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The soil conditions of the forests of Zala County and their impact on the growth of beech

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Introduction

The growth of plants is basically determined by site factors, especially for forests. There is limited ability to have any influence on site factors. Some of the site factors are in constant change. Much of these changes are small, so natural or near-natural forest ecosystems can adapt to external changes. In the last decades, site condition changes have accelerated due to anthropogenic effects, so forest ecosystems also need to adapt. In many cases, forest ecosystems are not able to adapt that is well demonstrated by significant forest damages or decays (BERKI et al., 2007; LAKATOS & MOLNÁR, 2009; CSÓKA & HIRKA, 2011; BERKI et al., 2014). As forests have a very long life cycle – even "managed" forests have 120-150 years long periods in Hungary as well – so they cannot adapt to rapid changes over a lifecycle (FÜHRER et al., 2011). Therefore, the support of adaptable forest stands is necessary for future plantations. Climate plays a prominent role in the change of site factors (IPCC, 2007; BARTHOLY et al., 2007; GÁLOS et al., 2007, BARTHOLY et al., 2008; BERKI et al., 2009; GÁLOS et al., 2009; CZÚCZ et al., 2011; FÜHRER et al., 2013; GÁLOS et al., 2014; HLÁSNY et al., 2014). Due to favourable site conditions and contiguous loess bedrock, some of the most productive forest stands of Hungary are located in this region. Some stand-forming tree species – especially beech (*Fagus sylvatica L.*) – are very sensitive to changes in the environment, so their future survival highly depends on climatic conditions (SOMOGYI, 2015).

Objectives

During the research, the expected changes on arable lands, meadows, pastures, forests of Zala County were examined and the possibilities to adapt to these changes in the future (MÁTYÁS & BOROVICS, 2014). As a priority, we have analysed the impact of climate change on forests and the effects to be expected in the future (HORVÁTH & MÁTYÁS, 2014). The impact of climate change is significantly influenced by other site factors (e.g. soil, hydrological conditions, orography, etc.). Therefore, we analyzed the condition of other site factors in Zala county's forests and their effect on the growth of tree species.

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The forests of Zala County belongs to the forest regions of Göcsej and East Zala Hills (BARTHA et al., 2006). The forest cover of the area exceeds the national average significantly. The forest rate is more than 36% in Göcsej and less than 26% in East Zala Hills, therefore forest has a prominent role in county life. However, environmental conditions of forest management are permanently changing. Therefore, the main goal of current research is to predict future conditions by examining the current conditions on the selected research area.

Material and methods

The examined area is located in the Zala Hills (DÖVÉNYI, 2010). The study area consists the following microregions: Upper Zala Valley, Kerka-land, Middle Zala Hills, Egerszeg-Letenye Hills, Principal Valley, Zalaapáti-hát, Lower Zala Valley, Zalavári-hát and left bank plain of Mura river. The region is covered with thousands of meters thick sandy, clayey, marly Pannon Sea sediment that fluvial sand deposited on the surface. At this level, the construction of the Ancient Raba and Mura's debris cone was started. The area emerged at the end of the Pliocene and at the beginning of the Pleistocene, in which rivers flooded the region. Erosion and deflation played the most important role during the formation of meridional valleys. In the north-south valleys, we often find swamps and bogs (VITÁLIS, 1957; BULLA, 1962; DÖVÉNYI, 2012; MEZŐSI, 2011). Soils were formed on lime-deficient periglacial loam and the Pannonian clay sediment (STEFANOVITS et al., 1999), which are covered by a tending loess cover in the east. Due to the forests with acidic bedrock and high amount of precipitation, pseudogley brown forest soils have emerged in the western part of the region. Clayic Luvisols (Lessivated brown forest soils) are typical in the eastern Zala Hills. In wide valleys, Vertisols (meadows soils) and Histosol (peat soils) were occurred (WRB, 2015). The soil of hills and crests are affected by erosion processes. Therefore illuvial and eluvial horizons of soil have also been destroyed (STEFANOVITS, 1963).

