CZECH UNIVERSITY OF LIFE SCIENCES PRAGUE

FACULTY OF FORESTRY AND WOOD SCIENCES

DEPARTMENT OF SILVICULTURE

EFFECT OF DOUGLAS-FIR (*PSEUDOTSUGA MENZIESII* (MIRB.) FRANCO) ON SOILS IN FOREST STANDS

DIPLOMA THESIS

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CZECH UNIVERSITY OF LIFE SCIENCES PRAGUE

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DIPLOMA THESIS ASSIGNMENT

Adrián Merchán Romero

Forestry, Water and Landscape Management

Thesis title

Effect of Douglas-fir (Pseudotsuga menziesii (Mirb.) Franco) on soils in forest stands

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Objectives of thesis

The aim of the diploma thesis is to evaluate the effect of the Douglas-fir (Pseudotsuga menziesii (Mirb.) Franco) on the upper soil horizons in stands of important commercial tree species Norway spruce (Picea abies [L.] Karst.) and oak (Quercus spp.). The accumulation of the surface humus and the soil chemistry in the holorganic horizons as well as in the upper mineral horizons will be compared.

Methodology

- literature review
- selection of suitable sites with respect to available data sets
- statistical analyzes of formulation of research results
- comparison with similar research results, discussion and formulation of main conclusions
- recommendations for forestry sector with respect to importance and impact of Douglas-fir in the Czech Republic

The proposed extent of the thesis

60 pages

Keywords

Douglas-fir, species introduction, forest soil, humus forms, soil chemistry

Recommended information sources

Bušina F. 2007. Natural regeneration of Douglas fir (Pseudotsuga menziesii [Mirb.] Franco) in forest stands of Training Forest District Hůrky, Higher Forestry School and Secondary Forestry School in Písek. Journal of Forest Science 53:20–34.

Podrázský V., Martiník A., Matějka K., Viewegh J. 2014. Effects of Douglas-fir (Pseudotsuga menziesii [Mirb.] Franco) on understorey layer species diversity in managed forests. Journal of Forest Science 60(7):263–271.

Podrázský V., Remeš J., Sloup R., Pulkrab K., Novotný S. 2016. Douglas-fir – partial substitution for declining conifer timber supply – review of Czech data. Wood Research 61(4):525–530.

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Prague on 06. 02. 2018

I declare that I wrote my Diploma thesis independently, and that I have cited all the information sources and literature I used. Neither this thesis nor any substantial part of it have been submitted for the acquisition of another or the same academic degree.

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ABSTRACT

The Czech Republic is a country with a great forestry vocation, its climate, topography and culture are perfect for the development of this type of economic activity. In recent years there has been a progressive abandonment of agricultural land, which has allowed an increase in forestry activity. In the past centuries an important need of wood appeared which led to the realization of massive reforestations with the most productive indigenous tree species, Norway spruce. Some of these plantations were not carried out in the most suitable areas and now certain ecological problems are arising. In this work we will assess the possible introduction of new species in areas where Norway spruce is causing problems.

The aim of this project is to see the effects of Douglas-fir on the upper soil status in the stands of different species: Norway spruce (*Picea abies*), Grand fir (Abies grandis) and Oak (Quercus sp.). The accumulation of the surface humus and the soil chemistry in the holorganic horizons as well as in the upper mineral horizons was compared.

The study was carried out in two locations: Orlík and Vyžlovka (separate studies were developed in each location). The sampling was realized in monospecific forest stand parts with four replications per species. The samples were examined in the laboratory and the obtained results analysed with the one-way ANOVA statistical test.

The conclusions obtained were that Norway spruce acidifies more than the rest of the species and that a possible substitution would be good for enhancement of the volume production of forest stands, the increase of the value production and the reduction of the negative effects on the forest soils comparing to native conifers.

Key words: Douglas-fir, species introduction, forest soils, humus forms and soil chemistry.

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1. Introduction

This Diploma thesis will be based on Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) and its relation with soil attributes. It is a worldwide species planted widely for its high productivity, good wood quality and favourable ecological character. Species, originally native to the pacific part of the North America found wide use in many temperate regions of the World.

It is an important tree species in the western part of North America. It is valuated for its high timber quality, fast growth and strong resistance to pests and diseases. After the Second World War it became a major reforestation tree species in the western Europe, reaching values of 750.000 ha (0,66 % of total forest areas) covered of it (mainly in France, Germany and the United Kingdom). It is also remarkable its fast growth, being able to reach 30 m and 600-800 m^3 (15-20 m^3 per ha per year) at the proper sites in a very short time. In Europe, the species is occupying a niche, vacant since the Tertiary Age because of species extinction during the Ice Ages.

The main point of this diploma thesis roots in the necessity of knowledge about the behaviour of the species in different zones and under different conditions to introduce it on the correct places.

It will be developed in the following way: first, the literature review, where was made a study (literature review) about the different processes that occurs in soil formation, an exposition of the different soil parameters and an explanation and the interpretation of two practical cases about Douglas-fir effects on soil based on two scientifically articles original data, given by the Department of Silviculture of Faculty of Forestry and Wood Sciences of the CULS in Prague. Second, the methodology, where will be explained how the sampling was done and the exhibition of the data. Third, the results and discussion, where will be contained the analyses and interpretation of the obtained data. And fourth, the conclusion with the true facts extracted from the diploma thesis.

2. Aim

The aim of the diploma thesis is to evaluate the effects of Douglas-fir on the upper soil status in the stands of different species: Norway spruce (*Picea abies*), Grand fir (*Abies grandis*) and Oak (*Quercus* sp.). The accumulation of the surface humus and the soil chemistry in the holorganic horizons as well as in the upper mineral horizons was compared. There will be two study locations, Orlík and Vyžlovka. On each of them will be developed one separate study.

3. Literature review

3.1. Introduction of the species

3.1.1. Brief description of the species

Douglas-fir (*Pseudotsuga menziesii* /Mirb./ Franco) is one of the most known species in forest sciences as well as in the forestry practice in the world. It has been used for decades in most of the regions suitable for its exploitation in the temperate regions at particular continents. Next is going to be shortly introduced the main characteristics of the species in relation to its ecology and botanical description.

If we speak about its ecology it is necessary to mention that on its natural distribution it lives in an oceanic climate zone with small temperature variations between seasons. Winter time is mild with short frost period whereas summer is relatively dry and cold. The precipitations are concentrated in winter months. Speaking about its shade behaviour it is important to say that is quite tolerant to shade with middle light-intensive preferences while is growing up. To finish, on its soil demands it is remarkable its tendency to deep and clayey soils, well-stocked in nutrients, pervious, well aerated and with pHs around 5-6 (LEUGNEROVÁ 2008).

In the case of its botanical description the main characteristics are the following: it is a coniferous tree that can reach 55-100 meters height and from 1 to 3 meter thick measured at breast height. Its treetop can have different shapes along its life, conical at the beginning and ending rounded in old aged trees. The classical stem shape is long and cylindrical (in elderly trees naturally pruned) with 15 to 30 cm bark thickness. Needles length can fluctuate between 15 to 35 mm and they stay in branches from five to eight years. The seeds are 7 mm long with triangular shape and winged. The lifespan of the species swings from 500 to 1.000 years (LEUGNEROVÁ 2008). At present time, Douglas-fir represents the highest tree not only in the "World competition", but it is in the same time the highest tree of the Europe (Germany) and of the Czech Republic as well.

3.1.2. Distribution

The natural distribution of the species is also well defined by (LEUGNEROVÁ 2008), in which is necessary to remark that the species is original from a coastal area of western part of Northern America (north of the U.S.A. and south-western part of the Canada). Its borders are conformed in the following way: the northern ends in Vancouver Island in Canadian British Columbia, the area continue to the south about 2.200 km along the pacific coast. The eastern border finish in the mountain ridges of Cascade Range and Sierra Nevada; and finally, the southern border dies in Mexico. Its vertical range goes from the sea level to 2.300 meter altitude (Figure 1).

Figure 1: Natural distribution of *Pseudotsuga menziesii* (Mirb.) Franco.

Source: https://www.pinterest.com/pin/283093526557651291/

Here it is also necessary to speak about the current distribution of the species paying special attention on it distribution in Europe. It was initially planted as ornamental in parks of the U.K.. In the Czech Republic the first one was planted in Chudenice castle’s park, cca at 1838. In the forests, it was used at the end of the 19^{th} century in bigger extent,. Several years later (after the Second World War) it was done a huge reforestation in the west of the continent principally (most of them supported by grants of the states). The 80 % of the current areas cover by this tree are contained in France (half of the European area), Germany and the U.K. (Figure 2, Figure 3). It is also important to remark that it is the most abundant non-native tree species cultivated in Europe (SAN-MIGUEL-AYANZ et al. 2016).

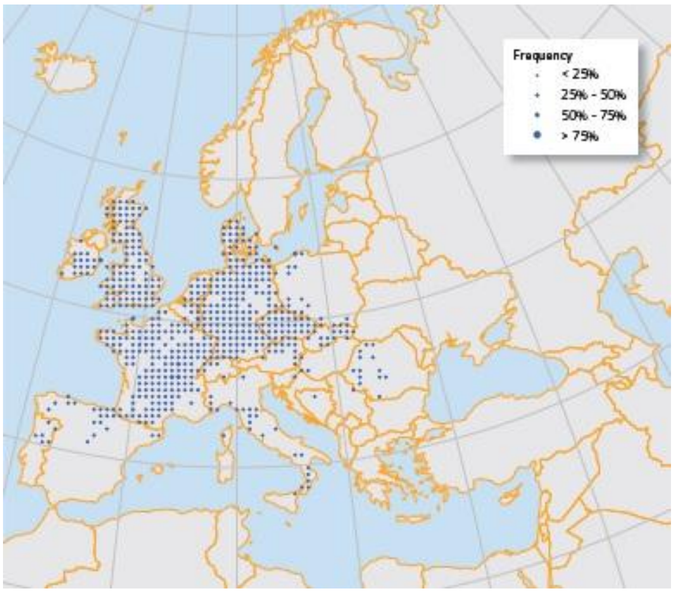

Figure 2: Current distribution of *Pseudotsuga menziesii* (Mirb.) Franco.

Source: San-Miguel-Ayanz, J., ... et al. (2016)

Table 1: Douglas-fir area per country in Europe (2013).

Source: Forest Tree Breeding in Europe

Table 7.1 Douglas-fir area per country in Europe (total sums in bold)

Country	Total forest area (ha)	Surface planted with Douglas fir (ha)	%
Austria	3,940,900	1,000	0.02
Belgium (Walloon region)	553,009	13,288	2.39
Bulgaria	3,700,000	6,714	0.18
Czech Republic	2,680,000	4,000	0.14
Denmark	527,000	6,392	1.21
France	15,500,000	400,000	2.58
Germany	1,1075,799	179,607	1.62
Ireland	625,750	10,200	1.63
Italy	8,675,000	3,000	0.35
Poland	9,049,000	4,852	0.05
Portugal	3,200,000	4,200	0.13
Romania	6,315,000	9,000	0.14
Spain	17,565,000	19,600	0.11
Sweden	27,528,000	500	0.002
The Netherlands	320,000	16,000	5.00
Turkey	1,008,800	1,400	0.14
United Kingdom	1,849,520	44,824	2.42
Total	**114,112,778**	**751,477**	**0.66**

After analysing the previous data of it original and present distribution it is natural to reach the conclusion, that the species has made a wide and fast spread in the different forest lands on temperate climate regions.

After this, an important question appears: why its distribution grows that much? The answer seems to be the values (economic and ecological) that this species provide to the society.

3.1.3. Benefits of the Douglas-fir cultivation

There are different reasons that had make *Pseudotsuga menziesii* the most abundant non-native tree species in the Europe. With this species it seems like the most valuated characteristics for its introduction were economic and ecologic. In the next paragraphs will be explained that reasons paying special attention in the Czech Republic particular case.

❖ Economic

The importance of this value lies down on it higher productivity and faster growing in comparison with the native tree species. It has a great wood quality. (REMES AND ZEIDLER (2014) confirmed high timber quality of Douglas-fir, which makes it suitable for the wood European industry. It is also important to support these affirmations with verified information obtained from different contrasted scientific articles. Analysing them we can affirm that the most productive species are *Pseudotsuga menziesii* and *Abies grandis* with a huge difference to the others. That conclusion is supported by different affirmations in some scientific articles like in (PULKRAB et al. 2014) where is said that Douglas-fir has a production dominance in comparison with other species. In the Czech Republic it is better than all native tree species and most of the introduced. It would be only less productive than Grand fir in the suitable places for it. Accepting it higher productivity, it would make no sense to introduce it if you would not receive a higher economic income with it than with the native species. According to PULKRAB et al. (2014) the potential introducing area (following all the ecological restrictions contained in the Czech legislation) has to oscillate in a range from 149.616 to 163.173 ha which would mean a significant increase on Czech forest surface covered by this species (from 0,22 % to 5,7-6,2 %).

The attainment of those introduction values would generate a potential economic effect of 27-30 mill. € per year (using for the income prediction the criterion of the gross yield of forest production). Therefore we are allowed to affirm that Douglas-fir would increase the economic income in comparison with the of the tree species (excepting Grand fir).

- ❖ Ecologic

Among all the ecologic characteristics of the species there are a few that made it suitable for its introduction in Europe and in the Czech Republic. Here I am going to get on the main ones: soil, erosion, water and biodiversity.

In relation to the soil there are different facts to take in consideration. One of them is the soil-forming effect, which was considered negative for this species at the beginning of its introduction processes. As is said in PULKRAB et al. (2014) paper: the soil forming function of the species has been deeply analysed and the results of the investigation has conclude with the discard of the negative effects of the species on humus and mineral horizons. In addition, this result was also obtained in the less advisable monocultures (for soil parameters). After analysing the previous affirmation there is no reason to think that *Pseudotsuga menziesii* can cause any unfavourable effect on soil chemistry or structure. Moreover, in other papers like *Changes of agricultural land characteristics as a result of afforestation using introduced tree species* (PODRÁZSKÝ et al. 2016) is affirmed that Douglas-fir causes better effects in soil characteristics than native coniferous species (in Europe).

Other characteristic that make this tree good for its development in European forests is its great behaviour with erosion. The USDA (United States Department of Agriculture) Plant Fact Sheet says that Douglas-fir is an ecologically friendly tree and is excellent in restoration of eroded lands, watersheds and strip-mined areas. It is also a good tree for bearing strong winds and avoiding windbreaks (USDA. NRCS 2002).

The next studied characteristic will be *Pseudotsuga menziesii* water usage. It is extremely important for it correct management, spread and thrive among European forests. The sentence: water management styles of Douglas-fir and Norway spruce are different, being Douglas-fir more drought resistant (better water usage characteristics) (PULKRAB et al. 2014) can lead us to think that, first, Douglas-fir is an ecologically friendly tree to introduce in central Europe and, second, it is a possible substitution for Norway Spruce on it distribution limits in lower altitude zones.

There are also several considerations about the biodiversity that this tree generates among it. The most important which is necessary to consider is that Douglas-fir cultivation decreases the abundance of the species but increases species diversity of the stands (PODRÁZSKÝ et al. 2014). Facts that can be good for the ecosystem if this make it richer on it variability.

❖ Particular case: The Czech Republic and Douglas-fir

A species substitution from Norway spruce to Douflas-fir would be appropriate in the lower altitudinal zones of the native species for both ecological and economic reasons. On one hand, Norway spruce is the most important native tree species in the Czech Republic (is spread around all the country and has quite strict ecological requirements) for both economic (is the most productive of the native species) and ecological reasons (PODRÁZSKÝ 2014). On the other hand, Douglas-fir could be a suitable substitution species for Norway spruce in part of its distribution where is not native at all (there will not be allowed a substitution in the natural distribution area of Norway spruce). The minimum acceptable area of Douglas-fir introduction has to be from 149.616 to 163.713 ha (which would increment the timber production continuously from 300.000 to 600.000 m^3 per year in that time period) (PODRÁZSKÝ et al. 2014).

