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Variation in the morphological structure of the crown of Norway spruce in North Estonian alkalised soil

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ABSTRACT

Characterisation of tree crown structure provides critical information to assess a variety of ecological conditions for multiple purposes and applications. The aim of investigation was to elucidate the influence of the alkaline soil on the formation of the crown of Norway spruce (*Picea abies* (L.) Karst.). The seven sample plots (0.05 ha) with 75–90-year-old spruce stands of *Oxalis–Myrtillus* site type were selected at different distances from a cement plant influenced over 40 years by alkaline dust pollution. The studies were conducted 13 years after dust pollution had practically stopped. High pH values (6.1–7.8), large concentrations of dominant dust components (Ca, Mg, K) and a lower level of N and organic matter in the upper layers of soil within about 6 km from the emission source compared to the unpolluted control area 30.4 km from the source (pH 3.3) were found. Disbalance in mineral composition in needles and shoots was established, deficite in N and excess in Ca and K concentrations were brought about a great differentiation in growth and biomass formation between unpolluted and polluted trees. On the most polluted area the average height of trees and living crown, the length and dry mass of shoots and needles were lower, and average life span of needles were shorter than in unpolluted area, indicating an increased defoliation rate of the crown.

1. Introduction

The external morphology and viability of woody plants reflect the dynamics of environmental factors, on the one hand, and plant response to them, on the other. Tree crown have basic physiological functions for biomass production and it is an important feature for tree survival, quality and stability (Kantola, 2008; Rasmussen et al., 2009). The tree crown research contributes to several key forest ecosystem attributes: productivity, forest management, forest environment, etc. (Avery and Burkhart, 2001).

Although today, there is no generally accepted theory of morphogenesis of trees, it is known, that dense and large crowns are associated with high potential growth rates, while sparse and small crowns can indicate to unfavourable site conditions (Kozlowski et al., 1991). Thus measurement of a tree crown is often used to assist in the quantification of tree growth (Waring and Running, 2007). In bioindication crown transparency and premature casting off needles or leaves are general symptoms of decline in many tree species under a wide range of edaphic or climatic conditions and under air pollution impact (Portsmuth and Niinemets, 2007; Levanič et al., 2009). In conifers a large proportion of tree crown biomass is bound to living branches, where the mass of needles is of great importance. Changes in leaf position due to irregularities in branching habit, or decreased number of lateral shoots, lead to increased transparency of tree crowns and anomalies of tree growth (Polák et al., 2006; Sellier and Fourcaud, 2009).

Norway spruce (*Picea abies* (L.) Karst.) is one of the most abundant tree species of natural forests in boreal Europe, which represents about 20% of the world's landmass (Walker and Kenkel, 2000) and is globally and locally important for forest economy. The volume of Norway spruce on forest land in Estonia makes 23.7% in total and its importance to Estonian forestry is the second after Scots pine (Yearbook Forest, 2009, 2010).

Norway spruce prefer acidic types of soils for optimal growth (Laas, 2004) and the increase of soil pH may be one of the reasons for the decline of its stands in industrial territories influenced by alkaline solid pollutants (Farmer, 1993). As its roots are located near the ground surface, the physiological state of spruce is strongly affected by pollutants deposited on the ground and accumulated into the upper layers of soil (Laas, 2004). Norway spruce is relatively sensitive to air and soil pollution impacts; the biochemical and physiological responses to pollution lead to its declining survival, growth and biomass (Rauk, 1995). Increased defoliation of

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the crown of Norway spruce has been often observed in heavily polluted industrial regions (Ots, 2002). Turnover rates of needles and the number of needles on branches are indicators of the density of the crown and the state of trees (Muukkonen and Lehtonen, 2004). The crown architecture of Norway spruce is largely determined and highly dependent on light, water availability and carbon utilisation and the partitioning of carbohydrates and nutrients among the different parts of the tree (Grassi and Giannini, 2005; Portsmuth and Niinemets, 2007; Fulé et al., 2009; Mandre, 2009).

The objective of this research was to characterise the dynamics of the morphological status of Norway spruce (*Picea abies*) in even-aged *Oxalis–Myrtillus* site type stands located at different distances from a cement plant. This study tests the age-specific structure of shoots and needles in the crown and the chemical composition of needles and shoots and soil 13 years after dust emission had decreased and practically stopped. Crown, shoot and needle characteristics can reflect relative growth and acclimation to different soil conditions, and age-specific structure will help to describe the dynamics of tree development over years. Analysis of the chemical composition of soil will serve as a foundation for understanding relationships between nutrient availability and the morphology of needles and shoots of spruces growing on soils of different pH. A better understanding of the response and acclimation of Norway spruce to unfavourable growth conditions could improve the ability to manage ecosystems.

