

Impact of Urban Green Spaces, Native Tree Species and Seasons on Soil pH in Kaunas, Lithuania

LINA STRAIGYTĖ*, TADAS VAIDELYS, REMIGIJUS ŽALKAUSKAS AND MICHAEL MANTON

Vytautas Magnus University, Department of Forest Research and Ecology, Studentu 11, LT-53361 Akademija, Kaunas district, Lithuania, email address: lina.straigyte@vdu.lt; tadas.vaidelys@vdu.lt;

remigijus.zalkauskas@vdu.lt; michael.manton@vdu.lt

**Corresponding author email address: lina.straigyte@vdu.lt*

Straigyte, L., Vaidelys, T., Žalkauskas, R., and Manton, M. 2019. Impact of Urban Green Spaces, Native Tree Species and Seasons on Soil pH in Kaunas, Lithuania. *Baltic Forestry* 25(2): 257–262.

Abstract

Tree growth is sensitive to soil pH in urban areas and is often higher than in rural forest. However, there are knowledge gaps on how soil pH and alkalization are affected by urban environments and seasonal climate as well as the cascading effects on tree species. In order to fulfil these gaps, we analyzed the topsoil pH_{CaCl} of four common native deciduous tree species: *Acer platanoides*, *Tilia cordata*, *Quercus robur* and *Betula pendula* in five different types of urban green spaces in Kaunas city municipality (Lithuania). The results show that topsoil pH in urban environments with *Betula pendula* sites were most alkaline (pH 7.04), whereas the topsoil pH of urban environments with *Acer platanoides* (pH 6.7) and *Tilia cordata* (pH 6.8) were most acidic. The topsoil pH of street tree greeneries were alkaline, while the topsoil profiles of the peri-urban forests and large urban parks were acidic. Differently to natural conditions in peri-urban forests, the topsoil pH level drop down by 0.5 is observed during spring-autumn period in broad street greeneries with largest urban pressure. The variation in soil pH of the different types of green space and tree species shows that city planner should consider the unique conditions of all green space to maximize their potential for human well-being.

Keywords: green spaces, native tree, peri-urban forest, topsoil pH, street trees

Introduction

Urban environments are extremely modified compared to natural and semi-natural environments and may have different environmental properties (Benvenuti 2004). Physical, chemical, and biological properties of urban green infrastructure can be modified through site disturbances (Scharenbroch et al. 2005). These include local man-induced changes to climate, soil, water and air quality. These are challenging environmental factors city planners need to consider for healthy tree growth in urban green spaces. In addition, poor site condition, artificial ecosystem and a lack of professional tree care may also create unhealthy growing conditions for trees in urban areas (Vezina 1965, Bradshaw et al. 1995). Thus, these conditions combined with other external modifications influence tree growth and other key processes.

Soil pH is one of the most important properties involved in plant growth (Foth 1990). Patterson (1977) suggested that as much as 90% of all urban tree health issues are soil-related. Most urban soils are substantially altered from their natural state, or even completely manufactured, however urban soils must still provide

the necessary resources for root growth and tree development (Watson et al. 2014).

Soils are distinguishable within urban environments (Scharenbroch et al. 2005). Usually soils in urban green spaces have limited and inferior nutrients profiles for tree growth compared to woodlands and forests. Urban soil alkalisation is another important factor that influences the growing conditions of trees in urban green spaces, as soil pH determines nutrients accessibility. These soils have fewer nutrients, minerals and trace elements and often the pH values are too high (e.g. alkaline, > 7.3) and thus have a negative effect on the growth of many tree species.

Calcium is available in neutral pH, iron – from medium acid to strongly acid, molybdenum available in strongly alkaline soil (Samson et al. 2017). Most nutrients, minerals and trace elements are available at optimal levels in slightly acidic to neutral soils (e.g. at a pH in the range of 5.5 to 7.2 pH) (Watson et al. 2014). Therefore, trees generally grow best in this pH range. On the contrary, many trees species cannot tolerate alkaline soil, which leads to poorer quality and nutrient deficient pale green to yellow foliage (Ware 1990). Mickelbart et al.