With the substitution could be avoided problems like the declining timber production of Norway spruce and its ecological problems in the not appropriate zones for its thrive. Favourable effects can be generated in soil, plant communities and wealthy of the country and the rural zones nearby the forests.

3.2. Factors of soil formation

An accurate definition of soil could be “The unconsolidated mineral or organic matter on the surface of the Earth that has been subjected to and shows effects of genetic and environmental factors of: climate (including water and temperature effects), and macro- and microorganisms, conditioned by relief, acting on parent material over a period of time" (SOIL SCIENCE SOCIETY OF AMERICA 2017).

It is the part of the earth where life is sustained. It has been developing for thousands of years and is the only element in our ecosystems we cannot recover in case of loss. For that reason is extremely necessary to know how it works to preserve and manage it in the correct way. There are different factors that influence the soil on its formation and composition. In the following pages it is going to be exposed that different factors and its effects act on soil formation. These are the parental material, topography, climate, organism and time.

3.2.1. Parental material

Soil parent material is the material that soil develops from and can have different origins. One is the rock that has been decomposed by weathering processes. Others are the materials that have been deposited by climatic factors like wind, water and ice (RITTER M. E. 2006).

To start, are going to be introduced several basic considerations about the parental material. First, it is the factor where the rest of the elements act in the soil formation, thus, there is where the soil develop its characteristics. Second, its influence on soil characteristics is more noticeable in the early formation stages of soil. In a mature soil the climate can make it almost disappear. Third, in the soil are only contained small pieces of the parent material (in lower quantity when the development of the soil increases).

There are different characteristics of the parent material that influence the soil formation and its final composition. The mineralogical composition influence the speed of development and evolution capacity of soils. In parent materials with rocks formed from unstable minerals will happen an easy and fast soil formation. On the other side, on parent material with rocks formed from stable minerals will proceed a slowly and probably not complete soil formation (hard minerals to disperse by the formative factors acting on it). The permeability is responsible of the penetration and circulation of air and water. Therefore it controls the phenomenon of materials fragmentation, alteration and translocation. The granulometry is based in the size of the particles of the soil. Sand materials (big particles) will have a great stability while clay materials offer opposite properties.

3.2.2. Topography

Topography is defined by the slope, landscape position and surface shape of a certain piece of territory (NZ SOIL –FROM WHICH WE GROW 2011). This is one of the principal points which influence the soil formation and its characteristics. The main factors are the slope and length of the hillside and the location and orientation. On one hand, we have stable surfaces (flat terrains and the lower part of the mountain, the glacis) where the action of the formative effects is continuous and for a long period of time. Therefore, the horizons will be well formed and will be easy to distinguish them among the soil profile. On the other hand, we can find unstable surfaces (escarpments, floodplains and valley bottoms) where the soil is continuously renewed making more difficult the stratification.

To finish, in this factor it is necessary to point out other phenomenon that occurs in relation with the relief. One is that depending on it slope the soil absorbs more or less water (which is important for the speed of the formative soil processes). Other is that the relief generates different microclimates that are function of it. There are three factors controlling it: the slope, the orientation (which will mark the hours of calorific energy received) and the altitude, which influence all the climatic factors (GANDULLO 2000).

3.2.3. Climate

Climate refers to the temperature and moisture conditions (rainfall) that exist in a place over time. It can be considered a pattern because it does not change for a long period of time. It has a significant importance on soil characteristics because it controls the two main forming factors of soil: moisture conditions, which regulate weathering processes, and temperature, which control the reactions speed (SOIL SCIENCE SOCIETY OF AMERICA 2017).

It is the main and more influent factor on soil formation. This happen because it is the one who regulate the input of water (influence the processes of mobilization and elimination of components), the temperatures and indirectly the vegetation that will appear on each zone (element that will also influence the soil development and characteristics).

Consequently will be exposed the different soil formation processes where climate is the main influencer. One is the weathering, which can be physical for low temperatures (water entering in rock pores, freezing and breaking it) and chemical for high temperatures. Other one is the chemical alteration which will be higher as temperature and rainfall increases. As well, the infiltration intensity is one of the most important factors considering that it regulate the speed development of most soil processes.

It is also important to get in deep on the climate influence on soil components (clay and organic matter mainly). On one hand, high values of temperatures and rainfall will generate higher amounts of clay. On the other hand, the organic matter will increase with the rainfall and decrease with high temperatures.

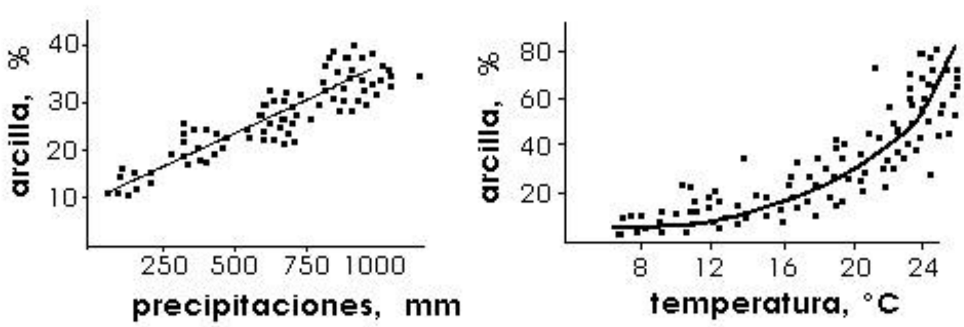

Figure 3: Clay amount in soil as function of rainfall and temperature.

Source: http://www.edafologia.net/introeda/tema01/factform.htm

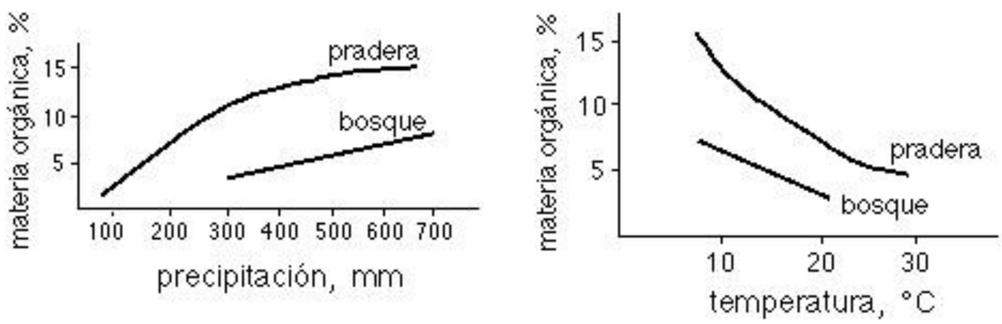

Figure 4: Organic matter amount in soil in function of rainfall and temperature.

Source: http://www.edafologia.net/introeda/tema01/factform.htm

Climate also influences the soil chemical features. One is on the cation exchange capacity (“Cation-exchange capacity (CEC) is a measure of how many cations can be retained on soil particle surfaces.” (WIKIPEDIA THE FREE ENCYCLOPEDIA 2017).) which increases proportionally with rainfall. Other case is with the precipitation increase, where is generated a progressive acidification that ends with the desaturation of the cation exchange capacity (substitution of Ca^{2+}, Mg^{2+}, Na^{+}, and K^{+} for H^{+}).

Summarizing, high temperatures and rainfall will accelerate all soil forming processes and therefore it thickness.

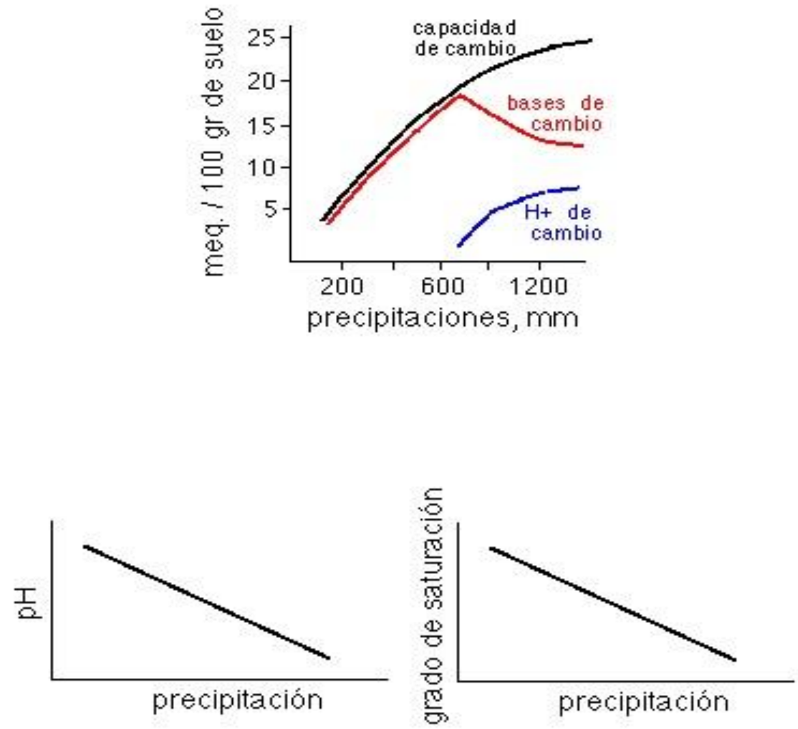

Figure 5: Cation exchange capacity, pH and saturation degree as function of rainfall.

Source: http://www.edafologia.net/introeda/tema01/factform.htm

3.2.4. Organisms

Animals, plants, bacteria, fungi and algae are some of the organism that participate in soil forming processes. They have important functions in carbon and nitrogen cycles.

The main ones are the plants that influence the processes with two different types of actions. On one side, direct actions, controls the addition of organic matter, accelerates the weathering and increases the porosity and controls the water and air movement on the soil profile. On the other side, indirect actions, generate protection effects from the canopy, giving shade to soil and catching the water drops (reducing it erosive effect) It also slows down the erosion and stops the superficial runoff with the increasing of the infiltration capacity. In addition, the root system breaths, segregates substances and absorbs water, which causes translocations of soil materials.

3.2.5. Time

Time is one of the main forming factors of soil and in function of it will be developed its different characteristics. It influence the weathering rates (as much time as much weathered material) soil horizon formation (more time will produce more developed horizons), erosion processes, vegetation growth and accumulation of organic matter or its removal by decomposition. All the processes are headed to reach an equilibrium, which will get closer with the pass of time. The time period to reach that balance could be around 10.000 years (PIDWIRNY 2006), that is to say that soil develop its characteristics with the time.

3.3. Chemical parameters of soil

In this part will be briefly explained the parameters through which will be interpreted the soil data analysed (in further chapters will be exposed the sampling, analyses and statistical interpretation of the data).

- Dry matter

It has a great capacity of cation exchange which can allow it to retain an important amount of principal cations which are absorbed from the plants to its develop. It is a good indicator of soil fertility because on it is a source for origin the humus of soil (has to exist in a certain amount to the correct growth of plants).

❖ pH

It "is a measure of the active hydrogen ion (H^+) concentration. It is an indication of the acidity or alkalinity of a soil, and also known as "soil reaction"." (UNITED STATE DEPARTMENT OF AGRICULTURE 2014). It moves from 0 to 14 being 7 the neutrality, 0 the most acidity and 14 the highest alkalinity.

Different phenomena appear with it variation. On one side, in high acidity soils the exchange complex will be full of H^+ and Al^{3+} which avoids the presence of principal cations (Ca^{2+}, Mg^{2+}, Na^+ and K^+), making them pass to the soil solution and exposing to leaching. On the other side, on high alkaline soil, the exchange complex saturates and causes an elevate calcium storage which avoid the absorption of other elements like iron.

The plants generally develop better their characteristics and functions in pHs close to the neutrality where they can find easily the nutrients they need.

Table 2: Evaluation of soil reaction, according to the pH values

Source: Mª Soledad Garrido Valero. *Interpretación de análisis de suelos*

EVALUATION OF SOIL REACTION, ACCORDING TO THE PH VALUES		
Ph (measured in water, in disolution of 1/2)	Type	Observations
0 - 5,5	Very acid	Difficulty in the development of most crops, difficulty in retaining many nutrients
5,5 - 6,5	Acid	
6,5 - 7,5	Neutral or close to neutrality	Optimum range for crops
7,5 - 8,5	Alkaline	
8,5 - 14	Really alkaline	Difficulty of development of most crops, possible appearance of ferric chlorosis

❖ Cation exchange capacity (T, CEC)

It is the amount of absorbed cations in an exchangeable way which neutralise the negative charges of a certain weight of soil. That is to say that it is the measure of cations that can be retained on soil particle surface (GARRIDO 1994). Below will be exposed a table with reference values for this parameter.

Table 3: Cation exchange capacity of a soil (T).

Source: Mª Soledad Garrido Valero. *Interpretación de análisis de suelos*

CATION EXCHANGE CAPACITY OF A SOIL (T)		
Total T (mval/100 g)	Level	Observations
0 - 10	Very low	Very poor soil; needs important adition of organic matter to raise T
oct-20	Low	Poor soil; needs organic matter addition
20 - 35	Medium	Medium soil
35 - 45	Medium high	Rich soil
Higher than 45	High	Vert rich soil

❖ Base saturation (V(%))

Base saturation indicates the balance between acid and base cations adsorbed by the cation exchange complex (CEC) of a soil (BACHE 2008). It is the percentage of the amount of principal/basic cations (Na^+ and K^+) in the exchange complex. It expresses the amount of free places for principal cations available on soil because the rest will be filled with H^+.

$$V(\%) = \frac{[Ca^{2+}] + [\mathrm{Mg}^{2+}] + [\mathrm{Na}^{+}] + [\mathrm{K}^{+}]}{T} * 100$$

In acid soils V(%) will be low while in an alkaline one will be close to 100 % or 100 %. In conclusion, the big it is V(%) the big is the soil capacity of cation retain.

Table 4: Base content V(%).

Source: Garrido (1994)

Base content V(%).	
V(%) Base content	Observations
Less than 50	Very acid soil; present difficulties in the nutrition of crops; it is advisable to add a limestone amendment
50-90	Average soil; its fertility will depend on the value of the total T.
Higher than 90	Soil saturated in bases; its exchange sites are being used. Its pH is almost neutral or basic.

❖ Bases content (S)

It is the amount of principal/basic cations in the exchange complex.

$$S = [Ca^{2+}] + [\mathrm{Mg}^{2+}] + [\mathrm{Na}^{+}] + [\mathrm{K}^{+}]$$

❖ Hydrolytic acidity (H)

It is the amount of H^{+} and Al^{3+} in the exchange complex.

$$H = [H^{+}] + [Al^{3+}]$$

❖ Exchangeable titration acidity

It is composed from exchangeable aluminium and hydrogen content and it is the amount of [H + Al] released from a soil upon exchange by an unbuffered KCl solution (BRIX 2008). It indicates soil acidity.

❖ Humus

It is the organic matter under different stage decomposition processes in soil. It can help to increase the amount of nutrients on soil because it high cation exchange capacity (great principal cation retain capacity). It is also a good indicator of soil fertility.

❖ Nitrogen

It usually appears in two forms in soil: NO^{3-} and NH^{4+}. NO^{3-} is easily absorbed by plants and NH^{4+} transforms fast to NO^{3-} so the most of nitrogen soil measurements are based in NO^{3-} measure. If it presence is shortfall, plants will suffer of chlorosis and premature necrosis, otherwise, if it presence is above the regular limits, plants will develop a huge canopy and decreases of fruit production and root growth.

❖ C/N ratio

Carbon to Nitrogen ratio (C:N) is a ratio of the mass of carbon to the mass of nitrogen in a substance (USDA 2011). It indicates the decomposition rates of the organic material. As bigger is the ratio as slower is the decomposition processes.

Values under 20 are considered as a positive value for the affirmation of an ongoing humification.

