ROCZNIKI GLEBOZNAWCZE (SOIL SCIENCE ANNUAL) SUPPL. T. XLIV, WARSZAWA 1994: 85–93

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MAGNETIC SUSCEPTIBILITY AS INDICATOR OF SOILS CONTAMINATION IN SOME REGIONS OF POLAND

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INTRODUCTION

All substances have certain magnetic properties depending on their magnetic susceptibility [Sukiennicki 1982]. Three different groups are distinguished: diamagnetic, paramagnetic, and ferromagnetic ones. The last group contains substances which show ferro-, ferri- and antiferromagnetic properties. According to Thompson and Oldfield [1986] the magnetic properties of soil depend on the magnetic properties of minerals which form the soil. Quartz, orthoclase, calcium carbonates, organic matter, and water have diamagnetic properties, olivine, pyroxene, garnet, biotite, iron and manganese carbonate are paramagnetic. Ferromagnetic minerals are magnetite and maghaemite, whereas goethite, lepidocrocite, and hematite are antiferromagnetic minerals.

Under some conditions, titanomagnetites and pyrrhotite also play some role in soils. In spite of numerous investigations of magnetic properties of soils, described in the review by Mullins [1977] there are few papers on content and distribution of ferromagnetics in soils. Among the natural causes that can influence an increase in magnetic susceptibility, the same author gives several ones, but the majority of them is of theoretical character only without experimental confirmation [Vodyanitskiy 1981]. The causes which were experimentally confirmed, show that, in quantitative terms, the process of ferromagnetics formation is very slow and it is impossible on this basis to explain the increase in magnetic susceptibility of soils in some regions of our country. To be sure; Thompson and Oldfield [1986] suggest that close to town and industrial centers the soil surface have a higher magnetic susceptibility in result of magnetic particulates fall originating from the fuels combustion processes, however, according to the authors this phenomenon both in quantitative and qualitative terms, remains still inscrutable.

Mineralogical investigations of metallurgical and industrial dusts, fly ashes from combustion of hard and brown coal in which the presence of magnetite was stated also called attention to the role of industrial emissions in increase in magnetic susceptibility of upper soil horizons [Manecki et al. 1981; Mitchell,Gluskoter 1976; Schejbal-Chwastek,Tarkowski 1988; Wilczyńska-Michalik 1981]. According to Lauf et al. [1982] framboidal pyrite is the source of magnetite in fly ash. The magnetite concentration in Polish ashes ranges from 0.9 to 12% [Łączny 1983].

Considering the effect of industrial emissions on increase in the soil magnetic susceptibility it should be taken into account that the use of the electrofilter with 98% efficiency results in emission of 2.6 t/h of fly ash (1.7 t/h within the aerosol fraction – 0–10 μm, it is about 65%) from the coal power plant of 1200 MW [Konieczyński 1982]. The aerosol fraction is characterized by a high content of iron which was stated by Tomza [1987] who has found 1.76–30.9 $\mu g\ Fe/m^3$ of air in Katowice area. In 1988 in Poland were 1527 industrial plants of which 1339 were equipped with dust collectors but only 241 ones decreased dust emission with efficiency above 90% and 649 within the range of 70–90%.

Collected data allow to bring hypothesis that in many regions of Poland and particularly in the Katowice province the increase in soil magnetic susceptibility caused by industrial imissions should be expected. For many years in Poland 100–160 mln t/a of hard coal and 30 to 75 mln t/a of brown coal have been burnt up. Due to high stacks fly ashes spread all over the country and other dusts are only of a local importance.

MATERIAL AND METHODS

Investigation of the magnetic susceptibility of arable soils was started in the Katowice province in the vicinity of the "Pokój" steel plant in 1987 [Strzyszcz et al. 1988].

In the next years the investigations of the area of all the 30 chief forestries of the Katowice State Forests Regional Directorate, some national parks (Słowiński, Ojcowski, Karkonoski, Wielkopolski, Świętokrzyski, Kampinoski) and other chosen regions of country [Strzyszcz 1989a, b, 1991] were carried out. The pit strips were made mainly in pine and spruce stands more than 50-year-old, 1.5 m from a trunk and the sampling was carried out selectively from particular litter subhorizons (Ol, Of, Oh) as well as from other horizons. The samples were comminuted and sieved through an 1 mm screen and dried at 150°C. In total, more than 500 samples were taken out from the chief forestries of the Katowice SFRD and more than 1000 samples all over the country area.

