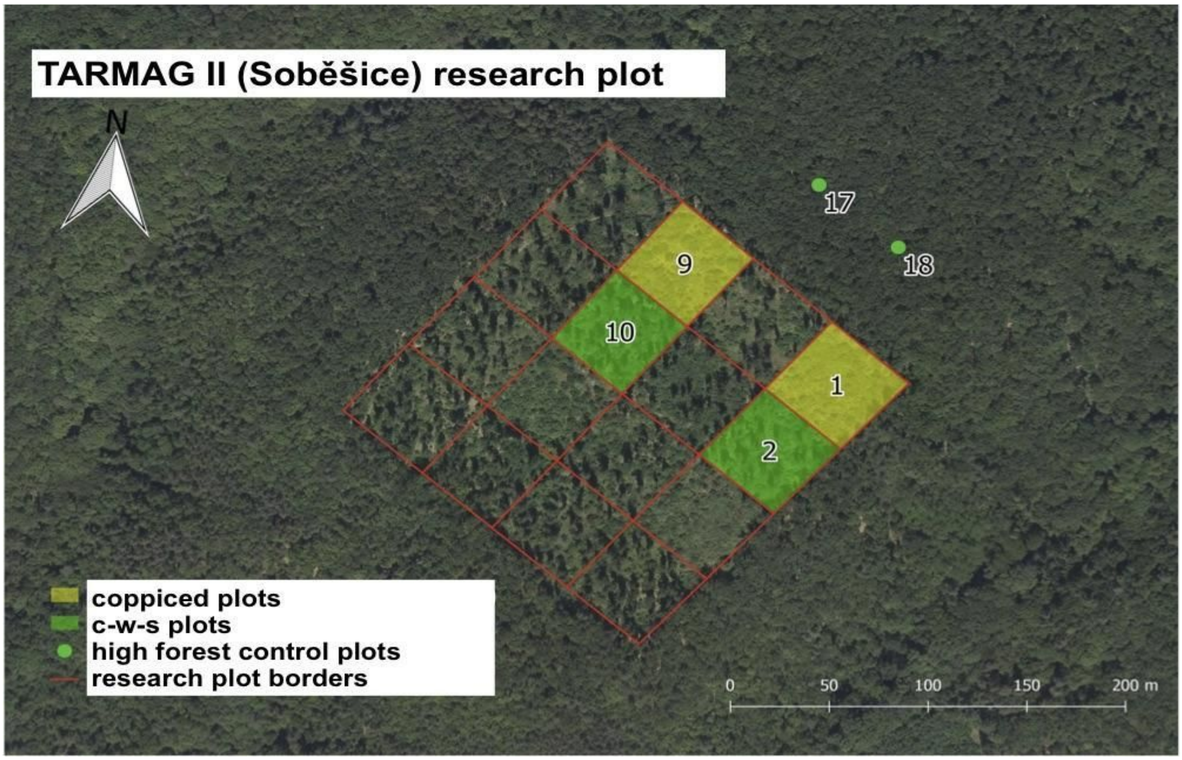


Figure 6: Location of coppiced, c-w-s and high forest control plots of Sobesice.

7.2 Sample Collection

Soil samples from the TARMAG II research plot were collected quarterly during the years of 2017, 2018 and the beginning of 2019 (winter of 2016/17 to winter of 2018/19). Each time period was to represent distinct vegetative phase of the temperate forest biome, typical for central Europe, and was to follow vernacular seasonality in order to be able to compare the characteristics of SOM content dynamics between the beginning and the end of growing season and the period of vegetative dormancy.

Samples were collected systematically according to simple randomized Latin square design as shown in (Figure 7) where each individual square was 4 by 4 meters of size. The sampling sequence, hence the pattern, was replicated for each studied subplot. Each subplot is marked in situ with a wooden stake. Finding the centres of the Latin squares was simply carried out with a compass (adhering to cardinal directions) and a scaled rope. Soil samples were extracted as close to the center of each Latin square as possible (avoiding trees, stumps and large root systems).

Each subplot was sampled at three points marked a, b and c and at two distinct depths of 0 - 5 cm and 10 - 15 cm (Figure 8). The total of three samples was collected at each plot resulting in one mixed subplot-representative soil sample. Mixed soil samples were created by thoroughly blending equal quantities of soil samples from all three points of each subplot with respect to sample depth. Mixed samples were stored in plastic flasks.

