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Urban Leaf Litters as a Potential Compost Component

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ABSTRACT

Trees shed leaf litters throughout the year with varying intensity. In urban areas, due to the regular pruning of tree branches, the leaves which are used as a compost component have dominant share in the litterfall. The amount of nutrients released during composting depends on the abundance of the shed leaves. The research aimed to analyse and determine which of the deciduous tree species provide the highest amount of macronutrients and whether or not the heavy metals contained in them exceed the toxic level. It was found that the leaves of *Alnus glutinosa* (C/N = 20.57), *Tilia cordata* (33.31) and *Fraxinus excelsior* (33.88), which are the source of the highest amounts of nitrogen among the examined deciduous tree species, decompose at the fastest pace in the composting process. The process of decomposition of *Quercus rubra* (C/N = 64.30), *Aesculus hippocastanum* (58.16) and *Fagus sylvatica* (58.06) leaves, which are poorer in nitrogen compounds, takes much longer and is more difficult. It has also been shown that the heavy metals (Zn, Cu, Pb) contained in leaf litters do not pose any threat to the environment, as they do not exceed the permissible level of contamination.

Keywords: urban area, litterfall removal, macroelements, heavy metals, compost.

INTRODUCTION

Urban areas are ecosystems with a predominant human influence, where the prevailing elements include buildings, communication networks and green areas, performing aesthetic, recreational, health and protective functions [Prądzyńska and Śmielak 2009]. In waters, soils and vegetation of these ecosystems, there are usually increased concentrations of heavy metals observed [Dąbkowska-Naskręt and Różański 2009]. These pollutants come mainly from industrial plants and means of transport [Krauss et al. 2000]. They are most often deposited in soil and accumulated by vegetation, predominantly trees. The amount of components taken is characteristic of the species, relating to the physiological needs and the so-called safe storage capacity of excess nutrients [Ostrowska and Porębska 2002]. As part of the frugal management of nutrients, many tree species withdraw deficient elements from aging foliage in autumn, before shedding leaves, and store them in the branches and trunks [Parzych et al. 2010]. The accumulated stocks are remobilised and partially cover the demand for nutrients in the subsequent vegetation season. As a result, small amounts of biogenic components are transferred to the soil, and the litterfall, with significantly depleted nitrogen, phosphorus and potassium levels, is not very attractive to saprophages. The processes of leaf litter decomposition and the release of elements then proceed slowly, with the main participation of microorganisms. In the case of some tree species, i.e. alder, the entire pool of elements contained in the leaves is recycled every year as the process of withdrawing nutrients from the foliage is very limited. Owing to this, the leaf litter shed is abundant in nitrogen and phosphorus compounds and quickly decomposed with a large share of saprophages, which accelerates the process of releasing elements [Stachurski and Zimka 2004].

Leaf litter, with nutrients stored in it, constitutes an important link in the circulation of matter and energy flow. Its quantity and quality influence the morphology and properties of soils [Jonczak et al. 2015] as well as the nutrition of plants and heterotrophs inhabiting the soil. Leaves, twigs, bark, seeds, seed teguments and other organic debris are shed by trees throughout the year with varying intensity [Parzych and Trojanowski 2009]. Dead fragments of vegetation contain, among others, nitrogen, phosphorus, potassium, magnesium, calcium, zinc, copper, iron, manganese and many others, making them a valuable source of nutrients [Hilty and Prabha 2015]. The qualitative composition of leaf litter varies, depending on the place, time and trophic status of the ecosystem [Diaz-Maroto and Vila-Lameiro 2005]. The greatest amount of leaf litter (even up to 60%) is shed by plants in autumn [Diaz-Maroto and Vila-Lameiro 2006]. In urban areas, due to the aesthetics of the landscape and frequent pruning of tree branches, leaves constitute the dominant share in the autumn litterfall. Raking up leaf litter deprives the soil of valuable nutrients. According to Law et al. [2004] and Templer et al. [2015], up to 6.5 kg N $ha^{-1}yr^{-1}$ are removed together with urban leaf litter. Leaf litter, raked from urban areas, is most often used as a compost component. The amount of nutrients in the autumn leaf litter varies depending on the species and is undoubtedly valuable, but is it entirely "safe"? The conducted research aimed to analyse and determine the leaves of which deciduous tree species found in the city of Słupsk contain the most nutrients, and whether the leaf litter is a "safe" component of compost regarding the possibility of accumulating toxic components, i.e. heavy metals, in its tissues.

MATERIALS AND METHODS

Research area

Słupsk is a medium-sized city (area 4315 ha, number of citizens 90.681 [GUS, 2020], located by the Słupia river (54°27′N 17°01′E), around 18 km south from the Baltic Sea. Słupsk is the center of footwear, machinery, plastics, windows as well as furniture, cosmetics and confectionery industries. Despite the diverse industrial and economic activities, traffic is mainly responsible for dust emissions in the city. The urban green areas within the city's administrative borders amount to 137 ha, which is 3.2% of the total area. Forests and wooded lands cover an area of 574 ha (13.3%) and are located mainly in the southern and north-eastern parts of the city and the Słupia valley. Most of the green spaces are located in the city centre (35 ha), covering 9.8% of the urbanised areas [Prądzyńska and Śmielak 2009]. Urban wooded green areas have a positive effect on the air quality in the city. In the years preceding the research, the values of dust concentrations of PM10 and PM2.5, which were 26 $\mu g/m^3$ and 17 $\mu g/m^3$, respectively, did not exceed the permissible levels and the concentrations of toxic gases, i.e. NO_2 and SO_2, remained at the permissible level as well [Raport WIOŚ, 2020]. The research on the chemical composition of leaves was carried out in a park with an area of 12.5 ha, squares (4.2 ha) and urban greens (5.6 ha), located in the central part of Słupsk (Table 1). These places are dominated by groups of trees and shrubs, complemented by low greenery.