(2012) showed that height and width of all *Spiraea alba* were reduced when grown in soils with a high alkaline soil pH. The ideal pH range for most trees is about 5 to 6.5 (Day and Dickinson 2008). Indeed, most urban soils are too alkaline for optimal plant nutrient availability (Kelsey and Hootmann 1988).

Different tree species can affect soil pH. The effect of different tree species on soil pH is most significant in the first ten centimetres of the topsoil (Binkley and Valentine 1991, Norden 1994, Augusto et al. 2003). However, the impact of a tree species on soil fertility varies depending on the type of bedrock, climate and forest management (Augusto et al. 2002). For instance, tree species rich in calcium are associated with increased soil pH (Reich et al. 2005).

Soil pH levels fluctuate both spatially and temporally (Wuest 2015). Spatial pH variation has been found to be greater than the seasonal variation (Skjellberg 1991). Seasonal pH fluctuations are related mostly with soil moisture, soil temperature and microbial activity (Bower and Leat 1958). For instance, the spring snow melt may saturate the soil and leach out nutrients that can cause changes in soil pH.

The aim of this study is to quantify the impact of urban green spaces, tree species, and seasons on pH of topsoil up to 10 cm depth in Kaunas city municipality and its surrounds. We hypothesized that: a) pH of topsoil up to 10 cm depth in peri-urban forests is more acidic than in other urban green spaces; b) different native tree species have different impact on topsoil alkalization; c) pH of topsoil up to 10 cm depth for all tree species in spring is more alkaline.

Material and Methods

Study Area

The study was carried out in 2014 within Kaunas city municipality (54°53'25.03" N, 23°53'25.103" E), the second largest city in Lithuania with a territory of 158 km². According to the degree of urbanization Kaunas city municipality is densely populated (Eurostat 2016). The average temperature in January is -3.6°C, and in July +18.6°C (Official statistics portal 2019). Urban green space in Kaunas city municipality are characteristic of the hemi-boreal ecoregion sharing species from both temperate and boreal forest.

Study Design

The design of this research focused on three different aspects related to topsoil pH. Firstly, five different types of green spaces were analyzed: These were the following: 1) urban parks (>1 ha); 2) small urban parks (<1 ha); 3) narrow street (maximum two traffic lanes) greeneries; 4) broad street (minimum four traffic lanes)

greeneries, and 5) peri-urban forests within 15 km of Kaunas city. Secondly, four common native deciduous tree species were analyzed: *Tilia cordata* Mill., *Acer platanoides* L., *Betula pendula* Roth, and *Quercus robur* L. All trees were 60 (±5) year old, with normally and healthy development. Thirdly, seasonal variation was measured during spring (in April), summer (in July), and autumn (in October).

Soil group and pH studies

A finger test was used to estimate soil type. The soil type in green spaces was defined according to World Reference Base for Soil Resources (IUSS Working Group WRB 2015).

Soil samples (N = 9 × 4 tree species × 5 green spaces types × 3 seasons = 540) for pH analysis were collected during the 2014 vegetation season (spring, summer and autumn). Soil samples were collected from the topsoil at a depth of 0 to 10 cm below O horizon (Figure 1).

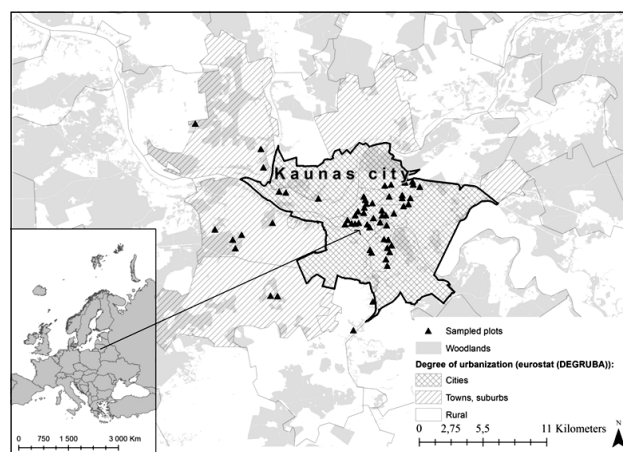


Figure 1. Location of green space in Kaunas city municipality where soil pH and tree species were sampled

The soil pH_{CaCl2} samples were analyzed in a laboratory with a Metrom 781 pH meter. The soil type for each green space was determined according to the World Reference Base for Soil Resources (IUSS Working Group WRB 2015) (Table 1).

