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COMPREHENSIVE SOLUTION OF THE PROBLEM OF ACIDIFICATION OF SOILS IN THE PROVINCE OF SILESIA CAUSED BY ANTHROPOGENIC TRANSFORMATIONS

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1. INTRODUCTION

Acid soils are characterised by unfavourable properties from both the agricultural and ecological points of view (Kaczor 2002, Lipiński 2005). The process of acidification of soils is related with weakening of their microbiological activity and with negative changes in a number of their physical properties. The greatest changes, however, are caused by acidification in the chemical properties of soils, primary among which are the leaching of components with alkaline character, reduced availability of plant nutrients, increased solubility of aluminium and manganese compounds and of other phytotoxic substances, including heavy metals (Jackowska 1998, Józefaciuk and Szatanik-Kloc 2002, Kaniuczak 2007). As a result of those changes, in acid soils there is usually a deficit of basic components, magnesium, calcium, phosphorus and molybdenum in particular. Under such conditions plants absorb excessive amounts of ions characteristic of an acid environment (aluminium, manganese, sulphur, heavy metals). Imbalance between ions of acid and alkaline character is one of the most dangerous effects of chemical degradation of soils. Real chemical degradation of soils usually takes place when soil acidification resulting from the effect of natural factors is augmented by anthropopressure. Such a situation occurs mainly in areas with a high level of industrialisation (Filipek et al. 2006, Kaczor and Brodowska 2008, Słowik *et al*. 2008, Wójcikowska-Kapusta and Martyn 1996).

In the context of the above, this work presents an analysis of the status of soil acidification in the Province of Silesia. The analysis comprises also the causes and effects of the acidification of soils in that region, and presents recommendations for actions aimed at the optimisation of the reaction of the soils.

2. GENERAL CHARACTERISATION OF THE PROVINCE OF SILESIA

Silesian Province (Silesian Voivodeship) was created on January 1, 1999, out of the former Katowice, Bielsko-Biała, and Częstochowa Voivodeships. It is localized in southern part of Poland and is bordered by four other Polish voivodeships: Opole, Łódź, Świętokrzyskie, and Lesser Poland. Silesian Province borders both the Czech Republic and Slovakia to the south. It occupies 12 294 km^2, which makes up 3.9% of Polish area. Population of Silesian Province amounts up to 4 659 000 inhabitants, which is over 12% of whole-Poland population. It has the highest population density in the country – 393 people per 1 km^2, at whole-Poland average 124 people per 1 km^2 (National Report 2010, Materials of SChR 2010, Report by WIOŚ 2009). Referring the area, Silesian Province ranks at the 14th place in Poland, while the second place in relation to population number (just after Masovian Province).

Longitudinal length of Silesian Province is 190 km, while parallel span is 138 km. Its borders are 1024 km long. The peak point is localized in Pilsko massif (Jeleśnia commune) – 1534 m alt., while Kuźnia Raciborska is situated in the lowest site – 173 m above sea level. Forests cover 31.7% of the total province area with average for the whole country 28.4%.

According to data collected by GUS (Central Statistical Office), Silesian Province was divided into four sub-regions in 2006: Bielsko-Biała, Częstochowa, Silesian, and Rybnik-Jastrzębie.

The administration structure of Silesian Province consists of 19 cities having the legal status of city county and 17 land counties further divided into 148 communes. The administration reform created the Silesian Province of 86% of the former Katowice voivodeship area (besides communes in Olkusz and Chrzanów county, as well as Brzeszcze commune), 70% of Częstochowa voivodeship (apart from communes in Olkusz county – 6 communes, Pajęczno – 3 communes, Radomsko – 2 communes, and Włoszczowa – 3 communes, as well as 60% of Bielsko-Biała voivodeship (except from communes in Susiec, Wadowice, and Oświęcim counties).

Silesian Province is characterized by a great diversity of geographic environments; both mountains, uplands, and lowlands are present here. Considering the physico-geographical division by Kondracki, Silesian Province is situated within three provinces: North European Plain, Polish Highlands, and Western Carpathians with Subcarpathian.

The central part of Silesian Province is covered by Silesian Highland. There is a basin filled with Carboniferous rocks near Silesian Highland. Carpathian Nappes are pulled over on south, and Triassic and Jurassic sedimentary rocks forming characteristic inselbergs are localized on north and east of the region. Land configuration is diverse: maximum altitudes reach up to 400 m above sea level (Saint Ann Mountain).

Two another macro-regions of Silesia-Cracow Upland are situated north and north-east of Silesian Highland: Wozniki-Wielun Upland and Cracow-Częstochowa Upland. Three highland ranges being the thresholds of more resistant Triassic and Jurassic rocks directing from north-west to south-east can be distinguished within Wozniki-Wielun Upland. Relief lowering in forms of Liswarta, Prosna, and Warta river valleys are situated among hills. Despite of significant land configuration, the area does not exceed 350 m altitude (southern fragment of Wozniki Escarpment) with average heights of 220-300 m above sea level.

Considering the Cracow-Częstochowa Upland macro-region, only Częstochowa Upland is situated in Silesian Province. It is built of Upper-Jurassic limestone forming characteristic rocky inselbergs on a surface. Flat river valleys filled with sands, and periodically with water (which is associated with their geological structure) can be found among hills. Large number of caves and other karst formations occur here as well. Maximum altitude reaches up to over 500 m above sea level with average values of 400-300 meters.