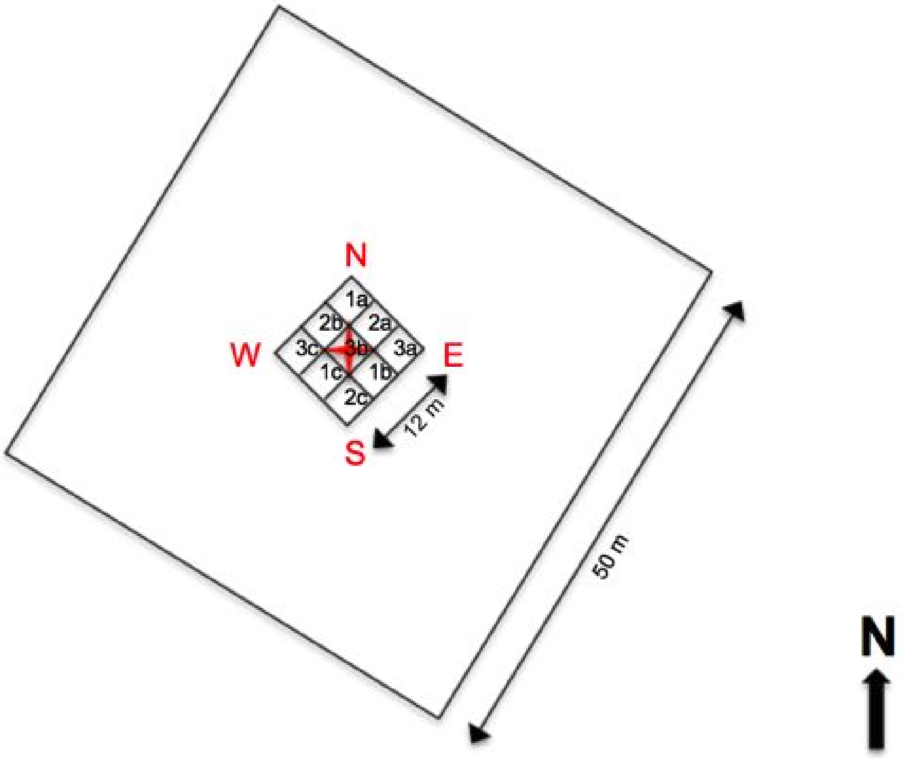


Figure 7: Topographical representation of the systematic approach to sample collection for all studied subplots based on randomized Latin square experimental design, where the large square denotes each subplot and its orientation to north, the subdivided smaller square indicates sampled area oriented according to cardinal directions (numbers in each Latin square stand for sampling periods: 1 autumn, 2 winter, 3 spring and the letters denote sampling points), the red cross is for the subplot center.

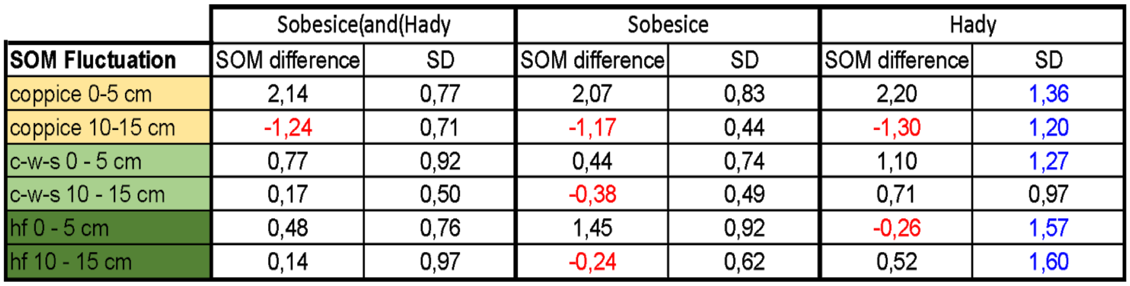
Figure 8: Typical preparations for soil sample collection at 10 cm depth. Sample ID clarification (exemplary case 1-9a10 and 1-9s10): first number stands for sampling period (1 – autumn), second number denotes subplot (9), the letters a and s are for sampling point and mixed sample identification respectively and the third letter (10) marks the depth of sampling. Note how dry the soil profiles were during th first sampling.

7.3 Determination Of Loss On Ignition (LOI)

The LOI method is used in accordance with JPP operational methods last updated in 2011 by Central Institute for Supervising and Testing in Agriculture in Brno (ÚKZÚZ) and is based on unified national norm (ČSN EN 15935 (838126) and, not to say, the international European standard EN 15935:2012). It is to estimate the organic matter content in sludge, treated biowaste, soil and waste.