Statistical data analysis

Data was analyzed using General linear models (GLM) in Statistica 10.0 software package (Statsoft 2010) to identify significant differences in pH between the three environmental factors: urban green space type, tree species and season. Graphs present results of univariate tests of significance with Sigma-restricted parametrization. Vertical whiskers denote 0.95 confidence intervals of the mean (Figures 2-5).

For separating the effects of explanatory variables (environmental factors) from covariables partial Redundancy analyses (partial RDA) were performed using the CANOCO program (Lepš and Šmilauer 2003, Microcomputer Power 2012).

Results

Soil group and pH in different types of green spaces

The dominant soil type was loam with some recordings of silt loam (Table 1).

Table 1. Soil type by tree species green space type within Kaunas city municipality (IUSS Working Group WRB 2015)

Green spaces	<i>Betula pendula</i>	<i>Acer platanoides</i>	<i>Tilia cordata</i>	<i>Quercus robur</i>
Peri-urban forest	Loam	Silt loam	Loam	Loam
Large park	Silt loam	Loam	Silt loam	Silt loam
Small park	Loam	Loam	Loam	Loam
Narrow street	Loam	Loam	Loam	Loam
Broad street	Loam	Loam	Loam	Loam

Soil pH up to 10 cm depth in the different green spaces showed firstly that both types of street greeneries was alkaline, and secondly that topsoil pH for small parks was neutral and finally the soil pH in the large parks and peri-urban forests are acidic (Figure 2).

When analyzing data by individual tree species, the results showed the same trends for all types of green spaces (Figure 3).

Soil pH up to 10 cm depth differences between tree species

In comparison to other tree species, the soil pH differences (0.9 units) in all types of green spaces with *Quercus robur* are the lowest. The most acidic soil was associated to *Acer platanoides* in all greeneries. The most alkaline soil was recorded in sites with *Betula pendula* (Figure 4).

Soil pH up to 10 cm depth differences by tree species and green space

The most alkaline soil pH (7.6-7.8) was found in street greeneries, where *Betula pendula* grow (Figure 3). The most acidic soil (5.9-6.1) was found in the large parks and peri-urban forests with *Acer platanoides*.

The soil pH levels of the *Betula pendula*, *Acer platanoides* and *Tilia cordata* sites increased from 5.5 to 6.6 in the peri-urban forests. The greatest pH fluctuation (1.7 units) between types of green spaces was in the *Betula pendula* sites (Figure 3).

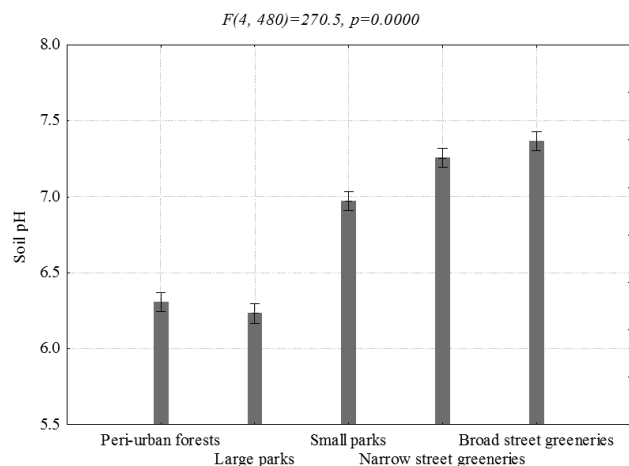


Figure 2. Differences among the different types of green spaces according to soil pH up to 10 cm depth in Kaunas city municipality (mean ± 0.95 conf. interval, n-108)

