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EVALUATION OF SITE QUALITY AND MODELLING TREE PRODUCTIVITY BY LIDAR TECHNOLOGY IN SALT-AFFECTED OAK FOREST TERRITORY

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Abstract

Forest site quality evaluation is an important part of forest planning and forest management. A forest site is characterized by forest biomass, which is determined by elevation characteristics, soil type and climate. Height of tree is widely used parameter for terroir typifying, but measuring of tree height is sometimes time- and labour-consuming and could affected by errors. Airborne LiDAR technology is an effective tool for determine fast and accurate the tree height on relative larger area. GIS software environment provides to prepare the high resolution digital elevation model (DEM) and digital surface model (DSM) for pixel-based canopy height. Traditionally, the operational tree height estimation can significant differ from the actual tree heights. In our investigation, between the LiDAR-based elevation parcel map and operational tree height estimation, a close correlation (r=0.7935) was detected. The aim of our research was creating a site qualification map, based on airborne LiDAR data. Tree height map was completed with soil type data. Trees are different age on the plot area, so age-based standardization was carried out by modified Chapman-Richards growth function to examine the increments of trees. In order to evaluate the forest site quality, created increment map was categorized. Based on the results, surface hydrology features are mainly influenced the tree increment, so the dendromass. Nevertheless, significant differences were observed between the tree increments in different soil types; higher salt content resulted smaller (62.49%) trees in Solonetz soil.

Key words: Airborne LiDAR, remote sensing, digital surface model (DSM), digital elevation model (DEM), annual increment, Chapman-Richards growth function, agroforestry, salinization, dendromass

INTRODUCTION

Evaluation of forest site quality is one of the most important task for forest planning and management. Selection of the optimal tree species is a very complex part of an afforestation project. Soil analysis (Carr et al., 1991; Craigg et al., 2015), examination and evaluation the composition and distribution of forest communities (Fekete et al., 2000), using meteorological, hydrological (Hibbert, 1976; Xu et al., 2010) and plant geography data (Cain, 1944) are essential to establish the ecological point of view of forest planning (Bettinger et al., 2008). In order to evaluate a terroir, most (laboratory and field) investigations are time- and labour-consuming. Suitable sites conditions and management provide optimal stand volumes, maximal annual growth and timber volume of forest trees (Cailliez, 1980).

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Different traditional methods are available to measure tree parameters, which can help to evaluate the forest sites. Indicators, like trunk and crown diameter, tree height, stand basal area and stand volumes, tree ring analysis are such parameters, which proved information about forest grow dynamics and these parameters are responses to site conditions (Leal et al., 2017). Tree height (related with age) is one of the most informative value in a forest to evaluate of forest sites. Direct estimation of site index is based on height and age measurements from free-growing, uninjured, dominant, or dominant and codominant trees (Carmean, 1975). To determine the individual tree heights (above 6 m) by conventional methods is sometimes more difficult than younger (smaller) trees (Reid, Stephen, 1999). Nevertheless, measurement accuracy is influenced by the limits of field instruments, so incorrect conclusions can be drawn (Abed, Stephens, 2003; West, 2009).

