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The Content of Sulphur in the Soil and Plant from Park Areas Exposed to Traffic Pollution

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Abstract

Sulphur occurs in many environmental compounds. Source of this element may be natural as also anthropogenic origin, for example related with the development of road traffic. The aim of this study was to evaluate the impact of traffic on the content of total and sulphate sulphur in forest soils and plant material. The selected physicochemical properties of soils were determined: soil texture by laser diffraction method, soil pH by potentiometric method, total organic carbon (TOC) by Tiurin method. The content of total and sulphate sulphur in research material was determined by Bardsley-Lancaster method modified by COMN-IUNG. All analyses were performed in three replicates and the verification of the results was based on the certified material Till-3. Statistical analysis of the results were performed in Statistica 12.0 for Windows Pl software. Examined research material was characterized by medium, high and anthropogenic origin content of total and sulphate sulphur. Undertaken studies showed that the traffic could have an adverse influence on the content of sulphur in soils and plant material.

Keywords: total sulphur, sulphate sulphur, forest soils, pine bark, pine needle, traffic road

1. Intoduction

Landscape parks are unique places in terms of species richness, diversity of landscape and variety of geomorphic forms (Helmuth & Dudek, 2002). Through insight into many advantages, these areas are under legal protection (Regulation No. 92, item. 880). Myślęcinek Forest Park for Culture and Leisure, constituting an area of research, is the biggest city park in Poland. These site is located near to urban areas and the surface takes 830 ha (Dynarz & Wiśniewski, 1997).

Sulphur occurs in many environmental components e.g. air, water, soil. It is an element widely occurring in ecosystems. Sources of sulphur in environment may be natural as also anthropogenic origin. The biggest threat with regard to the amount of sulphur emissions to the environment comes from human activities i.e. exploitation of natural resources, the development of road traffic, storage of waste and many others (Sherer, 2001). Road traffic is the source of substances in environmental components (Pallvani & Harrison, 2013). The content of selected compounds are directly proportional to vehicle speed. Higher velocity causes the increased emissions (Duong & Byeong-Kyu, 2011). Pollution from traffic contributes to gradual degradation process of soil and vegetation cover in the areas located about 500 m from road (Sławiński, Gołąbek, & Senderak, 2014). Dust fall and gas concentrations have major impact on the calculated percentage of deterioration environmental quality of the forest taking into account the distance of forest surface from the emission source. This is because it undoubtedly determines the amount of precipitation and the concentration of gases in base: the farther the distance, the smaller fall of the dust and gas concentrations (K. Sporek & M. Sporek, 2007). Furthermore, fuel combustion processes are the main source of sulphur in environment (Bąbelewska, 2013). Sulphur compounds may be affected directly on change the soil pH (Jaggi & Freedman, 1992). Lower soil pH can cause launching other compounds for example heavy metals like aluminium, nickel, mercury (Karczewska & Kabała, 2010). Therefore, pollutant emissions such as sulphur must be monitored to provide proper quality of environmental components and prevent of their degradation (Franco et al., 2013).

The increased concentration of sulphate sulphur ($S\text{-}SO_4^{-2}$), which has the highly significance as a phytotoxic factor, contribute to changes in a given ecosystem (Jakubus, 2006). Sulphate sulphur which is a source of sulphur for flora is considered as a measure of the availability of this element in the soil (Filipek-Mazur, Lepiarczyk, & Tabak, 2013). Sulphate sulphur constitute from 3-50% of the total content of this element in the soil. This is an unstable form, which provides an easy leaching and also an easy consumption by plants (Motowicka-Terelak & Terelak, 1998; Jakubus, 2006). Furthermore, high content of sulphur may cause the disturbance of photosynthesis process and plant growth (Eguagie et al., 2015). Increased content of sulphate sulphur in the soil, as well as the content of trace elements, is not only a significant phytotoxic factor but it can also be considered as an indicator of human pressure, contributing to the dying forests (Jakubus, 2006). Exists four degrees of content assessment of total and sulphate sulphur, from low content to anthropogenic to increase (Kabata-Pendias, 2010).