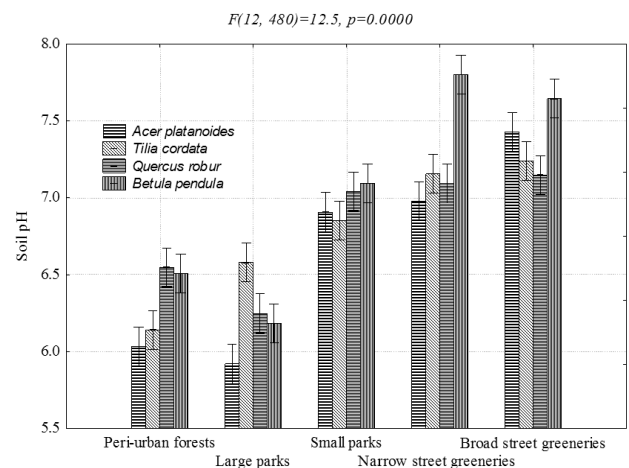


Figure 3. Soil pH up to 10 cm depth variation related to the site condition: type of green space and tree species in Kaunas city municipality (mean ± 0.95 conf. interval, n-27)

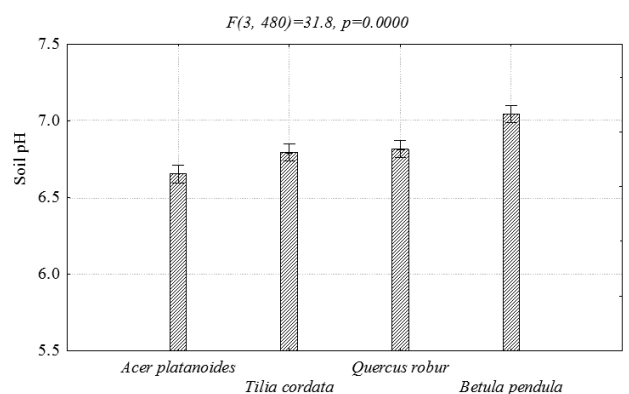


Figure 4. Soil pH up to 10 cm depth differences among tree species in Kaunas city municipality (mean ± 0.95 conf. interval, n-135)

Soil pH seasonal fluctuates

The soil pH fluctuated throughout the spring-autumn period and were more obvious in peri-urban forests with more natural conditions (increases from 6.0 to 6.5) and broad streets environment (decreases from 7.6 to 7.1) (Figure 5).

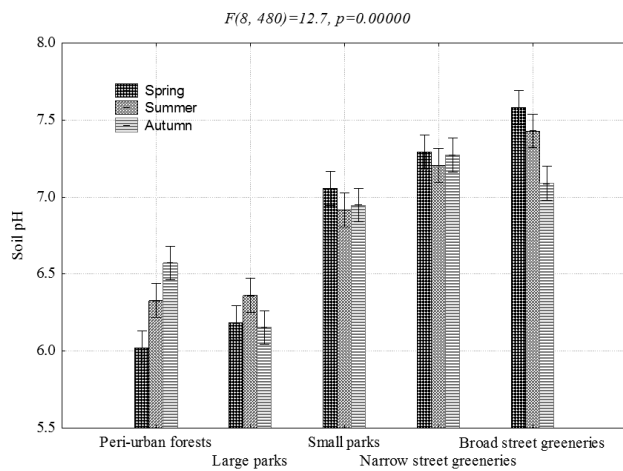


Figure 5. Soil pH up to 10 cm depth fluctuation depending on the season and type of green area in Kaunas city municipality (mean ± 0.95 conf. interval, n=36).

Separating the environmental factors that affect soil pH

The RDA results showed that 57.8% of total variation in soil pH data can be explained by green space types, tree species and season together (Table 2). According to partial RDA, the green space type was the most important factor which explains the most total variability in soil pH data, which cannot be explained by other covariables, 53.1%, whereas tree species as an explanatory factor influenced soil pH much less, 4.5%. We could not distinguish which of the explanatory variables/environmental factors was responsible for the remaining 0.2% of soil pH variability.