Nowadays, remote sensing technologies and GIS software provides to survey a forest site rapidly, more accurate on relatively large area, compared to the field measurement. LiDAR (Light Detection and Ranging) technology is an effective tool for acquiring structural information about the trees, and about those surroundings (White et al., 2013; Maltamo et al., 2014; Hyyppä et al., 2008; Næsset, 2003; Csiha et al., 2017; Riczu et al., 2016; Tamás et al., 2014; Tamás, et al., 2014) by a laser beam. Gathering forest resource information, or create forest inventory, both terrestrial laser scanning (TLS) and airborne laser scanning (ALS) are applied (Ma et al., 2017; Tamás et al., 2011). TLS systems are capable for obtaining millimeter-level (almost leaf-level), high density 3D data about the tree (van Leeuwen, Nieuwenhuis, 2010; Calders, 2015; Liang et al., 2016), but ALS can measure larger area per unit time, in lower, sub-meter 3D spatial resolution than TLS. Due to the shorter measurement ranges of TLS, large forest sites cannot be surveyed time-efficient (Bremer, Sass, 2012). Early experiments with laser-based 3D data collection from the earth surface was carried out in the 80s by the NASA (Krabill et al., 1980; Nelson et al., 1984). These investigations were established the basis of forestry survey by laser scanning system (estimating forest volume and biomass from the airborne canopy profiles, description the advantages and disadvantages the LiDAR data collection of leaf-on and leaf-off canopy conditions) (Nelson et al., 1984; Maclean, Krabill, 1986). The early LiDAR altimeter systems (Airborne Oceanographic LiDAR) were operated in visible range (green laser wavelength); penetrated to water, so applied in bathymetric researches (Hickman, Hogg, 1969). These AOL systems used discrete laser return ranging, so only one echo recorded by the laser detector (Harding, 2008). With the evolution of ALS systems and with the development of the technology, more information can be acquired about the forest. Airborne laser scanning has already been adopted and accepted as a very valuable tool in forestry applications in the 1990s (Maas, 2010). Profiling Airborne Topographic Laser Altimeter System (ATLAS) and Airborne Topographic Mapper (ATM) systems were available in commercial use. Later, Scanning Lidar Imager of Canopies by Echo Recovery (SLICER) and the wide-swath mapping Laser Vegetation Imaging Sensor (LVIS) and waveform-recording and analyzing systems were spread (Harding et al., 2001; Maas, 2010). The emitted laser pulse hit the highest point of the object and the other part of the tree or bush (leaves, branches, trunks), and multiple reflections (multiple echoes) will be generated. The last echo deriving from the grass or the bare soil (Beraldin et al., 2010; Hollaus et al., 2014). Due to the waveform digitization techniques, the coniferous and deciduous canopy could be divided in different layers (Brandtberg et al., 2003; Persson et al., 2005; Qin et al., 2017). Beyond the acquired crown information (Korhonen et al., 2013), estimation the number of trees and the tree height (Unger et al., 2014), detection of individual trees (Persson et al., 2002), determine of each tree position (Valbuena, 2014), or the lying trees (dead woods) (Mücke et al., 2013 a; Mücke et al., 2013 b) are suitable by the airborne LiDAR technology. Obtaining this detailed information about the trees could incorporated into the modern forestry systems.

Afforestation and forest management under extreme (soil and weather) conditions is sometimes a great forestry challenge. Different experiments are worldwide to evaluate the growing parameters of trees under harsh conditions. Poor soil depth is an important factor, which limiting forest growth (Zhang et al., 1996), but water scarcity (Mutke et al., 2005) and inland water (Fugère et al., 2016) in rooting depth cause growing problems in trees. Water transport is strongly influenced by salinization and sodification processes. Use of these salt-affected soils are sometimes difficult across the world. Around 3.8 million ha of saline soils are in Europe, and the area of saline and sodic soils are in the highest rate in Hungary (around 1 million ha, more than 25 % of European saline soils) (Jones et al., 2010). In the aspect of rational and optimal land use, afforestation experiments in salt-affected area were started in the 1800s in Hungary (Láng, 1870; Hóman, 1880; Prokopovics, 1881). Nevertheless, afforestation investigations were beginning at operational level from 1924 (Tóth et al., 1972).

The aim of our study to evaluate a salt-affected forest site, using LiDAR- and GIS-based tree heights. In order to evaluate forest terroir, a mathematical grow model is used to estimate tree increments. Based on the increments of trees, investigated area is classified in our experiment.

MATERIAL AND METHOD

One of the most comprehensive scientific afforestation and site evaluation experiment in salt-affected area are in Forest Research Institute, Püspökladány Expetimental Station, in Hungary (47°20'44.06"N; 21° 5'21.68"E). Technological salinization investigations are carrying out more than on 400 hectares (from which 300 ha forest and 100 ha saline-sodic grass-land) area, in order to give guidelines to forest practice in extreme soil conditions (Fig. 1).

