Root-Plate Characteristics of Common Aspen in Hemiboreal Forests of Latvia: A Case Study

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Abstract: Climate change will cause winds to strengthen and storms to become more frequent in Northern Europe. Windstorms reduce the financial value of forests by bending, breaking, or uprooting trees, and wind-thrown trees cause additional economic losses. The resistance of trees to wind damage depends on tree species, tree- and stand-scale parameters, and root-soil plate characteristics such as root-plate size, weight, and rooting depth. The root-soil plate is a complex structure whose mechanical strength is dependent on root-plate width and depth, as the root system provides root attachment with soil and structural support. In Latvia, the common aspen (Populus tremula L.) root system has been studied to develop a belowground biomass model, because information about root system characteristics in relation to tree wind resistance is scarce. The aim of this study was to assess the root-plate dimensions of common aspen stands on fertile mineral soil (luvisol). Study material was collected in the central region of Latvia, where pure mature (41–60 years old) common aspen stands were randomly selected, and dominant trees within the stand were chosen. In total, ten sample trees from ten stands were uprooted. The diameter at breast height (DBH) and tree height (H) were measured for each sample tree, and their roots were excavated, divided into groups, washed, measured, and weighed. The highest naturally moist biomass values were observed for coarse roots, and fine root biomass was significantly lower compared to other root groups. All root group biomass values had a strong correlation with the tree DBH. The obtained results show that there is a close, negative relationship between the relative distance from the stem and the relative root-plate depth distribution.

Keywords: belowground biomass; coarse roots; Populus tremula L.; root biomass; root distribution; wind resistance

1. Introduction

The world’s forests face a rapidly changing climate [1], and a better understanding of how changing conditions may affect them is needed [2]. It is projected that in the future, stronger winds and storms will become more frequent in Northern Europe [3]. Wind is a natural hazard that poses a significant threat to forests, specifically wind-throw of trees. In the last 30 years, the number of storms and their intensity has increased in European forests [4]. Windstorms cause heavy losses in forestry by bending, breaking, or uprooting trees, thus considerably reducing their monetary value. Also, storms create large openings in the forest stand [5,6] and increase the probability of secondary damages due to newly formed stand edges [7]. The effects of climate change on forests manifest as the replacement of less adapted trees species with the ones more suitable for the new conditions, including new wind climate [8]. This has already occurred in Switzerland, where Pinus sylvestris L. has been replaced by Quercus pubescens Willd., and in Spain, where Fagus sylvatica L. has been replaced by Quercus ilex L. [9]. Additionally, a drop in the financial value of stands, due to increased frequency of disturbances and other socio-economic reasons, increase...
the share of natural regeneration and unmanaged areas [6]. It, in turn, will increase the proportion of broadleaved trees over forests, including common aspen (Populus tremula L.). Therefore, it is important to evaluate the traits related to aspen wind resistance.

Tree susceptibility to wind is affected by several factors, including stand parameters, tree species, tree dimensions and shape, root-soil plate size, and changes caused by forestry operations (i.e., thinning and tending) [2,10]. Trees have the capacity to adapt to wind influence. In storms, relatively young and middle-aged trees are damaged more often because of insufficient mechanical strength [11,12]. Also, trees in areas with lower wind speeds or trees after thinning are more damaged in storms because of a lack of adaptation to the influence of wind [12]. Additionally, poor root development reduces tree stability [13].

The common aspen is a fast-growing tree species that is widely distributed across European boreal forests [14,15] and grows on fertile and well-drained soils alongside other tree species [16]. In Latvia, common aspen stands cover 7% of the total forest area [17]. The aspen has a plate root system characterized by wide but shallow rooting. The main elements of the plate root system are the large lateral roots, which elongate horizontally out from the stump before tapering and branching into narrower absorption roots. Another important element is the vertical sinker roots, which emerge from the laterals and branch downwards into the subsoil [18]. The interaction between root architecture and soil type is important for the robustness of the root system, such that roots resist bending more effectively as rooting depth, soil density, and compaction increase [19]. In addition, the mechanical strength of the root system is dependent on root-plate radius (width) and depth [19]; hence, the root-plate in complex with coarse and small roots determines tree stability in the soil [20]. Fine roots with a diameter smaller than 2 mm are often excluded from analysis because they are not related to wind resistance [21]. Aspen achieves tight root contact with the soil by forming an abundance of small roots that significantly increase the root surface area [22]. Additionally, the symmetry of the root system is important to ensure the stability of the tree, especially in conditions, where root depth is limited by soil conditions [23].