Univariate tests of significance confirmed effect of environmental factors on soil pH in exception for season influence as single factor (Table 3).

Table 2. Partitioning of variance of the soil pH, explained by green space type, tree species and season

Analysis	Response variables	Explanatory variables (as dummy variables)	Covariables (as dummy variables)	Sum of all canonical eigen-values	Test of significance of all canonical axes (Monte Carlo test (499 permutations))		Exploratory variables explain total variability of response data by eliminating influence of covariables
					F-ratio	P-value	
RDA	Soil pH	Green space type; tree species; season	-	0.578	72.4	0.002	57.8%
Partial RDA	Soil pH	Green space type	Species, season	0.531	132.9	0.002	53.1%
Partial RDA	Soil pH	Species	Green space type, season	0.045	18.8	0.002	4.5%
Partial RDA	Soil pH	Season	Green space type, species	0.001	0.4	0.658	Not significant

Table 3. Environmental factor significance after effective hypothesis decomposition of univariate tests with Sigma-restricted parameterization

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	25,168.6	1	25,168.6	225,203.3	0.000
Green space type	120.9	4	30.2	270.5	0.000
Tree species	10.7	3	3.6	31.8	0.000
Season	0.2	2	0.08	0.7	0.507
Green space type*Tree species	16.8	12	1.4	12.5	0.000
Green space type*Season	11.3	8	1.4	12.7	0.000
Tree species*Season	3.9	6	0.65	5.8	0.000
Green space type*Tree species*Season	11.8	24	0.49	4.4	0.000

Discussion

Soil alkalization

The topsoil acidification in Kaunas city municipality green spaces can be explained by leaf litter decomposition. Throughout green spaces of Kaunas, accumulated leaf litter is routinely removed in early spring. Thus, soil microorganisms can only actively decay leaf litter from autumn to spring (Vaidelys et al. 2017). Leaf litter decomposition decreases the soil pH. The removal of leaf litter by park maintenance thus causes the soil pH to increase, because there is no leaf litter on the ground to decompose and water and nutrients leach through the soil after rain and during the snow melt. The topsoil alkalization of street greeneries can be explained by two main reasons. Firstly, there is no decomposition of leaf litter, as litter is constantly collected from the street. Secondly, irrigation with calcium-enriched water and the use of calcium or sodium chloride as road deicing agents in northern latitudes (Bockheim 1974). In Austria anti-freezing and deicing agents with potassium carbonate (K₂CO₃) have increased soil pH in comparison to sodium chloride (NaCl) (Hartl and Erhart 2002). The study in Poland on soil pH showed that when soil was exposed to a high level of NaCl, it tended to be more alkaline and also exhibited increased content of Na⁺ and Cl⁻ (Czerniawska-Kusza et al. 2004). In addition, the difference between alkaline street greeneries and the more acidic urban parks has also been linked to acid rain (Ware 1990).

Research from 6 different world cities indicated that the soil pH values range between 6 and 7 and have minimal differences among urban landscapes (Scharenbroch et al. 2005). Urban soils of Philadelphia, Pennsylvania, USA, ranged from 3.7 to 9.0 with a mean of 7.6 (Bockheim 1974). Street greenery soils of Syracuse, New York, USA, had a pH range of 6.6 to 9.0 with an average of about 8.0 (Craul and Klein 1980). Street greenery soils in Opole, Poland, had a pH_{H_2O} level equal to 7.85 and pH_{KCl} equal to 7.65, and soil in the parks had a pH_{H_2O} level of 7.35 and pH_{KCl} level of 7.05 (Czerniawska-Kusza et al. 2004). The soil pH of street greenery with linden (*Tilia* sp.) trees in Riga, Latvia, were neutral to slightly alkaline (pH_{KCl} 6.54 to 7.60); this high pH level was probably due to the use of sodium chloride as the main street de-icing agent in winter (Cekstere et al. 2008). Soil pH in the street greenery in Edmonton, Canada, was also significantly higher compared to the control sites, with values ranging from 7.6 to 8.5 (Equiza et al. 2017). In a study on the urban green spaces of Alytus, Lithuania (Žeimavičius et al. 2011), showed that soil pH levels range from 5.0 to 6.0 in urban parks and from 7.1 to 8.2 in street greeneries. Our result shows that the pH of soils up to 10 cm depth in the urban parks of Kaunas were more acidic and topsoils of street greeneries are more alkaline (Figure 2).