Sampling of samples

From among the numerous group of deciduous tree species found in the study area, for chemical analyses, the ones characterized by the highest stability class and coverage factor are: *Aesculus hippocastanum* L., *Acer platanoides* L., *Acer pseudoplatanus* L., *Acer saccharinum* L., *Alnus glutinosa* (L.) Gaertn., *Betula pendula* Roth, *Fagus sylvatica* L., *Fraxinus excelsior* L., *Quercus robur* L., *Quercus rubra* L., *Tilia cordata* Mill., and *Tilia tomentosa* Moench. (Table 2).

Table 1. Green urban areas in Słupsk

Generic name		Specific name	Area [ha]
Park	1	Park of Culture and Recreation	12.50
Squares	2	Square them. Jerzy Waldorff	1.77
	3	Square near Słoneczna Street	1.23
	4	Square near Partyzantów Street	1.20
Lawns	5	Lawns near Kaszubska Street	2.84
	6	Boulevard on the Słupia river	1.52
	7	Birch alley	1.19

The study used freshly shed leaves of 12 deciduous tree species, growing in the city park, squares and greens. The leaves of litterfall were collected off the ground in October 2020. A single sample consisted of several leaves of a given tree species. The samples were placed in properly labelled paper bags and transported to the laboratory. The number of samples taken ranged from 15 to 30 pieces (Table 2), depending on the species. In total, from the area of 22.25 ha, 267 samples from 12 species of deciduous trees were collected and tested.

Chemical analysis of leaf samples

After transporting to the laboratory, the leaf samples were dried in a fan oven (Pol-Eco) to constant weight at the temperature of 65°C and then homogenized in a laboratory mill (IKA A11 basic). Until the analyses, the samples were stored in tightly closed polyethylene bags. For each sample, the pH in a water solution (1:10) was determined using the potentiometric method (CPI 551 Elmetron), according to Karczewska and Kabała (2008). The total content of C and N was determined using CHNS Elementary Analyzer (Flash Smart, ThermoScientific), against standard and reference materials - methionine (Certificate number analysis – 291468, ThermoScientific). For the determination of the metal content, a sample of leaves (0.25 g) was digested in a solution of 65% nitric acid (V) and 30% H_2O_2 Suprapur (Merck) in a microwave digestion system (ETHOS EASY, Milestone connect). After mineralization, the samples were replenished with deionized water (Hydrolab HLP10) to the volume of 25 mL. The P content in the obtained solutions was determined with the molybdate method (UV-VIS, Hitachi U-5100) and the content of K, Mg, Ca, Fe, Mn, Zn, Cu, and Pb using the ASA atomic absorption spectrometry (ICE 3000, Thermo Scientific). The analyses were performed in the oxyacetylene flame. The wavelengths at which various metals were detected were as follows: 766.5 nm K, 285.2 nm Mg, 422.7 nm Ca, 248.3 nm Fe, 213.9 nm Zn, 324.8 nm Cu and 217.0 nm Pb. All tests were carried out following the Fluka Analytical Standards (1g/1000 mL). All analytical measurements were made in triplicate. The quality of analysis was controlled based on certified reference material (aquatic plants, CRM 060). The error associated with the analysis of certified materials did not exceed the range deemed permissible (±3%).

Statistical analysis

Data distribution was checked using the Shapiro-Wilk's test. The non-parametric Kruskall-Wallis test (p<005) was used to compare the content of macroelements and heavy metals in the leaves of 12 tree species. Statistically significant correlation coefficients between the studied components are presented in the matrix charts at $p < 0.001$, $p < 0.01$ and $p < 0.05$. The overall exploration of the analytical data was accomplished via Factor Analysis (FA) with Principal Component Analysis (PCA) as a method of latent factors extraction. A rotated PCA solution was then interpreted via the use of a normalised varimax rotation algorithm. The presented case study analysed the factor loadings higher than 0.7. The factor values of the objects were presented in the form of a categorised scatter plot, showing the dispersion of the studied tree species in relation to FC1 and FC2. All calculations were performed using Statistica 13.3 software package (Statsoft Inc., USA).

RESULTS

Reaction and macroelements content in leaf litters

The leaves freshly shed from 12 species of deciduous trees showed varied pH, and the differences were statistically significant (p=0.000) (Figure 1). The lowest pH values were found in the leaves of *Ace_sac* (4.4), *Ace*_pse (4.6) and *Ace_pla* (4.7). The highest pH values and – at the same time – the lowest acidity, were determined

Table 2. Characteristic of deciduous trees species

Species	Code	Number of samples (N)
Aesculus hippocastanum L.	*Aes_hip*	18
Acer platanoides L.	*Ace_pla*	30
Acer pseudoplatanus L.	*Ace_pse*	30
Acer saccharinum L.	*Ace_sac*	24
Alnus glutinosa (L.) Gaertn.	*Aln_glu*	15
Betula pendula Roth	*Bet_pen*	18
Fagus sylvatica L.	*Fag_syl*	21
Fraxinus excelsior L.	*Fra_exe*	27
Quercus robur L.	*Que_rob*	18
Quercus rubra L.	*Que_cor*	18
Tilia cordata Mill.	*Til_cor*	30
Tilia tomentosa Moench	*Til_tom*	18