Responses of the aboveground parts of trees to different stress factors, including wind, has been well studied in controlled and forest environments, but until recently, relatively fewer studies have been conducted on root response to different stresses due to technical complications [8,24–27]. Models had been developed to characterize the effects of root architecture on tree anchorage [28,29], and root traits, including root-soil plate volume, have been linked to parameters of the aboveground part of trees [30,31] for economically important tree species. However, studies of the root system of common aspen are very scarce [32] and, to the best of our knowledge, none address wind resistance. Based on studies of other species, we hypothesize that there is a close relationship between tree diameter at breast height (DBH) and soil-root plate volume. The aim of this study was to assess the root-plate dimensions of common aspen stands on fertile mineral soil (luvisol).

2. Materials and Methods

The study was conducted in the central region of Latvia (56°52’ N, 24°21’ E) in pure, mature (41–60 years old) common aspen stands, growing on freely drained mineral soil [33], corresponding to luvisol [34]. Because a thick layer of sediment covers the territory of Latvia, bedrock cannot limit rooting depth. The soil in such a forest type is characterized by rich, sandy loam, loamy soil, typical podzolic or sod podzolic, and fine sand soil [26,35].

Study data were obtained in ten randomly selected common aspen stands from ten dominant trees that corresponded to the average DBH² in the stand. DBH and height (H) of each tree were measured (Table 1). Sample trees were pulled with steel cable and manual winch, fixed at the base of opposite trees until uprooting was achieved. The cable (pulling line) was fixed at 50% of the tree height [36].
Table 1. Sample tree above- and belowground dimensions.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Tree Age (Years)</th>
<th>H (m)</th>
<th>DBH (cm)</th>
<th>Root-Plate Width (m)</th>
<th>Root-Plate Depth (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Min</td>
<td>41–60</td>
<td>23.3</td>
<td>21.0</td>
<td>1.5</td>
<td>0.2</td>
</tr>
<tr>
<td>Max</td>
<td>26.7</td>
<td>36.0</td>
<td>2.5</td>
<td>1.2</td>
<td>0.8</td>
</tr>
<tr>
<td>Average (±CI *)</td>
<td>25.0 ± 0.7</td>
<td>27.5 ± 3.3</td>
<td>1.2 ± 0.2</td>
<td>0.8 ± 0.1</td>
<td></td>
</tr>
</tbody>
</table>

* CI: ± 95% confidence interval. DBH: diameter at breast height; H: tree height.

For every uprooted tree, we measured root-plate dimensions and parameters. Common aspen root-plate width was measured parallel to the ground surface and perpendicular to the stem in all cardinal directions (0°, 45°, 90°, 135°, 180°, 225°, 270°, and 315°) as the distance from the centre to the edge of the root-plate. Root-plate width was used as the radius of the root-plate for volume and shape estimation. The rooting depth from the root-plate ground surface to the bottom of the root-plate was measured on the northern and southern direction of the root-plate to assess root depth distribution. The first depth measurement was conducted as close as possible to the stem, while the others were conducted after every 50 cm. At each depth measurement point in every 20 cm-thick layer, sample tree roots were manually dug out, removed, divided into four biomass groups, and weighed in these groups. Root group classification was based on root diameter: F—fine roots (diameter < 2 mm), S—small roots (diameter 2–20 mm), C—coarse roots (diameter > 20 mm), and TS—tree stump [37]. The number of depth observations and observed layers was dependent on root-plate width and thickness, respectively. F biomass was assessed with a 100 cm³ cylinder by taking soil samples (20 repetitions) in the root-plate area at six depths measurement points at every 10 cm-thick layer. Later these samples were delivered to the laboratory, washed, separated from the soil or other small fragments, and weighed. TS, C, and S biomass were assessed on the spot by manually excavating the roots, washing them, separating them from the soil, and weighing them on a scale. TS was defined as the non-root fraction, leftover after root excavation and removal, and not exceeding 30 cm in height from the ground surface. Every sample tree root fraction was assessed and dried at 105 °C until they reached a constant weight (ISO 11465, 1993) [38] to determine the relative moisture content [37].