Tree species and pH

Our study supports Swantje et al. (2006), who found that tree species contribute to different soil pH levels within the O-horizon. Our results show slightly higher soil pH levels in the peri-urban forest: 6.5 with *Betula pendula*, 6.2 with *Tilia cordata* and 6.1 with *Quercus robur*. In other studies, on broad-leaved tree species, such as *Acer platanoides*, *Carpinus betulus* and *Tilia cordata*, results have shown a lower acidifying impact than *Fagus sylvatica* or *Quercus robur* (Norden 1994). In a previous study on forest soil pH Hagen-Thorn et al. (2004) did not find any significant differences between tree species: *Betula pendula* - 5.0, *Tilia cordata* - 5.5 and *Quercus robur* - 5.1. In addition, the topsoil pH of *Picea abies* and *Pinus sylvestris* green spaces were significantly lower compared to green spaces with *Fagus sylvatica*, *Quercus petraea* or *Quercus robur* (Augusto 2002). Conifers, such as *Picea abies*, promote higher soil acidification and decrease soil pH. The pH of soil under deciduous broadleaf stands was at least 0.5 units higher than under coniferous stands (Augusto and Ranger 2001).

Seasonal pH fluctuations

According to Augusto and Ranger (2001) the more rainfall, the higher soil pH. In Lithuania, there are clear season differences in soil moisture. During spring, after

the snow melt, and during autumn rains the soil moisture is the highest. According to the results of Collins et al. (1970), pH in field-moist samples in water showed a maximum seasonal variability of 1.6 pH units and an average variation of 0.8 pH units. The pH in KCl showed the least seasonal variability of the methods used 0.2 pH units. Soil pH of street greeneries in Riga (Latvia) showed that seasonal fluctuation were 0.16 units, pH_{KCl} varied from 6.47 in March to 6.63 in July (Cekstere et al. 2008). Skyllberg (1991) showed increases of pH_{H_2O} and pH_{CaCl_2} during autumn and winter. The maximum was recorded in April and was followed by a drastic decrease reaching the pH_{H_2O} minimum in June. The minimum pH_{CaCl_2} appeared in August (Skyllberg 1991). Seasonal variations of 1.1 to 1.3 units were observed in all soil types tested. Humus pH was the highest in midsummer and decreased with the approach of winter (Vezina 1965). Our research shows seasonal fluctuations in topsoil pH for all green spaces.

In conclusion, our results show that topsoil pH differs between both the types of green spaces and tree species. The most significant differences were found between trees in peri-urban forests and broad street greeneries. Increased topsoil acidity was found in the larger green spaces (such as peri-urban forests and urban large parks) with lower management activity, whilst, more alkaline soils were found in the street greeneries with greater urban pressure and worse tree growth conditions. The variation in soil pH of the different types of green space and tree species shows that city planner should consider the unique conditions of all green spaces to maximize their potential for human well-being.