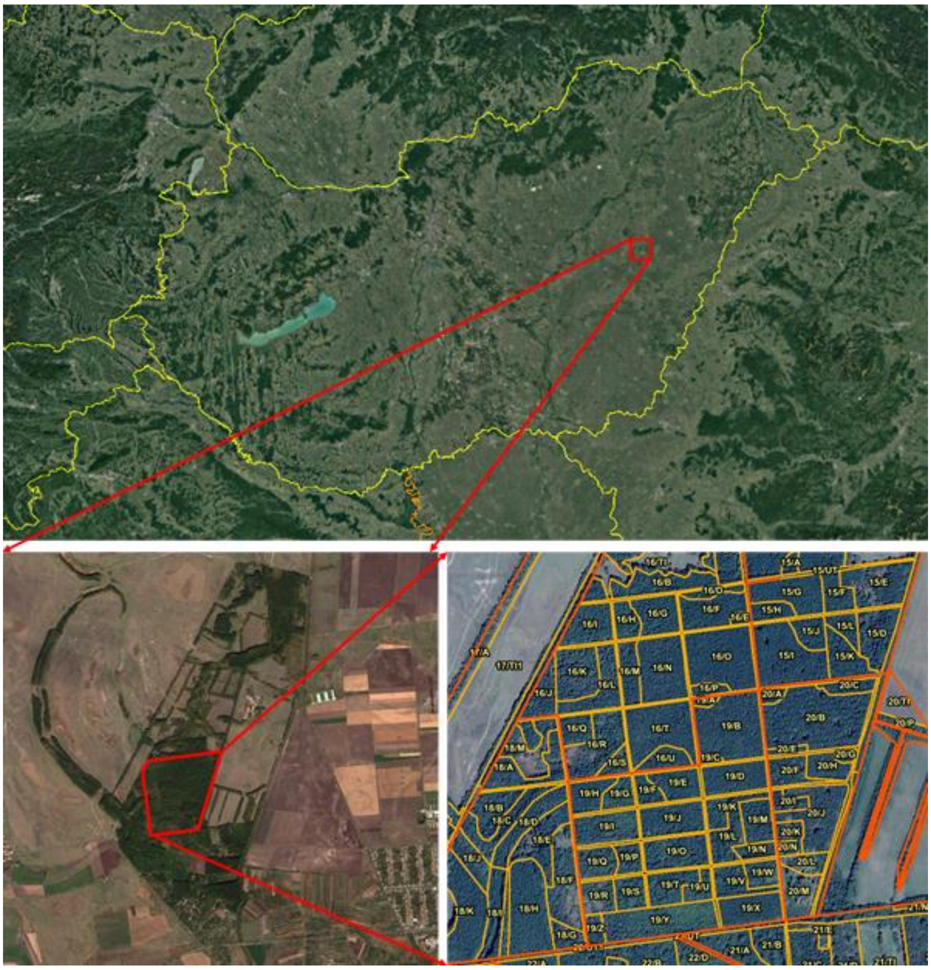

Fig. 1. Localization of the experimental forestry area

During these long-time experiments, terroir researches evaluation and tree growing assessment are prepared and also now preparing.

Forestry treatment map is derived from the Hungarian forestry web map service by the National Food Chain Safety Office. Based on the World Reference Base (WRB, 2014), soil properties of the investigated area can be divided into soil types (Solonetz and Gleysol) and these subtype classes (Fig. 2).

Soil map of the plot area is derived from early afforestation planning data (Tóth, Várallyay, 2001). Categories of salt-affected areas are detailed by the Hungarian Soil Classification System (HSCS) (Tóth, Várallyay, 2001; Tóth, 2010). Spatial distribution of soil types is strongly depend on terrain characteristics, depth and quality of groundwater level (Szabolcs, 1959).