- ❖ Phosphorus

Phosphorus is an essential macro-nutrient which is necessary for plant growth in a certain levels (its excess or lack can cause different problems). It also participates on photosynthesis, energy transfer and synthesis and breakdown of carbohydrates (PHOSPHORUS IN SOIL AND PLANTS 2017). Its lack causes dwarfism and maturity retardation and its excess a huge root development.

- ❖ Potassium

It is contained on exchange sites in clays and organic matter and can pass easily to soil solution. Its scarcity causes weakness in the stalk, more sensitivity to pathogenic agents and growth retardation. Its excess could complicate the absorption of Ca^{2+} and Mg^{2+}.

- ❖ Calcium

It is a secondary plant macronutrient and it is basic for plant health. It is extremely necessary for leaves, stems and root formation because it participate in cell formation. In addition it is used for plants to combat disease attacks or pests (PLANTPROBS.NET 2017).

- ❖ Magnesium

It has a key role in many plant functions. It is basic in photosynthesis processes and it is a chlorophyll builder, which makes the leaves appear green (PITA 2013).

3.4. Particular cases of Douglas-fir

In this part is going to be studied two particular papers of the species where it produced different effects on soil. These are *Changes of agricultural land characteristics as a result of afforestation using introduced tree species* (PODRÁZSKÝ 2016) and *Soil-forming effect of Douglas fir at lower altitudes – a case study* (KUPKA 2013).

3.4.1.- Particular case 1: *Changes of agricultural land characteristics as a result of afforestation using introduced tree species*

The target of this paper is to document the changes of soil characteristics and upper soil dynamics in a mid-term period of time. The study was developed in stands of two introduced tree species (Douglas-fir and Grand fir) on lands with a previous agricultural use (PODRÁZSKÝ et al. 2016). The obtained results were compared with the ones of Norway spruce and grassland. In the following paragraphs are going to be analyzed the different soil parameter regarding to each species and its values, paying special attention on them statistical significance.

- Dry matter: No differences were revealed between them though the grassland value was slightly higher. Grand-fir had the lowest value and Norway spruce and Douglas-fir made no difference.
- Humus (Springel-Klee), Oxidizable carbon (Cox) and Combustible matter: Grass cover has significantly less because it has part of turf or mineral particles.
- Nitrogen (Kjeldahl): No significance differences between them (although grass showed less concentration under deeper layers).
- C/N ratio: No substantial differences were found between them. However, Norway spruce had the highest value with a significant difference with grassland. The second high value was from Grand-fir and the lowest ratios were measured on Douglas-fir and grasslands with more or less the same value. Although Norway spruce had the worst value (around 20) it is still considered that are acting humification processes.
- pH: Significant differences between grass and Grand-fir in comparison with Douglas-fir were found. The highest acidification level was found in Norway spruce stand.
- S: Grass had significantly the lowest level, slightly higher in Douglas-fir and significantly higher for the other tree species.
- H: It was significantly higher in the tree species (no significance between them) than in grass.
- T: The lowest level was found in grass with significantly higher values in the tree species.
- V (%): It was significantly higher in Grand-fir and grass. Lower values were registered for Norway spruce and especially poor percentage for Douglas-fir.

- Exchangeable titration acidity: In holorganic horizons it had significantly higher values in Douglas-fir and Norway spruce while in mineral soil horizons the biggest was Douglas-fir with a significantly difference with the others.
- Nitrogen (L – H horizons): It was significantly lower in grass. No differences between tree species were found.
- Phosphorus (L – H horizons): No significant differences although grass had the lowest value.
- Potassium (L – H horizons): Same behaviour than in phosphorus.
- Calcium (L – H horizons): Significantly differences appeared between grass and Douglas-fir and Norway spruce and Grand-fir (this two last with the higher values).
- Magnesium (L – H horizons): It was the same under grass and Douglas-fir and statistical differences were found with Norway spruce and Grand fir (Higher values).
- Phosphorus (Mehlich III): No significantly differences (though grass was the highest).
- Potassium (Mehlich III): In the grassland appeared much more than in the tree species ones.
- Calcium (Mehlich III): Much more presence on it in the forest species soils.
- Magnesium (Mehlich III): It was higher in the holorganic horizons of grasslands.

To conclude, as is said in the article: the prominent soil-improving function of Douglas-fir documented in other localities was not find out in this study (according to the surveyed nutrient-rich site). (PODRÁZSKÝ et al. 2016).

3.4.2. Particular case 2: *Soil-forming effect of Douglas fir at lower altitudes – a case study*

The aim of this paper is double, one particular and one general. The general is to make a comparison between Douglas-fir and Norway spruce (in a site corresponding to broadleaved species) whereas the particular get focused a little bit more on their effects on soil. It is a comparison between humus form quality and soil chemical characteristics the two species shape. The study is developed in a site corresponding to broadleaved species (KUPKA et al. 2013).

- Dry matter (L+F1, F2+H): It was found the lowest amount of it in the mixed broadleaved stands. On the F2+H layer was found a significantly higher amount (implies a less humification capacity).
- Nitrogen (L+F1, F2+H): Not statistical significantly differences (though Douglas-fir had the highest values).
- Potassium (L+F1, F2+H): Same behaviour than in nitrogen and with the lowest amount in Norway spruce.
- Magnesium (L+F1, F2+H): Not statistical significantly differences.
- S: It appears in higher amount in broadleaved stands, medium in Douglas-fir and low in Douglas-fir.
- pH: Significantly differences were found in F2+H. Douglas-fir was an acidifying species but Norway spruce did it in a bigger grade.
- V (%): It was bigger in broadleaved stands.
- T-S: Douglas-fir appeared between Norway spruce and broadleaved plots (Norway spruce with the higher values)
- Exchangeable acidity: It was significantly higher in broadleaved stands. However, in Al^{3+} the conifer stands had bigger values.
- Nitrogen (Kjeldahl): Not statistical significantly differences (though Douglas-fir had the highest values).
- C/N ratio: Douglas-fir had significantly lower values in comparison with the rest of the species except in F2+H layer.
- Phosphorus: It was significantly higher in broadleaved species in the holorganic horizon than in the other two. Douglas fir had better values in the mineral horizons than the rest.
- Potassium: The mixed stands had better amount than the coniferous species (Douglas-fir higher amount than Norway spruce).
- Calcium and magnesium: Same tendency than with potassium.

To finish, as is concluded in the article: The results of the article documented favourable effects of Douglas-fir on soil chemistry, organic matter and in nutrient dynamics. In comparison to native coniferous tree species it produces acidification in a lower level and recycles nutrients more effectively. It also contributes to the origin of better humus forms and produces litter easy to decompose and transform (KUPKA et al. 2013).

4. Material and methods

4.1.- Study areas

The soil sampling has been provided at two localities (1) locality Orlík, property of the family Schwarzenberg and (2) at the territory of the University Training Forest Kostelec nad Černými lesy (locality Vyžlovka).In the first case, the upper soil status was compared between Douglas-fir, native Norway spruce and oak, in the second one, between Douglas-fir, introduced Grand fir and old mixed coniferous stand, composed on domestic species. It was compared the humus form, i.e. the surface humus layers (L + F + H – holorganic layers) and uppermost mineral (organomineral) horizon A (Ah), accordingly to (GREEN et al. 1993). This approach allows to determine the effects of particular tree species in relatively short time.

4.1.1. Orlík

At the first locality, forest soils were sampled in 3 stands, their characteristics are documented in the Table 1. The property is Orlík nad Vltavou, s.r.o. The Forest management plan was valid since 2010 – the data in the table are related to this time. Soil sampling was performed in the monospecific forest stand parts.

Table 5: Stand and site conditions of studied stands (2010).

Stand	Age (2010) (years)	Area (ha)	FHG	Altitude (meters)	Species	Percentage (%)	MU	Rotation (years)	Regeneration period (years)
244A11a	112	4,05	3K	480	Norway spruce	85	43	110	30
					Scots pine	10			
					European larch	5			
246A13b	132	1,18	3S	480	Douglas fir	100	43	110	30
250 B 7	72	4,08	3S	480	Oak	50	43	140	40
					Norway spruce	45			
					Beech	3			
					European larch	1			
					Scots pine	1			

Notes:

Stand: forest differentiation administrative unit, marked in the forest maps

Age – age of the even-aged stand at the year of the Forest Management Plan validity

Area – extent of the forest stand as a management unit

FHG – Forest Habitat Group – the site differentiation unit accordingly to the Czech Forest typology System (VIEWEGH 1970)

Alt.: - altitude of the locality

Species – main forest tree species involved in the stand

Percent. – percentage of the species in the species composition

MU – management Unit – broader units, determining the main types of forest management (species composition, rotation, regeneration)

Rotation – prescribed age of the rotation

Reg. period – length of the regeneration of the stand

Species compositin: SM – Norway spruce, BO – Scots pine, MD – European larch, DG – Douglas-fir, BK – beech, DB - oak

- Stand 1: Age of the Norway spruce stand is 112 years (2011), the tree species composition: Norway spruce 85%, Scots pine 10%, European larch 5%. Plot was located in the pure spruce part, in a flat terrain. The natural forest type group is described as 3K – acid oak-beech forest. The stocking is 90%.

- Stand 2: The Douglas-fir stand is 132 years old, located on mild W slope. The stocking is 70%, determined by to looser Douglas-fir canopy. The natural forest type group is determined as 3S – medium rich oak-beech stand.

- Stand 3: The last stand is mixed broad-leaved forest with oak dominance, the plot was delimited in the pure oak part. The age was 72 years. Forest type group is determined also as 3S.

Soil type was Luvisol to Pseudogley. Sampling was done in March 2012 (March 8th) in the stand of Douglas-fir, oak and spruce, respectively in pure monospecific parts of individual stands. It was done by a corer of 6,5 cm diameter. Particular layers were separated, F+H, Ah, B, accordingly to GREEN et al. (1993). The thickness of each horizon was measured for each core (holorganic, A, B). Four bulk samples were done at each plot (species), each from 5 cores. So for each species and horizon, 4 replications were done. Laboratory analyses were provided in the accredited laboratory Tomáš, seating in FGMRI Opočno. By standard methodic, it was determined:

- Amount of dry matter (t/ha) at 105 ^{o}C, using re-calculation: amount of the sample originated from 5 cores of 6.5 cm diameter (g/sample). This needs calculation of amount per 1 m^2 and consequently to t/ha.
- pH active (H_2O) and potential by glass electrode, potentiometrically. Ratio of solid and water part was 1 : 2.5.
- Characteristics of soil adsorption complex by (KAPPEN 1929): S – bases content, documenting the amount of the basic cations fixed by the soil adsorption complex, H – hydrolytic acidity, expressing the amount of acid cations fixed by the soil adsorption complex, T – cation exchangeable acidity, as a sum of S + H, indicationg the total capacity of the soil to fix cations, V – base saturation, showing the ratio S:T, the proportion of fixing points of the complex occupied ba basic cations.
- Characteristics of exchangeable acidity and the content of exchangeable aluminum and exchangeable hydrogen.
- Total nutrient contents in the holorganic horizons (P, K, Ca, Mg) after mineralization by sulphuric acid and selen (ZBÍRAL 2001).
- Total carbon content (Springer-Klee method – *e.g.* CIAVATTA et al. 1989),
- Total nitrogen content by Kjeldahl (*e.g.* KIRK 1950),
- Plant avalilable nutrients contents (P, K, Ca, Mg) by Mehlich III (MEHLICH 1984) and in citric acid leachate.

4.1.2. Vyžlovka

Plot was established in the stand 405B4, roughly 100 m E from the Vyžlovka village, on the territory of former forest nursery. The extent of the plantation is circa 1200 m^2, rectangular shape. The altitude of the locality is 415 m a.s.l., soils are of Luvisol to Pseudogley type. Part of the nursery area was planted by Douglas-fir

(*Pseudotsuga menziesii*), part with grand fir (*Abies grandis*). Age was at the year of sampling 42 years. Prevailing forest type (Forest habitat type) is 3P1 (acid oak-fir forest, higher degree with spruce), management unit is 441. Stand was established in the spacing 1.5 x 1.5 m, a thinning was performed in 2013. The soil character was compared with the permanently afforested forest soil in the neighboring stand (100 years) of Norway spruce. Sampling was performed in September-October 2013. It was done by a corer of 6,5 cm diameter. Particular layers were separated, F+H, Ah, B, accordingly to (GREEN et al. 1993). The thickness of each horizon was measured for each core (holorganic, A, B). Four bulk samples were done at each plot (species), each from 5 cores. So for each species and horizon, 4 replications were done. Laboratory analyses were provided in the accredited laboratory Tomáš, seating in FGMRI Opočno. By standard methodic, it was determined:

- Amount of dry matter (t/ha) at 105 ^{o}C, using re-calculation: amount of the sample originated from 5 cores of 6.5 cm diameter (g/sample). This needs calculation of amount per 1 m^2 and consequently to t/ha.
- pH active (H_2O) and potential by glass electrode, potentiometrically. Ratio of solid and water part was 1 : 2.5.
- Characteristics of soil adsorption complex by KAPPEN (1929): S – bases content, documenting the amount of the basic cations fixed by the soil adsorption complex, H – hydrolytic acidity, expressing the amount of acid cations fixed by the soil adsorption complex, T – cation exchangeable acidity, as a sum of S + H, indicationg the total capacity of the soil to fix cations, V – base saturation, showing the ratio S:T, the proportion of fixing points of the complex occupied ba basic cations.
- Characteristics of exchangeable acidity and the content of exchangeable aluminum and exchangeable hydrogen.
- Total nutrient contents in the holorganic horizons (P, K, Ca, Mg) after mineralization by sulphuric acid and selen (ZBÍRAL 2001).
- Total carbon content (Springer-Klee method – *e.g.* CIAVATTA et al. 1989),
- Total nitrogen content by Kjeldahl (*e.g.* KIRK 1950),
- Plant available nutrients contents (P, K, Ca, Mg) by Mehlich III (MEHLICH 1984) and in citric acid leachate.

The results of the analyses were processed.

4.2.- Statistical evaluations the horizon soil properties

The influence of tree species on basic soil characteristics were evaluated by using one-way ANOVA methods. The comparison was done within the corresponding soil horizons for all three species on each case i.e. Douglas-fir, Norway spruce and oak stands in Orlík and Douglas-fir, Norway spruce and Grand fir in Vyžlovka. After checking the data normality the use of post-hoc test of significance differences on the level $\alpha=0.05$ between soil horizons under different species were done. Post-hoc test used in this study was Scheffe's test. The significant differences are labeled by different letters while the cases where the values are not significantly different have the same letter.

5. Results

5.1. Orlík

The results obtained at the research plot Orlík are documented in the Table 6 and Figures 6 – 22. In the table, there are documented the summary results, including the statistically significant differences. The same indexes indicate insignificant relations, the different indexes (for the same horizon, different tree species) indicate statistically significant differences. For each variable, i.e. pedochemical characteristics, the results are in detail shoved in the respective graphical form, i.e. Figure.

Table 6: Pedochemical characteristics in the soil horizons of particular tree species at the plot 1 – Orlík.

Source: Department of Silviculture. Faculty of Forestry and Wood Sciences. (CULS).