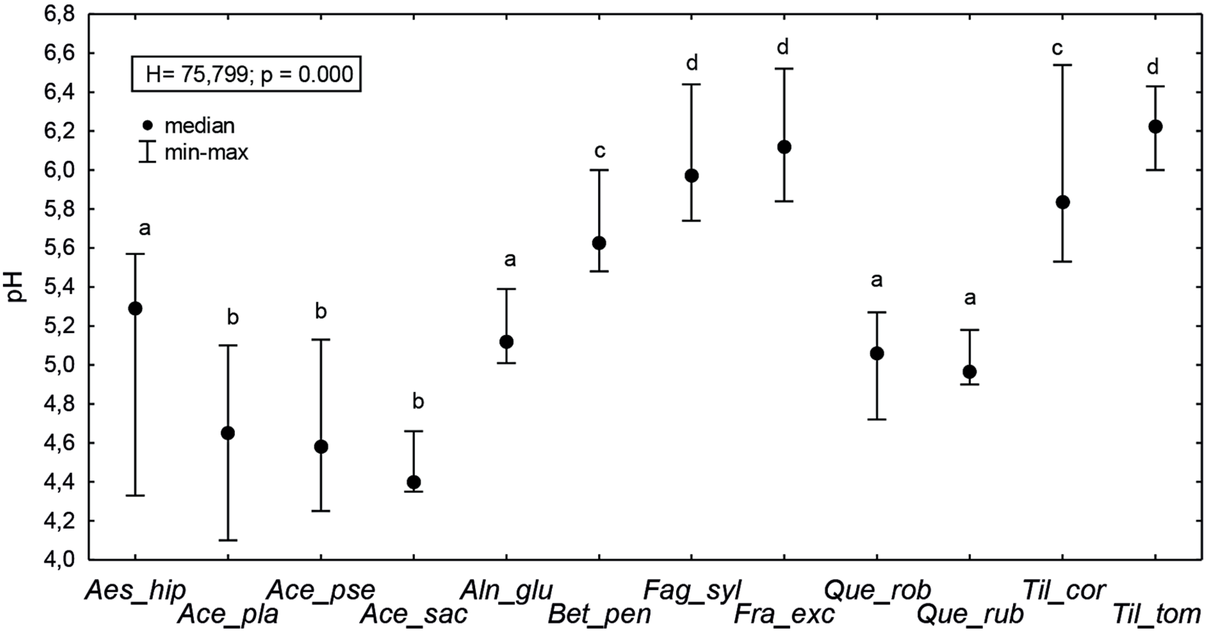

Figure 1. Leaf pH values of 12 tree species with Kruskal-Wallis test results. a-d (the same letters – no statistically significant differences between species of trees)

in the leaves of *Til_tom* (6.2), *Fra_exc* (6.1) and *Fag_syl* (5.9), (Figure 1). The carbon content in the tested samples ranged from 39.62%±4.3 (*Fra_exe*) to 46.38%±5.7 (*Fag_syl*) (Tab. 3). The highest amounts of nitrogen were found in *Aln_glu* samples (2.2231%±0.2) while the lowest in *Que_rub* (0.7148±0.1) and *Aes_hip* (0.7678±0.2) samples. The phosphorus content ranged from 0.0194% ± 0.1 in *Ace_pla* leaves to 0.0515%± 0.1 in *Til_tom* samples. The values of the C/N ratios ranged from 20.57±2.3 (*Aln*_glu) to 64.30±4.2 (*Que_rub*), and the N/P ratio took the values between 15.61±1.0 (*Que_rub*) and 49.09±5.2 (*Aln_glu*). Among the studied species, the highest amounts of K were found in the leaves of *Fra_exe* (19709.2±1469 mg·kg^{-1}), *Til_cor* (19537.4±4072 mg·kg^{-1}) and *Til_tom* (19203.8±1678 mg·kg^{-1}), while *Aes_hip* had the smallest amounts of this biogenic element (5342.8±718 mg·kg^{-1}), (Table 3). The content of Mg ranged from 6494.0±2231mg.kg^{-1} (*Ace_sac*) to 28799±2677mg.kg^{-1} (*Til_cor)*. The studied species were characterized by varying calcium content. The highest amounts of Ca were found in the leaves of *Ace_pse* (33526.2±927 mg·kg^{-1}) and *Til_cor*

Table 3. Macroelements content and carbon/nitrogen and nitrogen/phosphorus ratios in leaf litters in 12 species of trees (means ± standard deviation) with Kruskal-Wallis test results