The examination is based on data from National Forest Data Base (NFDB). NFDB contains professional tasks specified in ACT XXXVII. (2009) about forests, protection of forests and forestry (planning, professional management of forestry works, protection of forests and property). The collection of forest inventory data is consistent with planned forest management. The database is currently managed by the Hungarian Forestry Directorate - NÉBIH (National Food Chain Safety Office) and the Forestry Directorates of County Government Offices. The database contains the most important site and stand data for all forest sub-compartments. The site data can be derived from several sources. In some cases, they are based on on-site and laboratory soil analysis; in the other hand, the site conditions of a given forest subcompartment were determined based on the vegetation indicating the site and soil maps. Species composition, growth, yield potential were assessed by different dendrometrical surveys with different reliability.

In the course of the investigations, only factors determining the varieties of soil type (climate, hydrology, soil type, topsoil layer thickness and texture) were taken into account from the NFDB. To characterize the site conditions of the county, 35387 forest subcompartments (total area: 119 205 hectares) were investigated for the study. Based on data, the following research questions were raised: How the growth of beech tree species are determined by different site factors in Zala County? For the analysis, Veperdi-type "yield rate" or "production capacity" was used (VEPERDI, 2014). This index number is the mean annual increment (MAI) of total yield (yield table), for 75 years old unmixed beech (*Fagus sylvatica*) stands. Further filtering conditions: mixture ratio >= 50%, canopy closure > 70%, yield classes: 1 or 2, age: 30-120 years, height >= 2 m. The MAI determinates the growth potential of stands thus indirectly indicates the quality of the site. To confirm the quality of site, it was determined how many percentage of the forest region can be characterized by the different physical soil properties and topsoil layer thickness based on forest inventory data. To validate the database, field measurements were carried out to estimate how the available amount of water is changing in soils under different hydrological condition. Soil samples were collected from selected plots and soil analysis were carried out based on BELLÉR (1997). Based on result, we used the modified Thornthwaite-type monthly model for the investigation of the water-balance and determined water stress when the relative extractable water (REW) decreased below 40% (Granier et al., 1999). The statistical processing was completed with EXCEL and STATISTICA 11 (ANOVA, Basic Statistic). During the analysis, the data of 35387 forest subcompartments were evaluated. After filtering (mixture ratio >= 50%, canopy closure > 70%, index: 1 or 2, age: 30-120, elevation >= 2 m), 9 soil types were separated. Due to few subcompartments, 2 soil types (brown forest soil with carbonate rests (2 pcs) and erubase 1 pc.) were excluded from the study. Thus 933 forest subcompartments were included in the analysis. Most of statistical analyses has criteria for the normal distribution of the data series. Therefore distribution tests were performed (e.g. Kolmogorov-Smirnov test). In the case of not normal distribution, logarithm transformation were carried out. Where normal distribution were found there one-way ANOVA (t-test) were made.

Results and discussion

The conditions of the forests in Zala County

Of the forests of Zala County, 77% are located at altitude below 150 m. Percentage of forest at altitude between 150-250 m is low (10%) and 1% of forests stand at altitude above 250 m. According to orographical conditions, the distribution of forests is very diverse. By aspect, the highest proportion were found in the following types: variable (30%), flat (18%), eastern exposure (18%) and western exposure (18%). These data corresponded to the geographical conditions because north-south oriented Hills are characteristics of the county (DÖVÉNYI, 2010). Sloping conditions were similarly varied; percentage of flat forests (0^{o}, 20%)

and forest with gently slopes (0-5^o, 21%) were typical. On moderate slopes (5-10^o, 16 %) and steep slopes (10-15^o, 22 %), a few of forest stand occurred.

