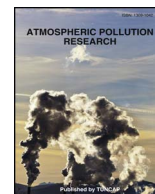


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# Seasonal variability of leaf water capacity and wettability under the influence of pollution in different city zones

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## ABSTRACT

Can dust and tarry substances that are rich in polycyclic aromatic hydrocarbons (PAHs), which are deposited on leaves, cause changes in the water retention of tree crowns? It is hypothesized that the contact angle between droplets and a leaf's surface and water capacity changes because of the content of PAHs. This angle is treated as a bioindicator of environmental pollution. The goal of this study was to analyse the relationship between rainfall water capacity and wettability of small-leaved lime and poplar in different zones in a city centre during the period from April through November. We implemented a series of simulated rainfall and angle measurements under laboratory conditions of tree twigs collected at three locations inside the city centre and one from an area outside the city. The background for the water capacity values were results acquired from selected PAHs contents determined in leaves using high-performance liquid chromatography (HPLC), and images of the leaves' surface were acquired via Scanning Electron Microscope (SEM). Based on the obtained results, we concluded that there were significant differences in water capacity between the areas for each month. In the city centre, water capacity from April to July was lower than that in the forested area. From July to the end of the growing season, the water capacity was lower in the city compared to the forest area. The contact angle was strongly correlated with water capacity. With a decreasing contact angle, the raindrops increasingly adhered to the leaf surface, and water capacity increased.

It was found that the effects of pollution on water capacity cannot be ignored in developing forecasts or in models describing ecosystem and hydrological changes in natural and urbanized environments.

## 1. Introduction

Water capacity is defined as the amount of rainfall stored along canopy and stem surfaces and is one of the main components of the water balance of forest and urban ecosystems (Xiao and McPherson, 2016). In equations describing hydrologic balance, crown water capacity is treated as a direct loss of precipitation (Wang et al., 2012) and is a key element of ecohydrological processes (Llorens and Gallart, 2000; Muzylo et al., 2009). Usually, it does not have a large value, as expressed in millimetres, but as part of total precipitation, it can reach 10–50% (Chang, 2006; Holder, 2013). It is one of the least understood and parametrized components of hydrological equations (Pypker et al., 2005), and it is measured by different field and laboratory methods (Keim et al., 2006; Sadeghi et al., 2016). Water capacity vary in response to vegetation structure like tree species, leaf area index, crown size (Rosado and Holder, 2013) and meteorological factors as rainfall

intensity, size of rain drops (Hall and Calder, 1993; Nanko et al., 2006). Long exposure to contaminations leads to a change in the texture of leaf surface, which affects the surface tension. Scanning electron microscopy images are often used to analyse a leaf surface (Fernández et al., 2011). Additionally, precise measurements of the amount of impure particles that are deposited are considered (Neinhuis and Barthlott, 1997; Sgrigna et al., 2016). The amount of pollutants in the air and their chemical composition affect the condition of a leaf's surface (Kosiba, 2008; Popek et al., 2012), so it is reasonable to consider water capacity along a gradient of pollution.

Moreover, the contact angle between the droplets and the surface of the leaves changes and can be considered a bioindicator of environmental pollution (Tranquada and Erb, 2014). Aryal and Neuner (2010) created a system for classifying the degree of wettability that was later used by Rosado and Holder (2013) and Klamerus-Iwan and Błońska (2016). The significance of leaf water repellency, as expressed by

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contact angles and water capacity, to ecohydrological relationships is becoming increasingly prominent (Doerr et al., 2006; Murakami, 2007). Even small changes in the hydrophilicity of tree crowns can have ecological consequences in urbanized catchments (Shaneyfelt et al., 2017; Koryto et al., 2017).

Growing urbanization leads to the necessity for adapting water capacity studies to consider urban problems. The important advantage of this research is the ability to compare the course of changes in water capacity and wettability over the growing season in polluted and unpolluted areas. The amount of water retention in cities should be considered in parallel with pollution mitigation (Pietrzykowski et al., 2014; Pajak et al., 2016) and carbon sequestration (Brienen et al., 2015) as well as during the development of models and strategic plans for Green Urban strategies (Serengil et al., 2011; Calfapietra et al., 2015).

Tree species differ in terms of the amount of impurities that accumulate on their surface (Dzierżanowski et al., 2011; Sæbø et al., 2012; Popek et al., 2012). Therefore, two species were examined for comparison: small-leaved lime (*Tilia cordata* Mill) and hybrid poplar (*Populus robusta*). The air in urban areas has been polluted and *Tilia cordata* leaves have showed significant seasonal accumulation especially for Pb, Cr, Fe, Ni, Zn and Mn (Aničić et al., 2011). *Populus robusta* is highly tolerant of urban pollution and will thrive in inner city environments (Jaworski, 2011). That's why they are the most popular and favourite tree species in cities and parks. Leaf samples were collected in a forest and in Cracow (southern Poland), where the air pollution is among the worst in Europe. The geographical location, predominant wind direction, and historical and current deposition of industrial dust affect the concentration of contaminants (Muskala et al., 2015; Błońska et al., 2016).