Pinus sylvestris L. is a species characterized by high variability, which is associated with the wide prevalence. Pine bark and needles are extremely sensitive bioindicators of pollution of natural environment (Chrzan, 2012, Robles et al., 2003). Pine needles remain on the plant for several seasons and under the accumulation of contaminants followed by accumulation these toxins in to them (Dmuchowski & Bytnerowicz, 1995). Tree bark is a tissue commonly used in many environmental research as an bioindicator because of its ability for long-term accumulation of pollution both dusts and gases (Grodzińska, 1977). Assessment of sulphur content in soils is necessary in terms of impact of this element for mobility of heavy metals and deterioration of chemical properties of soil especially launch of aluminium and losses of magnesium (Motowicka-Terlak & Dudka, 1991). The content of sulphur in Polish soils takes average values from 500 to 5000 mg·100 g^{-1} (Gorlach & Mazur, 2001).

The aim of conducted study was to assess the content of total and sulphate sulphur in forest soils and bark and three-years increments of needles of *Pinus sylvestris* L. from park areas exposed to traffic pollution. Due to the proximity of high-traffic road the area must be monitored.

2. Materials and Methods

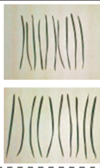
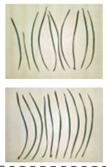
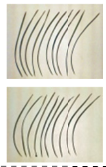
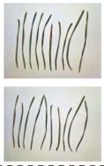
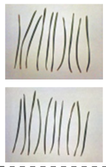
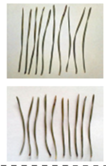
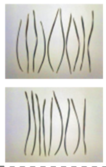
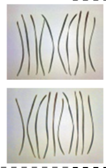
2.1 Materials

Research material was collected along the exit road of Bydgoszcz with high-traffic from Myślęcinek Forest Park for Culture and Leisure (Poland) (Figure 1). Bydgoszcz is located in the temperate transitional climate zone (Bąk & Łabędzki, 2014). Soil material included 26 soil samples collected from 13 research points located 75 m away from road, and the distance between points was 50 m. Samples were taken from two depths: 0-20 cm (surface samples) and 20-40 cm (subsurface samples) during three years of investigation.

Plant material included 13 bark samples and 13 three-years increments of needles of Pinus sylvestris L. collected from 13 research points located in the same way as the soil research points (Table 1) during one years of investigation.

Figure 1. Location of research points

Table 1. Three-years increments of pine needles

Sample	Repeating	Year		
		1	2	3
1	(1)			
	(2)			
2	(1)			
	(2)			
3	(1)			
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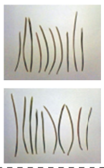
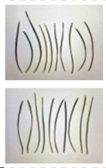
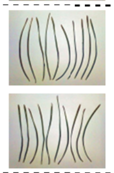
4	(1)			
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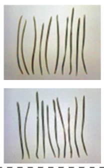
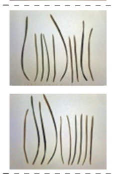
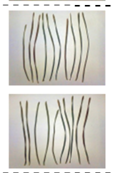
5	(1)			
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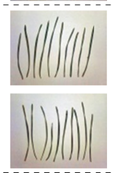
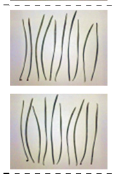
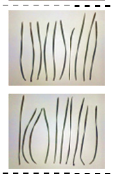
6	(1)			
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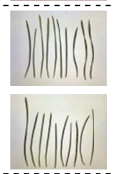
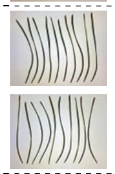
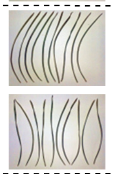
7	(1)			
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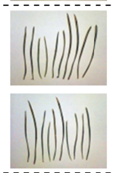
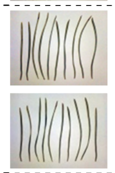
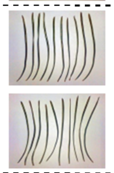
8	(1)			
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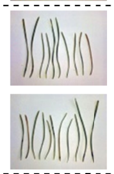
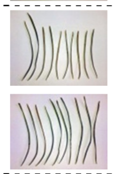
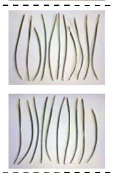
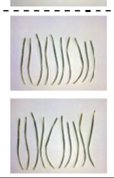
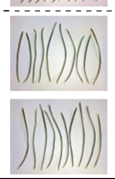
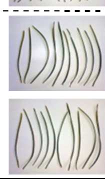
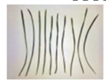
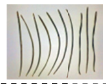
9	(1)			
	(2)			
10	(1)			
	(2)			