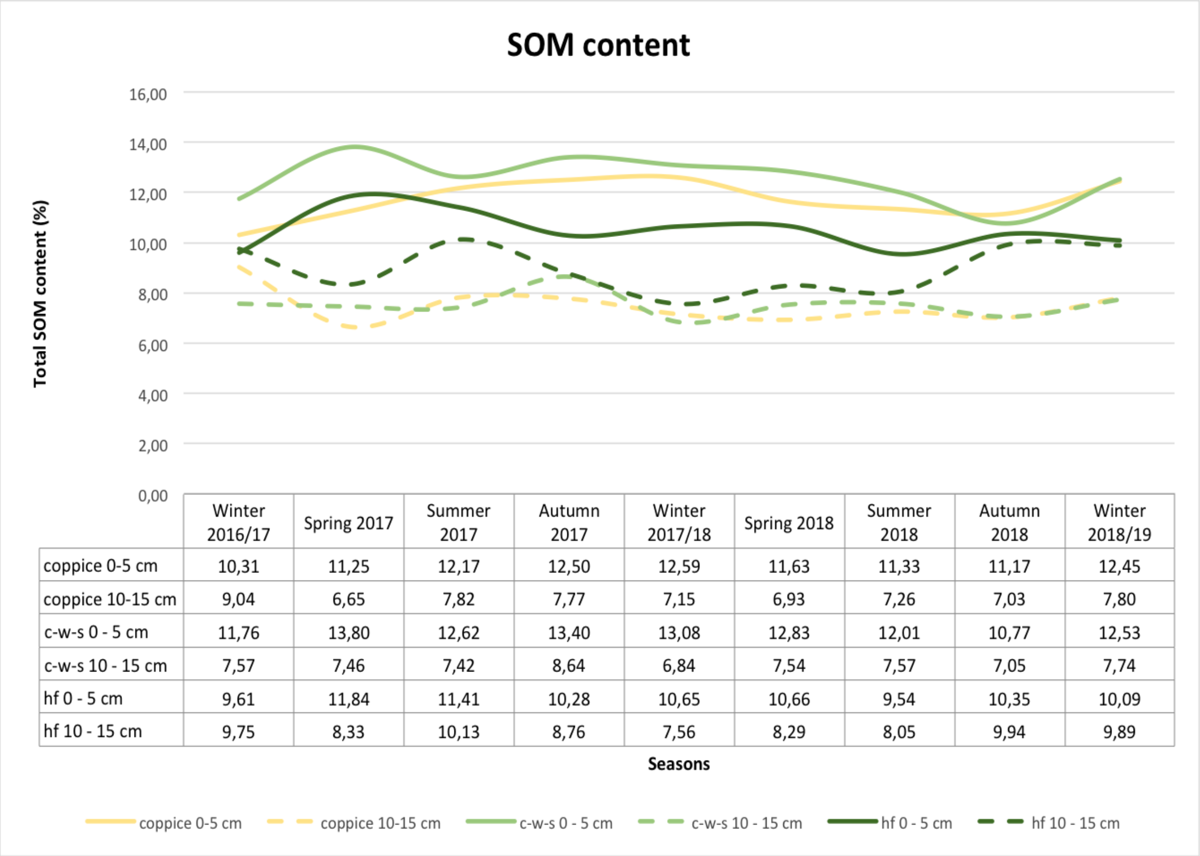
Dried test sample is furnace heated to constant mass at (550 ± 25) °C. The difference in the mass before and after the ignition process is used to calculate the loss on ignition (LOI). LOI is expressed as weight percentage of dry mass (DM).

8. Results



	Sobesice(and(Hady		Sobesice		Hady	
SOM Fluctuation	SOM difference	SD	SOM difference	SD	SOM difference	SD
coppice 0-5 cm	2,14	0,77	2,07	0,83	2,20	1,36
coppice 10-15 cm	-1,24	0,71	-1,17	0,44	-1,30	1,20
c-w-s 0 - 5 cm	0,77	0,92	0,44	0,74	1,10	1,27
c-w-s 10 - 15 cm	0,17	0,50	-0,38	0,49	0,71	0,97
hf 0 - 5 cm	0,48	0,76	1,45	0,92	-0,26	1,57
hf 10 - 15 cm	0,14	0,97	-0,24	0,62	0,52	1,60

Figure 9: In this table all the percentages of soil organic matter content fluctuations are showed.