Fig. 2. Soil types of the investigated area

Using the available most modern technology in these investigations, more effective analysis can be implemented. LiDAR survey from the whole forested area was carried out at August 23, 2012 in the framework of ChangeHabitats2 international project. The aim of this project was to promote the use of new LiDAR technology for habitat mapping, biodiversity monitoring, environmental and nature conservation in NATURA 2000 habitat sites. The applied ALS system had analyzed the waveform, so full canopy structural investigation and terrain modeling were performed. The area was surveyed in 14 flight ranges, with 60.19 point/m^2 point density; the full point cloud contains more than 700 million 3D laser points with laser intensity (laser reflectance property) values.

In order to pre-process the LiDAR data (spatial cropping, cleaning the point cloud), GlobalMapper 15 software was used. Automatic LiDAR point cloud classification was not proper, so another software (ENVI LiDAR™)

was applied. Based on the spatial neighbourhood of points, automated surface recognition was prepared by ENVI LiDAR. Buildings, trees, power lines, power poles, DEM, DSM layers can be produces by the built-in algorithms. For the high-resolution analysis, DSM and DEM resolution were 50 cm. Subtracted the two layers, pixel-based tree elevation was calculated.

In order to evaluate the forest site quality, treatments of different plantation time were standardized by the tree age. Based on the Chapman-Richards growth function (Richards, 1959) – which is modified by Gál and Smith (Gál, Smith, 1985) – was applied the "general common denominator" for each forest stand (Equation 1). Beside the maximum yield estimation and maximum mean annual tree increment, Chapman-Richards equation provides the mean annual increment culminates, respectively.

$$y=p_1 \cdot (1-e^{p_2 \cdot t})^{p_3}$$

where,

p_1 – asymptotic value of the stand parameter (y) being modelled,

t – time in years,

p_2, p_3 – coefficients to be estimated.

The plot area was a 57.68 ha, which contains 71 separated examination plot. The average plot size is 0.81 ha. The investigated tree stands contain with common oak (*Quercus robur* L.), thus age-standardization and estimation of tree incrementing could be more effective than in the case of mixed stands. Using the equation, each forest stand plot was standardized (at an 81-year-old common oak, which was the oldest common oak stand of the experimental area) and a calculated increment layer was created for further GIS analysis. This calculated increment layer was added to laser-based real tree height in IDRISI Taiga software environment, so a potential tree height can be estimated. Bases on the differences between the estimated tree heights, forest site evaluation can be carried out.

Beside the assessment of increment by LiDAR and their relation between elevation and hydrology, the utilization of LiDAR for detecting the impact of different soil types on the increment of *Quercus robur* was also assessed by Tukey variance analysis to determine the statistical differences among increment of the two dominant soil types (Solonetz and Gleysol). There are two types of salinization in the investigated territory such as Saline soil (Solonchak) with high amount of water soluble soils and alkaline soil/sodic (Solonetz) high alkalinity and high exchangeable sodium percentage (ESP). High exchangeable sodium saturation of heavy-textured soil with large amount of expanding clay minerals results in unfavourable soil properties (alkaline pH in B-horizon, swelling/shrinking colloids, degradation of soil structure, limited infiltration and leaching conditions, low water and nutrient storage capacity of shallow A-horizon), which limit their fertility, productivity and utility.

RESULTS AND DISCUSSION

Based on the surveyed LiDAR data, high resolution DEM and DSM were created in ENVI LiDAR software environment. Beside the relief map of the extreme flat forested area, accurate tree height map was created (Fig. 3), which is the main basis of the forest site evaluation. It can be observed, soil types (Fig. 2) are influenced by terrain characteristics.