In the 1950s, in absence of sufficient meteorological time series, the Hungarian forestry praxis started to classify climate based on the distribution of the main climate indicator tree species (JÁRÓ, 1972). Contrary to other Middle-European regions, the Carpathian Basin can be characterized by relatively large horizontal variability of temperature and precipitation combinations that enabled to divide four forest climate categories: Beech – *Fagus sylvatica* (with the lowest temperatures and highest precipitation amount), Hornbeam-oak (*Carpinus betulus*), Sessile oak (*Quercus petraea*) – Turkey oak (*Quercus cerris*) and Forest steppe. These categories were completed with a fifth one and it is called Stepe. The latest one is the warmest and driest category where the macroclimate conditions are not suitable for closed forests (MÁTYÁS et al., 2018). The foundation of this new forest climate category means that we can expect to significant changes of site factors and its properties (BIDLÓ & HORVÁTH ,2018, CZIMBER et al., 2018). In order according to the forest climate zones of Hungary, most of the forest regions belong to the Hornbeam-oak climate zone (74%). Besides, 21% of forest belong to beech zone and 5% belong to sessile oak-Turkey oak zone.

According to hydrological conditions, forest soils contain no surplus water (83%) generally. So precipitation is the only source of available water for the vegetation.

Periodic water effect (7%) and permanent water effect (6%) is not characteristic for the study area. For vegetation, the water holding capacity of soils is very important, because surplus water is not available from the groundwater.

Several of soil types occur only in very small proportions. The most characteristic soil types of the area are forest soils:

clayic Luvisol (lessivated brown forest soil)	47 %,
gleyic Luvisol (pseudogley brown forest soil)	16 %,
Cambisol (brown earth)	8 % and
stagnic Luvisol (rusty brown forest soil)	10 %.

Leptosol (rendzina) (3.2%), Vertisol (typical meadow soil) (5.5 %), Regosol (colluvial forest soil) (2.4 %) and Histosol (peaty meadow soil) (2.3 %) ratios are significant. Loose bedrock (loess and sand) covered most of the area, whereas deep soils (75%) formed largely. Topsoil layer thickness is one of the determining factors – under favourable climatic conditions – that hardly had an influence on the growth of forests of Zala County. Loam texture (80%) is the most typical physical assessment in the County, which is characterized by favourable water and nutrition budget (STEFANOVITS, 1992). The proportion of sand texture (12%) is significant near to Nagykanizsa city. The forest lands of Zala County are characterized by a relatively small difference.

Due to geological circumstances, low altitude differences, balanced orographical conditions and loess (smaller proportion of sand) bedrock, similar site conditions were evolved in the whole area. The surplus water from groundwater influences these site conditions only in few places. During the examination, the mentioned small difference had benefits and disadvantages. It was advantageous to compare forest stands with similar site conditions. But as a disadvantage, the effect of the site on growth could not be displayed spectacularly.

Site factors determining the growth of studied beech forests

During the evaluation of data, we used the categories of the prescribed site description from NÉBIH. Based on altitude, the best-growing stands were found on 0-150 m (12.74 m^3/ha/year) and beech stands <150 m (12.41 m^3/ha/year). Yield potential of stands on 150-250 m was 11.67 m^3/ha/year and stands on 250-350 m (9.07 m^3/ha/year) showed the weakest growth potential. The largest number of beech forests – 707 beech forest subcompartments on 5333 hectares – were found at 150-250 m altitude. At 250 – 350 m altitude, 200 forest subcompartments on 1546 hectares were detected. Regarding the exposure of beech forests, beech forest subcompartments occurred in each category; 307 subcompartments with varied altitude, 180 subcompartments with an eastern aspect and 227 subcompartments with a western aspect. Based on ANOVA, the exposure has a significant effect on the growth of beech trees. During the detailed examination of data we found that the difference between the categories was significant in only one case.