The objective of this study was to determine the changes in both the trend of the water capacity curves and the contact angles during the growing season, depending on the location and the amount of pollutants, as expressed by the content of polycyclic aromatic hydrocarbons (PAHs). Numerous studies have reported the problem of plant material being contaminated by polycyclic aromatic hydrocarbons (Sadowska-Rociek et al., 2016; Yang et al., 2017). PAHs were chosen because they are solid compounds in the environment and are characterized by low volatility and solubility in water; thus, they may affect the amount of water retained on leaves. PAHs also influence the water properties of soil (Klamerus-Iwan et al., 2015).

To achieve the research objective, a series of laboratory tests combined with rainfall simulation and contact angle measurements were performed. Additionally, a series of images using a scanning electron microscope was taken to evaluate the surface condition of the leaves and the distribution of contaminants. We tested the following hypotheses: 1) the water capacity and contact angles change during the growing season, but the dynamics of these changes depend on the number of PAHs in the leaves; 2) there is a strong correlation between wettability and water capacity; and 3) species differ in their seasonal patterns of water capacity and wettability.

## 2. Methodology

### 2.1. Sample collection

Two species that are frequently used in European urban forestry were selected: small-leaved lime (*Tilia cordata* Mill) and hybrid poplar (*Populus robusta*). In the area of Cracow, 3 zones were identified. The exact centre of Cracow (WGS84: 50°4'58.081"N, 19°57'5.478"E) was considered the first zone (Z1). The second zone (Z2) was a series of settlements dominated by parking places for residents. The third zone (Z3) was urban parks, located as far as possible from the main streets and without traffic (Fig. 1). Moreover, a control area, zone 4 (Z4), was established in the Miechów Forest District (WGS84: 20° 03' 52"N; 50° 10' 17"E), approximately 40 km from northern Cracow (Fig. 1). According to Błońska et al. (2016) as for the soil contamination, the

cleanest forest area was located on the north of Krakow, in Miechów Forest District. The choice of areas with varying degrees of contamination was dictated by an analysis of pollutants from measuring stations of the Provincial Environment Protection Inspectorate in Krakow (<http://monitoring.krakow.pios.gov.pl/dane-pomiarowe/automatyczne/stacja/6/parametry/1711-44-46-202-43-42-45/roczny/> 2016).

Within each of the 4 zones, 6 trees of each species were selected. For each tree, 4 branches with a length of approximately 1.0 m were collected. Branches were taken from the 4 main sites of the whorl at half the height of the crown. Trees aged 30–40 years with a well-developed crown were chosen. Leafy twigs were collected using a telescopic tree pruner. The cut end was secured with liquid paraffin and transported in a separate container to the laboratory, where further analyses were carried out. Determination of the water capacity and contact angles occurred immediately after arrival at the laboratory. Leaves intended for chemical analysis were frozen because PAHs remain constant and can be analysed at a later time. The entire research process was repeated between the 15th and 20th days of each month from April to November 2015.

### 2.2. Determination of the water capacity and the contact angle

All analyses were performed under constant and controlled temperature (22 °C) and humidity conditions (50%), without considering the effect of varying wind, air pressure or humidity. Previous studies have indicated that the effect of temperature is important for the water density and the way in which droplets adhere to the leaves (Owsiak et al., 2013).

In the laboratory, twigs were weighed and subjected to a simulation with a fixed amount of precipitation followed by further re-weighing. The biomass (BM) obtained was used to calculate the water capacity per biomass unit.

Precipitation (P) was estimated at 200.00 g. Water in specified doses fell from a scaled container over the twig (Klamerus-Iwan and Błońska, 2016). The intensity was constant throughout the rain duration, which gave comparable results in each case. The container, over which the branch was sprinkled was 50 × 50 cm, so we covered with rain 0.25 m<sup>2</sup>. Sprinkling was continued for 10 min, giving a constant intensity of 4,8 mm h<sup>-1</sup>.

The position of the twigs during spraying was similar to their natural orientation on the tree. The twigs were sprayed from a fixed distance with water at a temperature of 21 °C, 1° lower than that occurring in the laboratory. Studies on water capacity, using simulated precipitation of a fixed amount, were carried out using twigs ranging in length from 30 to 35 cm that were selected from the twigs transported to the laboratory. The experiment was carried out immediately after transporting plant material to the laboratory.

Crown water capacity was related to the biomass unit (BM). From the literature it appears that biomass is the good predictor for quantifying rainwater retention (Garcia-Estringana et al., 2010).

The pattern used for calculation: Water capacity per BM = amount of water retained/BM.

Amount of water retained was treated as the difference between the amount of water used to simulate precipitation and the amount of water that was not retained on twigs.

Every time the amount of stored water was converted by the mass of the branches.

The amount of simulated precipitation (P) was treated as 100% and knowing the amount of water (in grams) that stopped on a particular branch, percentage of total precipitation was calculated. The expression of water capacity as a percentage and not in millimetres provides a better picture of the process and allows the results to be expressed for the entire tree or for a tree stand as a percentage of the precipitation retained.

Very similar measurements were provided by Xiao and McPherson

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