Species		C, %	N, %	P, %	C/N	N/P	K, mg·kg^{-1}	Mg, mg·kg^{-1}	Ca, mg·kg^{-1}
Aes_hip		43.18±1.5^{a}	0.7678±0.2^{a}	0.0199±0.0^{a}	58.16±10.2^{a}	17.80±4.2^{a}	5342.8±718^{a}	15450.0±1831^{a}	29909.6±1827^{a}
Ace_pla		40.87±1.1^{b}	0.8500±0.2^{a}	0.0194±0.1^{a}	50.12±9.9^{a}	20.72±4.4^{a}	16025.8±783^{b}	17010.0±2136^{a}	31535.2±1852^{a}
Ace_pse		40.56±2.5^{b}	1.0575±0.3^{b}	0.0352±0.0^{a}	40.01±8.1^{b}	26.09±6.1^{b}	14057.8±2024^{b}	15186.0±1640^{a}	33526.2±927^{a}
Ace_sac		46.10±1.0^{c}	0.9202±0.1^{ab}	0.0224±0.1^{a}	50.94±6.7^{a}	19.93±2.6^{a}	15073.8±2024^{b}	6494.0±2231^{b}	22032.2±2005^{b}
Aln_glu		45.27±0.5^{c}	2.2231±0.2^{c}	0.0247±0.1^{a}	20.57±2.3^{c}	49.09±5.2^{c}	10155.4±2148^{c}	10164.0±1472^{b}	23935.6±1858^{b}
Bet_pen		46.12±1.0^{c}	0.9077±0.2^{a}	0.0505±0.1^{a}	51.99±8.1^{a}	19.67±3.4^{a}	9455.2±1102^{c}	19026.7±2785^{a}	27135.4±2624^{c}
Fag_syl		46.38±5.7^{c}	0.8087±0.1^{a}	0.0288±0.1^{a}	58.06±9.1^{a}	17.61±2.9^{a}	8585.0±1317^{c}	17804.0±2068^{a}	22843.4±1305^{b}
Fra_exe		39.62±4.3^{b}	1.1759±0.1^{b}	0.0511±0.0^{a}	33.88±3.1^{d}	29.85±3.0^{b}	19709.2±1469^{d}	25726.0±2838^{c}	31215.2±1379^{a}
Que_rob		44.72±1.9^{c}	0.9449±0.1^{a}	0.0325±0.1^{a}	47.69±4.9^{b}	21.13±1.9^{b}	9379.2±1649^{c}	16230.0±2753^{a}	21358.4±4285^{b}
Que_rub		45.77±1.6^{c}	0.7148±0.1^{a}	0.0356±0.1^{a}	64.30±4.2^{a}	15.61±1.0^{a}	7448.6±1033^{c}	15268.0±1434^{a}	23767.6±2568^{b}
Til_cor		41.01±1.3^{b}	1.2400±0.1^{b}	0.0419±0.1^{b}	33.31±3.1^{d}	30.31±3.1^{d}	19537.4±4072^{d}	28799.0±2677^{c}	32632.0±1144^{a}
Til_tom		41.92±1.3^{a}	0.9947±0.1^{b}	0.0515±0.1^{a}	42.21±2.0^{b}	23.74±1.1^{b}	19203.8±1678^{d}	27369.6±5985^{c}	23795.5±3083^{b}
mean		43.46±2.6	1.7746±0.4	0.0344±0.1	45.94±12.6	24.29±9.1	13635.5±5648	19055.7±7563	27204±4726
K-W	H	63.712	58.396	46.189	65.569	49.781	55.101	47.969	65.568
	p	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

Note: The same letters - no statistically significant differences between species of trees.

(32632.0±1144 mg·kg^{-1}), and the samples of *Que_rub* were the lowest in Ca (21358.4±4285 mg·kg^{-1}).

Heavy metals content in leaves litterfall

Urban leaf litter showed statistically significant (p = 0.000, p<0.001) differences in the contents of Zn, Cu, Fe and Pb between the studied species (Figure 2). The highest amounts of Zn were found in *Bet_pen* leaves (423.1±42.5 mg·kg^{-1}), and the lowest in *Aes_hip* samples (26.5±8.1 mg·kg^{-1}). The Cu content ranged from 8.1±1.3 mg·kg^{-1} in *Que_rub* leaves to 18.1±1.3 mg.kg-1 in the case of *Til_cor*. Among the tested species, the highest content of Fe was found in the leaves of *Til_tom* (342.1±33.2 mg·kg^{-1}), and