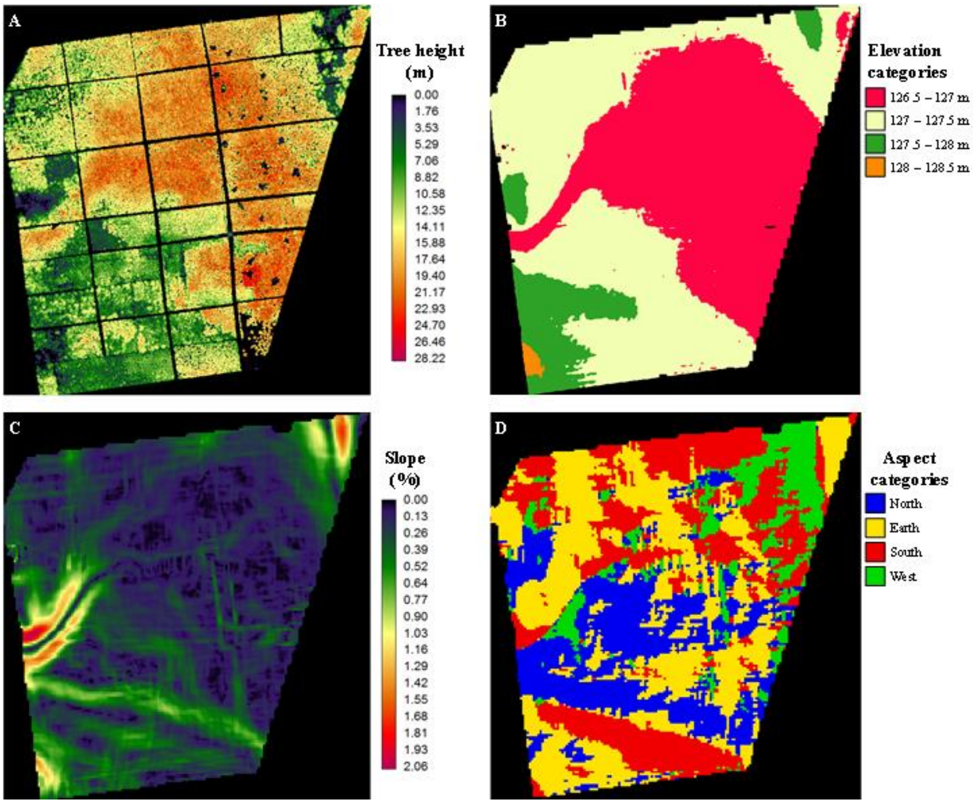

Fig. 3. Tree height map (A), elevation (B), slope (C) and aspect (D) maps of the investigated area

The figure shows, significant differences in tree height in the given forest stands, which generally thank to the different plantation time (different age of trees). Age-based increment standardization provided the compatibility and comparability of each treatment, so a rasterized age-based treatment map was prepared. Increment calculated GIS layer for an 81-year-old common oak with the tree height map was combined. The standardized tree-increment map showed differences, which is not directly derived from the age of trees, so standardization was successful. This standardization is strongly depend on soil characteristics and the hydrological features of the area, so early digitized soil type map was used to compare the results with soil characteristics. One of the main problem of soil maps is, that these maps were created with the cartography technique of the 1960s, and soil types or subtypes have sometimes regularly followed the borders of the treatments (Fig. 2).

Tree-incrementing and site evaluation were carried out by individual tree detection. Based on general and experimental parameters (tree height and canopy radius) of oak in different age, individual trees were detected by ENVI LiDAR software (Fig. 4). Different treatments and different ages of forest parcels on different soil type can result different growing features. Thus, automated tree identification can difficult and sometimes time-consuming. Thus, 30 m maximal tree height and 100-400 cm canopy radius values were used for individual tree detection.