References

- Augusto, L., Dupouey J.-L. and Ranger, J. 2003. Effects of tree species on understory vegetation and environmental conditions in temperate forests. *Annals of Forest Science* 60 (8): 823-831. Available online at: <https://hal.archives-ouvertes.fr/hal-00883757/document>
- Augusto, L. and Ranger, J. 2001. Impact of tree species on soil solutions in acidic conditions, *Annals of Forest Science* 58: 47-58.
- Augusto, L., Ranger, J., Binkley, D. and Roth, A. 2002. Impact of some common tree species of European temperate forests on soil fertility. *Annals of Forest Science* 59: 233-253.
- Benvenuti, S. 2004. Weed dynamics in the Mediterranean urban ecosystem: Ecology, biodiversity and management. *Weed Research* 44: 341-354. doi:10.1111/j.1365-3180.2004.00410.x
- Binkley, D. and Valentine, D. 1991. Fifty-year biogeochemical effects of green ash, white pine and Norway spruce in a replicated experiment. *Forest Ecology and Management* 40: 13-25.
- Bradshaw, A., Hunt, B. and Walmsley, T. 1995. Trees in the Urban Landscape: principles and practice. Spon, London; Taylor and Francis, London, 288 pp.
- Bockheim, J. G. 1974. Nature and properties of highly-disturbed urban soils, Philadelphia, Pennsylvania. Paper pre-