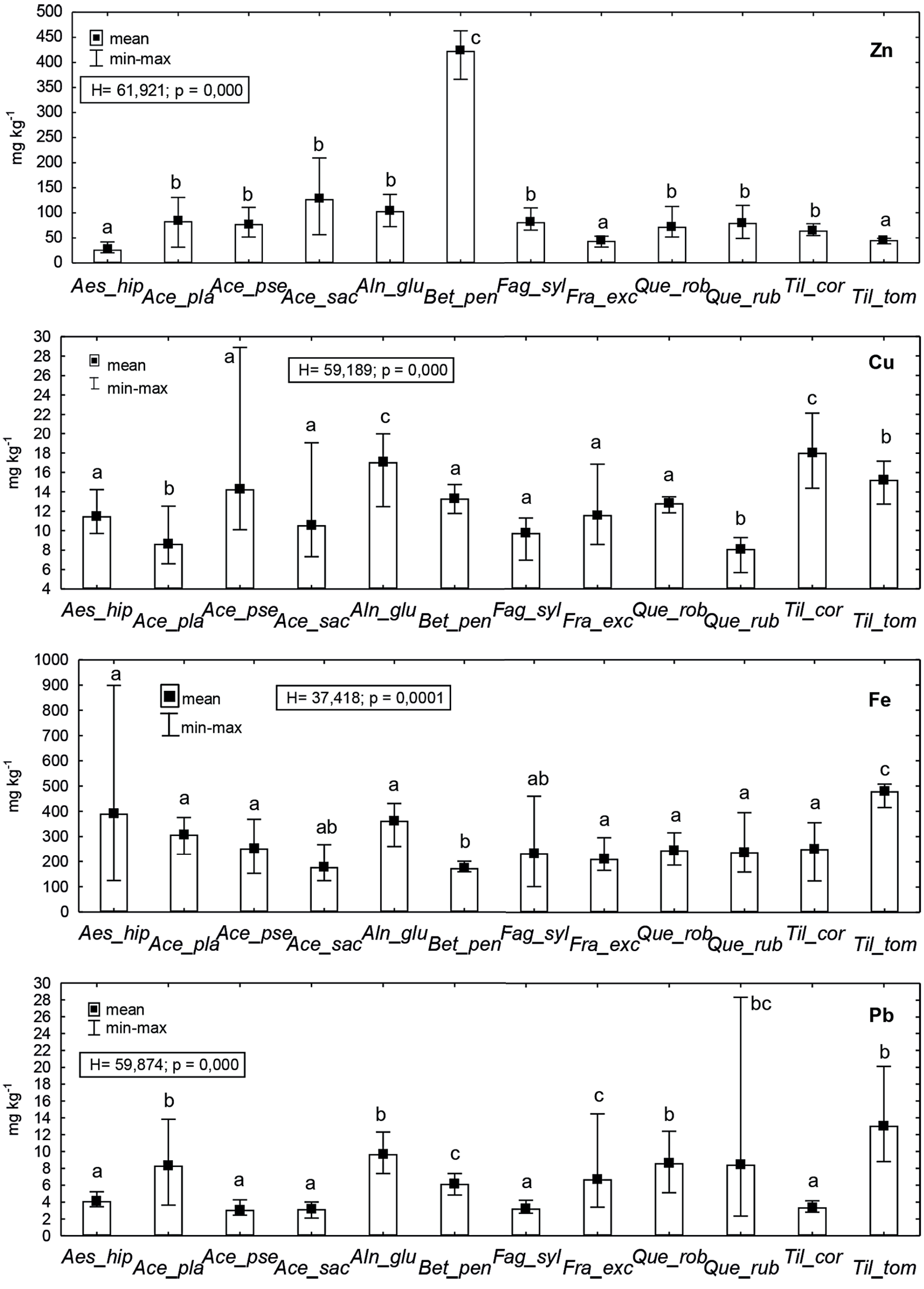

Figure 2. Mean of heavy metals content with minimum and maximum values in leaf litters in 12 species of trees with Kruskal-Wallis test results. (The same letters – no statistically significant differences between species of trees)

the lowest in the *Bet_pen* samples (174.1± 18.9 mg·kg^{-1}). On the other hand, the Pb content ranged from 3.1±0.5 mg·kg^{-1} (*Ace_pse*) and 3.2±0.6 mg·kg^{-1} (*Ace_sac*) to 8.4±4.5 mg·kg^{-1} (*Til_tom*).

DISCUSSION

Reaction and macroelements content in leaf litters

The acidic pH of leaf litter is typical of deciduous tree species [Małek et al. 2000, Jonczak et al. 2015]. During the growing season, trees take up and accumulate different amounts of nutrients, depending on the species, which is related to the ongoing processes of development and aging [Malzahn 2002]. Although in autumn the macronutrient content in the leaves decreases rapidly, they are still a valuable source of nutrients. The largest C reservoirs were found in the leaves of *Fag_syl, Bet_pen* and *Ace_sac,* N in *Aln_glu, Til_cor, Fra_exe* and *Ace*_pse, and P in the samples: *Til_tom, Fra_exe* and *Bet_pen* (Tab. 3), being reflected in the values of the mutual C/N and N/P ratios, which depend on the content of the above elements in the soil.

The studies by Yamamoto and Fukushima [2014] indicate that the decomposition processes of organic matter are strictly dependent on the content of carbon and nitrogen in the composted material. Optimal composting conditions are obtained by selecting the ingredients with the appropriate C/N ratio. The research by Seyedbagher [2010] shows that the decomposition of organic materials during composting occurs most efficiently at C/N from 25 to 30. When the C/N ratio is too high [Komilis and Ham 2003] the mineralization processes slow down, which subsequently necessitates the use of additives lowering the C/N ratio and accelerating the mineralization of the composted organic matter. According to Yulipriyanto [2001], the components with high C/N ratio are very difficult to be composted, which could take over 10 months. It is also known that leaves of deciduous tree species are much easier to decompose than conifer needles [Prescott et al. 2004, Yamamoto and Fukushima 2014], they are much richer in nutrients [Dziadowiec 2005], and the rate of their decomposition is determined by the starting (initial) C/N ratio [Enloe et al. 2015]. The average value of the C/N ratio in the leaves of 12 tree species obtained in Słupsk was 45.94, which is typical for deciduous species [Silva et al. 2008, Dovendorf et al. 2015, Azim et al. 2017]. The conducted research indicates that degradation in the composting process proceeds the fastest in the case of the leaves of *Aln_glu* (C/N = 20.57), *Til_cor* (33.31) and *Fra_exe* (33.88), which simultaneously are those of the 12 tree species studied that will provide the highest amounts of nitrogen (Tab. 3). The decomposition process of *Que_rub* (C/N = 64.30), *Aes_hip* (58.16) and *Fag*_syl (58.06) leaves, which are much poorer in nitrogen compounds, takes longer and is more difficult. Similar C/N values in the leaves of *Acer*, *Alnus* and *Quercus* in the urban area were also obtained by Dovendorf et al. [2015].

The N/P ratio was also significantly differentiated, and its value is characteristic for each species [Townsend et al. 2006]. During the growing season, the N/P ratio in plants usually ranges from 10 to 20 [Güsewell 2004), and the optimal supply of nitrogen and phosphorus to tree leaves occurs at N/P from 7 to 10 [Malzahn 2002]. According to Koerselman and Meuleman [1996], the values of N/P>16 most often indicate phosphorus deficiency. Plants accumulate macronutrients mainly in leaves, which – according to Sharma et al. [2006] – is fully justified due to the photosynthetic processes taking place in them. In autumn, the macronutrient content in the leaves decreases, except for Ca [Malzahn 2002], the concentration of which increases with the age of the trees. Retranslocation of macronutrients in leaves is diversified and in the case of *Betula pendula* it is on average 55–60% of the components [Aosaar et al. 2007, Jonczak et al. 2020]. The research by Hagen-Thorn et al. [2006] shows that in autumn, 70.9% N, 50.9% K and 46.6% P from *B. pendula* leaves are withdrawn. Leaf litters of the studied 12 tree species are an excellent source of macronutrients. *Fra_exe* and Til*_cor* species show the highest abundance of N, P, K, Mg and Ca. *Til_tom* and *Aln_glu* also deserve attention, mainly due to the content of: P, K, Mg and N. It was also determined that there are statistically significant correlations between some macronutrients (Figure 3). The strongest relationships were found in the case of K and Mg ($r=0.58$, $p<0.001$), K and P ($r = 0.43$, $p < 0.001$) as well as Mg and P ($r = 0.42$, $p < 0.001$). Slightly weaker correlations occurred between Mg and Ca ($r = 0.40$, $p < 0.01$) and K and Ca ($r = 0.35$, $p < 0.05$).