11	(1)			
	(2)			
12	(1)			
	(2)			
13	(1)			
	(2)			

2.2 Methods

Following analysis were conducted on soil samples: pH by the potentiometric method in H_2O (in the ratio 1:2.5) and in 1 M KCl (in the ratio 1:2.5), total organic carbon (TOC) by Tiurin method in the solution of dichromate (VI) potassium and soil texture by laser diffraction method using a Mastersizer 2000. The content of total sulphur and sulphate sulphur in the soil was determined by Bardsley-Lancaster method (Bardsley & Lancaster, 1960) modified by COMN-IUNG. All analysis were performed in three replicates and the verification of the results was based on the certified material Till-3.

Following analysis were conducted on pine bark samples: the content of total sulphur and sulphate sulphur were determined by Bardsley-Lancaster method (Bardsley & Lancaster, 1960) modified by COMN-IUNG.

Following analyses were conducted on pine three-years increments needles samples: the content of total sulphur and sulphate sulphur was determined by Bardsley-Lancaster method (Bardsley & Lancaster, 1960) modified by COMN-IUNG. Furthermore morphological analysis of pine needles was performed with the use of computer software radixNova 1.0 (Stypczyńska et al., 2012). This analysis allows to obtain a length, width and surfaces of the pine needles at each increment. Calculations were performed using this software are carried out with the use of non-statistical methods. They consist in on a detailed analysis of the course of pixel images or scans forming the axes of the various parts of the plant.

Pearson correlation coefficient ($p < 0.05$) was calculated between the content of total and sulphate sulphur in all kinds of samples and their measured properties. Statistical analysis were performed in the Statistica 12.0 for Windows Pl software.

3. Results

3.1 Soil Properties

The analysis of texture allowed to classify the investigated soils to 2 texture classes: sand and loamy sand (USDA, 2012). Content of organic carbon ranged from 12.8 to 48.3 $g \cdot kg^{-1}$ in surface samples and from 4.3 to 19.9 $g \cdot kg^{-1}$ in subsurface samples. In the analysed samples pH_{H2O} ranged from 4.6 to 7.1, while pH_{KCl} from 3.8 to 6.8 (Table 2).

Table 2. Physicochemical properties and the content of total and sulphate sulphur in soil samples (mean for three years of investigation)