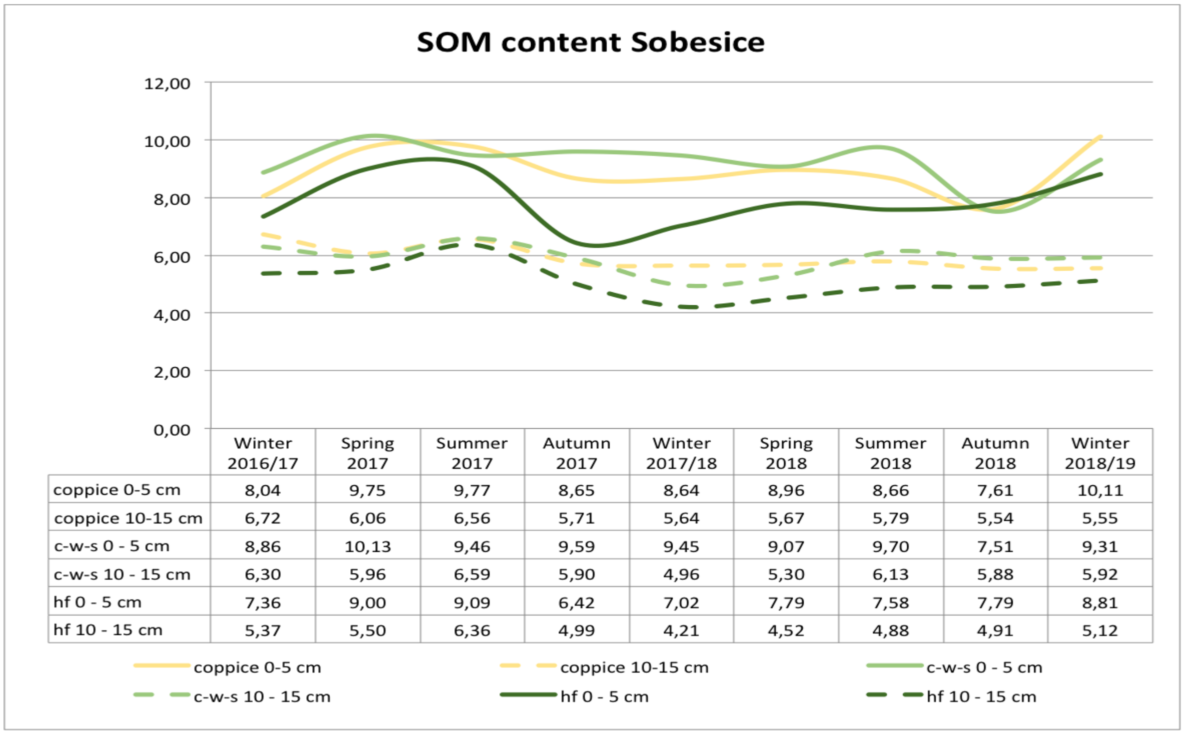


	Winter 2016/17	Spring 2017	Summer 2017	Autumn 2017	Winter 2017/18	Spring 2018	Summer 2018	Autumn 2018	Winter 2018/19
coppice 0-5 cm	10,31	11,25	12,17	12,50	12,59	11,63	11,33	11,17	12,45
coppice 10-15 cm	9,04	6,65	7,82	7,77	7,15	6,93	7,26	7,03	7,80
c-w-s 0 - 5 cm	11,76	13,80	12,62	13,40	13,08	12,83	12,01	10,77	12,53
c-w-s 10 - 15 cm	7,57	7,46	7,42	8,64	6,84	7,54	7,57	7,05	7,74
hf 0 - 5 cm	9,61	11,84	11,41	10,28	10,65	10,66	9,54	10,35	10,09
hf 10 - 15 cm	9,75	8,33	10,13	8,76	7,56	8,29	8,05	9,94	9,89

Figure 10: Here we can observe the % fluctuations (Sobesice and Hady)

As we can see in this graph in terms of coppice, in Sobesice and in Hady, the soil content in organic matter has increased by 2.14% since in winter of 2016/17 the soil had a content of 10.31% and in winter of 2018/19 has reached 12.45% in the first depth (0-5 cm) and in the second depth (10-15cm) the soil organic matter content has decreased 1,24%.

In c-w-s management the organic matter content of the soil has varied, reaching a gain of 0.77% in the 2 year period in the first depth (0-5 cm) but in the second depth (10-15 cm) has only varied just 0,17 %. Finally, in the high forest, the organic matter content of the soil varied 0.48% in the first depth and 0.14% in the second.