PEDOCHEMICAL CHARACTERISTICS IN THE SOIL HORIZONS OF PARTICULAR TREE SPECIES AT THE PLOT 1 - ORLIK										
SPECIES		Douglas-fir			Norway spruce			Oak sp.		
HORIZONS		F+H	Ah	B	F+H	Ah	B	F+H	Ah	B
CHARACTERISTICS	pH/H2O	4.84 a	4.43 a	4.31 a	3.91 b	3.66 b	3.82 b	5.25 a	4.52 a	4.57 a
	pH/KCl	3.98 a	3.29 a	3.18 a	2.85 b	2.85 b	3.11 a	4.27 a	3.31 a	3.30 a
	S (mval/100g)	24.44 ab	9.32 a	8.16 a	16.93 b	4.40 b	3.95 b	28.23 a	6.27 ab	4.42 b
	T-S (mval/100 g)	19.35 a	10.00 a	8.95 a	38.50 b	15.19 b	11.96 b	13.42 a	8.06 a	7.68 a
	T (mval/100 g)	43.79 a	19.32 a	17.12 a	55.42 a	19.60 a	15.91 ab	41.65 a	14.32 a	12.11 b
	V (%)	57.50 a	48.13 a	47.32 a	30.49 b	22.56 b	25.04 b	66.87 a	43.06 a	36.31 c
	Humus (Springel-Klee) (%)	18.30 a	8.35 a	6.50 a	28.26 b	7.09 a	4.53 b	17.77 a	4.97 a	2.18 c
	Oxidizable carbon Cox (%)	10.62 a	4.84 a	3.77 a	16.39 b	4.11 a	2.63 b	10.31 a	2.88 a	1.26 c
	N (Kjeldahl) (%)	0.690 a	0.134 a	0.063 a	0.770 a	0.156 a	0.079 a	0.846 a	0.222 b	0.094 b
	Titration acidity (mval/kg)	13.490 a	48.620 a	71.490 a	56.430 b	112.840 b	105.510 b	9.430 a	72.630 c	66.870 a
	H+ (mval/kg)	0.588 a	0.088 a	0.738 a	3.838 a	0.231 a	0.169 a	0.975 a	0.138 a	0.025 a
	Al^{3+} (mval/kg)	12.90 a	48.53 a	70.76 a	52.59 b	112.61 b	105.34 b	8.45 a	72.49 c	66.84 a
	Fe_2O_3 (mg/kg)	1243.20 a	1428.20 a	1467.40 a	1233.20 a	1686.50 a	1557.30 a	1746.50 b	1732.30 a	1626.50 a
	P (mg/kg) (Mehlich III)	61.50 a	85.00 a	82.00 a	37.00 b	58.25 b	61.00 b	49.00 a	18.25 c	21.75 c
	K (mg/kg) (Mehlich III)	645.50 a	123.25 ab	83.00 a	568.00 a	87.50 a	57.15 a	588.50 a	138.75 b	73.25 a
	Ca (mg/kg) (Mehlich III)	3690.00 a	964.25 a	717.50 a	1968.50 b	600.00 b	372.00 b	2717.50 b	603.50 b	480.00 b
	Mg (mg/kg) (Mehlich III)	288.50 a	108.25 a	96.00 a	329.00 a	101.25 a	82.75 a	488.50 b	132.25 a	106.00 a
	N (%)	0.742 a			0.836 a			0.885 a		
	P (%)	0.180 a			0.097 b			0.145 a		
	K (%)	0.490 a			0.345 b			0.495 a		
	Ca (%)	0.244 a			0.026 b			0.060 c		
	Mg (%)	0.370 a			0.118 b			0.160 c		

❖ pH (H_2O)

The Figure 6 shows the dynamics of active pH in particular soil horizons of individual tree species. These characteristics showed the highest values in the oak stand and the lowest in the spruce stand. The highest values for each species were documented always in the surface humus (organic – holorganic) horizon. The Douglas-fir stand exhibited the values closer to the oak one. The values were so much more favourable in the soil of Douglas-fir stand comparing to the stand of Norway spruce, but comparing to the oak stand, the values of the active soil reaction were insignificantly lower. The results were significantly different between oak and Douglas-fir at one side and Norway spruce at second side in the whole studied soil profile.

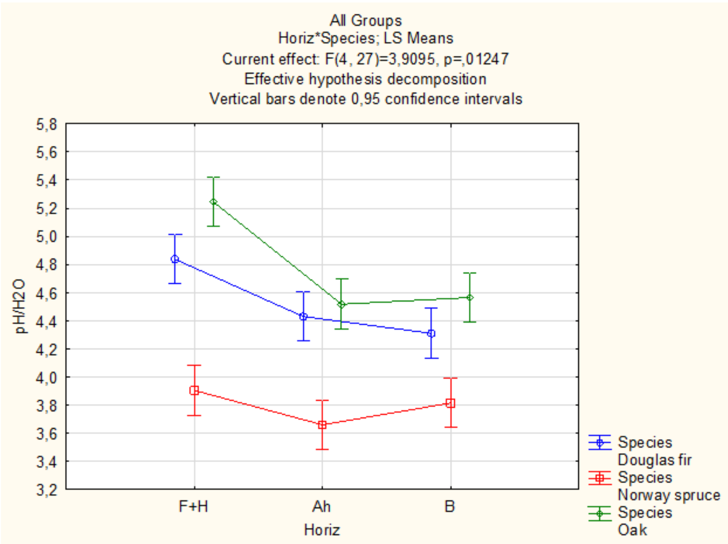

Figure 6: Soil reaction (pH H_2O) in particular soil horizons of different tree species at the plot Orlík.

❖ pH (KCl)

The Figure 7 documents the values of potential pH (in KCl). The differences among species showed the same dynamics, but the differences in the B-horizons were not significant. In the spruce, it was obvious, that the soil surface was acidified – the values decreased with increasing depth. In all other cases (also in the case of pH active) the values of pH were higher in the surface horizons.

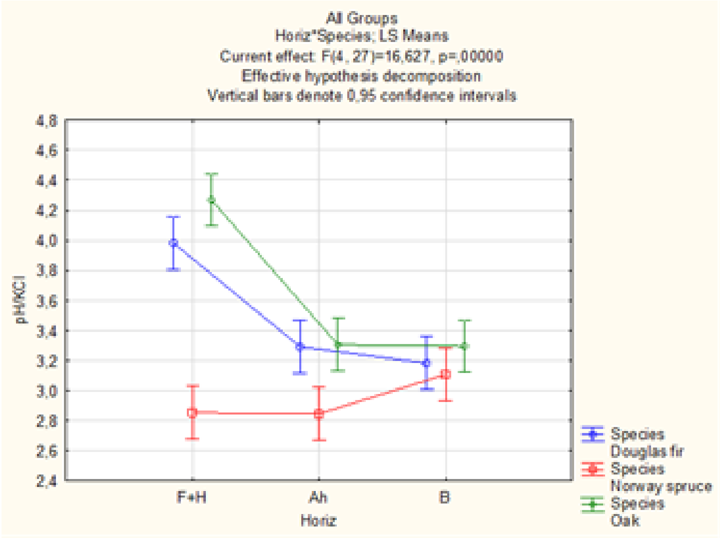

Figure 7: Soil reaction (pH KCl) in particular soil horizons of different tree species at the plot Orlík.

❖ Bases content (S)

Next Figure 8 summarizes the analytical results concerning the bases content (S-value). In the holorganic horizon, the values were in the order Oak-Douglas-fir-Norway spruce, statistical differences were between oak and spruce. In mineral horizons were the values the highest under Douglas-fir. The differences were significant between Douglas-fir and spruce.

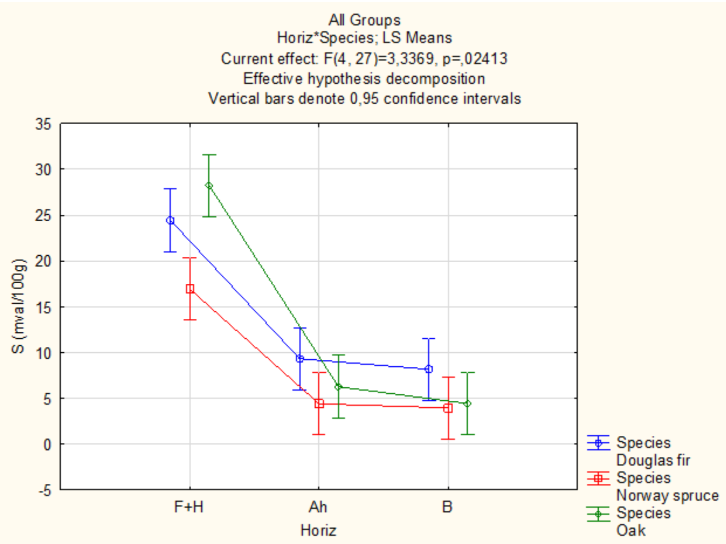

Figure 8: Bases content in particular soil horizons of different tree species at the plot Orlík.

❖ Hydrolytical acidity (T-S)

On the contrary, the values of the hydrolytical acidity (H-values) were the highest under spruce (Figure 9). The values decreased from F+H until B horizons, the differences were significant between Douglas-fir and oak on one side and spruce on the other one, being highest in the surface humus horizon and clearly showing the role of litter in this characteristics formation.

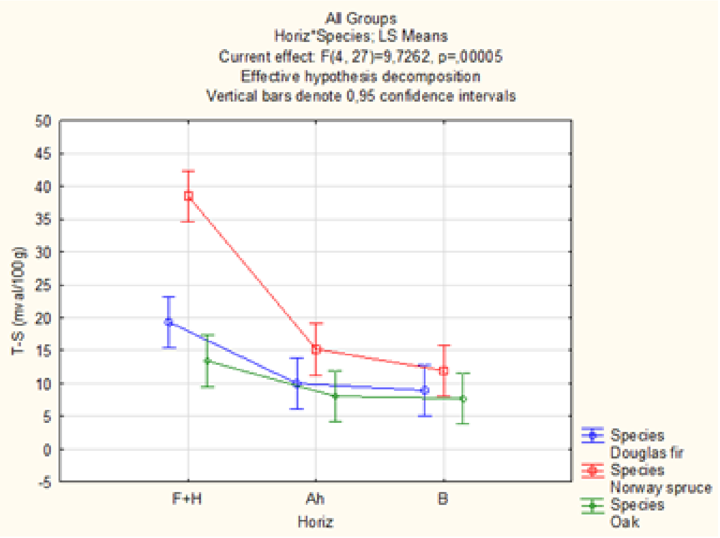

Figure 9: Hydrological acidity values in the particular soil horizons of different tree species at the plot Orlík.

❖ Cation exchange capacity

As a result, the Figure 10 documents the values of cation exchange capacity, as a sum of acid (H-vaue) and basic (S-values) cations. The results are not significant, only in the B-horizon, there are significant differences between oak (lowest) and Douglas-fir (highest values).

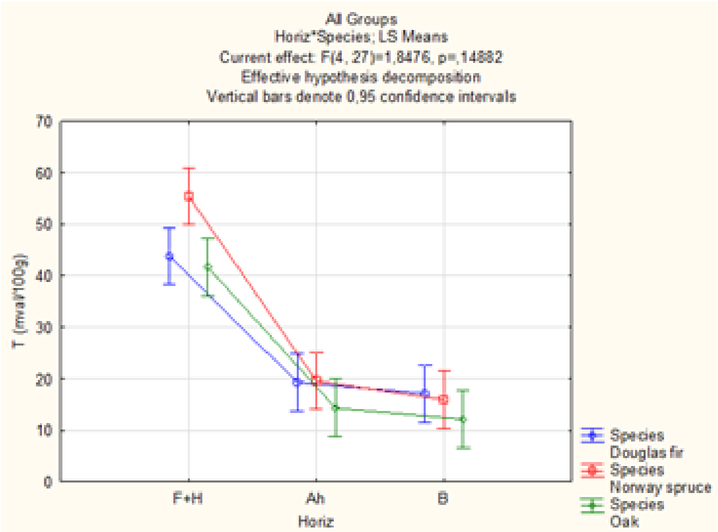

Figure 10: Cation exchange capacity (T-value) values in the particular soil horizons of different tree species at the plot Orlík.

❖ Base saturation

In the Figure 11 it is described the base saturation (%) on particular soil horizons of different tree species. The highest values were registered in the holorganic horizons and were getting smaller with the depth. In relation with the tree species, the highest values appeared in the Douglas-fir and oak stands while the lowest was in Norway spruce stands. Significantly statistical differences did not show between Douglas-fir and oak in the two first horizons although it exists with Norway spruce. In the deepest soil horizon (B) were found significantly statistical differences between all tree species (with Douglas-fir highest values and Norway spruce the lowest).

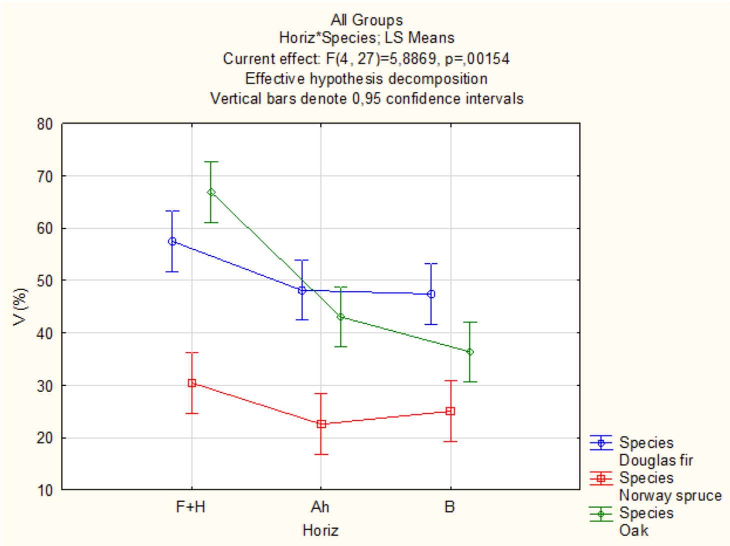

Figure 11: Base content (V(%)) values in the particular soil horizons of different tree species at the plot Orlík.

❖ Humus (Springel-Klee) (%)

Here it will be expressed the percentage of humus existing in the different soil horizons for the studied tree species. As usual, the highest amount appeared in the holorganic horizons (where it is deposited the biggest amount of organic matter that the ecosystem produces) where was registered the highest value in Norway spruce with significantly differences with the other tree species. With the depth, the humus amount decreases strongly with no statistical differences in the Ah horizon but with significantly differences between all tree species in B horizon (order from highest to lowest values: Douglas-fir – Norway spruce – oak).

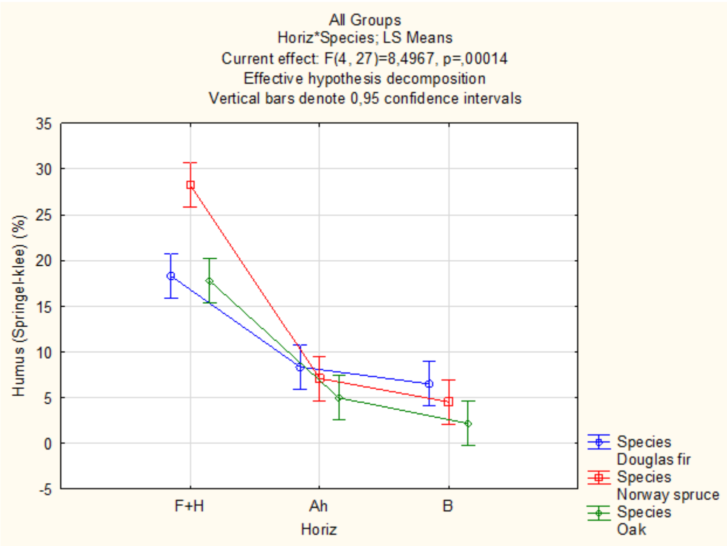

Figure 12: Humus (Springel-Klee) (%) values in the particular soil horizons of different tree species at the plot Orlík.

❖ Oxidizable carbon Cox (%)

In this paragraph is represented the oxidizable carbon amount. It follows the same behaviour than Humus (Springel-Klee) (%) and the same significantly differences between species and horizons.