Soil sample	and depth (cm)	pH $_{H2O}$	pH $_{KCl}$	TOC ($g \cdot kg^{-1}$)	Clay (%)	S total ($mg \cdot 100\ g^{-1}$)	S-SO_4^{2-} ($mg \cdot 100\ g^{-1}$)
1	0-20	5.7	4.9	48.3	0	53.1	-
	20-40	5.2	4.4	11.2	1	23.5	3.7
2	0-20	5.0	4.1	20.6	1	23.4	2.1
	20-40	4.7	4.0	19.9	1	24.3	2.8
3	0-20	5.2	4.1	14.1	1	25.1	3.5
	20-40	5.2	4.6	4.3	1	23.8	2.8
4	0-20	5.1	4.2	30.4	0	27.4	-
	20-40	4.9	4.2	7.7	0	22.3	2.6
5	0-20	5.2	4.3	17.2	1	24.8	2.3
	20-40	5.2	4.4	11.1	1	23.6	3.0
6	0-20	4.9	4.0	27.9	1	25.4	2.9
	20-40	5.0	4.4	6.7	1	23.9	3.6
7	0-20	6.3	5.6	32.9	1	26.4	2.4
	20-40	5.5	4.6	10.9	1	22.2	2.7
8	0-20	5.2	4.4	16.3	1	22.4	1.3
	20-40	5.6	4.7	11.5	2	24.4	2.3
9	0-20	5.0	4.2	18.0	3	25.6	1.8
	20-40	4.9	4.3	14.4	3	19.3	2.1
10	0-20	4.6	3.8	32.3	1	27.4	2.2
	20-40	4.7	4.0	17.9	1	23.3	2.6
11	0-20	7.1	6.8	18.9	1	26.5	1.9
	20-40	5.4	4.4	18.9	1	25.4	1.1
12	0-20	6.2	5.8	13.4	1	25.4	3.8
	20-40	6.0	5.5	13.3	2	26.6	1.8
13	0-20	4.9	4.1	12.8	1	26.1	1.8
	20-40	5.2	4.2	7.4	1	27.2	1.5

Note. "-" lack of samples.

3.2 Analysis of the Sulphur Content

Total content of analysed elements have taken the following values in soil samples: total sulphur from 22.4 $mg \cdot 100\ g^{-1}$ to 53.1 $mg \cdot 100\ g^{-1}$ in surface samples and from 19.3 to 27.2 in subsurface samples, sulphate sulphur from 1.3 to 3.8 $mg \cdot 100\ g^{-1}$ in surface samples and from 1.5 to 3.7 $mg \cdot 100\ g^{-1}$ in subsurface samples (Table 2).

Total content of analysed elements have taken the following values in pine bark samples: total sulphur from 39.2 $mg \cdot 100\ g^{-1}$ to 84.4 $mg \cdot 100\ g^{-1}$ and sulphate sulphur from 10.5 to 157.8 $mg \cdot 100\ g^{-1}$ (Table 3).

Total content of analysed elements have taken the following values in pine needles samples: 1-years increments of needles total sulphur from 78.3 $mg \cdot 100\ g^{-1}$ to 341.9 $mg \cdot 100\ g^{-1}$ and sulphate sulphur from 1.2 to 4.9 $mg \cdot 100\ g^{-1}$, 2-years increments of needles total sulphur from 87.1 to 415.0 $mg \cdot 100\ g^{-1}$ and sulphate sulphur from 1.5 to 5.3 $mg \cdot 100\ g^{-1}$, 3-years increments of needles total sulphur from 159.2 to 461.5 $mg \cdot 100\ g^{-1}$ and sulphate sulphur from 0.8 to 5.7 $mg \cdot 100\ g^{-1}$ (Table 4).

Table 3. The content of total and sulphate sulphur in pine bark

Sample	S total ($mg \cdot 100\ g^{-1}$)	$S\text{-}SO_4^{2-}$ ($mg \cdot 100\ g^{-1}$)
1	39.2	41.7
2	62.4	97.4
3	46.6	46.9
4	39.3	157.8
5	64.4	124.9
6	73.1	119.6
7	49.8	113.7
8	51.1	10.7
9	80.5	14.5
10	84.4	56.3
11	57.6	20.1
12	53.4	10.5
13	55.1	92.9

3.3 Morphological Analysis of Pine Needles

Morphological analysis of three-years increments of needles of *Pinus sylvestris* L. allows to determine length, width and surface at each increment.