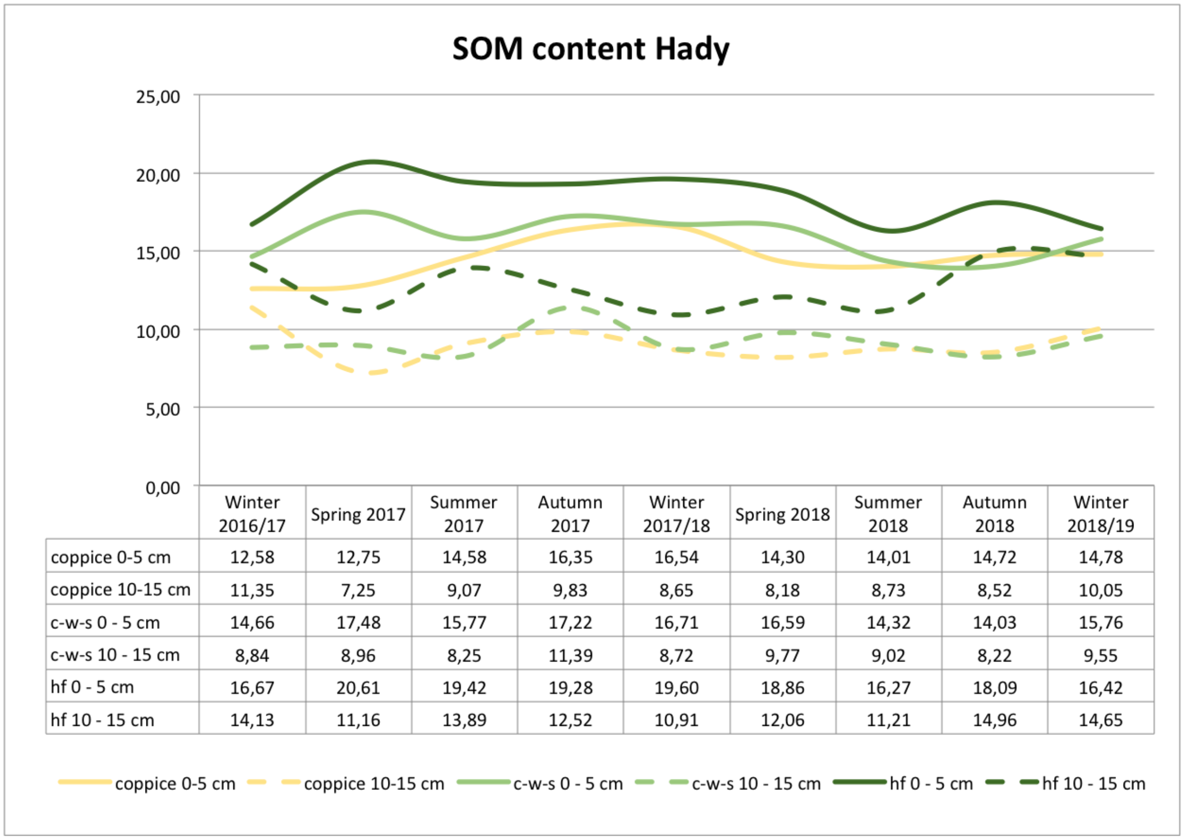


	Winter 2016/17	Spring 2017	Summer 2017	Autumn 2017	Winter 2017/18	Spring 2018	Summer 2018	Autumn 2018	Winter 2018/19
coppice 0-5 cm	8,04	9,75	9,77	8,65	8,64	8,96	8,66	7,61	10,11
coppice 10-15 cm	6,72	6,06	6,56	5,71	5,64	5,67	5,79	5,54	5,55
c-w-s 0 - 5 cm	8,86	10,13	9,46	9,59	9,45	9,07	9,70	7,51	9,31
c-w-s 10 - 15 cm	6,30	5,96	6,59	5,90	4,96	5,30	6,13	5,88	5,92
hf 0 - 5 cm	7,36	9,00	9,09	6,42	7,02	7,79	7,58	7,79	8,81
hf 10 - 15 cm	5,37	5,50	6,36	4,99	4,21	4,52	4,88	4,91	5,12

Figure 11: All % fluctuations about soil organic matter content in Sobesice are shown.

As we can see in this figure the content of organic matter in Sobesice forest follows the same pattern that is expected, less organic matter in the warmer seasons and more organic matter in the cooler seasons, soil organic matter content in coppice has increased 2,07% in the first depth and decreased 1,17% in the second depth. In c-w-s increased 0,44% in the first depth and decreased

0,38%, instead, in high forest increased a 1,45 % in the first depth and decreased a 0,24% in the second depth.



	Winter 2016/17	Spring 2017	Summer 2017	Autumn 2017	Winter 2017/18	Spring 2018	Summer 2018	Autumn 2018	Winter 2018/19
coppice 0-5 cm	12,58	12,75	14,58	16,35	16,54	14,30	14,01	14,72	14,78
coppice 10-15 cm	11,35	7,25	9,07	9,83	8,65	8,18	8,73	8,52	10,05
c-w-s 0 - 5 cm	14,66	17,48	15,77	17,22	16,71	16,59	14,32	14,03	15,76
c-w-s 10 - 15 cm	8,84	8,96	8,25	11,39	8,72	9,77	9,02	8,22	9,55
hf 0 - 5 cm	16,67	20,61	19,42	19,28	19,60	18,86	16,27	18,09	16,42
hf 10 - 15 cm	14,13	11,16	13,89	12,52	10,91	12,06	11,21	14,96	14,65

Figure 12: All % fluctuations about soil organic matter content in Hady are shown.