Additionally, magnetic susceptibility of metallurgical (12 samples), and cement dusts (18 samples), as well as fly ashes after combustion of brown (7 samples) and hard coal (35 samples) were tested.

Magnetic measurements were taken by a home-made instrument [Strzyszcz et al. 1988] availing the method of application of ferrite as an indicator in investigations of soil erosion worked out by Tölle [1986]. The instrument consists of: feeder of direct current, tension stabilizer, generator, coil, amplifier and frequency meter. Measurement involves sliding a definite weighed amount of examined substance into the holder and next in the magnetic field of current-carrying solenoid. Generated high frequency current derived by the coil is a subject of considerable change of its frequency which is recorded in the system amplifier – frequency meter.

The specific susceptibility may be expressed in terms of Hz/5 g. These values have been cross-calibrated and converted into SI specific susceptibilities (m^3/kg) by comparative measurements of 127 soil, metallurgical dust, cement dust and fly ash samples that were carried out on a KLY-2 susceptibility bridge.

RESULTS AND DISCUSSION

The metallurgical dusts showed the highest magnetic susceptibility and it is probably connected with processing of magnetite ores as well as with formation of ferromagnetics from other iron compounds and with emission of iron in the metallic form characterized by a significant magnetic susceptibility. It is interesting that metallurgical dusts show the highest fluctuation in the susceptibility values (Table 1).

The values of magnetic susceptibility for cement dusts are significantly lower. The values depend mainly on additives used for cement production (fly ashes, pyrite wastes). Upper values for cement dusts and fly ashes from brown coal are similar whereas the susceptibility of ashes from hard coal is significantly higher (Table 1). It probably results from iron content in Polish hard coals which ranges from 6.8 to 13.2% Fe [Różkowska 1984]. Content of iron in brown coal is lower – 0.70–1.24% Fe [Pacyna 1980]. Among iron compounds in hard coal about 1.50% of magnetite [Kuhl 1961] and up to 15% of pyrite were found. Pyrite in the combustion process transform into magnetite.

As it was shown in earlier investigations [Strzyszcz et al. 1988] the arable soils close to steel plants showed a significant susceptibility over all ploughed layer (20–25 cm). Its value depends on the distance from the plant and direction of prevailing winds. The susceptibility decreases along with distance and due to ploughing its "dilution" in all the plough layers takes place. As it was mentioned earlier in forest soils being under influence of industrial emissions the increase in the magnetic susceptibility is observed mainly in litter, especially in Of/Oh subhorizons.

The magnetic susceptibility of forest soils of Katowice SFRD is differentiated; its level increases from the west to the east (Fig. 1). Soils of the chief forestries like Brzeg, Kup, Krasiejów, Prószków, Turawa, and Olesno show the values lower than $150 \cdot 10^{-8}$ m^3/kg. On the other hand in the chief forestries like Prudnik, Tułowice, Namysłów, Kluczbork, Strzelce Opolskie, Kolonowskie, Lubliniec, Herby, Kłobuck, Złoty Potok, and Koniecpol the above mentioned value is exceeded but is not higher than $300 \cdot 10^{-8}$ m^3/kg.

TABLE 1. Magnetic susceptibility of dusts and fly ashes

Type of dusts	No of samples	Specific susceptibility x 10^{-8} [m^3/kg] min–max	$\bar{x}$
Metallurgical	12	21–45816	13776
Cement	18	9–1620	363
Fly ashes from hard coal	35	666–3605	2006
Fly ashes from brown coal	7	508–1602	1047

From the Rudy Raciborskie-Kędzierzyn-Rudziniec line, the values of forest soils magnetic susceptibility increase up to 300–400, and increase up to 600 further eastward and in the area of Kobiór and Katowice chief forestries increase up to $1000 \cdot 10^{-8}$ m^3/kg.

The increase in magnetic susceptibility of soils is observed not only in central part of the Katowice province but also in areas adjoining the border with Czech Republic, particularly in the region of Wisła, Ustroń, and Rybnik (Fig.1). The high values of magnetic susceptibility may be expected in forest soils in Czech Republic which is caused by the activity of power and metallurgical plants located in Ostrawa region.