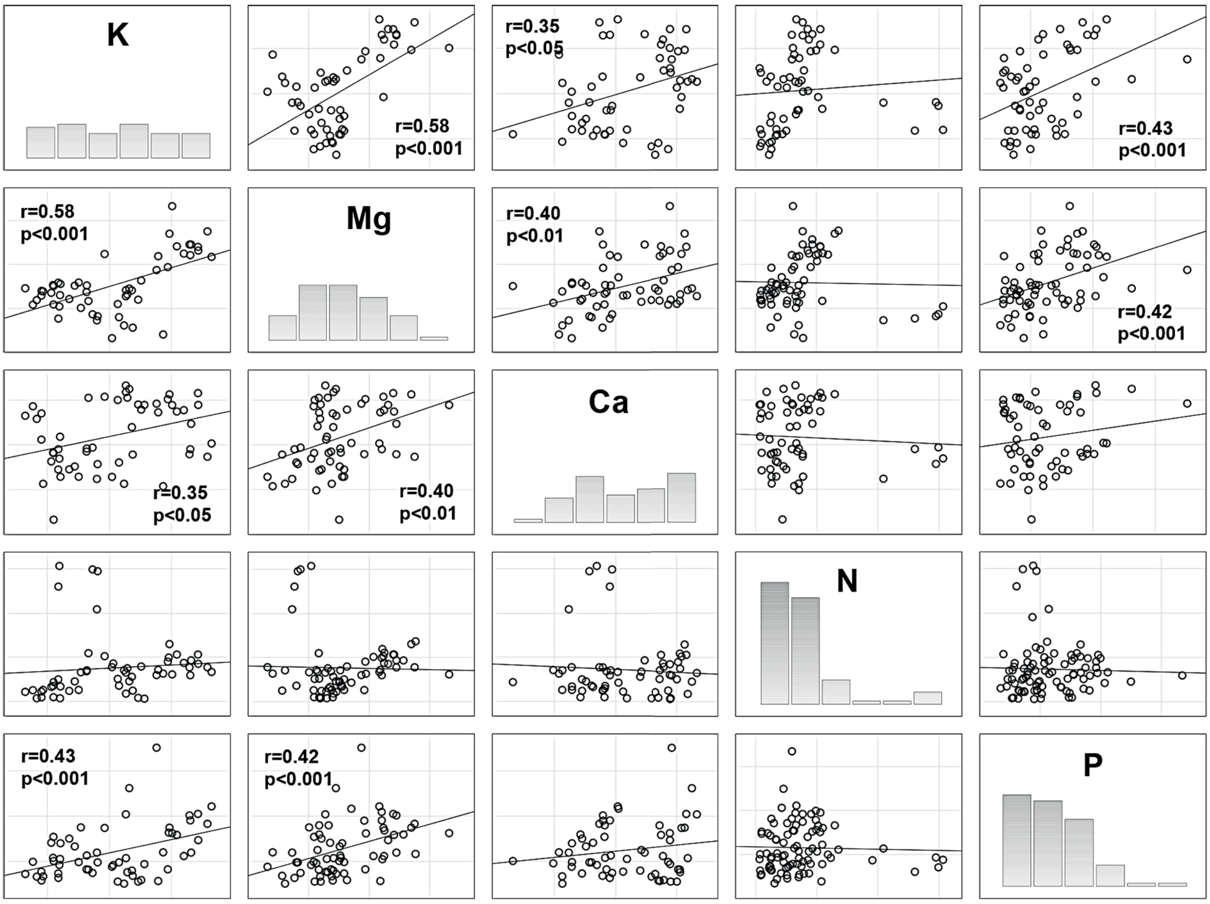

Figure 3. Matrix chart of macroelements content in leaf litters in 12 species of trees with histograms, correlation coefficients (r) and statistical significances ($p < 0.05$)

Heavy metals content in leaf litters

Thus far, many studies have been carried out to assess the fertilization value of composts, both in terms of the organic additives used, the content of macro- and micronutrients, as well as the presence of heavy metals [Czyżyk et al. 2002, Wołoszyk 2003], mobile forms of which may enter the soil solution and pose a threat to the environment. The introduction of compost containing a small amount of heavy metals into the soil does not have a negative effect on it; on the contrary, it stimulates the proper growth and development of plants. However, the use of urban leaf litters with increased heavy metal content as an additive to compost is undesirable, due to the toxic effects on animals, plants and humans in contact with soil. The results of the research show that the content of heavy metals in the samples of urban leaf litters from 12 species of deciduous trees did not exceed, as initially assumed, the permissible level specified by the Regulation of the Minister of Agriculture and Rural Development (of June 18, 2008) on the implementation of certain provisions of the Act on fertilizers and fertilization (Journal of Laws of 2008, No. 119, item 765). The permissible heavy metal contents in fertilizers are as follows: Zn (1500 mg·kg^{-1}), Cu (400 mg·kg^{-1}) and Pb (100 mg·kg^{-1}). Therefore, the addition of leaf litterfall containing <423 mg·kg^{-1} Zn, <18.0 mg·kg^{-1} Cu and < 9.7 mg·kg^{-1} Pb (Tab. 4) does not pose a threat to the quality of the compost. Moreover, it was established that the significant values of the correlation coefficients between Zn and Fe ($r = -0.24$, $p < 0.05$) and Fe and Pb ($r = 0.34$, $p < 0.001$) (Figure 4) indicate that these elements may come from similar sources of pollution [Sut-Lohmann et al. 2020], which results from the location of the park, urban squares and greens in the central part of the city.