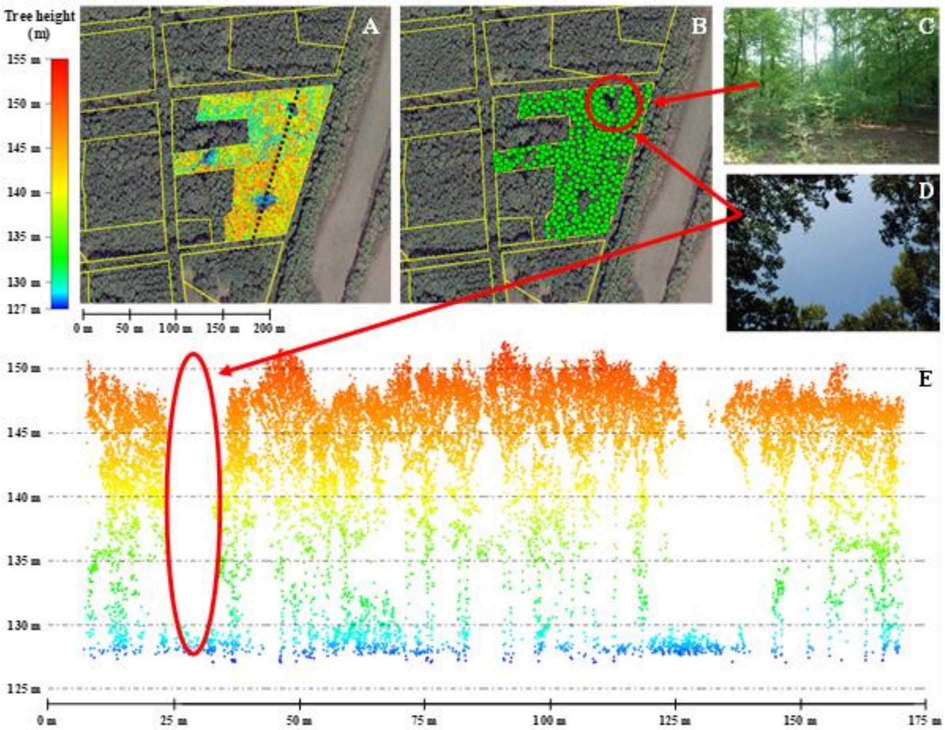

Fig. 4. Elevation colored laser points in the case of 20/J forest parcel (A), location of the automated tree detection (B) with the gaps (C, D) and the vertical profile of the parcel (E), along the dotted line.

Beside individual detection of trees, 2D profile of forest parcels were analyzed in Global Mapper (Fig. 4/E). Therefor tree height (and GPS position), derived from automated tree detection and DSM-DEM-based height of trees can be compared. A close correlation (r=0.7997) was found between heights from automated tree-segmentation and tree heights calculated from surface-terrain model. In the case of different age of trees and in the case of different managements (forest thinning), to get the accurate parameters (height of tree and radius of canopy) for automated tree detection by ENVI LiDAR software, is sometimes very difficult.

Thus, it is more effective, if DSM/DEM layers are using for defining the pixel-based tree heights. Determination of tree heights at operational level is carrying out in the most cases by coarse estimation, which is sometimes affected by significant errors. Compared the LiDAR-based elevation parcel map with operational tree height estimation, a close correlation (r=0.7935) was measured, but the operational estimation was overestimated with 3.13 m, however there were parcels with almost 7 m overestimation by the forest planner specialist (Fig. 5). Nevertheless, operational height estimation was occurred at parcel level, but LIDAR point cloud provides to determine the height of individual tree.