In other investigated regions the higher values were found close to Kraków and Turoszów, and the border with Germany as well as close to Konin and other higher industrial centres (Fig. 2). Among the national parks the highest values were found in Ojcowski and Świętokrzyski ones.

The data presented in Table 2 testify to the dependence between magnetic susceptibility and dust fall. It was found that an increase in dust fall is accompanied by increase in magnetic susceptibility of forest soils, particularly of Of/Oh horizon.

The dependence between magnetic susceptibility of soils and some emission and imission indices is testified also by high correlation factor (Table 3). Lower correlation factor between magnetic susceptibility and cement dust emission results from the height of stacks, granulation of dusts emitted, conditions of their falling and content of ferromagnetics in cement dusts.

Besides an indirect determination of magnetics presence in forest soils by measurement of the magnetic susceptibility value the photos of litter layers from "Jaworzno" power station were taken under SEM. 10 particles were taken for magnification and for analysis by the X-ray fluorescence. SEM photos of litter layers show the presence of spherules in them and it was found by the X-ray fluorescence analysis that the composition of particles is dominated by iron [Strzyszcz 1991].

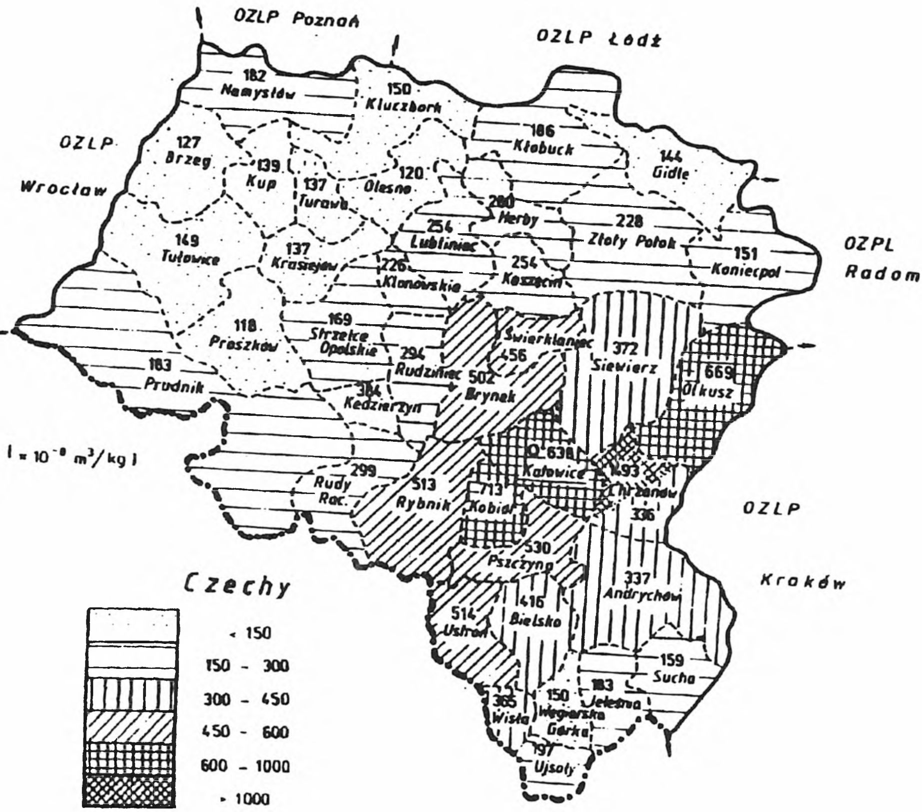

Fig. 1. Magnetic susceptibility of Of/Oh-horizon in forest soils in the Katowice State Forests Regional Directorates

Few data are found in literature on magnetic susceptibility of forest soils, the source of which are industrial imissions. High values of magnetic susceptibility of forest soils close to Moscow – 4000–6000 · 10^{-8} m^3/kg were found by Vodyanitskiy, who attributed the increase to natural processes [Vodyanitskiy 1981] but such explanation seems to be little possible. The dependence

TABLE 2. Magnetic susceptibility of particular horizons in forest soils

Localization	No of strip pits	Specific susceptibility x 10^{-8} [m^3/kg]								Dust fall [T/km^2 · a]
		Ol	Of	Oh	Ah	E	B	Bbr	C	
Słowiński NP	22	108	168	254	268	258	286	–	266	4
Częstochowa	15	197	400	294	223	206	–	225	–	27
Opole	29	222	363	317	265	347	376	266	210	73
Ojcowski NP	18	228	691	787	342	220	231	261	286	246
Katowice	22	425	922	725	305	198	232	207	–	328
USIR	27	1024	1729	1940	697	206	203	295	157	457

between such magnitudes as content of loamy particulates and iron oxides as well as a mother rock containing ferromagnetics and the value of magnetic susceptibility of soils with different chronosequence are discussed by Fine et al. [1989] and Singer and Fine [1989].