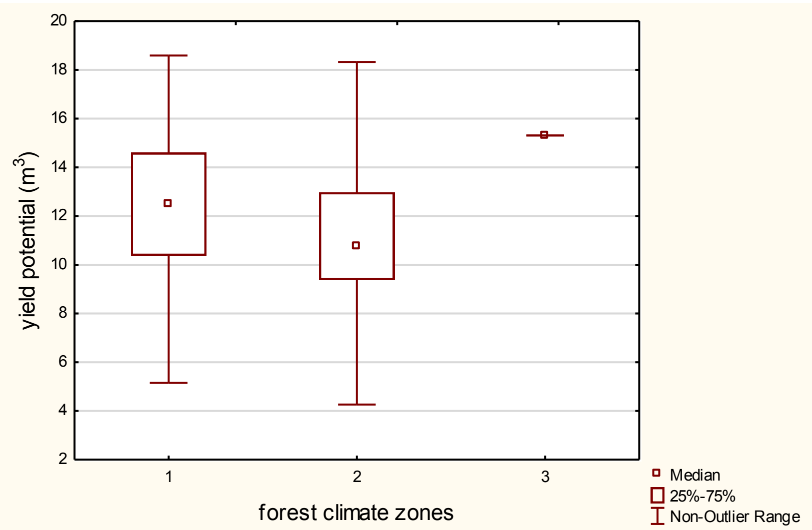

Figure 1
Box plots of yield potential classified by forest climate zones. (1 - beech forest climate, 2 - hornbeam-oak forest climate, 3 sessile oak-Turkey oak forest climate zone)

87% of the samples, belonged to beech climate category and 13% into hornbeam-oak forest climate zone (*Figure 1*). In addition, with a small area ratio (2.0 ha total), the sessile oak-Turkey oak forest climate zone also appeared. The best growth potential (12.46 m^{3}ha /year) was found on beech climate, but the beech stands on hornbeam-oak climate also represented a similar value (11.21 m^3/ha/year). Based on ANOVA, the effect of the three climate categories on the growth significantly differed.

In Zala County, more than 98% of the beech forests located on areas with no surplus water. Without surplus water, the forests were able to produce an average growth (12.17 m^3/ha/year) in the county. In the examined area, periodic water resources were recorded in only two stands with 11.45 m^3/ha/year on average. Therefore it was concluded that all of the beech forests of Zala County are referred to precipitation because roots are not able to reach the groundwater level (DÖVÉNYI 2010). During the evaluation of dataset, 15 soil types were described in beech forests of Zala County.

After filtering (mixture ratio >= 50%, canopy closure > 70%, index: 1 or 2, age: 30-120, elevation >= 2 m), 9 soil types were separated. Due to few subcompartments, 2 soil types (brown forest soil with carbonate rests (2 pcs) and erubase 1 pc.) were excluded from the study. Thus 933 forest subcompartments were included in the analysis (*Figure 2*).