Common aspen total root biomass was calculated by summing the TS, C, and S root group weight of naturally moist samples. ANOVA was used to determine the differences in statistical parameters between root groups. Most studies determine tree wind resistance with maximum base bending moment [28,30,36]; however, scientists have found that H multiplied by DBH² yielded the best prediction of maximum base bending moment for uprooting for two conifers (Scots pine (Pinus sylvestris L.), Norway spruce (Picea abies (L.) Karst.)) and silver birch (Betula pendula Roth.) in mineral soils (unfrozen) [30]. We based tree wind resistance indication modelling on aboveground parameters, where H was multiplied by DBH² to determine stem susceptibility to uprooting [30]. Pearson’s correlation analysis was used to assess the relationship between tree size, measured variables, and calculated variables (H, DBH, H × DBH², depth, and biomass). Root-plate depth and width at measurement points were expressed in relative values. Relative root depth and relative distance from the stem were used as model predictors to calculate root depth distribution using a generalized additive model. For each model, the 95% confidence interval (CI) was calculated. Data processing and analysis were performed using the statistical software R 4.0.0. [39].

3. Results

3.1. Root-Plate Biomass

Average biomass values for the root groups expressed as naturally moist weight (Figure 1), were 177.5 ± 94.5 kg, 101.2 ± 45.2 kg, and 84.2 ± 30.7 kg, for C, S, and TS, respectively, and 6.7 ± 2.4 kg for F, which was significantly lower than the other root groups. Biomass of the C, S, and TS root groups did not differ significantly, but all root
group biomass values had a strong correlation (0.86 < r < 0.96) with DBH. Relative moisture content varied between root groups: 43%, 55%, and 61% for TS, C, and S, respectively.

Accordingly, total naturally moist root biomass values ranged from 147.7 kg to 895.3 kg, and the average belowground biomass per tree was 362.9 ± 166.3 kg. DBH and total root biomass of naturally moist samples had a strong correlation (r = 0.96) (Figure 2).

**Figure 1.** Average naturally moist root biomass per tree by root group (defined by diameter: F—fine roots (<2 mm), S—small roots (2–20 mm), C—coarse roots (>20 mm), and TS—tree stump).

**Figure 2.** Total naturally moist root biomass per tree against diameter at breast height (DBH). Grey area denotes a 95% confidence interval.
3.2. Structural Root-Plate Depth Distribution

In the structural root distribution analysis, F roots were excluded because their low biomass could not affect wind resistance (Figure 1).

Relative root depth and relative distance from the stem were used as model predictors to assess the structural root-plate depth distribution of common aspen (Figure 3). An analysis of the data obtained in the study confirmed a close, negative relationship \( r = -0.96 \) between the relative distance from the stem and the relative root-plate depth. As the measurement point distance from the stem increased, the root depth decreased. At the edge of the root plate, relative rooting depth decreased to 31% of the total root depth.

![Figure 3](image_url)

**Figure 3.** Relative root-plate depth distribution of measurement points at a relative distance from the stem. Grey area denotes a 95% confidence interval.

Vertical rooting is an important factor that ensures tree resistance; trees with larger and deeper root systems are less prone to wind-throw, as roots resist bending more effectively as rooting depth, soil density, and compactness increase [19]. The average depth of the aspen root plate was 0.8 ± 0.1 m. The average depth in the center of the root plate was 1.1 ± 0.2 m. Maximum depth values (1.2 m) were concentrated in the first 50 cm from the stem; thus, the deepest roots were located close to the centre of the root plate.