The high values of magnetic susceptibility (above $300 \cdot 10^{-8}$ m^3/kg) were found in eluvial horizons of soils from rocks like phyllite, serpentinite, schist,

TABLE 3. Correlation coefficient between soil magnetic susceptibility and some air pollutants

R – Specific susceptibility				
Emission – T/a				Imission – $T/km^2 \cdot a$
Dust	Fly ash	Cement	Metalurgical	Dustfall
0.903	0.868	0.365	0.918	0.871

sandstone, basalt, diabase, granodiorite. In soils formed of diabase and granodiorite the values of magnetic susceptibility in E horizon exceeding $1000 \cdot 10^{-8}$ m^3/kg were found. However, this susceptibility is pedo- and geogenical origin but not the anthropogenical one. This kind of susceptibility shows another

Fig. 2. Magnetic susceptibility of Of/Oh-horizon in forest soils in Poland

pattern of distribution in a soil profile. The highest values were found in E and Bt horizons but often a high value was found in horizon A. The authors did not investigate a litter layer and it makes these values difficult to compare.

CONCLUSIONS

1. The regularity of soil magnetic susceptibility values was found for area of the Katowice State Forests Regional Directorate; the values increase from the west to the east and from south to the north up to Brynek-Świerklaniec line.

2. Increase in magnetic susceptibility of soil from the west to the east is connected with pollutants transport along the prevailing winds direction and with the local influence of such emitters like Blachownia, Rybnik, Zabrze, Halemba power stations and the boiler houses in particular towns.

3. In the eastern part of Katowice SFRD influence of industrial imissions from "Jaworzno", "Łagisza" and "Siersza" and may be "Katowice" steel works on increase in magnetic susceptibility of soils is highly probable.

4. In the southern part of Katowice SFRD increase in soils magnetic susceptibility is connected with the activity of "Łaziska" steel works and power station, the local sources of Rybnik area and also with pollutants transported from Ostrawa (Wisła-Ustroń area).

5. In other country regions the elevated values of magnetic susceptibility of soils were observed in Turoszów and Jelenia Góra areas, near the western border with Germany and also in Konin, Kraków, Tarnów regions, in Świętokrzyski National Park and close to Warszawa and other big towns.

6. The higher values of soils magnetic susceptibility are found in the litter horizon, particularly in Of/Oh subhorizon what testifies to their anthropogenic origin.

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PODATNOŚĆ MAGNETYCZNA JAKO WSKAŹNIK ZANIECZYSZCZENIA GLEB W NIEKTÓRYCH REJONACH POLSKI

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STRESZCZENIE

Pomiary podatności magnetycznej gleb leśnych OZLP Katowice i innych rejonów kraju wykazały, że największe wartości wykazuje poziom ściółki, a w nim głównie podpoziomy Of i Oh. Gleby leśne OZLP Katowice wykazują zróżnicowaną podatność magnetyczną. Jej poziom wzrasta z zachodu na wschód i z północy na południe. Daje się zauważyć wzrost podatności magnetycznej gleb nie tylko w centralnej części województwa katowickiego, ale również jej wysoki poziom na terenach przygranicznych z Czechami, zwłaszcza w rejonie Wisły, Ustronia i Rybnika. W pozostałych rejonach badań wyższe wartości stwierdzono w okolicach Krakowa, Tarnowa, Turoszowa i na granicy z Niemcami, a także w pobliżu Konina i innych większych ośrodków przemysłowych. Spośród parków narodowych, najwyższe wartości stwierdzono w Ojcowskim i Świętokrzyskim. Przyczyną są imisje przemysłowe, o czym świadczą: wysoka podatność magnetyczna pyłów metalurgicznych, cementowych i popiołów lotnych oraz wysokie współczynniki korelacji między podatnością magnetyczną a niektórymi wskaźnikami emisji.

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