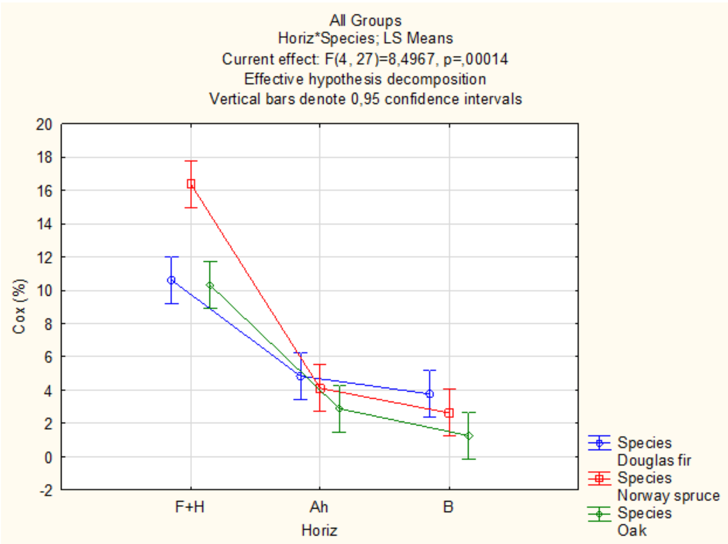

Figure 13: Oxidizable carbon Cox (%) values in the particular soil horizons of different tree species at the plot Orlík.

❖ N (Kjeldahl) (%)

In the Figure 14 it is expressed the content of nitrogenous in the different horizons of the studied tree species. The highest values were found in the holorganic horizons without significantly differences between species. In the mineral horizons the values decreases in all the tree species with higher values registered in oak stands with significantly differences with the coniferous species.

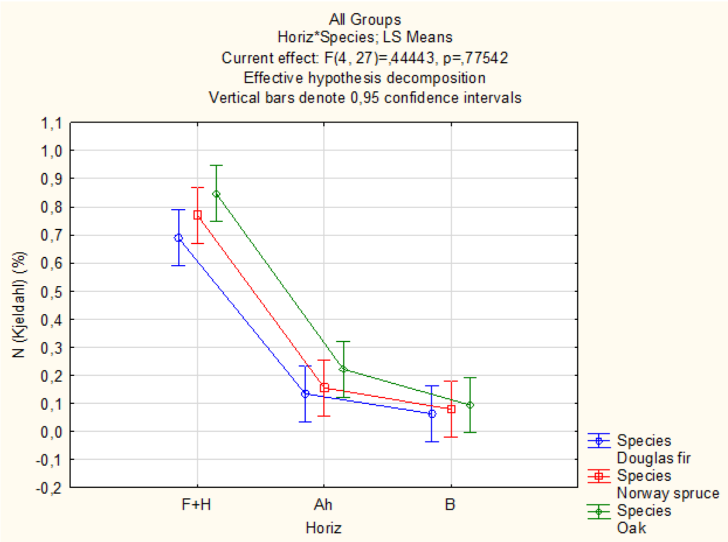

Figure 14: N (Kjeldahl) (%) values in the particular soil horizons of different tree species at the plot Orlík.

❖ Titration acidity (mval/kg)

In the following figure it is expressed the acidity in the different horizons. The highest values were found always in Norway spruce stands with big and significantly differences with the other tree species stands. In relation to Douglas-fir and oak it only appeared significantly differences in Ah layer with a higher value registered in oak stands.

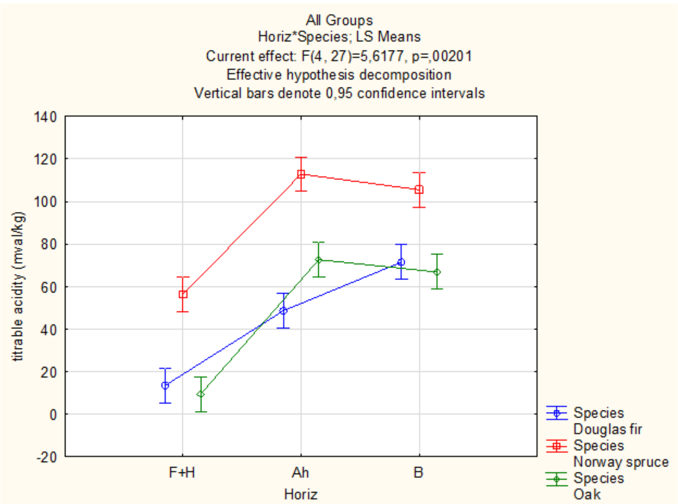

Figure 15: Titration acidity (mval/kg) values in the particular soil horizons of different tree species at the plot Orlík.

❖ H^+ (mval/kg)

In the Figure 16 it is expressed the H^+ concentration. Here was not found significantly differences between species and horizons, however appeared slightly higher values in Norway spruce holorganic horizons.

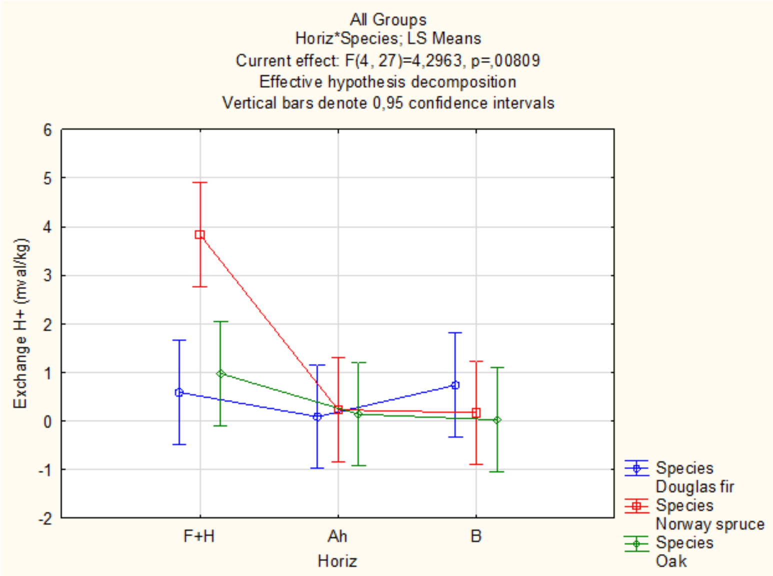

Figure 16: H^+ (mval/kg) values in the particular soil horizons of different tree species at the plot Orlík.

❖ Al^{3+} (mval/kg)

In the chart below it is represented the amount of Al^{3+} cations. It follows the same pattern the titration acidity does (both in values and statistical significance).

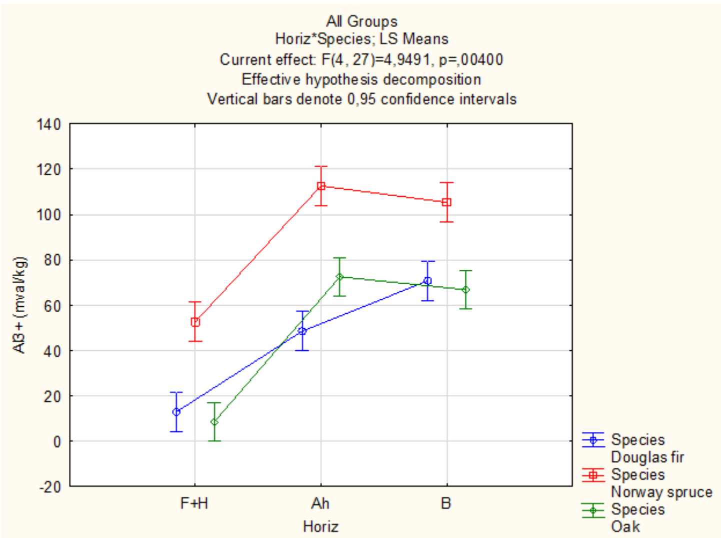

Figure 17: H^+ (mval/kg) values in the particular soil horizons of different tree species at the plot Orlík.

❖ Fe_2O_3 (mg/kg)

Here is exposed the Fe_2O_3 content in soil horizons. In the holorganic horizon appeared a significant difference between the coniferous species and the oak stands, being registered the highest values in the broadleaved species soil samples. No significantly differences were found in mineral horizons although oak obtained the biggest values.

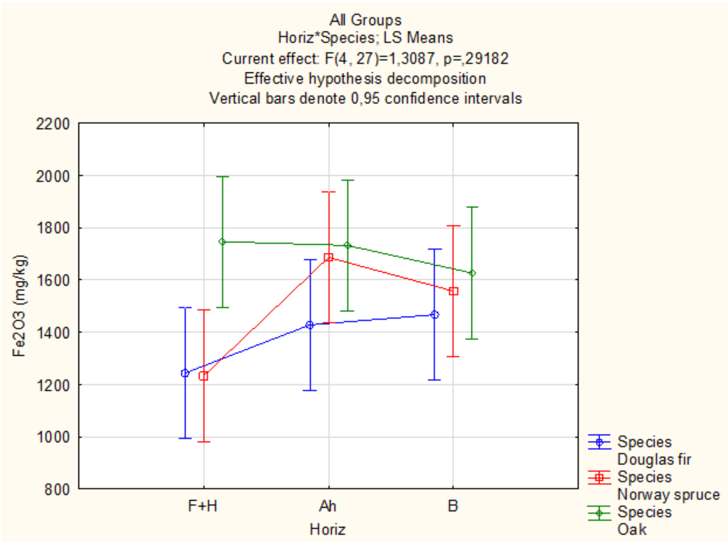

Figure 18: Fe_2O_3 values in the particular soil horizons of different tree species at the plot Orlík.

❖ P (mg/kg) (Mehlich III)

In the following graph is represented the phosphorus amount in different soil horizons of the tree species on study. The higher values appeared in this order: Douglas-fir – Norway spruce – oak (only oak is slightly bigger than Norway spruce in the holorganic horizon). There exist significantly differences among all tree species and horizons except in the F+H horizon between oak and Norway spruce (where oak is bigger than Norway spruce).

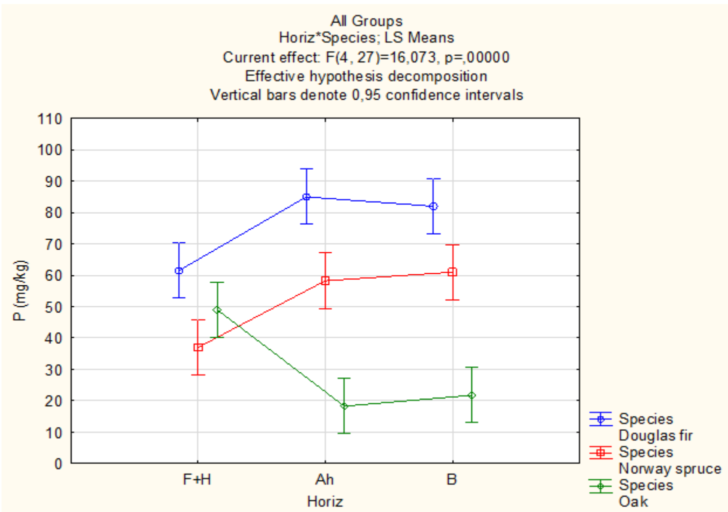

Figure 19: Phosphorus (mg/kg) (Mehlich III) values in the particular soil horizons of different tree species at the plot Orlík.

❖ K (mg/kg) (Mehlich III)

The Figure 20 expresses the potassium content of the different soil horizons of the tree species under study. They have quite similar values between species (usually with oak slightly higher). There were only found significant differences between spruce and oak in the Ah horizon (oak bigger values).

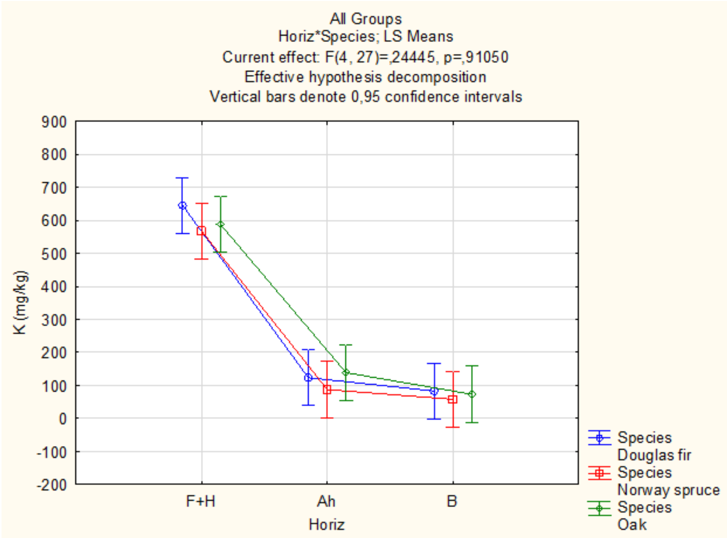

Figure 20: Potassium (mg/kg) (Mehlich III) values in the particular soil horizons of different tree species at the plot Orlík.

❖ Ca (mg/kg) (Mehlich III)

In the next figure is exposed the different calcium values for different horizons and tree species. The higher values were found in Douglas-fir stands with statistical significantly differences with spruce and oak (which had similar values).

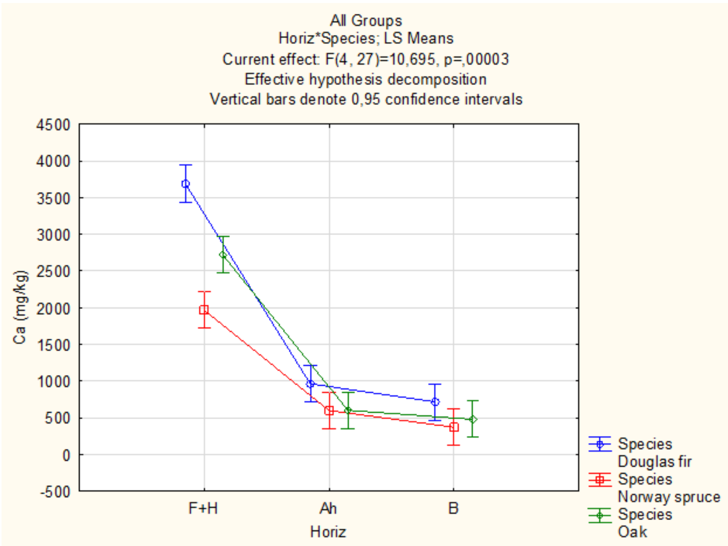

Figure 21: Calcium (mg/kg) (Mehlich III) values in the particular soil horizons of different tree species at the plot Orlík.

❖ Mg (mg/kg) (Mehlich III)

In the following chart is exposed the amount of magnesium in the different horizons for the tree species. The higher values were always found in the samples obtained in oak stands. There also appeared statistical significantly differences in F+H horizon between spruce and oak (which obtained higher values).

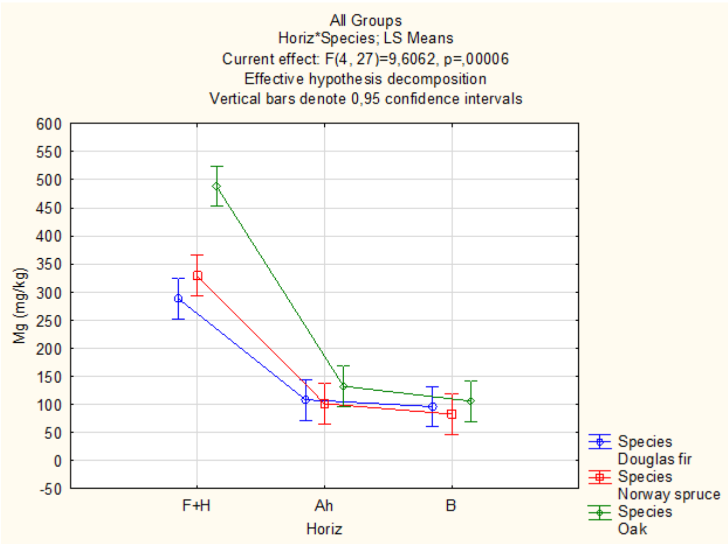

Figure 22: Magnesium (mg/kg) (Mehlich III) values in the particular soil horizons of different tree species at the plot Orlík.

❖ N (%), P (%), K (%), Ca (%), Mg (%)

The nutrient plant availability in the holorganic horizon is expressed in the table below. In the nitrogen amount was registered more or less the same values with no statistical significantly differences between them. In the phosphorus availability appeared higher values in Douglas-fir and oak, having a significantly statistical difference with Norway spruce (lower value). In potassium was registered the same behaviour than in phosphorus. The calcium responds to the order (higher to lower): Douglas-fir – oak – Norway spruce with significantly differences between all of them. Finally, in magnesium appeared the same pattern than in calcium.

