Impact of Alkalisation of the Soil on the Anatomy of Norway Spruce (Picea abies) Needles

Aljona Lukjanova · Malle Mandre · Gerly Saarman

Received: 20 December 2012 / Accepted: 6 June 2013 / Published online: 21 June 2013
© Springer Science+Business Media Dordrecht 2013

Abstract In this study, we evaluated the needle anatomy of Norway spruce trees growing on a territory that was exposed to different alkaline dust pollution. The anatomy of the needles of spruce growing on a polluted site in the vicinity of the Kunda cement plant (Northeast Estonia) was compared with the anatomy and physiological state of the needles from an unpolluted site. The needles from polluted sites had a significantly larger average mesophyll area and thicker epidermis. These needles also had significantly smaller average vascular bundles and xylem areas than needles from the unpolluted site. Although in the alkalised growth conditions, the mesophyll area enlarged, the number of damaged mesophyll cells increased, and as a result, the concentration of chlorophylls decreased reducing the photosynthetic potential of trees. Our study indicates that even though cement dust pollution has practically ceased in the area, the alkalised soil is affecting physiological processes in trees for a long time.

Keywords Norway spruce · Needle anatomy · Alkalisation · Pigments · Lignification

1 Introduction

The aim of the earlier research into the anatomy of conifers was to study and describe the structure of different tissues in healthy plants (Marco 1939; Sutinen 1987; Walles et al. 1973), but later research concentrates on changes in tree anatomy due to changes in the environment. Several environmental factors such as irradiance, ambient carbon dioxide concentration, temperature, and water availability or air pollution are known to affect both leaf structure and functioning. The anatomical structure of conifer needles has been considered as an important diagnostic tool in the field and has been used as a bioindicator of environmental pollution (Huttunen and Manninen 2005; Sutinen and Koivisto 1995). Likewise, structural characteristics of conifer needles can be applied to determine the effects of changes in the light intensity (Gebauer et al. 2012; Skuodienė 2001) and elevated CO₂ (Lin et al. 2001; Luomala et al. 2005). Anatomical differences of needles of conifers were also established during increasing tree age (Apple et al. 2002) and under nutrient stress such as N, Mg and K deficiency (Fink 1991; Jokela et al. 1997) or excess of Ca, K and Fe (Mandre and Lukjanova 2011) as well as due to fertilisation (Lukjanova and Mandre 2010; Makoto and Koike 2007; Sutinen and Saarsalmi 2008).
Environmental pollution seems to be one of the serious factors that cause changes in the anatomy and morphology of leaves, and conifers belong to the most affected trees. There are studies on the influence of acid rain (Albrechtová et al. 2007), NOx, and SOx (Karolewski et al. 2005), O3 (Maier-Maercker 1998; Wieser et al. 2002) as well as road salting (Forcícek et al. 2011) on the anatomy of conifers. However, too little attention has been paid to research into the impact of alkaline types of pollutants such as industrial dusts or ashes. As was pointed out by Farmer (1993), Mandre (2009) and Kaasik et al. (2005), the influence of alkaline types of pollutants is accompanied by changes in soil, expressed as increased pH and disbalances in the mineral nutrient composition. Dust emitted from the cement plants usually has a very high pH and causes alkalisation of territories surrounding the emission source. Alkalisation of the environment and disbalances in the nutrient composition of soil and trees retard the growth and radial increment of conifers (Pām 2000; Rauk 1995) due to serious physiological and biochemical alterations in the organism (Farmer 1993; Mandre 1995). A decrease in the content of carbohydrates (Kloščétok 2005), nitrogen (Mandre 2009) and chlorophylls and carotenoids (Mandre and Lukjanova 2011) in the needles as well as changes in the needle anatomy (Lukjanova and Mandre 2010) has been described.

Trees have vital needs for both mechanical support and water transport. Rigidity and compressive strength of the cell walls facilitate water supply and obstruct the degradation of wall polysaccharides imported by the lignin polymer (Campbell and Sederoff 1996; Hatfield and Vermerris 2001). Lignin content varies between different plant species and plant organs: it makes up about 5 to 10 % of the dry mass of spruce and pine needles while the roots may contain three times as much lignin (Mandre 2002a; Mandre and Lukjanova 2008; Miksche and Yasuda 1977). The content of carbohydrates and intensity of lignification determine the growth and stress tolerance of trees (Mandre 2002b; Mandre and Korsjukov 2007). Lignin accumulation into the cell wall may be affected by exposure to various biotic and abiotic stressors (Mandre 2000); for example, lignification of trees will intensify under extreme growth conditions caused by air pollution (Mandre 2002b; Mandre and Lukjanova 2008). Moura et al. (2010) claim that lignin biosynthesis depends on the stressors that are acting during plant growth and development. Lignin content increases also with the age of needles (Mandre and Lukjanova 2008). This means that environmental conditions influence lignification processes and the so-called stress lignin as a response to unfavourable growth conditions may be synthesised (Mandre 2002b; Ziegler 1997).

Over 50 years in Estonia, one of the major sources of dust pollution was the cement plant at Kunda, Northeast Estonia. Since 1996, when the dust emission from this plant almost stopped, it has stayed within permissible limits. However, the alkaline dust pollution that affected the environment for half a century has caused alkalisation of the environment. Nowadays, the Kunda cement plant uses the wet technology, which pollutes the environment less than the formerly used technology. During the production process, CO2 and also SO2, NOx and other inorganic compounds are generated, but the proportion of dispersed alkaline dust is relatively small (Jäätsusutilvikus.ee 2007). Nevertheless, today, the soil pH in the vicinity of the cement plant is high (up to 7.8) and the content of Ca2+, Mg2+ and K+ ions has remained large (Mandre 2000). As the neutralisation of alkalisod soils is proceeding at a slow pace, the alkaline environment is still affecting physiological and biochemical processes in trees. Therefore, studies that focus not only on direct consequences of dust emission but also on the effect of long-term pollution on the forest ecosystem, including the anatomy of trees, have not lost their significance.

The purpose of the present study was (1) to compare the anatomy of needles of Norway spruce trees from an alkaline cement dust-polluted area with the needles from an unpolluted area and (2) to determine the influence of alkaline soil on the anatomy and lignification of the needles of Norway spruce.

2 Materials and Methods

2.1 Study Area, Soil Sampling and Analyses

The sampling sites were located on an east–west transect near the Kunda cement plant (59°30’N, 26°32’E), Northeast Estonia. The investigated sampling sites (0.05 ha each) were in the zone of high pollution. Two of them were located 2 and 3 km to the east (K 2 and K 3) and one was 2.7 km to the west (T) of the cement plant. The control sampling site (C, 0.15 ha) was selected in similar climatic and edaphic conditions on a