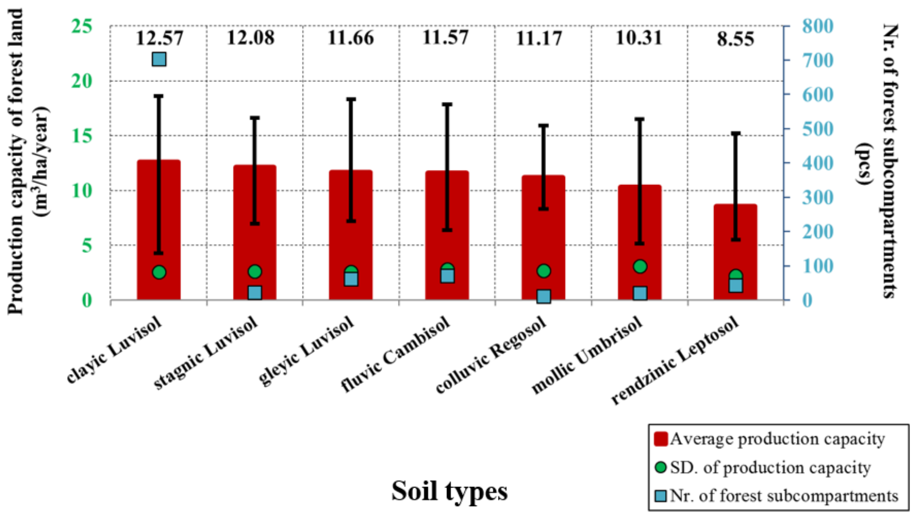

Figure 2
The production capacity of investigated beech forests by soil types

Clayic Luvisols (lessivated brown forest soils) were found in the largest proportion (75.3%) with the best yield production (12.57 m^3/ha/year). The distribution of 12.57 m^3/ha/year: 53% of trees belongs to I. yield class, 30% of trees belongs to II. yield class and 12.3% of trees belongs to III. yield class). Therefore it is important to determinate how drought period affects a soil with good soil properties and high production capacity (*Figure 3*). For the investigation of the water-balance the modified Thornthwaite-type monthly model was used.

Water stress: when the relative extractable water (REW) dropped below 40% (GRANIER et al., 1999).

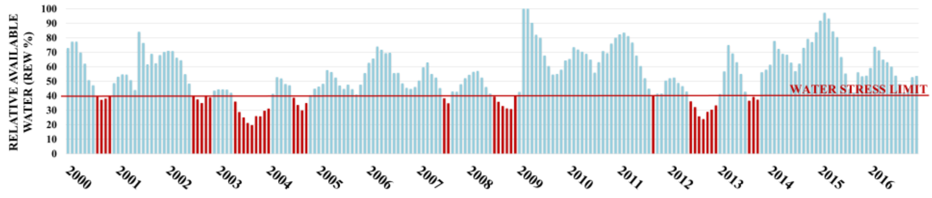

Figure 3
The modified Thornthwaite-type monthly model for a clayic Luvisol (Boncodfölde)

The ratio of Cambisol was 7.6% with relative high yield potential (11.57 m^3/ha/year), as the proportion of gleyic Luvisols (6.6 % - 11.66 m^3/ha/year) as well. These two soil types have good water holding capacity and can store enough water for longer drought periods (*Figure 4*).

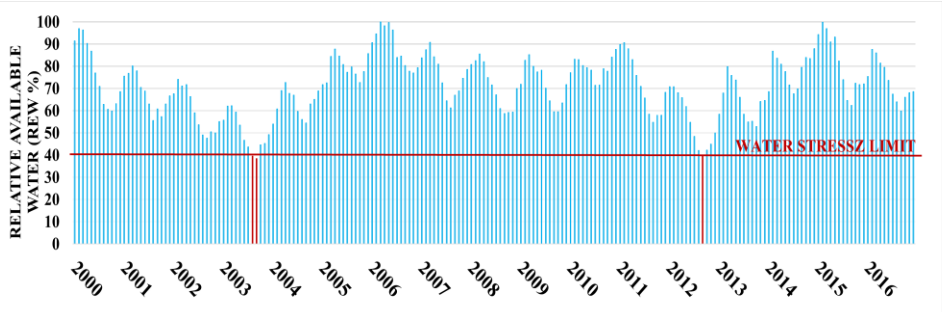

Figure 4
The modified Thornthwaite-type monthly model for a gleyic Luvisol

There were also 12.08 m^3/ha/year growth on stagnic Luvisols (2.4%). Yield of rendzinic Leptosols (4.6%) characterized the lowest capacity with 8.55 m3/ha/year (*Figure 5*)