Table 7: Plant nutrient availability in F+H soil horizon of different tree species at the plot Orlík.

PLANT NUTRIENT AVAILABILITY IN THE SOIL HORIZON F+H AT THE PLOT 1 - ORLIK				
SPECIES		Douglas-fir	Norway spruce	Oak sp.
HORIZONS		F+H	F+H	F+H
CHARACTERISTICS	N (%)	0.742 a	0.836 a	0.885 a
	P (%)	0.180 a	0.097 b	0.145 a
	K (%)	0.490 a	0.345 b	0.495 a
	Ca (%)	0.244 a	0.026 b	0.060 c
	Mg (%)	0.370 a	0.118 b	0.160 c

5.2. Vyžlovka

The results obtained at the research plot Vyžlovka are documented in the Table 8 and Figures 23 – 39. In the table, there are documented the summary results, including the statistically significant differences. The same indexes indicate insignificant relations, the different indexes (for the same horizon, different tree species) indicate statistically significant differences. For each variable, i.e. pedochemical characteristics, the results are in detail shoved in the respective graphical form, i.e. Figures.

Table 8: Pedochemical characteristics in the soil horizons of particular tree species at the plot 2 – Vyžlovka.

Source: Department of Silviculture. Faculty of Forestry and Wood Sciences. (CULS).

PEDOCHEMICAL CHARACTERISTICS IN THE SOIL HORIZONS OF PARTICULAR TREE SPECIES AT THE PLOT 2- VYŽLOVKA										
SPECIES		Norway spruce			Douglas-fir			Abies grandis		
HORIZONS		F+H	Ah	B	F+H	Ah	B	F+H	Ah	B
CHARACTERISTICS	pH/H2O	5.270 a	4.080 a	4.120 a	4.960 ab	5.250 b	6.280 b	4.400 b	4.500 a	5.420 c
	pH/KCl	4.320 a	3.440 a	3.530 a	4.490 a	4.940 b	5.930 b	4.170 a	4.160 c	4.670 c
	S (mval/100g)	24.078 a	6.055 a	1.953 a	26.100 a	12.444 b	15.260 b	23.773 a	10.391 b	11.916 c
	T-S (mval/100 g)	37.097 a	20.614 a	12.424 a	22.525 b	4.753 b	1.269 b	13.525 c	4.796 b	2.361 b
	T (mval/100 g)	61.174 a	26.669 a	14.376 a	48.625 a	17.196 b	16.528 a	37.298 b	15.188 c	14.278 a
	V (%)	39.69 a	22.71 a	13.55 a	53.83 ab	72.22 b	92.18 b	63.50 b	67.81 b	83.39 c
	Humus (Springel-Klee) (%)	43.25 a	13.86 a	5.09 a	32.53 a	5.26 b	3.53 b	19.72 b	4.79 b	2.53 b
	Oxidizable carbon Cox (%)	25.09 a	8.04 a	2.95 a	18.87 ab	3.05 b	2.05 b	11.44 b	2.78 b	1.47 b
	Combustible substance (%)	55.70 a	23.84 a	9.65 a	47.61 a	12.24 b	4.94 b	27.53 b	8.59 b	7.12 ab
	N (Kjeldahl) (%)	1.20 a	0.43 a	0.29 a	1.04 a	0.23 a	0.15 a	0.02 b	0.20 a	0.15 a
	Titration acidity (mval/kg)	30.35 a	72.78 a	87.00 a	13.28 b	2.63 b	1.23 b	12.80 b	4.49 b	1.91 b
	H+ (mval/kg)	8.05 a	0.79 a	1.26 a	5.38 b	0.25 a	0.01 b	6.05 a	0.63 a	0.15 b
	Al^{3+} (mval/kg)	22.30 a	71.99 a	85.74 a	7.90 b	2.38 b	1.22 b	6.75 b	3.87 b	1.76 b
	P (mg/kg) (Mehlich III)	48.50 a	61.00 a	55.00 a	59.00 a	63.50 a	61.25 a	46.50 a	30.75 b	24.75 b
	K (mg/kg) (Mehlich III)	403.00 a	141.00 a	99.50 a	545.50 a	138.25 a	116.50 a	588.00 a	139.00 a	105.80 a
	Ca (mg/kg) (Mehlich III)	2653.00 a	627.80 a	310.80 a	3266.00 a	1663.00 b	2286.80 b	2879.00 a	1538.50 b	2093.00 b
	Mg (mg/kg) (Mehlich III)	187.50 a	71.00 a	49.50 a	204.00 a	85.00 a	85.25 b	195.00 a	83.75 a	76.75 b
	N (%)	1250 a			1010 a			0.780 b		
	P (%)	0.119 a			0.092 a			0.107 a		
	K (%)	0.400 a			0.440 a			0.640 b		
	Ca (%)	0.144 ab			0.118 a			0.211 b		
	Mg (%)	0.036 a			0.148 b			0.136 b		

❖ pH (H_2O)

In the Figure 23 it is explained the different pH values in the different horizons and tree species of this locality. In the holorganic horizon were found the highest values in Norway spruce with significantly differences with Grand-fir (where was registered the lowest value). There were also found differences in the mineral horizons: first, in the Ah, the lowest values appeared in Norway spruce followed by Grand fir (without significantly statistical differences between them), with significantly differences with Douglas-fir (highest value); second, the deepest horizon, where was registered significantly differences between all tree species and the values order (from bigger to lowest value) was: Douglas fir - Grand fir - Norway spruce.

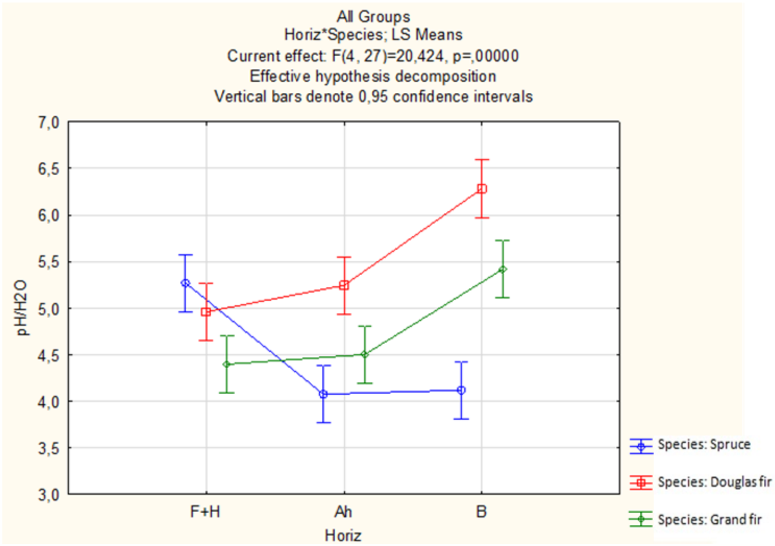

Figure 23: pH (H_2O) values in the particular soil horizons of different tree species at the plot Vyžlovka.

❖ pH (KCl)

The Figure 24 documents the values of potential pH (in KCl). In the holorganic horizon does not exist big differences between the data and did not appeared statistical differences. However, if we start getting on deep on soil, to the mineral horizons, appear statistical differences between all species and horizons. The values order in the mineral horizons was (form lower to bigger): Norway spruce – Grand fir – Douglas fir.

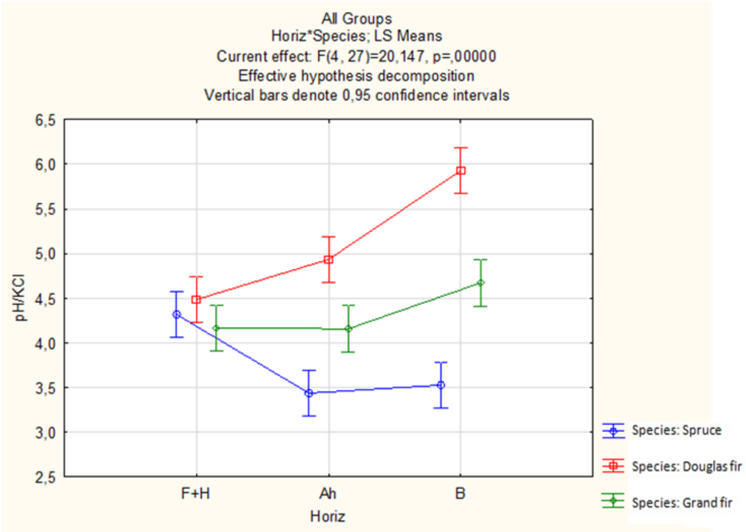

Figure 24: pH (KCl) values in the particular soil horizons of different tree species at the plot Vyžlovka.

❖ Bases content (S)

Next Figure 25 summarizes the analytical results concerning the bases content (S-value). In the holorganic horizon did not appeared any differences in the data between species. In the first mineral horizon the lowest values were found in Norway spruce, with significantly differences with the "firs". There were also found the lowest values in Norway spruce in the B horizon but here the statistical differences appeared among the tree species.

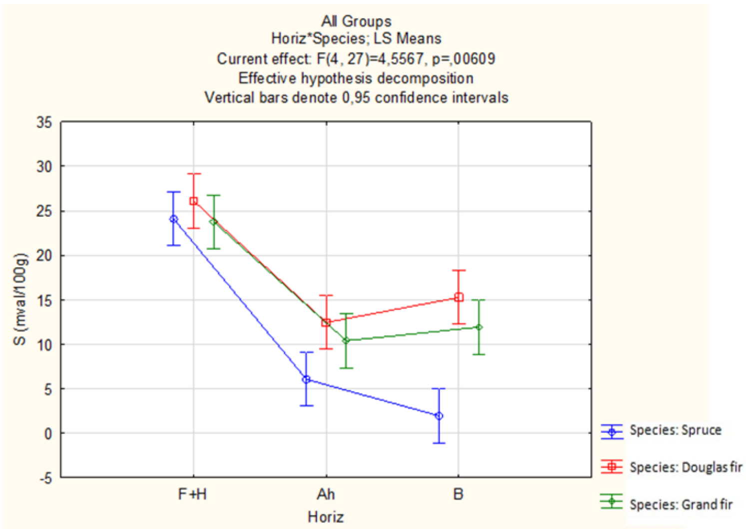

Figure 25: Bases content (S) values in the particular soil horizons of different tree species at the plot Vyžlovka.

❖ Hydrolytical acidity (T-S)

In the following chart will be exposed the values of the T-S. In this test the highest values were always found in Norway spruce. In holorganic horizons appeared statistical differences between all of them, values were decreasing from Norway spruce to Grand fir. On the other side, in the mineral horizons were registered statistical differences between Norway spruce and the rest of the tree species (no differences between firs).

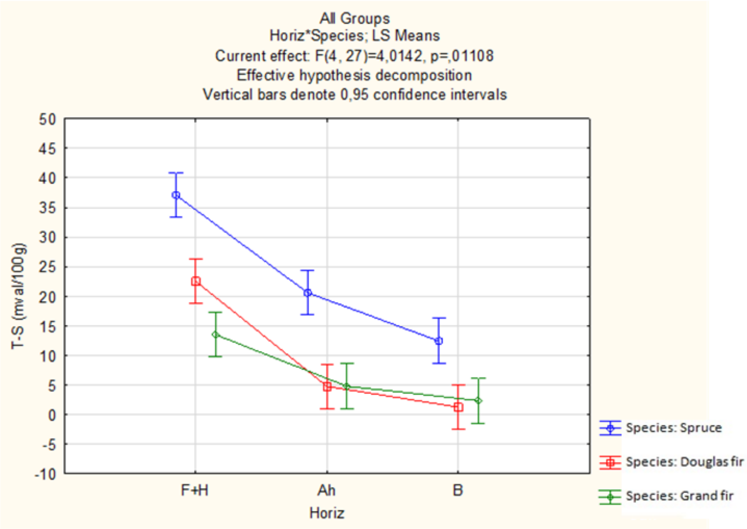

Figure 26: Hydrolytical acidity (T-S) values in the particular soil horizons of different tree species at the plot Vyžlovka.

❖ Cation exchange capacity (T)

The Figure 27 documents the values of cation exchange capacity, as a sum of acid (H-value) and basic (S-values) cations. In holorganic horizons the lower values were found in Grand fir with significantly differences with the other tree species. In the first mineral horizon appeared significantly differences among all species (with values decreasing from Norway spruce to Grand fir). Getting down on deep were not found significantly differences among the tree species.

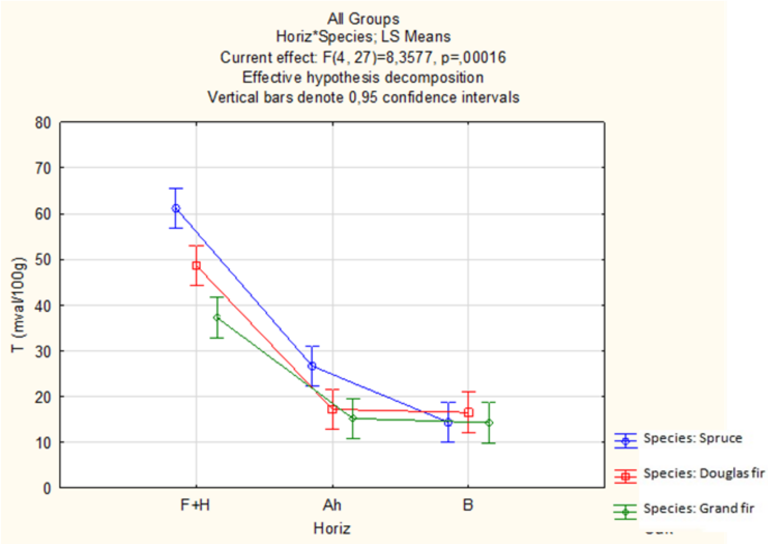

Figure 27: Cation exchange capacity (T) values in the particular soil horizons of different tree species at the plot Vyžlovka.

❖ Base saturation

In the Figure 28 it is described the base saturation (%) on particular soil horizons of different tree species. The lowest values (with an important difference) were found in Norway spruce, appearing the firs in more or less the same values. In holorganic horizons were registered differences between Norway spruce and Grand fir. In Ah horizon were also found differences now between Norway spruce and the firs (not between them). And in the deepest horizon appeared differences among all tree species.

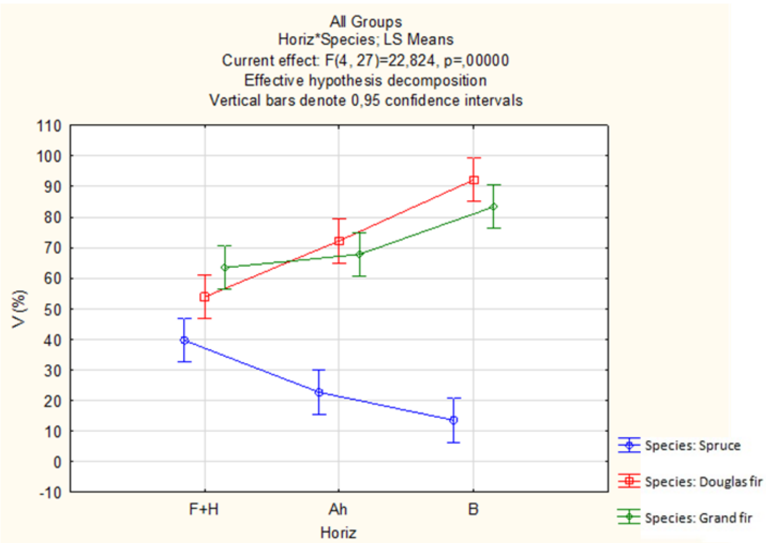

Figure 28: Base content (V) values in the particular soil horizons of different tree species at the plot Vyžlovka.