The 1-year increments of pine needles have taken the following values: length from 4.38 to 5.93 cm, width from 0.06 to 0.09 cm and surface from 0.25 to 0.52 cm. The 2-year increments of pine needles have taken the following values: length from 5.45 to 7.21 cm, width from 0.07 to 0.09 cm and surface from 0.40 to 0.63 cm. The 3-year increments of pine needles have taken the following values: length from 6.75 to 7.95 cm, width from 0.08 to 0.12 cm and surface from 0.56 to 0.97 cm (Table 4).

Table 4. Morphological analysis and the content of total and sulphate sulphur in pine needles

Sample	Year	Length (cm)	Width (cm)	Surface (cm^2)	S total ($mg \cdot 100\ g^{-1}$)	S-SO_4^{2-} ($mg \cdot 100\ g^{-1}$)
	1	4.38	0.08	0.33	152.3	4.9
1	2	6.39	0.08	0.51	185.9	5.3
	3	7.41	0.09	0.67	237.2	5.7
	1	5.93	0.07	0.40	206.6	3.4
2	2	6.11	0.09	0.52	114.9	4.9
	3	7.16	0.09	0.62	228.5	5.2
	1	4.17	0.08	0.33	216.5	3.5
3	2	7.21	0.07	0.53	266.6	4.2
	3	7.25	0.08	0.57	192.0	3.8
	1	5.37	0.06	0.33	78.3	3.4
4	2	6.08	0.08	0.51	87.1	1.5
	3	7.11	0.09	0.63	213.1	0.8
	1	5.51	0.07	0.37	341.9	1.2
5	2	6.61	0.08	0.55	415.0	3.9
	3	7.81	0.09	0.73	461.5	4.2
	1	4.82	0.09	0.43	215.5	3.0
6	2	6.04	0.09	0.56	272.8	3.9
	3	7.95	0.12	0.97	297.4	4.4
	1	5.74	0.08	0.48	208.3	3.6
7	2	6.90	0.09	0.59	242.5	3.2
	3	7.71	0.08	0.63	257.2	3.9
	1	4.90	0.09	0.44	194.0	3.4
8	2	7.16	0.09	0.63	198.4	4.1
	3	7.23	0.10	0.72	209.4	4.2
	1	5.33	0.09	0.52	158.9	2.3
9	2	6.42	0.10	0.59	184.5	2.9
	3	7.49	0.11	0.79	202.0	3.4
	1	5.72	0.07	0.38	146.3	3.7
10	2	6.03	0.07	0.40	146.2	3.8
	3	6.86	0.09	0.64	159.2	3.8
	1	4.73	0.08	0.36	117.6	2.9
11	2	5.45	0.09	0.47	182.3	3.2
	3	7.21	0.10	0.68	189.3	3.8
	1	4.02	0.06	0.25	120.7	1.8
12	2	6.81	0.08	0.55	159.3	2.8
	3	7.74	0.08	0.65	175.5	2.9
	1	5.44	0.06	0.34	113.6	3.4
13	2	5.83	0.07	0.43	116.4	3.7
	3	6.75	0.08	0.56	169.8	4.3

3.4 Statistical Analysis

Calculated correlation coefficients confirmed the significant relations: in soil samples between the content of total sulphur and the content of sulphate sulphur ($r = -0.532$ at $p < 0.05$) (Figure 2); in pine bark between the content of total sulphur and two properties of soil samples: [H+] in pH_{H2O} ($r = -0.441$ at $p < 0.05$) (Figure 3a) and the content of clay ($r = 0.534$ at $p < 0.05$) (Figure 3b); in pine needles between the content of total sulphur and the surface of needles ($r = 0.434$ at $p < 0.05$) (Figure 4).