3.3. Tree Wind Resistance Indicator

A strong correlation \( r = 0.96 \) indicated a good model fit (Figure 2) between DBH and total root biomass. Therefore, we used \( H \times DBH^2 \) as an indicator of tree wind resistance to uprooting in mineral soils [30]. Average \( H \times DBH^2 \) value was 2.0 ± 0.5, and the values ranged from 1.1 to 3.3 (Figure 4). The presented data also showed a good model fit \( r = 0.97 \) between \( H \times DBH^2 \) and total root biomass.
Figure 4. Tree wind resistance (H × DBH²) in relation to total naturally moist root biomass per tree. Grey area denotes 95% confidence interval.

4. Discussion

Vertical rooting is an important factor that ensures tree resistance: the larger a tree’s root system, the less prone it is to wind-throw [19]. In many cases, trees are able to adapt to growing conditions and form different types of roots to increase their resistance to wind [40]. In our study, the aspen root system was divided into four groups, and average root biomass values differed between these groups. The largest naturally moist root biomass was for C roots, and F root biomass was significantly lower than biomass in any other root group (Figure 1). Naturally moist root biomass values were lower for TS than for C or S roots. Furthermore, the biomass of all root groups had a strong correlation with DBH. Therefore, with increasing DBH, an increase in root biomass can be observed in aspen stands.

Several authors [25,28,41] have studied the relationship between the aboveground parts of the tree and the root system. Direct relationships between the root-plate width and depth had been found [12], determining root plate volume. Root plate volume has a close relationship with tree DBH, as established for European beech and Norway spruce [31], which was later confirmed in studies by other authors [30,42,43]. In our study, aspen DBH and total root biomass had a close relationship, as the correlation coefficient (r = 0.96) indicated a good model fit. Thus, our study hypothesis was confirmed (Figure 2).

In a study on the structural root-plate characteristics of Norway spruce [43], a strong correlation (r = 0.92) between H × DBH² and root-plate volume was observed in mineral soils. Our results are in accordance with the aforementioned study: the correlation we found between aspens’ H × DBH² and total root biomass was strong (r = 0.97). The model showed a good fit (r = 0.97) for common aspen, and the trend indicated that with an increase in total root biomass, an increase in H × DBH² could be observed (Figure 4).

The capacity of a tree to resist wind-throw and windbreak is determined not only by the tree’s height and relative crown height but also by a well-established root system, determined by its width and depth, as the root system provides soil attachment and structural support [10]. Establishing a strong linkage between the root system and the soil significantly increases root surface area [22]. To evaluate the depth distribution of the common aspen structural roots, TS, C, and S roots were used because they affect aspen tree resistance in wind-throw (Figure 1). C roots are located closer to the stem and bond more effectively with the soil [44], but the formation of C roots may be influenced by various factors, such as soil pressure, soil aeration, light, temperature, and humidity [45]. However, the data on the spatial arrangement of the root system still remains scarce. Several studies have been conducted on the persistence of pine and spruce roots during
windstorms [23,37,42,43]. The analysis of the data obtained in our study confirms findings of these studies: there is a close, negative relationship \((r = -0.96)\) between the relative distance from the stem and the relative root-plate depth (Figure 3).

Comparison of our results with those obtained for other tree species in similar conditions [4,30,42,43,46–48] revealed only slight differences in root plate width between aspen and spruce, pine, silver birch. However, root-plate depth of aspen was notably larger than that of mentioned other tree species [30,43,48]. Further research in details of root system development, e.g., in relation to various stand density and microclimatic as well as soil conditions could inform recommendations for foresters and forest owners to improve the resistance of stands in a period of increasing frequency of windstorms and droughts [49,50].

5. Conclusions

The increasing frequency of storms and the consequent probability of wind damage in the future might affect forest productivity. The aspen root system is deeper compared to those of other economically important tree species in hemiboreal forests, and aspen also grows faster. Therefore, it can be used to improve wind stability at forest edges, protecting the stands. The practical implication of this approach might be limited by high browsing pressure, but aspen regenerates abundantly by root sprouts and also can be preserved as retention trees of previous generations during the final harvest.

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Data Availability Statement: The data presented in this study are available on request from the corresponding author. The data are not publicly available due to policy of the institute.

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