❖ Humus (Springel-Klee) (%)

Here it will be expressed the percentage of humus existing in the different soil horizons for the studied tree species. The higher values were always found in the Norway spruce stands. The significantly statistical differences were found in all horizons between different tree species: first, in the F+H horizon were found between Norway spruce and Douglas-fir with Grand fir (appearing the lower values in Grand fir); second, the Ah horizon, where were discovered statistical differences between Norway spruce and the firs (lower values in firs); third, the B horizon, which followed the same pattern as Ah.

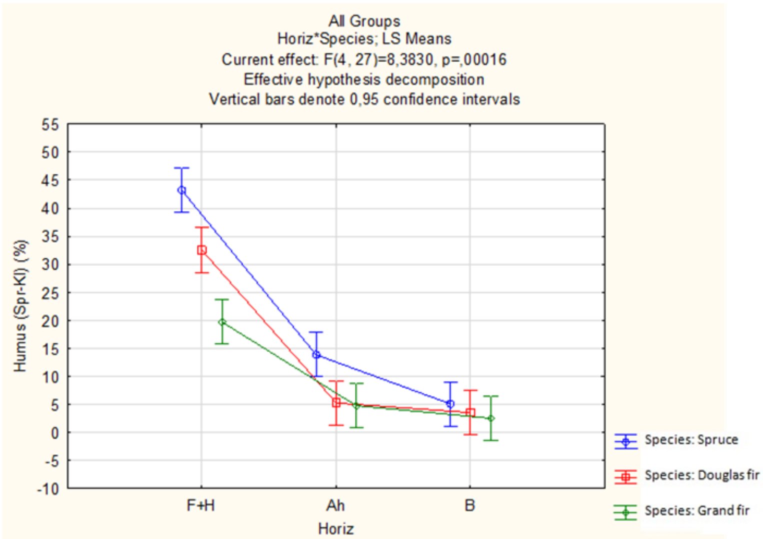

Figure 29: Humus (Springel-Klee) (%) values in the particular soil horizons of different tree species at the plot Vyžlovka.

❖ Oxidizable carbon Cox (%)

In this paragraph is represented the oxidizable carbon amount. Here it was always found the bigger values in Norway spruce stands. In relation to the statistical differences appeared the following results: on one hand, in the holorganic horizon the differences appeared between Norway spruce and Douglas-fir with Grand fir. On the other hand, in the mineral horizon were documented significantly differences between Norway spruce and the firs.

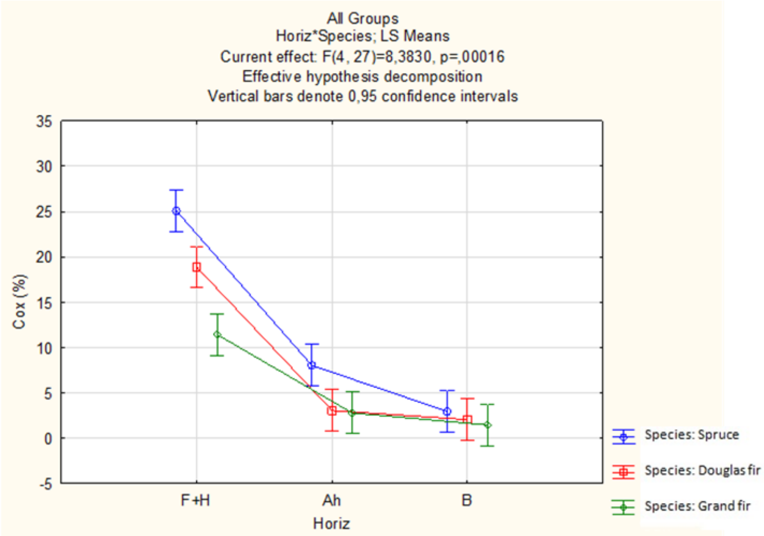

Figure 30: Oxidizable carbon Cox (%) values in the particular soil horizons of different tree species at the plot Vyžlovka.

❖ Combustible matter (%)

Here it will be expressed the percentage of combustible matter existing in the different soil horizons for the studied tree species. As in humus (%) and Cox (%) the higher values always appeared in Norway spruce. The significantly differences appeared in the following way: F+H horizon: between Norway spruce and Douglas-fir with Grand fir; Ah: between Norway spruce and the firs; and B: between Norway spruce and Douglas-fir.

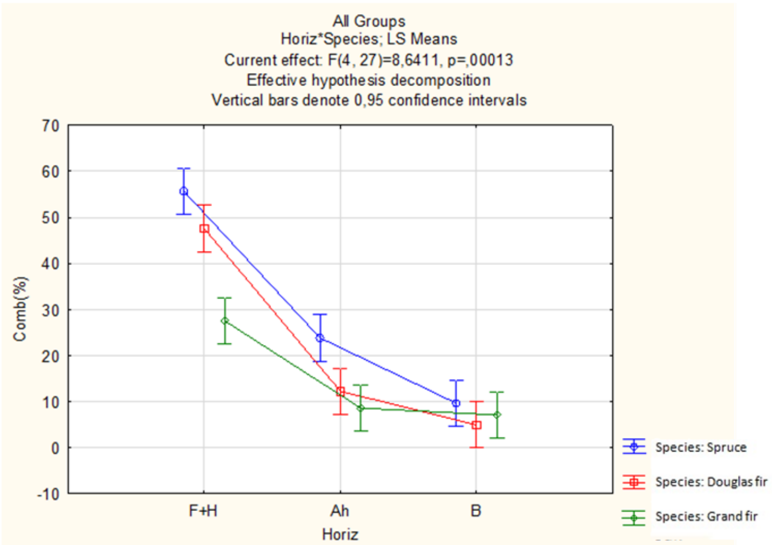

Figure 31: Combustible matter (%) values in the particular soil horizons of different tree species at the plot Vyžlovka.

❖ N (Kjeldahl) (%)

In the Figure 32 it is shown the nitrogen content in the different horizons of the studied tree species. The highest values were always found in Norway spruce but almost always without significantly differences (only in F+H horizon between Norway spruce and Douglas-fir with Grand fir, this last one with really low values).

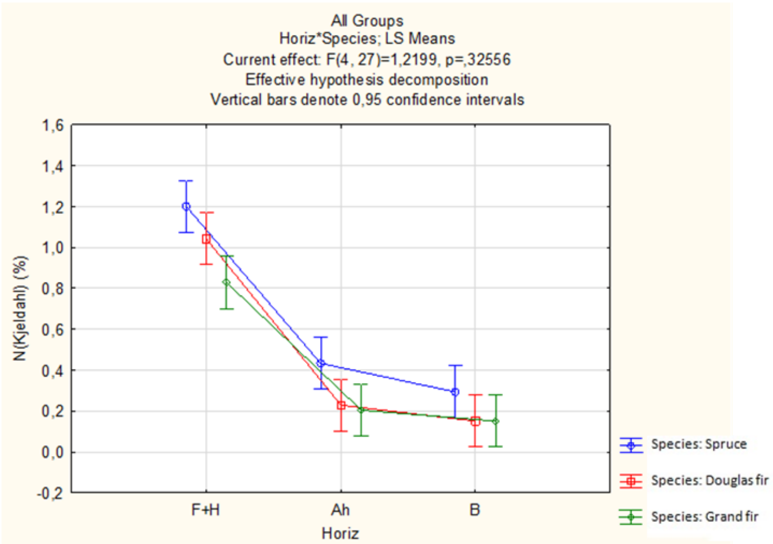

Figure 32: N (Kjeldahl) (%) values in the particular soil horizons of different tree species at the plot Vyžlovka.

❖ Titration acidity (mval/kg)

In the following figure it is expressed the acidity in the different horizons. The higher values were always found in Norway spruce with a huge difference comparing to the firs. There appeared significantly differences between Norway spruce and the rest tree species in all horizons.

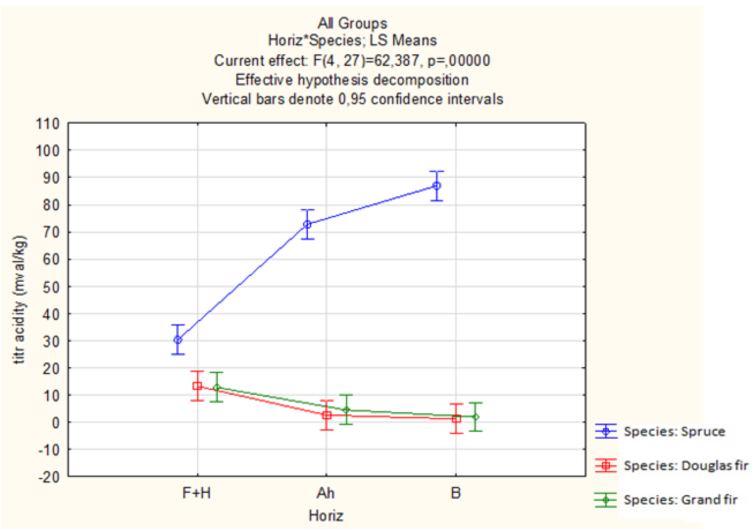

Figure 33: Titration acidity (mval/kg) values in the particular soil horizons of different tree species at the plot Vyžlovka.

❖ H^+ (mval/kg)

In the Figure 34 it is expressed the H^+ concentration. As in titration acidity the bigger values were documented in Norway spruce and the statistical differences manifested in the following way: in the holorganic horizon were between Norway spruce and Grand fir with Douglas-fir; did not appear in Ah; and in the deepest horizon were between Norway spruce and the firs.

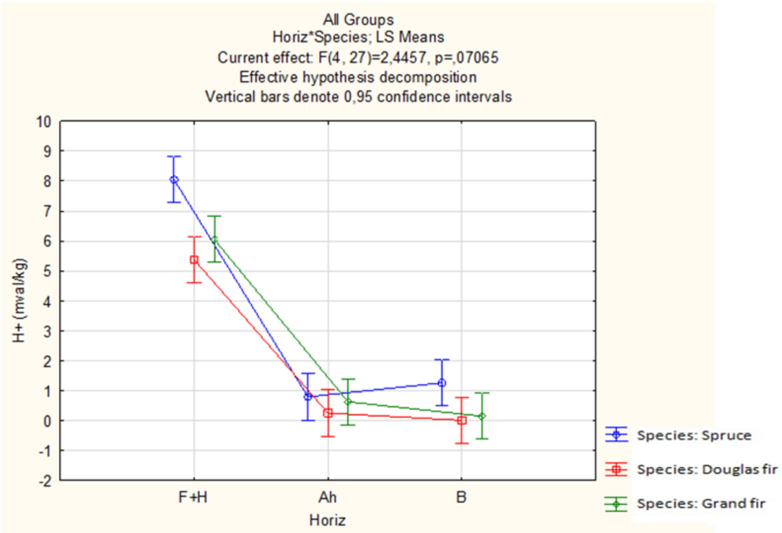

Figure 34: H^+ (mval/kg) values in the particular soil horizons of different tree species at the plot Vyžlovka.

❖ Al^{3+} (mval/kg)

In the chart below it is represented the amount of Al^{3+} cations. Here was registered the same pattern as titration acidity (mval/kg).

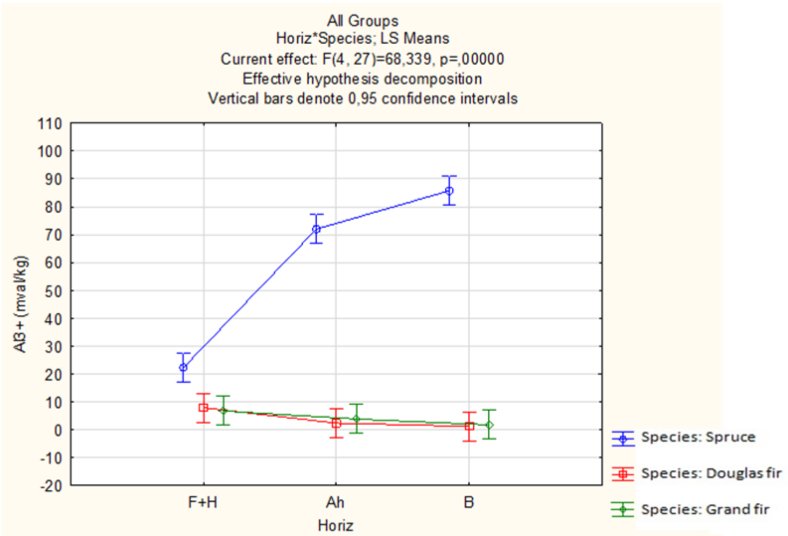

Figure 35: Al^{3+} (mval/kg) values in the particular soil horizons of different tree species at the plot Vyžlovka.

❖ P (mg/kg) (Mehlich III)

In the following graph is represented the phosphorus amount in different soil horizons of the tree species on study. The higher values were found in Norway spruce and Douglas-fir without statistical significantly differences between them. In the F+H horizon without significantly differences for Douglas-fir, but its values decreases in the mineral horizons where appeared significantly differences with Norway spruce and Douglas-fir (not between them).

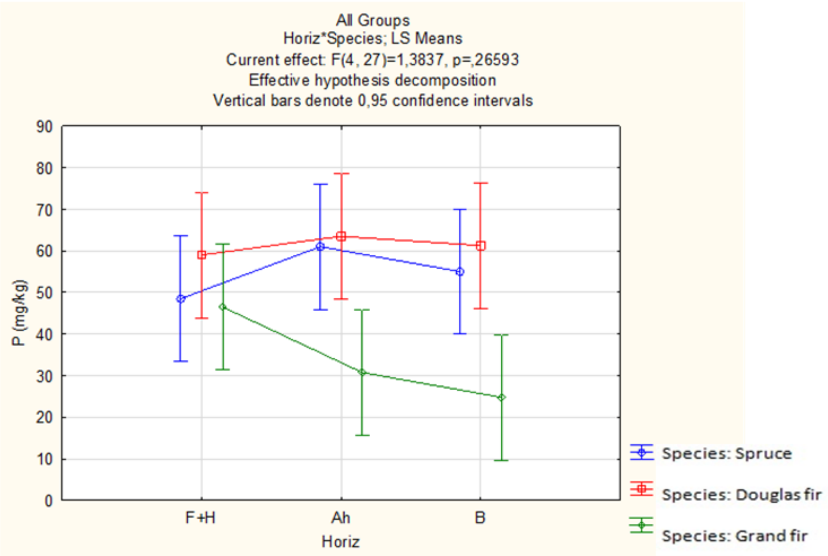

Figure 36: P (mg/kg) (Mehlich III) values in the particular soil horizons of different tree species at the plot Vyžlovka.

❖ K (mg/kg) (Mehlich III)

The Figure 37 expresses the potassium content on the different soil horizons of the tree species under study. Here were found values slightly higher in Grand fir but without significantly differences in any of the horizons.

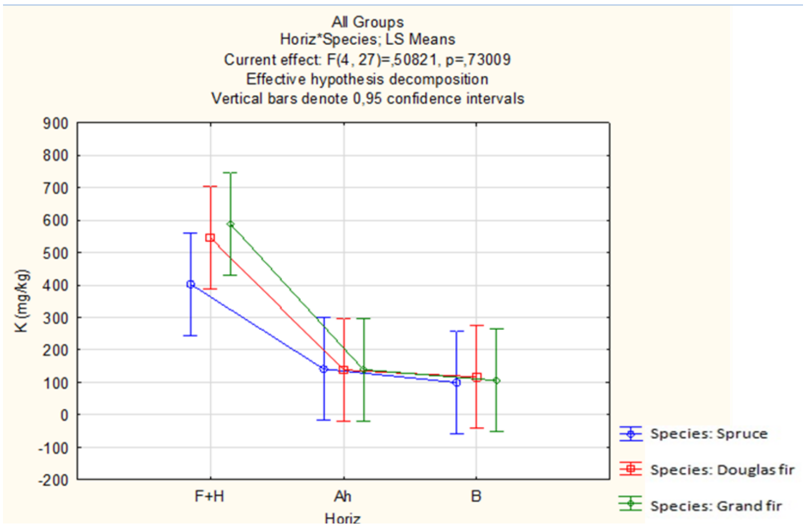

Figure 37: K (mg/kg) (Mehlich III) values in the particular soil horizons of different tree species at the plot Vyžlovka.