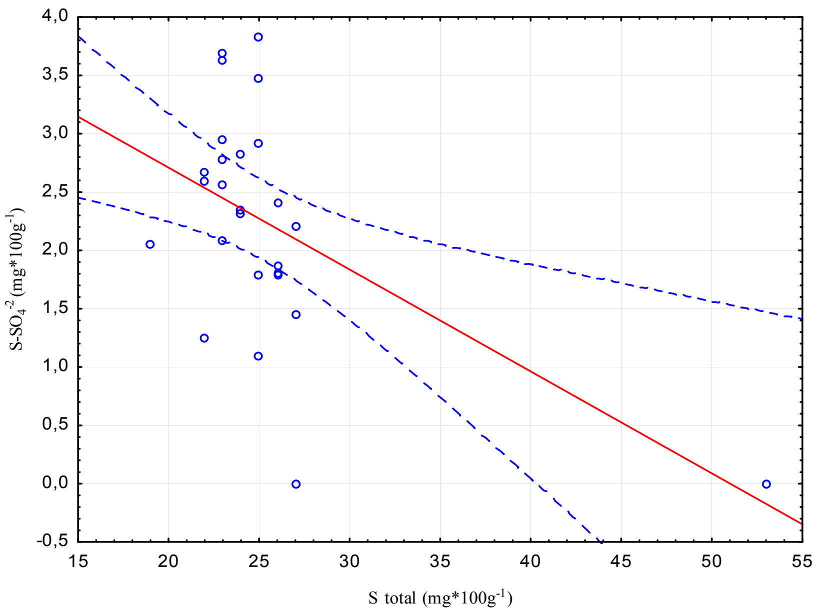
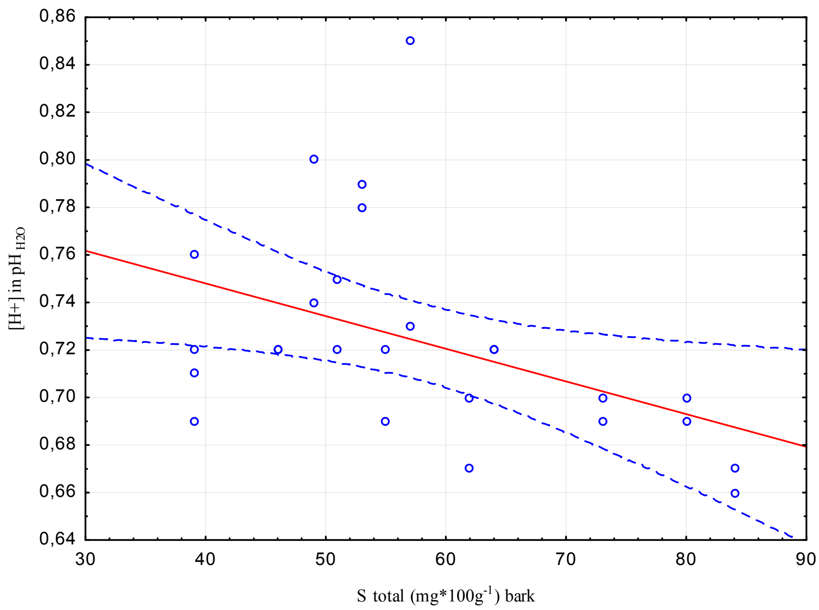


Figure 2. Correlation between the content of total sulphur and sulphate sulphur in soil samples