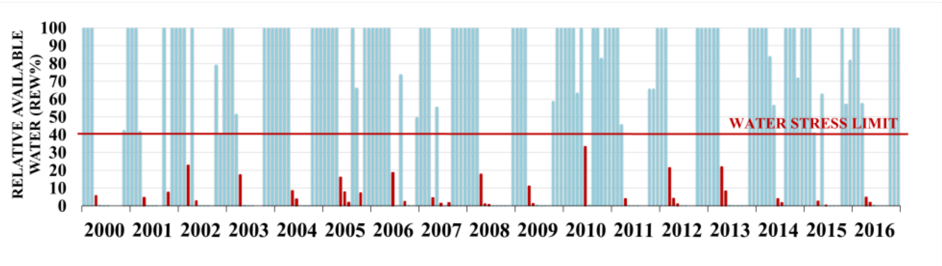

Figure 5
The modified Thornthwaite-type monthly model for a rendzinic Leptosol

Differences in topsoil layer thickness significantly determined the growth beech stands. Sites with very deep topsoil layer thickness were the most favourable (12.29 m^3/ha/year) in the 3.1% ratio. Sites with deep topsoil layer thickness characterized with 12.10 m^3/ha/year yield potential. Besides 90% of the soils of Zala County have deep soil layer thickness. Beech forest sites with medium soil layer thickness (5.9% ratio) produced 10.51 m^3/ha/year. The percentage of beech forests with shallow depth did not exceed 1%, which was characterized by a growth rate of 6.76 m^3/ha/year (*Figure 6*).

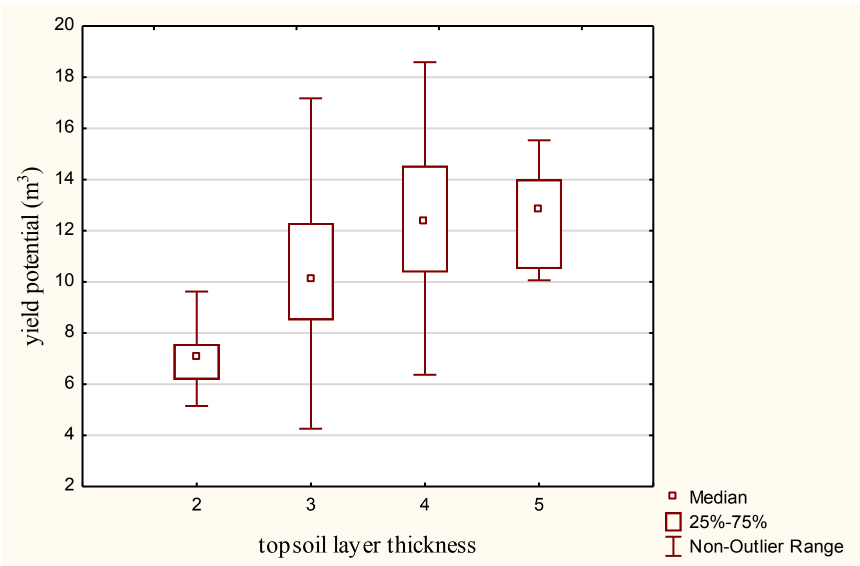

Figure 6
Box plot of yield potential grouped by topsoil layer thickness (2 – shallow (20-40 cm), 3 – medium (40-60 cm), 4 – deep (60-100 cm), 5 – very deep (>100 cm))

Based on the analysis – as expected –, topsoil layer thickness was one of the most important factors of growth of beech on the examined area. Of the data, 94% had loam texture with 11.90 m^3/ha/year yield. The most productive soil texture was the clayey loam (0.35 %) with 12.89 m^3/ha/year yield potential. A similar growth (11.87 m^3/ha/year) was detected on clay texture (ratio 2.3%). Sandy loam, which is 1.7% and sandy texture at 1.4%, was about 10.77 m^3/ha/year and 11.39 m^3/ha/year).

Based on preliminary studies and literature have shown that the growth of forest trees is influenced by several factors together. Therefore, the growth of tree species has been studied on different soil types. In addition, standard deviation has been calculated that expresses uncertainty. High standard deviation values can be caused by several other factors of the site (e.g. exposure). Based on the principal components analysis (PCA) of the selected variables, a total of 4 components have been determined that have significance (scree plot). The 4 main components explained 74.228% of the variance (*Table 1*).

Table 1
Results of (PCA) on selected site variables.