Principal Components Analysis

Using the Principal Components Analysis (PCA) method, four main components were

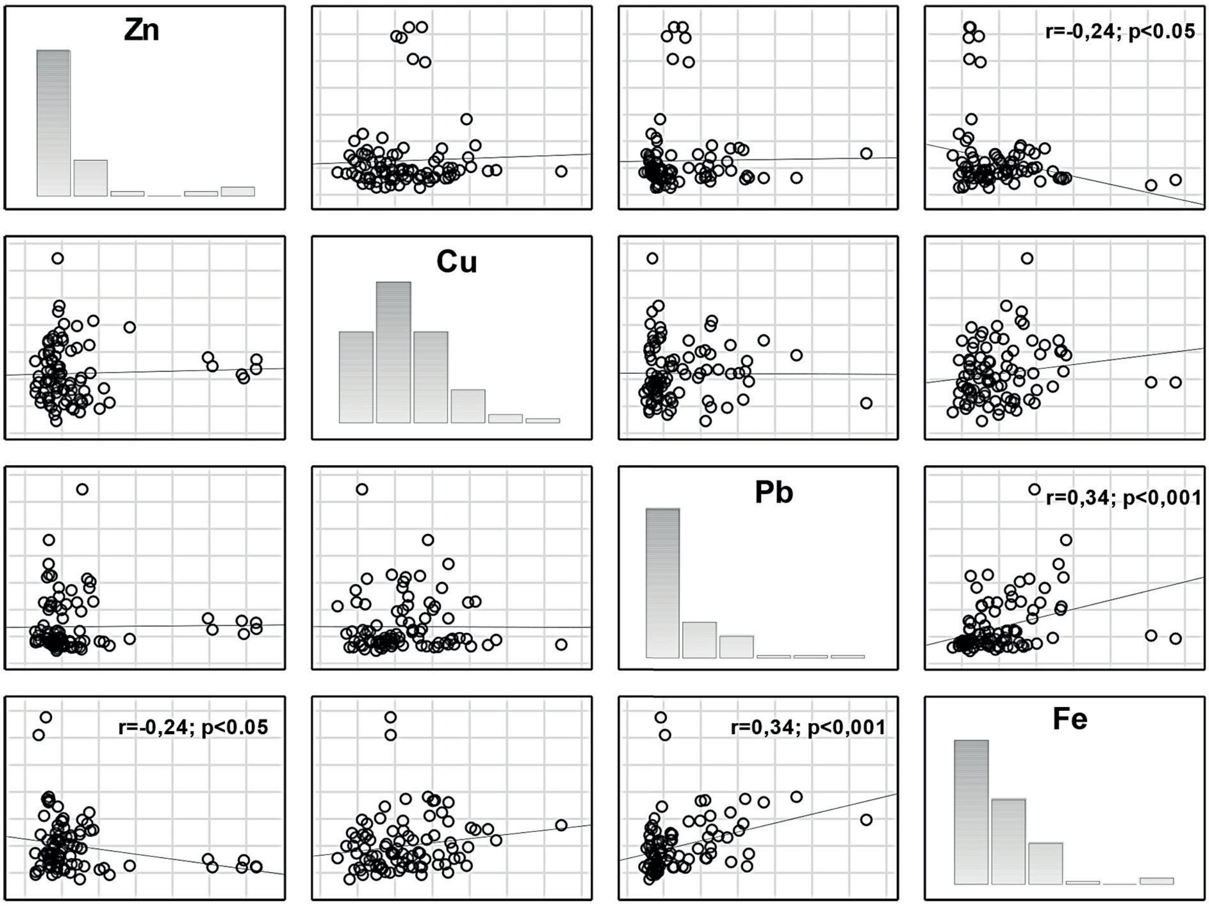

Figure 4. Matrix chart of heavy metals content in leaf litters in 12 species of trees with histograms, correlation coefficients (r) and statistical significances ($p<0.05$)

distinguished, characterizing the chemical composition of leaf litters from 12 species of trees, explaining in total 71% of the variance (Table 4). The first factor (*FC1*) explained 21% of the variance and grouped C and Ca, characterized by high factor loadings (negative and positive, respectively). The second factor (*FC2*) accounted for 16% of the variance and was formed by directly proportionally correlated N and Cu. These components were characterized by high positive factor loadings. The third factor (*FC3*) explained 21% of the variance and grouped Mg, Zn and pH, characterized by high factor loadings. The fourth factor (*FC4*) accounted for 13% of the variance and was constituted only by Pb. The share of Cu, Zn and Pb in the identified factors is the result of relatively old age of trees growing in parks, squares and greens, which increased the content of heavy metals in leaf litters due to long-term accumulation (Tab. 4). In the period preceding the research, the concentration of atmospheric dust in Słupsk did not exceed the permissible standard [Raport WIOŚ, 2020]. The content of nutrients, i.e. K and P in leaves typically decreases with the age of the stand. Ca, however, is an exception, as its concentration increases with the age of trees [Malzahn 2002], which is confirmed by the share of Ca in *FC1*. The factor values of the objects were presented in the form of a categorized scatter plot, showing the dispersion of the studied species against the factor loadings *FC1* (C, Ca) and *FC2* (N, Cu), see Figure 5. Close, mutual location of points, coming from one species, confirms the strong influence of tree species on the content of individual components in leaf litters [Townsend et al. 2006].