a



b

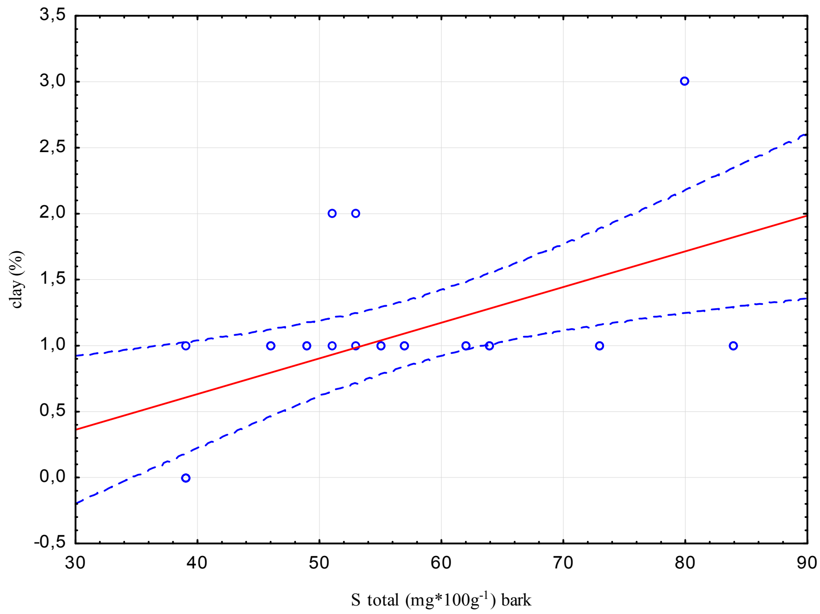


Figure 3. Correlation between [H+] in pH $_{H2O}$ (a) and clay (b) and the total content of sulphur in pine bark

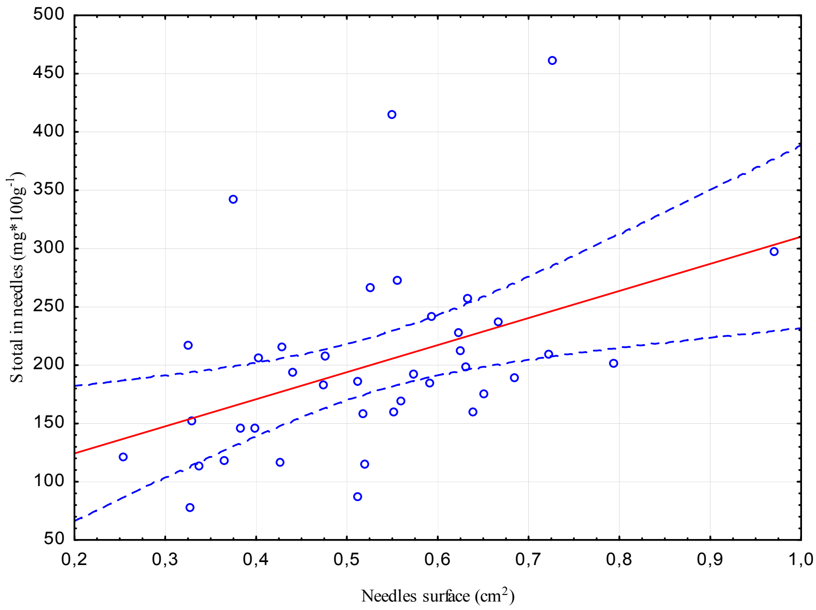


Figure 4. Correlation between the total content of sulphur in needles and their surface

4. Discussion

The content of total sulphur in examined soil sample ranged from 19.3 to 53.1 mg·100 g^{-1} and sulphate sulphur ranged from 1.3 to 3.7 mg·100 g^{-1}. Examined soils were characterized by medium and high content of total sulphur and also by medium, high and anthropogenic origin content of sulphate sulphur. According to the guidelines developed by Kabata-Pendias (2010) examined soil may be qualify as a soil with medium and high content of total sulphur and as a soil with medium, high and anthropogenic origin content of sulphate sulphur. Therefore, that sulphate sulphur is one of the forms in soil especially contributing to acidification of soils, monitoring the level of this compound is such an important factor. The content of total sulphur in examined pine barks ranged from 39.2 to 84.4 mg·100 g^{-1} and sulphate sulphur ranged from 10.5 to 157.8 mg·100 g^{-1}. Examined pine needles were characterized by a content of total sulphur in ranged from 78.3 to 461.5 and sulphate sulphur from 0.8 to 5.7 mg·100 g^{-1}. Referring the results obtained from the conducted research to the current state of knowledge can be stated that the total content of sulphur in plant materials was on a medium level and sulphate sulphur on low. This indicates a slight anthropogenic impact on the local flora. Despite this, due to the proximity of routes with high traffic occurs need for constant monitoring of the studied area.