Table 1
Average characteristics of the investigated Norway spruce stands of *Oxalis–Myrtillus* forest site type at different distances from the cement plant in Kunda. Site types on investigated transect were determined using the local classification of site types (Paal, 1997; Lõhmus, 2004). Relative stand density is calculated as ratio between growing stock of a given stand and fully stocked stand (Vaus, 2005). Density of understory is given after (Mandre et al., 1994).

Distance (km), direction	Composition of tree species	%	No. of trees per ha	Age (year)	Relative stand density	Height (m)	Diameter at breast height (cm)	Density of understory (No. per ha)
30.4 W	*Picea abies*	90	580	85	0.7	24	31	4000
	Pinus sylvestris	10						
6.0 W	*Picea abies*	90	500	90	0.8	26	30	3100
	Pinus sylvestris	10						
3.7 W	*Picea abies*	90	570	90	0.8	24	25	3900
	Pinus sylvestris	10						
	Betula spp.	<1						
2.7 W	*Picea abies*	100	660	80	0.8	22	25	700
	Pinus sylvestris	<1						
2.0 E	*Picea abies*	80	640	75	0.7	20	25	1100
	Pinus sylvestris	20						
	Betula spp.	<1						
3.0 E	*Picea abies*	80	720	75	0.8	23	28	2300
	Pinus sylvestris	10						
	Betula spp.	10						
10.6 E	*Picea abies*	80	770	75	0.8	23	31	3800
	Pinus sylvestris	20						
	Betula spp.	<1						

2. Material and methods

2.1. Environmental conditions in the study area

Investigations were carried out on a territory affected for over 40 years by a cement plant in the town of Kunda (59°30′N, 26°32′E), North-East Estonia. The soils in the area investigated are Gleic Podzols (Lkg) on sands.

The emission from the cement plant in 1987–1993 contained 87–91% technological dust and 9–13% gaseous pollutants (SO_2, NO_x, CO, etc.). The dust contains many components, among which the following are predominant: 40–50% CaO; 12–17% SiO_2; 6–9% K_2O; 4–8% SO_3; 3–5% Al_2O_3; 2–4% MgO; but also Fe, Mn, Zn, Cu, B, etc. occur. The water solution of dust from electric filters had pH values from 12.3 to 12.7 (Mandre, 2000). The dust emission

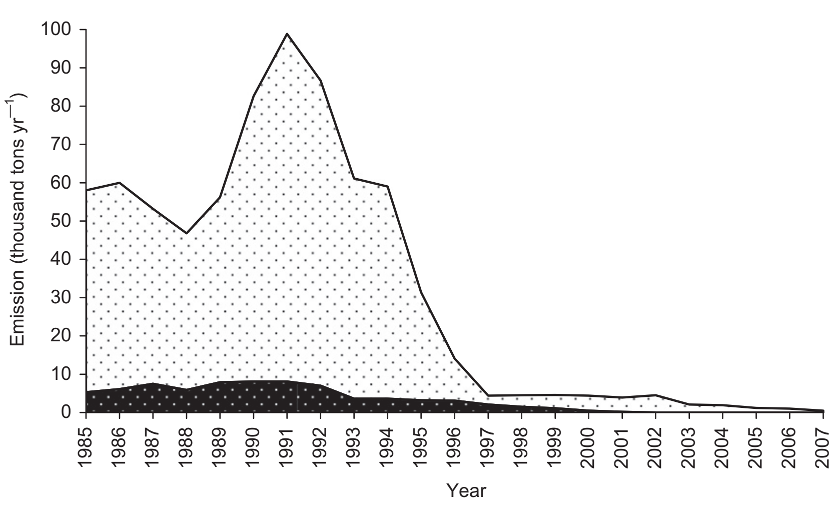

Fig. 1. Emission of dust and gaseous pollutants (SO_2, NO_x, H_2S, etc.) into the atmosphere from the cement plant in Kunda (Keskkond '88, 1989; Keskkond '89, 1990; Keskkond '90, 1991; Estonian Environment 1991, 1991; Environmental Review No. 16, 2007).