Rotated Component Matrix[a]				
	Component			
	1	2	3	4
topsoil layer thickness	,211	,173	**-,561**	-,234
soil texture	,089	,011	-,053	**,914**
mixture ratio	,102	,087	**,738**	-,302
canopy	-,290	,240	,360	,240
age	**,961**	-,154	-,039	,006
height	**,885**	,402	-,084	,019
diameter	**,918**	,012	-,191	,049
yield potential	,072	**,941**	-,104	,014
yield class	-,001	**-,924**	,091	,006

Extraction Method: Principal Component Analysis. Rotation Method: Varimax with Kaiser Normalization. a. Rotation converged in 5 iterations. High factor loadings are shown in bold.

The relationships between main components were confirmed by the correlation analysis shown in *Table 2*. With regard to soil characteristics, PCA results showed that topsoil layer thickness is a more important property than soil texture (*Table 1*).

Table 2
Correlation matrix for the results of selected site variables.

	topsoil l. thickness	texture	mixture ratio	canopy	age	height	diameter	yield pot.	yield class
topsoil l. thickness		**0.93*****							
texture									
mixture ratio					**0.68****	**0,67****			
canopy									
age									
height					**0.82*****				
diameter					**0.85*****	**0.79*****			
yield potential									
yield class								**-0.82*****	

R> 0.5 and R<−0.5, where p=0–0.001→"***", p=0.01→"**", p=0.05→"*", p>0.1 → "–"

Based on the correlation matrix, the strongest significant correlation (0.93***) were found between topsoil layer thickness and soil texture. The reason was the relatively small difference between soil sites. The most characteristic texture was loam with deep (60-100 cm) or medium (40-60 cm) topsoil layer thickness, which features were favourable for beech stands. The age of beech showed connection to height, diameter and mixture which properties are dependent variables. According to the results, even in the same site conditions, there may be a significant difference in growth of stands, which is best expressed by the standard deviation.

Conclusions

In the case of Hungarian forests, the most significant change is expected in climatic and hydrological conditions. Despite the early appearance of the term „site" in Hungarian forest literature (FEKETE, 1882), it has not changed significantly in the last century (BABOS, et. al., 1966; SZODFRIDT, 1993). For many years, the site was a permanent factor, which does not change for a long time.

The last decades have shown the importance of the changing site, because human induced rapid changes. Therefore a living organism has to adapt to more different conditions during a lifetime. Changes in soil type and texture are a slower process, while climatic and hydrological factors change relatively quickly. PCA results showed that topsoil layer thickness is a more important property than soil texture. Changes of soil-forming factors – especially climatic, biological and hydrological conditions –, have an impact on soil development (BIDLÓ et. al., 2014). On sites, where already low yield potential appeared due to climatic changes, damages will occur more quickly than in the currently favourable production sites. In Zala County, growth is mainly influenced by topsoil layer thickness and texture of the soil and climatic conditions. Since relatively small site potential differences have occurred in Zala County, these findings can only be limited to other areas. In order to yield estimation and health condition of stands, the effects of other factors on site should also take into consideration.

Summary

During the research, we studied the soil conditions in Zala County's forests and examined the effect on the growth of beech forests on these conditions. Data of National Forest Data Base (NFDB) were analysed for investigation. Most of the forests in Zala County are situated less than 150 m above sea level, their location and topography is very diverse. In most of the forests the groundwater level is deeply beneath the surface so the forests can utilize only the amount of precipitation. In accordance with the geological and climatic conditions, Luvisols were formed predominantly, especially the clayic Luvisols and the gleyic Luvisols are the most typical. In addition, there are still Cambisols and stagnic Luvisols as well. In a small percentage, there are forest stands on rendzinic Leptosols, Vertisol, Regosol and Histosol. According to the favourable parent material, forests have got a deep or medium thickness of soil and the typical texture is loam. Based on the research, soil layer thickness and texture had significant impact on the growth of beech forest stands in terms of soil properties.

Keywords: beech, yield, soil texture, topsoil layer thickness, Zala County

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