Again as we can see in this figure the content of organic matter in Hady's forest follows the same pattern that is expected, less organic matter in the warmer seasons and more organic matter in the cooler seasons. It is also noteworthy that during the nine years high forest has had the highest percentage in organic matter (0-5 cm depth).

This graph show as that in Hady soil organic matter content in coppice has increased 2,20% in the first depth and decreased 1,30% in the second depth. In c-w-s increased 1,10% in the first depth and increased 0,71%, instead, in high forest decreased 0,26% in the first depth and increased a 0,52% in the second depth.

As all graphs have shown there are a lot of differences regarding % of soil organic matter content. While in Sobesice the total SOM content is markedly lower than in Hady (almost half of the value), the two also show different seasonal dynamics. In Sobesice the most comparable behaviour is noticeable between the coppice and cws, whereas in Hady it is between the cws and high forest. This may be due to differences in plant density and soil type.

In Sobesice there is a lower plant density and therefore there is a lower production of organic matter and the soil is less protected against abiotic factors. And consequently more organic matter content of the soil is dragged to other areas or consumed by soil biota. It can also be noticed that while there is and overall SOM gain, the lower soil depth experiences an overall SOM loss over the studied period.

9. Discussion

Regarding the results obtained, it is important to say that the amount of organic matter in the soil is affected by the forestry processes. As our experiment shows, in Sobesice and in Hady there is a variation of the organic matter content of the soil in each type of management (coppice, c-w-s, and high forest).

In coppice it is observed that there is an increase of around 2% in Sobesice and hady. A similar situation occurs in another experiment, based on the calculation of organic matter and stored nutrients, in soils under contrasting management regimes: "The effects of management on organic matter and nutrient storage were clarified by eliminating the differences attributable to unequal soil masses.

The idea that nuffient masses must be normalized for differences in soil mass is not entirely new, but recent publications indicate a serious and persistent lack of awareness about the influence of soil mass on estimates of nutrient storage. The impact of management on organic matter storage at the Star City site was obscured by differences in soil bulk density and thickness, and consequently, the masses of the genetic horizons" (B. H. Ellertl and J. R. Bettan 1995)

It is then verified that, both in our experiment and in that of (B.H. Ellertl and J.R. Bettan 1995) there is a change in the organic matter content of the soil, the quantities of organic matter in the soil under silviculture being higher than in wild soil.

It should be noted that our work shares similar objectives with comparative work, and therefore we obtain a good confirmation that we are on the right way.

It was discovered that in the high forest stands, the percentage of organic matter in the first 5 cm of the soil did not increase as much as in coppice. In my opinion this is because the biota is more active in the first 5 cm in the high forest than in coppice. On the other hand, it is observed that in the second depth (10-15cm) there is a reduction of the SOM in coppice of 1,24%, while in the high forest in the same depth the SOM increases by 0,14%.

From my point of view this is because in coppice, being a homogenic crop, biodiversity decreases and also due to intensive harvesting the plant biomass is lower than in the high forest, resulting in less soil protection against abiotic factors and therefore dragging the content in organic matter.

In Sobesice, the most comparable data are obtained from coppice and from c-w-s. This is due to the difference in soil types and also in plant density. In Sobesice the soil is less protected against abiotic factors since plant density is lower than in Hady. Therefore, the SOM is mostly consumed or dragged by soil biota in Sobesice. It can also be observed that, although there is a total gain of SOM, the lowest depth of the soil experiences a total loss of SOM during the period studied.

Speaking of the moisture content of the soil it is important to know that microorganisms have a higher activity with moisture, therefore in dry soils there will be a lower amount of organic matter content than in humid soils due to the activity of the microorganisms. For this reason it is worth noting again that abiotic factors have a great influence on the SOM.

Due to the bacterial activity, as already mentioned in previous paragraphs, the SOM can vary considerably. However, the fact that SOM varies does not mean that the nutrient content of the soil decreases. It can happen on the contrary because if there is a correct soil moisture content for the activity of the microorganisms they will develop their work as well as the nitrifying bacteria. These bacteria will be responsible for fixing atmospheric nitrogen in the soil, providing a higher nitrogen content so that plants and other organisms can benefit.

The effects can be divided further into direct and indirect ones. Direct effects: additions of ammonium and nitrate to fresh, newly shed litter stimulate the initial decomposition of celluloses and solubles.

Indirect effects: long-term deposition leads to increases in litter concentrations of N and other nutrients. This N in litter forms "natural" organic compounds and the resulting effects are similar to those resulting from natural variation among litter types. Thus, initial decomposition is generally higher for N (nutrient) rich plant litters than for litters with a lower N (nutrient) content. In later stages, at which lignin-degradation rates regulate litter decomposition, N has a retarding effect on decomposition.

10. Summary

In the Masaryk forest, plots are monitored under different management of soils related to forestry, these managements are coppice, c-w-s and high forest.
One area where the samples are taken is in Sobesice and the other in Hady.