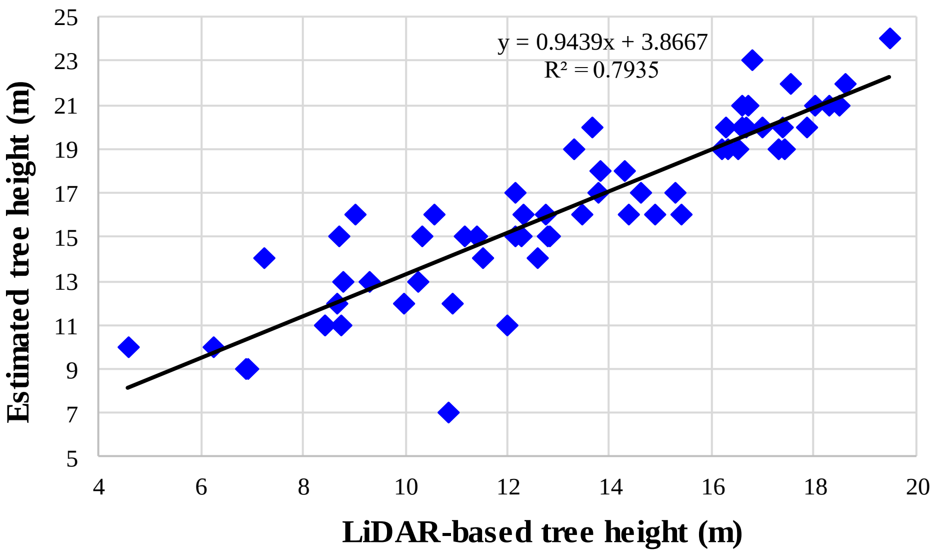

Fig. 5. Correlation between LiDAR-based tree height and estimated tree height by parcels

Using pixel-based elevation map from the investigated area, and applied the modified Chapman-Richards growth function, an increment map was prepared. This map strongly correlates with the tree canopy height map, but the age-based non-linear growing of trees, is more emphasize appeared on the increment map. Modified Chapman-Richards equation cannot be used for too young trees, so 17-year-old 20/I and 5-year-old 20/M parcels were ignored from the increment map.

According to the pixel-based frequency of increments, experimental area was categorized into three terroir classes; “better”, “moderate” and “worse” classes were determined. Each categories was prepared based on the histogram of tree increment. Percentiles of incremented canopy height distribution for 20 % were calculated. Lower 20 % of the increment was the "worst", upper 20 % was the "better" category (Fig. 6).

After filtering of the gaps, it could be established, 11.19 % of the experimental area is worse, 62.43 % is moderate and 26.38 % is better site quality. Artificial gaps in forest parcels cause false results using the equation. Thus, the twenty-four gaps, which were early prepared by the foresters in the investigated area, should have been ignored. The average area of artificial gaps is 407.69 m^2 and the whole gap area is almost one hectare (Fig. 7).