CONCLUSIONS

The obtained results indicate that leaf litters from 12 species of deciduous trees are acidic and show significant diversification of the content of macronutrient and heavy metals. The leaves of *Fra_exc* and *Til_cor* (N, P, K, Mg, Ca) as well as *Til_tom* (P, K, Mg) and *Aln_glu* (N) turned

Table 4. Factor loadings (*FC1, FC2, FC3, FC4*) obtained with the principal components analysis (PCA) method after normalized varimax rotation on the basis of the physicochemical properties of leaf litters from 12 species of trees

Parameters	*FC1*	*FC2*	*FC3*	*FC4*
pH	0.14	0.24	0.81	0.23
C	-0.84	0.02	0.01	0.03
N	-0.09	0.91	-0.16	0.02
P	0.44	0.13	0.36	0.32
K	0.68	0.26	0.23	0.17
Mg	0.50	0.05	0.73	0.19
Ca	0.78	-0.05	0.14	-0.25
Zn	-0.04	0.16	-0.84	0.19
Cu	0.25	0.83	0.28	0.08
Fe	-0.18	0.10	0.29	0.54
Pb	0.09	-0.01	-0.12	0.91
Eigenvalues	2.36	1.71	2.31	1.44
Explained variance [%]	21	16	21	13
	71			

Note: factor loading higher than 0.7 are in bold

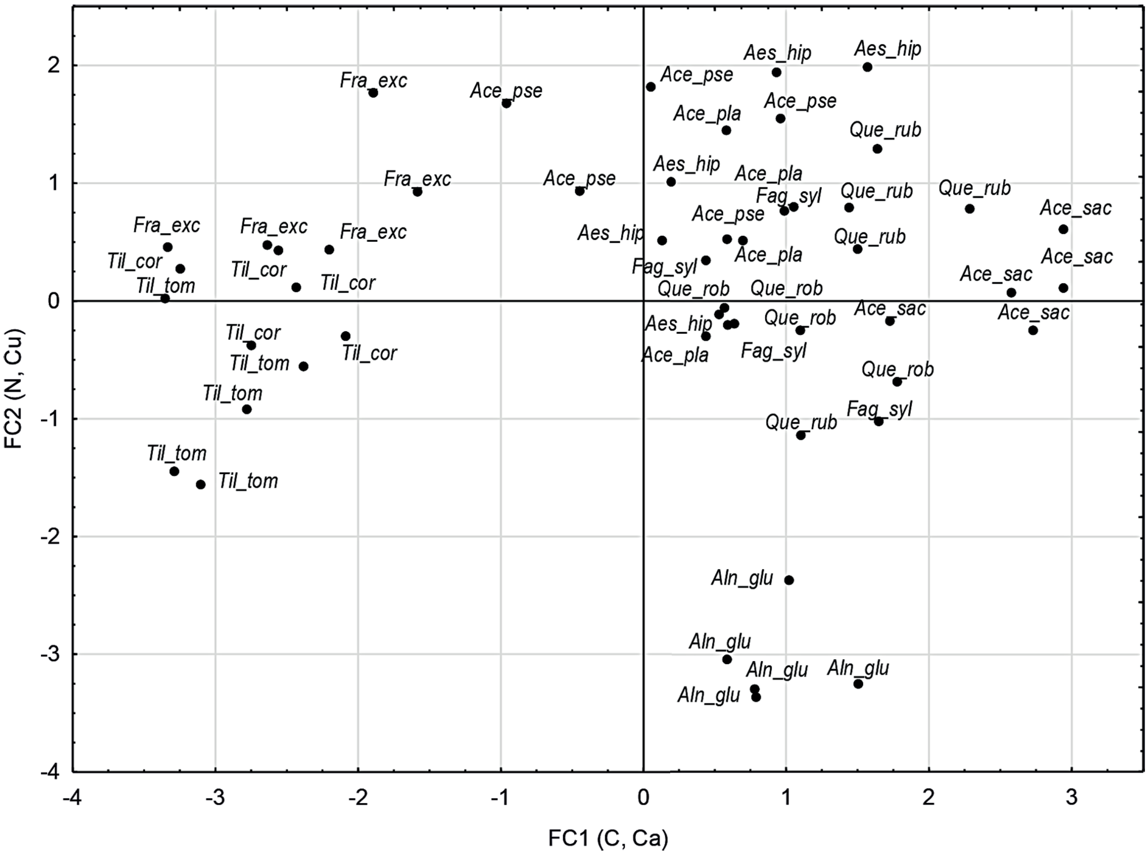

Figure 5. FC1 (C, Ca) and FC2 (N, Cu) relative to 12 species of trees

out to be the most abundant in macronutrients. It was found that the leaves of *Aln_glu, Til_cor* and *Fra_exc*, which are characterized by the correct C/N ratio, decompose the fastest in the composting process, and simultaneously provide the highest amounts of nitrogen among the studied tree species. The decomposition process of *Que_rub*, *Aes_hip* and *Fag_syl* leaves, which are low in nitrogen compounds, takes much longer and is more difficult. It was determined that the leaf litter from the central part of the city is a "safe" compost component. The heavy metals contained in it (Zn, Cu, Pb) do not pose a threat to the environment, as they do not exceed the permissible level of contamination.

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