Similar research were conducted by Licznar and Licznar (2005) in city park in Wroclaw (Poland). The mean content of total sulphur in soil from Szczytnicki Park (Wroclaw) was 116.0 mg·100 g^{-1}. Research conducted by Kalambasa and Godlewska (2010) showed that mean content of total sulphur in loamy sands was 6.5 mg·100 g^{-1}. In soil fertilised with macroelements mean content of sulphate sulphur ranged from 82.2 to 125.0 mg·100 g^{-1} (Siwik-Ziomek, Lemanowicz, & Koper, 2016). Another research reported that mean content of sulphate sulphur in forest soil ranged from 5.5 to 10.5 mg·100 g^{-1} (Koper, Piotrowska, & Siwik-Ziomek, 2008). Research conducted by Szopka et al. (2011) showed that soils from Karkonosze National Park were characterized by high volatility and the content of sulphate sulphur ranged from 200.0 to 36,000.0 mg·100 g^{-1}. Kulczycki and Spiak (2004) in the arable layer (0-20 cm) of eighty soils from south-west Poland, reported that the participation of the sulphate sulphur was about 700,000.0 mg·100 g^{-1}. Other studies indicated that the content of sulphate sulphur in soils of road Siedlce city ranged from 150,000.0 to 1,700,000.0 mg·100 g^{-1} (Kalembasa & Godlewska, 2005). Boratyński et al. (1975) reported that in methodological research of soil samples content of $S\text{-}SO_4^{-2}$ ranged from 0.3 to 0.5 mg·100 g^{-1}. According to research conducted by Terelak and Motowicka-Terelak (2000) the content of sulphate sulphur in Polish soils ranged from 0.01 to 50.0 mg·100 g^{-1}. More than 55% of soils are areas with low content of $S\text{-}SO_4^{-2}$. Surface of areas with medium and high content of sulphate sulphur constitutes appropriately: 25.1 and 13.1%, and anthropogenically contaminated by sulphur only 3.7% (Terelak, 2005).

Close to the Kola smelters content of total sulphur in pine bark was a twice as high as the other side of border of the Finland (Poikolainen, 1997). Research conducted by Manninen et al. (1997) showed that the content of sulphate sulphur in pine needles takes values from 0.6 to 1.2 mg·100 g^{-1}. In pine needles from northernmost Europe the content of sulphate sulphur ranged from 7,410.0 to 20,170.0 mg·100 g^{-1} (Raitio, Tuovinen, & Anttila, 1995). Received results were very high and probably it was connected with SO_2 emissions into the atmosphere in the surrounding areas. In areas highly industrialized the content of total sulphur in pine needles ranged from 6,000.0 to 10,000.0 mg·100 g^{-1}, while in areas where there is no pollution of air content of total sulphur ranged from 300.0 to 1,200.0 mg·100 g^{-1} (Grodzińska, 1977). Research conducted by Staszewski et al. (2008) reported that the content of sulphate sulphur in 1-year increments of pine needles from Pieniny National Park was 700.0 mg·100 g^{-1}. Other studies on the pine needles from this area showed that the content of total sulphur ranged from 500.0 to 999.0 mg·100 g^{-1} (Panek & Szczepańska, 2005). Assessment of sulphur content in soils is necessary in terms of impact of this element for mobility of heavy metals and deterioration of chemical properties of soil especially launch of aluminium and losses of magnesium (Motowicka-Terlak & Dudka, 1991). The content of sulphur in Polish soils takes average values from 500 to 5000 mg·100 g^{-1} (Gorlach & Mazur, 2001).

To sum up, undertaken studies shows that the traffic have slight influence on the content of total and sulphate sulphur in soils and plant material. So far, conducted only few similar studies, relating to the assessment of environmental pollution by sulphur compounds as a result of traffic road. Many other studies were primarily aimed to assess the various industries on the content these elements in environmental components. Therefore undertaken research complementing the state of knowledge.

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