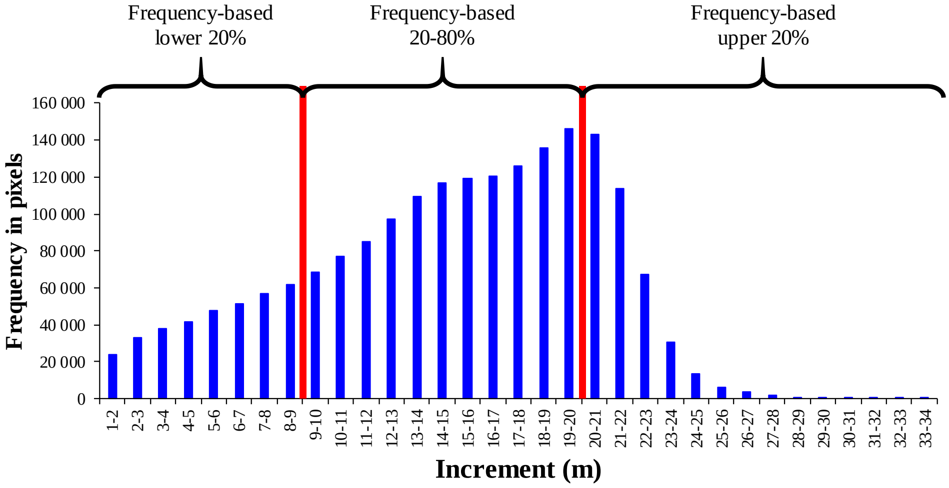

Fig. 6. Terroir classification based on the histogram of estimated increment

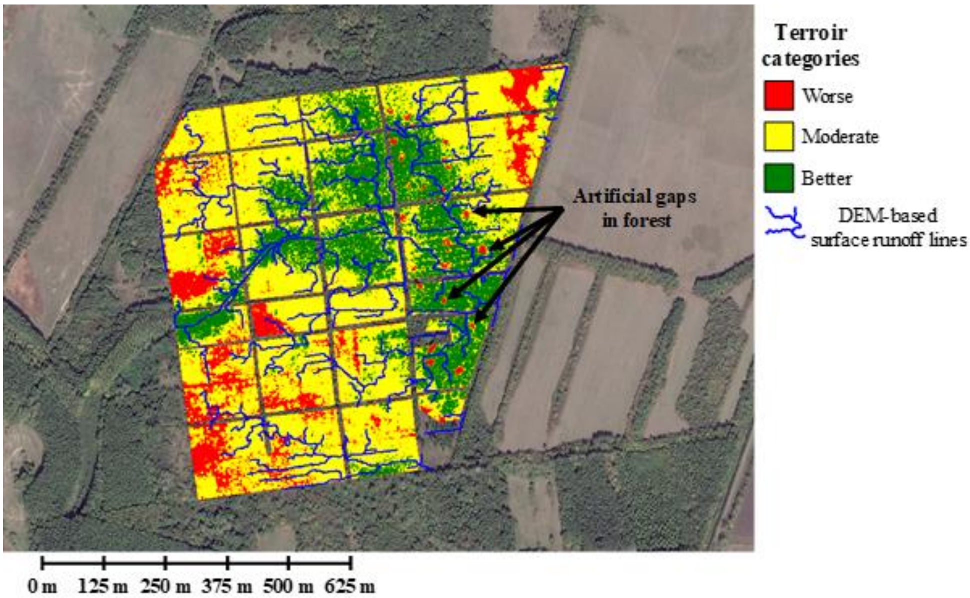

Fig. 7. Terroir categories with surface runoff

Compared the calculated terroir categories with soil types, similar "pattern" can be observed, the correlation between the variables was moderate (r=0.3615). Moreover, between increment map and DEM, a strong negative correlation was detected (r=-0.5502). The ratio of terroir categories in different soil types were analyzed (Table 1).

Table 1

Terroir categories on the investigated soil types

	Solonetz	**Gleysol**
Area of interest (ha)	12.21	39.40
"Worse" terroir category	28.59%	7.77%
"Moderate" terroir category	68.17%	59.19%
"Better" terroir category	3.23%	33.05%

Based on the LiDAR data the effect of soil types of increment can be evaluated. According to the results of Tukey variance analysis, increments of the two soil types are statistically different ($p<0.05$). The best results were detected on Gleysol for *Quercus robur* habitat, worse increment results were obtained on Solonetz soil type. The effect of soil types to increment is statistically proven (Table 2); trees were 62.49 % higher on Gleysol soil than on Solonetz.

Table 2

The result of Tukey variance analysis

Soil type	**Increment (m)**
Solonetz	9.677^{a}
Gleysol	15.485^{b}

There was no significant difference between the same numeric indices.
*Based on variance analysis ($p < 0.05$).

Gleysol and Solonetz soil types were occurred in the investigated area. The average tree height was larger on Gleysol, which suggest that *Quercus robur* is moderately salt tolerant. This moderate salt tolerating of the *Quercus robur* is reflected on the salt-sensitivity of the tree (Sehmer et al., 1995; Alaoui-Sossé et al., 1998; Tóth, 2010). In that way the effect of soil types on increment can be more effective monitored by LiDAR system.

CONCLUSIONS

Our research hypothesis was that soil type is an important factor in tree height, but examining the annual increment, the effect of runoff, so the surface hydrology is more emphasized.

Based on this study, modern technological element (GPS, GIS, RS) can partially provide opportunity to more effective forest planning and forest management. High resolution and large amounts of 3D data can be acquired by airborne LiDAR systems. LiDAR serves such structural information about the forest, which to determine by traditional method is time-consuming or sometimes unbelievable the measuring. Used modified Chapman-Richards growth function, trees (with different age) were standardized and an increment were calculated. Percentiles of incremented canopy height distribution for 20 % were calculated, and GIS-based terroir classification map was prepared.

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