❖ Ca (mg/kg) (Mehlich III)

In the next figure are exposed the different calcium values for different horizons and tree species. The lowest values were found under Norway spruce stands in all the horizons. The significantly differences appeared in the mineral horizons between Norway spruce and the firs.

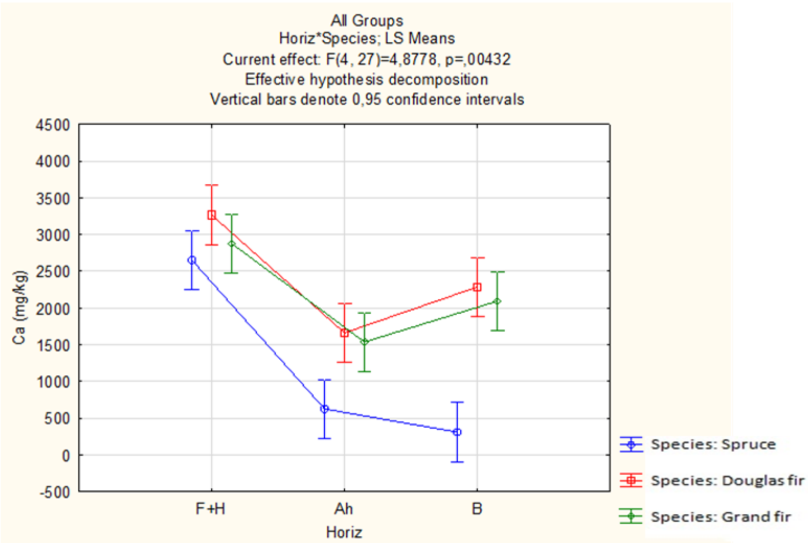

Figure 38: Ca (mg/kg) (Mehlich III) values in the particular soil horizons of different tree species at the plot Vyžlovka.

❖ Mg (mg/kg) (Mehlich III)

In the following chart is exposed the amount of magnesium in the different horizons for the tree species. It follows the same pattern than in calcium but the significantly differences were only found in B horizon.

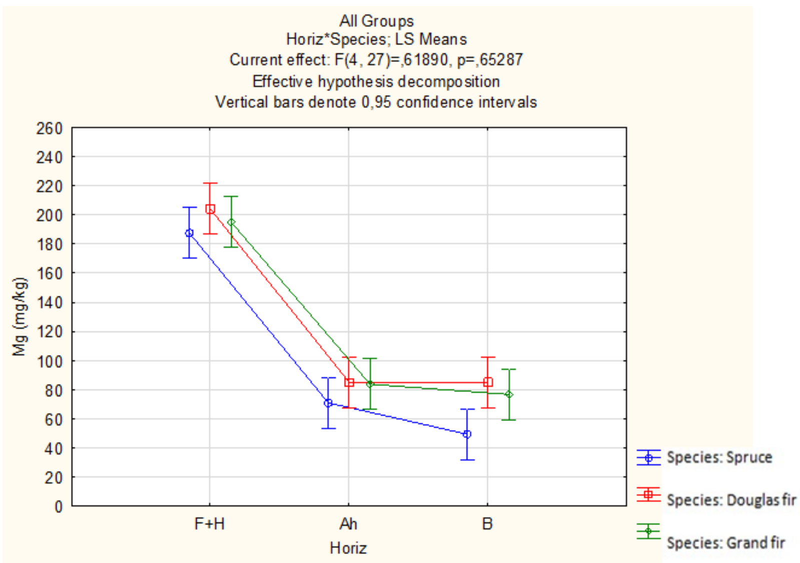

Figure 39: Mg (mg/kg) (Mehlich III) values in the particular soil horizons of different tree species at the plot Vyžlovka.

❖ N (%), P (%), K (%), Ca (%), Mg (%)

The nutrient plant availability in the holorganic horizon it is expressed in the table below. In the nitrogenous amount was registered higher values in Grand fir with statistical significantly differences with the other species. In the phosphorus availability did not appear significantly statistical difference among them. In potassium was registered the highest values in Grand fir (with significantly differences with the other tree species). The calcium documented significantly differences between Douglas-fir and Grand fir (Grand fir with higher values). Finally, in magnesium appeared significantly differences between Norway spruce and the firs (bigger values for firs).

Table 9: Plant nutrient availability in F+H soil horizon of different tree species at the plot Vyzlovká.

PLANT NUTRIENT AVAILABILITY IN THE SOIL HORIZON F+H AT THE PLOT 2 - VYZLOVKÁ				
SPECIES		Norway spruce	Douglas-fir	Abies grandis
HORIZONS		F+H	F+H	F+H
CHARACTERISTICS	N (%)	1250 a	1010 a	0.780 b
	P (%)	0.119 a	0.092 a	0.107 a
	K (%)	0.400 a	0.440 a	0.640 b
	Ca (%)	0.144 ab	0.118 a	0.211 b
	Mg (%)	0.036 a	0.148 b	0.136 b

6. Discussion

6.1. Orlík

In the following text will be exposed a comparison of the obtained results with others from different authors. It will also appear some observations or interpretations of the data.

To study the soil reaction and how it change among species one of the measurements used was: the pH/H_2O where appeared the lowest values in Norway spruce, existing a significantly statistical difference with oak and Douglas-fir (higher values for them). There was also found lower values for Norway spruce (statistically significantly) in comparison with Douglas-fir in PODRÁZSKÝ et al. (2016) and in comparison with Douglas-fir and oak in KUPKA et al. (2013). Then, after analysing the previous data, it could be said that Douglas-fir acidifies but not in the same quantity than Norway spruce does it (much more, lower values found in all studies under spruce).

To continue, below will be exposed all the data and comments concerning to the characteristics of the soil absorption complex. The bases content showed in the holorganic horizon the pattern that appears in KUPKA et al. (2013) article with the broadleaved species higher, medium for Douglas-fir and finally Norway spruce (this pattern was also documented by other authors: AUGUSTO et al. 2003; PODRÁZSKÝ, REMEŠ 2008; MENŠÍK et al. 2009; PODRÁZSKÝ et al. 2009). On the other side, in PODRÁZSKÝ et al. (2016) appears L-H horizon with higher values for Norway spruce than Douglas-fir. In the mineral horizons appears Douglas-fir with the higher values and then the rest of the tree species with lower values and significantly differences with Douglas-fir. Here it could be accepted to think that Douglas-fir is developing a soil forming improving function. The hydrolytic acidity registered the following results: significantly higher values for Norway spruce in comparison with the other tree species. In KUPKA et al. (2013) and PODRÁZSKÝ et al. (2016) was registered the same tendency, being higher the coniferous species but here without significant differences. The bases content observed in the samples gathered in this location showed higher values from Douglas-fir and oak with significantly differences with Norway spruce. In KUPKA et al. (2013) was observed the same pattern but without significant differences. This information could make us think on the positive effect of Douglas-fir on soil. However, there were also found data in PODRÁZSKÝ et al. (2016) where Norway spruce values were higher than Douglas-fir ones. It is also true that in this last mentioned article the stand had less age and this could be one of the reasons of why the soil improving effect of Douglas-fir have not started yet.

Regarding the total content of humus in this locality, significant differences were found in the holorganic horizon between Norway spruce (bigger values) on one side and oak and Douglas-fir on the other. This occurs because Norway spruce has less humidification capacity of the organic matter existing on the surface of the soil. This also appears in KUPKA et al. (2013) and in PODRÁZSKÝ et al. (2016). In the deepest horizons, higher values appeared in Douglas-fir and Norway spruce (with significant differences) than in oak. In the consulted bibliography there were no significant differences between Douglas-fir and Norway spruce but the values are always higher in the fir.

The N (Kjeldahl) recorded only higher values and significant differences in oak in the mineral horizons (Ah and B). However, observing in KUPKA et al. (2013) and PODRÁZSKÝ et al. (2016) no significant difference between species was found. The emergence of these values in the study may have been the only cause of chance.

The exchangeable acidity and its components showed the following data: Norway spruce always appears with the highest values (with significant differences with respect to the other species). In PODRAZSKY et al. (2016) was found the same pattern between Douglas-fir and Norway spruce in the holorganic horizon but in the mineral horizons where Douglas fir values were higher (could be thought that the Douglas-fir soil improving effect manifests with greater age). On the other hand, in KUPKA et al. (2013) Norway spruce normally records the highest values. In any case, the observed values indicate that Norway spruce acidifies the soil to a greater extent than Douglas-fir.

In contrast to the holorganic horizon in KUPKA et al. (2013), the lowest phosphorus values in Orlík appeared in oak stands, followed by Norway spruce and Douglas-fir while in KUPKA et al. (2013) appear in the following order: oak, Douglas-fir and Norway spruce. In the mineral horizons the amount of phosphorus drops drastically and they had the same pattern in the two studies.

The potassium content in the broadleaved species obtained higher values in the Ah horizon with significant differences, which agrees with KUPKA et al. (2013) where there are significant differences in potassium content of broadleaved in comparison to the “firs”.

Stocks of calcium in soil in Orlík locality appear in the order of biggest to smallest: Douglas-fir-oak-spruce. In PODRAZSKY et al. (2016) there are no significant differences between Norway spruce and Douglas-fir (although the highest values were always found in Norway spruce). In KUPKA et al (2013) there were significant differences between species following the order (from highest to lowest value) of oak-Douglas-fir-Norway spruce.

In the amount of nutrients available for the plants, the following information was obtained: first, nitrogen, in which no significant differences were found between species (as in PODRAZSKY et al. (2016) and in KUPKA et al. (2013)) ; second, potassium, where differences appeared with significantly lower Norway spruce values (these differences were not found in the literature used); third, calcium, significant differences were found among all species with order (from highest to lowest): Douglas-fir-oak - Norway spruce. No significant differences were found in the bibliography used.

6.2. Vyžlovka

In the part below will be exposed a comparison of the obtained results with others from different authors. It will also appear some observations or interpretations of the data.

The study of pH/H_2O in the Vyžlovka location reflects the lowest values generally in Norway spruce (with significant differences with the rest of the species). The order (from highest to lowest) was Douglas-fir - Grand fir - Norway spruce. On the one hand, in PODRÁZSKÝ et al. (2016) Grand fir appeared with values greater than Douglas-fir without significant differences between them but with Douglas-fir (values lower than the "firs"). On the other hand, in KUPKA et al. (2013) slightly lower values were found in Norway spruce with significant differences with Douglas-fir alone in the holorganic horizon. As for pH / KCl, it was observed in the mineralized horizons such as Douglas-fir and Grand-fir have values somewhat higher than Norway spruce (this phenomenon also occurs in PODRÁZSKÝ et al. (2016)). After analyzing the above data it can be concluded that Norway spruce acidifies the soil to a greater extent than Douglas-Fir and Grand Fir.

In the base content (S) the data observed in PODRÁZSKÝ et al. (2016) showed that Douglas-fir had values significantly lower than Norway spruce and Grand fir. In Vyžlovka location the following results were obtained: no differences appeared between species in the most superficial horizon. The differences appear on the Ah horizon between Norway spruce and the "firs" and on the B horizon between all the species in the following decreasing order: Douglas-fir - Grand fir - Norway spruce. The same pattern as in Vyžlovka was found in KUPKA et al. (2013) where Douglas-fir values were bigger than Norway spruce ones. Here it can also be thought that Douglas-fir is acting as soil improving species.

Hydrolytic acidity did not register significant differences among species in KUPKA et al. (2013) and PODRÁZSKÝ et al. (2016) but Norway spruce appears with always higher values. In Vyžlovka the same pattern appeared but significant differences were registered between the three species in F + H and between Norway spruce and the "firs" in the mineral horizons. These data may be one more proof of the greater acidification capacity of Norway spruce compared to the "firs".

In Vyžlovka the highest values of cation exchange capacity were found in Norway spruce, followed by Douglas-fir and Grand fir. In contrast, PODRÁZSKÝ et al. (2016) showed higher values for Grand fir, followed by Norway spruce and Douglas-fir.

The base saturation registered the lowest values in Norway spruce; always below Douglas-fir and Grand fir (the same occurs in KUPKA et al. (2013) where Douglas-fir had higher values than Norway spruce). In contrast, in PODRÁZSKÝ et al. (2016) appeared the values in the following decreasing order: Grand fir - Norway spruce - Douglas-fir.

In the humus content there were always found higher values under Norway spruce, with significant differences with Grand fir in the holorganic horizon and with Grand fir and Douglas-fir in the mineral horizons. This fact can be determined by the fact, that Norway spruce was growing on lonely forested site, but “firs” were planted at the locality of former forest nursery, depleted in organic matter. In PODRÁZSKÝ et al. (2016) were also recorded higher values in Norway spruce but with significant differences only in the holorganic horizon. In KUPKA et al. (2013) the same pattern appears but without significant differences between the species. These data may appear to be associated with the lower humification capacity of Norway spruce. Similar pattern were found in other studies in the Czech Republic conditions by other authors (MENŠÍK et al. 2009).

The N (Kjeldahl) documented only significant differences in Grand fir with much lower values than the other species. This compression was not recorded in the bibliography used. It can be ascribed to big demand of this fast growing species.

The exchangeable acidity and its components showed the following data: Norway spruce recorded values significantly higher than the "firs". In KUPKA et al. (2013) Norway spruce also appeared with bigger values than Douglas -fir and generally with significant differences. On the other hand, in PODRÁZSKÝ et al. (2016) there were significant differences in the following decreasing order: Douglas-fir - Norway spruce - Grand fir.

The content of phosphorus in the locality of Vyžlovka reduces its amount in the mineral horizons in Grand fir. This does not happen in PODRÁZSKÝ but in KUPKA there are significantly smaller values in Norway spruce (in Vyžlovka there are not significant differences for the values but they are smaller).

The calcium content recorded significantly lower values in Norway spruce than in the "firs" in the mineral horizons. This pattern does not appear in PODRÁZSKÝ et al. (2016), where Grand fir presents the highest values, followed by Norway spruce and Douglas-fir. However, in KUPKA et al. (2013) Douglas-fir registers significantly higher values than Douglas-fir.

Magnesium content is significantly lower in Vyžlovka in Norway spruce in the B horizon. This also occurs in KUPKA et al. (2013) on the horizon Ah. This process is does not happened in PODRÁZSKÝ et al. (2016).

In the amount of nutrients available for the plants, the following information was obtained: first, nitrogen, where appeared significantly differences with Grand fir (it had the lowest values). This was documented in FULÍN et al. (2010) where was said that Grand fir takes up a lot of nutrients for its fast growth; second, potassium, there were showed significant differences with Grand Fir (higher values), the same thing happened in PODRÁZSKÝ et al. (2016) but without finding significant differences; third, calcium, there were found significant differences between Douglas-Fir and Grand Fir (higher values). The same thing happened in PODRÁZSKÝ et al. (2016). Fourth, magnesium, significant differences were documented between Norway spruce and the "firs" (with the lowest values in Norway spruce). In PODRÁZSKÝ et al. (2016) Douglas-fir obtains significantly lower values than Norway spruce.

7. Conclusion

In the present study a greater effect of acidification has been manifested in Norway spruce than in the rest of the studied species. The possible function of soil improver of Douglas-fir has also been counted in some of the parameters studied. Among the firs there have not been excessive differences, only Grand fir seems that uses a greater amount of the nutrients contained in the soil. In the oak stands, higher pH values were recorded than in the rest of the species. Therefore, this work supports the statements of other authors as to the suitability of Douglas-fir to be introduced in Czech Republic and Central Europe forests in the appropriate places. It can contribute to soil improvement in the stands of native conifers. Its function is less negative than that of Norway spruce. Partial substitution of Norway spruce by this species can contribute to: first, enhancement of the volume production of forest stands; second, enhancement of the value production; third, low the negative effects on the forest soils comparing to native conifers.

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