The samples were taken systematically according to the Latin square (Figure 7), where each individual square was 4 by 4 meters in size.
Samples were also taken at different times of the year.

Once all the samples were collected properly, by means of the method known as Determination on loss of ignition, the percentage of organic matter of each soil sample was calculated.

Finally, the fluctuations of the content in organic matter of the soil in each plot and in each soil management were observed and compared so as to be able to deduce how the management of the organic matter of the soil has affected them.

11. References

- Abidoye, B., Mungatana, E., Mahlalela, L., Sacolo, T. & Babalola, F. 2015. Forest Ecosystems in the transition to a green economy and the role of REDD+ in the United Republic of Tanzania. United Nations Environment Programme, Nairobi.

- Abrahamsen G (1994) Soil chemical effects of liming-considerations related to forest liming. In: Nilsen P (ed) Proc. from an International seminar on counteractions against in forest ecosystems. March 3–4 1994, Mastemyr, Norway

- Agarwal, B. 2001. Participatory exclusions, community forestry, and gender: An analysis for South Asia and a conceptual framework. World Development, 29(10): 1623–1648.

- Arshad, M.A., B Lowery, and B. Grossman. 1996. Physical test for monitoring soil quality. P. 123-142. In: J.W. Doran and A.J. Jones (eds.) Methods for assessing soil quality. SSSA Spec. Publ. 49. Soil Science Society of America, Inc., Madison, Wisconsin, USA.

- Astier, M. et al. Derivación de indicadores de calidad de suelos en el contexto de la agricultura sustentable. Agrociencia. 36 (5):605. 2002

- Bockheim JG. 2003. Forest soils. In Young RA, RL Giese eds. Introduction to forest ecosystem science and management. Third edition. USA. Wiley. (PDF) SUELOS EN ECOSISTEMAS FORESTALES. Available from: https://www.researchgate.net/publication/277131964_SUELOS_EN_ECOSISTEMAS_FORESTALES

- Brady NC, RR Weil. 2002. The Nature and Properties of Soils. 13ª ed. United States, Prentice Hall.

- Buckman H.C., Brady N.C.. (1971): Gleba i jej właściwości. PWRiL, Warszawa.

- Burés, S. (2004). La Descomposición de la Materia Orgánica. [Documento en línea]. Disponible: http://www.inforganic.com/node/484 [Consulta: 2011, Junio 24]

- Casanova, E. (2005). Introducción a la Ciencia del Suelo. Venezuela. Consejo de Desarrollo Científico y Humanístico – Universidad Central de Venezuela.

- Corbella, R.; Fernández de Ullivarrí, J. (2006). Materia Orgánica del Suelo. Argentina. Facultad de Agronomía y Zootecnia – Universidad Nacional de Tucumán.

- Danikiewicz W. (1988): Chemia organiczna. WSiP, Warszawa.

- Díaz, B. et al. Evaluación de la sostenibilidad del manejo del suelo Pardo con Carbonato (Inceptisol) a través de indicadores de calidad del mismo. Centro Agrícola. 32 (2):73. 2005

- Dick, R.p., D.R. Thomas, and J.J. Halvorson. 1996. Standardizen methods, sampling, and sample pretreatment. P. 107-122. Inc: J.W. Doran and A.J. Jones (eds.) Methods for assessing soil quality. SSSA Spec. Publ. 49. Soil Science Society of America, Inc., Madison, Wisconsin, USA

- Drozd J. (1978): Studia nad właściwościami chemicznymi i fizykochemicznymi związków próchnicznych niektórych jednostek taksonomicznych gleb. Zeszyty Naukowe AR we Wrocławiu nr.13, Wrocław.

- Drozd J., Weber J. (red.) (1996): The role of humic substances in the ecosystem and in environmental protection. PTSH, Wrocław

- Flaig W. (1966): "The Chemistry of Humic Substances", w: The Use of Isotopes in Soil Organic Matter Studies. Report of FAO/AEA Technical Meeting. Pergamon, New York, 103-127.

- Fotyma M., Mercik St. (1992): Chemia rolna. PWN, Warszawa.