- sented before Division S-5, Soil Genesis, Morphology and Classification, Annual Meeting of the Soil Science Society of America, Chicago, IL.
- Bowser, W. E. and Leat, J. N.** 1958. Seasonal pH fluctuations in a grey wooded soil. *Canadian Journal of Soil Science* 38: 128–133.
- Cekstere, G., Nikodemus, O. and Osvalde, A.** 2008. Toxic impact of the de-icing material to street greenery in Riga, Latvia. *Urban Forestry and Urban Greening* 7(3): 207–217.
- Czerniawska-Kusza, I., Kusza, G. and Dużyński, M.** 2004. Effect of deicing salts on urban soils and health status of roadside trees in the Opole region. *Environmental Toxicology* 19: 296–301.
- Collins, J. B., Whiteside, E. P. and Cress, C. E.** 1970. Seasonal variability of pH and lime requirements in several southern Michigan soils when measured in different ways. *Soil Science Society of America Journal* 34: 56–61. doi:10.2136/sssaj1970.03615995003400010018x
- Craul, P. J. and Klein, C.F.** 1980. Characterization of street-side soils in Syracuse, New York. *METRIA* 3: 88–101.
- Day, S. D. and Dickinson, S. B.** 2008. Managing Storm Water for Urban Sustainability Using Trees and Structural Soils. Virginia Polytechnic Institute and State University, Blacksburg, VA, 63 pp.
- Equiza, M. A., Calvo-Polanco M., Cirelli, D., Señorans, J. and Zwiazek J. J.** 2017. Long-term impact of road salt (NaCl) on soil and urban trees in Edmonton, Canada. *Urban Forestry and Urban Greening* 21(1): 16–28.
- EuroStat 2016. Degree of urbanisation, 2018 – Population distribution – Dataset. European Commission, Eurostat (ESTAT), GISCO. Online resource: <https://myintracomm.ec.europa.eu/dg/ESTAT/6-tools/GISCO/AccessGeographicalRef%20Database/Pages/AccessGeographicalRefDatabase.aspx>
- Foth, H.D.** 1990. Fundamentals of Soil Science. 8th edition. John Wiley and Sons, Inc., New York, U.S., 380 pp.
- Hagen-Thorn, A.I., Armolaitis, K. and Nihlgard, B.** 2004. The impact of six European trees species on the chemistry of mineral top soil in forest plantations on former agricultural land. *Forest Ecology and Management* 195(3): 373–384. DOI: 10.1016/j.foreco.2004.02.036
- Hartl, W. and Erhart, E.** 2002. Effects of potassium carbonate as an alternative road de-icer to sodium chloride on soil chemical properties. *Annals of Applied Biology* 140: 271–277.
- IUSS Working Group WRB 2015.** World Reference Base for Soil Resources 2014, update 2015 International soil classification system for naming soils and creating legends for soil maps. World Soil Resources Reports No. 106. FAO, Rome. 203 pp.
- Kelsey, P.D. and Hootman, R.G.** 1988. Soil resource evaluation for a group of sidewalk street tree planters. *Journal of Arboriculture* 16: 113–117.
- Lepš, J. and Šmilauer, P.** 2003. Multivariate Analysis of Ecological Data using CANOCO. Cambridge University Press, Cambridge (UK), 269 pp. DOI: <https://doi.org/10.1017/CBO9780511615146>
- Mickelbart, M. V., Gosney, M. J., Camberato, J. and Stanton, K. M.** 2012. Soil pH effects on growth and foliar nutrient concentrations of *Spiraea alba* Du Roi and *Spiraea tomentosa* L. *HortScience* 47(7): 902–906.
- Microcomputer Power 2012. CANOCO, a program for multivariate statistical analysis using ordination methods in the field of ecology and several related fields. Version 5.0. Microcomputer Power, Inc., Ithaca, NY, USA. URL: <http://www.microcomputerpower.com/>
- Norden, U.** 1994. Influence of broad-leaved tree species on pH and organic matter content of forest topsoils in Scania, South Sweden. *Scandinavian Journal of Forest Research* 9: 1–8.
- Official statistics portal 2019. Geographical data. Average temperature. Online resource: <https://osp.stat.gov.lt/en/statistiniu-rodikliu-analize?hash=f2ee6809-6d05-450f-9a07-6154b95903c2#/>
- Patterson, J.C.** 1977. Soil compaction – effects on urban vegetation. *Journal of Arboriculture* 3(9): 161–167.
- Reich, P. B., Oleksyn, J., Modrzynski, J., Mrozinski, P., Hobbie, S. E., Eissenstat, D. M., Chorover, J., Chadwick, O. A., Hale, C. M. and Tjoelker, M. G.** 2005. Linking litter calcium, earthworms and soil properties: a common garden test with 14 tree species. *Ecology Letters* 8(8): 811–818.
- Scharenbroch, B. C., Bryant, C., Lloyd, J. E. and Johnson-Maynard, Jodi, L.** 2005. Distinguishing urban soils with physical, chemical, and biological properties. *Pedobiologia* 49(4): 283–296.
- Skyllberg, U.** 1991. Seasonal variation of pH_{H2O} and pH_{CaCl2} in centimeter layers of mor humus in a *Picea abies* (L.) Karst. Stand. *Scandinavian Journal of Forest Research* 6 (1-4): 3–18; DOI: 10.1080/02827589109382642
- Statsoft 2010. STATISTICA, an advanced analytics software package. Version 10.0. StatSoft Power Solutions, Inc., Tulsa, OK, USA.
- Swantje, O., Hooshang, M. and Mats, O.** 2006. Impact of tree species on soil carbon stocks and soil acidity in southern Sweden. *Scandinavian Journal of Forest Research* 21(5): 364–371; DOI: 10.1080/02827580600950172
- Vaidelys, T., Straigyte, L. and Manton, M.** 2017. The influence of urban green space on leaf litter decomposition, C, N quantity and soil pH. In: Green Infrastructure: Nature Based Solutions for Sustainable and Resilient Cities. Book of Abstracts. Orvieto, p. 142.
- Vezina, P. E.** 1965. Methods of pH Determination and Seasonal pH Fluctuations in Quebec Forest Humus. *Ecology* 46(5): 752–755.
- Watson, G. W., Hewitt, A. M., Custic, M. and Lo, M.** 2014. The Management of Tree Root Systems in Urban and Suburban Settings: A Review of Soil Influence on Root Growth. *Arboriculture and Urban Forestry* 40(4): 193–217.
- Ware, G.** 1990. Constrains to tree growth imposed by urban soil alkalinity. *Journal of Arboriculture* 16 (2): 35–38.
- Wuest, S. B.** 2015. Seasonal Variation in Soil Bulk Density, Organic Nitrogen, Available Phosphorus and pH. *Soil Science Society of America Journal* 79(4): 1188–1197.
- Žeimavičius, K., Snieškienė, V., Vaisvalavičius, R. and Stankevičienė, A.** 2011. Sumedėjusių augalų būklės ir edafinių sąlygų tyrimai Alytaus miesto želdynuose. [Investigations of wooden plant condition and edaphic characteristics of Alytus town greenery]. *Žemės ūkio mokslai* 18 (1): 15–21.