- Fuller W.H. et al. (1956): Soil Sci. Soc. Amer. Proc.. 20,218.
- Gershuny, G. And J. Smillie. 1995. The soul of soil: A guide to ecological soil management. 3rd ed. AgAccess, Davis, california, USA.
- Gliński J. (1993): "Chemiczne i fizykochemiczne właściwości gleb", w: red. Dobrzański B., Zawadzki S., Gleboznawstwo. PWRiL, Warszawa, 155-207.
- http://smallwoods.org.uk/our-work/woodland-products/a-brief-history-of-coppicing/
- http://www.countrysideinfo.co.uk/woodland_manage/coppice.htm
- https://www.rhs.org.uk/about-the-rhs/publications/the-garden/2013-issues/january/How-to-pollard-and-coppice-shrubs.pdf
- https://www.nrcresearchpress.com/doi/pdf/10.4141/cjss95-075
- Jaramillo, D. (2002). Introducción a la Ciencia del Suelo. Colombia. Facultad de Ciencias – Universidad Nacional de Colombia.
- Kononova M.M. (1966): Soil Organic Matter. Pergamon, Oxford.
- Kononowa M. (1968): Substancje organiczne gleby ich budowa, właściwości i metody badań. PWRiL, Warszawa.
- Kowaliński St. (1993): "Substancja organiczna gleby i jej przeobrażenia", w: Dobrzański B., Zawadzki S. (red.), Gleboznawstwo. PWRiL Warszawa, 209-237.
- Kowda W.A., Griszyna L.A. (1984): Podstawy nauki o glebach. PWRiL, Warszawa.
- Kumada K. (1987): Chemistry of soil organic matter. Elsevier.
- Lityński T., Jurkowska H. (1982): Żyzność gleby i odżywianie się roślin. PWN Warszawa.

- Mc Carthy P., Malcolm R.L., Clapp C.E., Bloom P.R. (1990): An introduction to soil humic substances, Humic substances in soil and crop sciences: selected readings, W: American Society of Agronomy, Soil Science of America. Madison, 1-12.

- Minakowski W. (1990): Biochemia kręgowców. PWN, Warszawa.

- Navarro, G. (2003). Química Agrícola. España. Ediciones Mundi-Prensa, S.A.

- Osman, K. (2013). Rocks, Minerals, and Soils. 10.1007/978-3-319-02541-4_1.

- Osman, K. (2013). Rocks, Minerals, and Soils. 10.1007/978-3-319-02541-4_1.

- Parkin, T.B. and J.W. Doran. 1996. Field and laboratory tests of soil respiration. P.231-246. In: J.W. Doran and A.J. jones (eds.) Methods for assessing soil quality. SSSA Spec. Publ. 49. Soil Science Society of America, Inc., Madison, Wisconsin, USA

- Perry, Charles H.; Amacher, Michael C. 2007. Chemical properties of forest soils. In: Forest health monitoring: 2005 national technical report. General Technical Report SRS-104. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. (pages 59-66)

- Piskornik Z. (1988): Fizjologia roślin cz.1. PWN, Warszawa.

- Powell, D. And J. Preatley. 1991. Sustainability kit manual. Centre for Conservation Farming. Charles Sturt University-Riverina, PO Box 588, Wagga 2650, Australia.

- Primo Yúfera, E.; Carrasco Dorrién, J.M. (1981). Química Agrícola I. Suelos y Fertilizantes. España. Editorial Alhambra, S.A.

- Richard G. Burns, Soil Biology & Biochemistry Citation Classics III, Soil Biology and Biochemistry, Volume 37, Issue 5, 2005, Page 809, ISSN 0038-0717.

- Riffaldi R., Schnitzer M. (1972): Soil Sci. Soc. Amer. Proc.. 36, 301.

- Rowell, D. L. 1994. Soil science:methods and applications. Longman Scietific & Technical, Singapore

- Schnitzer M., Kodama M. (1967): Soil Sci. Soc. Amer. Proc.. 31, 632.

- Soil Survey Laboratory [SSL] (1995). Information manual. Soil Survey Investigations Nº 45. Version 1.0. E.E.U.U. United States Department of Agriculture (USDA).

- Soil Survey Laboratory [SSL] (1996). Methods manual. Soil Survey Investigations Report Nº 42. Version 3.0. E.E.U.U. United States Department of Agriculture (USDA).

- Stevenson F.J. (1979): "Humus", The Encyclopedia of Soil Science Part 1. Dowden, Hutchinson and Ross, Pennsylvania.

- Stevenson F.J. (1982): Humus chemistry. Genesis, composition, reactions. John Wiley.

- Theng B.K.G. (1976): Geoderma. 15, 234.

- Thompson L.M., Troeh F.R. (1978): Gleba i jej żyzność. PWRiL, Warszawa.

- Tinsley J., Walker C.H. (1964): Trans. 8th Intern. Congr. Soil Sci.. 2, 149.

- Turski R. (1996): Substancja organiczna i jej znaczenie w ekosystemach. Zeszyty Problemowe.
- Waksman S.A. (1932): Humus, Williams and Wilkins. Baltimore.

- Williams C.B. et al. (1915): Report on the Piedmont Soils pariculary with reference to their nature, plant- food requirements and adaptability for different crops. Bul. North Carol. Depart. Agric., 2, 36.