Areas being a part of Silesian Lowland surround Silesian Highland from north and west. Silesian Lowland is a wide plain spreading at both sides of Oder river. This area had once been influenced by a glacier, thus numerous post-glacial forms can be found today.

Climate of Silesian Province is the warmest of all Poland – short winter and dry and warm summer. The climate is affected both by oceanic air masses from west and continental ones from east. Mean annual rainfall sum is high due to prevailing highland character of the area; average annual air temperatures oscillate within 7-8^{o}C. Western winds with small velocities blow most frequently. Natural processes are overlapped by anthropogenic factors, which makes forming local topo-climates within urbanized areas that differ in conditions from adjacent territories. Due to favorable climatic and soil conditions, Silesian Lowland became one of the most important agricultural regions in the country.

Malopolska Highland is localized north-east from Silesian-Cracow Highland; it includes Przedborska Upland and Nida Basin. Przedborska Upland is built of Cretaceous, Jurassic, and Triassic rocks covered in some places – mainly in depressions - by post-glacial formations. That region is of transitional character between lowlands and uplands. The altitudes usually reach to 300 m above sea level and only some peaks exceed that measure slightly.

Nida Basin is the depression between Cracow-Częstochowa Upland and Kielce Upland. Lithology thus soils, are very differentiated within this area – it is built of sandstones, limes, loams, gypsum, and loess. Miechów Upland – as part of Nida Basin within Silesian Province – is almost completely covered with loess, therefore soil are very fertile and the area is typically agricultural with small forest spots.

The south-western fragment of Silesian Province near Zebrzydowic is occupied by Ostrava Valley, that is the depression, at the base of which Carbonaceous rocks with hard coal are deposited, and sediment rocks covered by post-glacial forms at the top layers. Surface landscape is of lowland and sometimes of hilly character in part, although altitudes never reach 300 m above sea level.

Oświęcim Valley edges the Ostrava Valley from east. Its central part consists of Upper Vistula River Valley, where sandy flood area with small dunes and characteristic large number of smaller and larger fish breeding ponds can be found. Pszczyna Plain spreads north of Upper Vistula River Valley. Its surface is covered by Quaternary formations with thickness up to 40 m. It is sandy plain covered in majority by forests called Pszczyna Forests. Altitudes reach up to maximum 270 m above sea level. Wilamowice Highland is spread south of Upper Vistula River Valley, which is 30-70 m high over the valley bottoms of Vistula river tributaries. There are Quaternary forms covered by loess or other dusty material on the surface, thus good soils developed there, which favors the agriculture.

Foothills band spreads south of valley band. Silesian Foothills – as a part of Western-Beskids Foothills - is situated within Silesian Province. Silesian Plateau is mainly made of flysch rocks. Maximum altitudes reach to 520 m with average 280-450 m above sea level. Alluvial cones formed by rivers flowing down the mountains to more plain area (Vistula, Brennica, Soła) are characteristic.

Southern part of Silesian Province is occupied by macro-region Western Beskids that is built of mainly different types of sandstones and their altitudes range between 700 and 1750 m above sea level. Depending on the altitude of particular mountain ranges included in Western Beskids, from 2 to 5 landscape zones can be distinguished: foothills, lower mountain, upper mountain, subalpine, and alpine. The European watershed dividing Vistula river catchment from Danube river catchment crosses Żywiec Beskid. Watershed of two main Polish river catchments (Vistula and Oder) also passes through Silesian Province. Larger rivers flowing through the province are: Warta, Liswarta, Mała Panew, Pilica, and Soła.

The urban population of the province makes up 78.5% of the total number, including over 60% living in cities with inhabitants number above 50 000, whereas rural population includes 21.4%.

Silesian Province is strongly urbanized area, which can be proved by the highest urbanization coefficient at the level of 79.6%. There are 71 cities, while 1308 villages within the province.

Silesian Province has many mineral resources. The largest hard coal beds have been intensively exploited since 19th century. The hard coal resources within Upper Silesian Coal Basin are estimated for 78.3% of domestic deposits. Besides, wide beds of iron ores could be found in Silesian Province (almost completely exhausted at present), as well as zinc and lead ores.

Industry and services are the main economy branches with the most important mining, metallurgy, electric power production. Numerous railroads pass through the province and road network is also very well developed (Report of WIOŚ 2009, Annals of GUS 2009).

According to Report of WIOŚ "Status of the environment in Silesian Province in 2006", wastes from economic sector generated in Silesian Province in 2006 amounted to 41 678.1 thousand Mg, including those subject to recycling 37 106.8 thousand Mg. The largest quantity of wastes was produced from extracting and purifying the fossils – 28 528 thousand Mg (including recycled 25 387 thousand Mg). The amount of wastes from flotation hard coal enrichment was 2 041.9 thousand Mg (including recycled 1 788.6 thousand Mg).

The quantity of volatile dusts and solid wastes mixtures from lime methods of exhausting gases de-sulfating was 1 712.3 thousand Mg (including recycled 1 590.3 thousand Mg). Amount of volatile ashes from hard coal was 1 747.8 thousand Mg (including recycled 1 747.4 thousand Mg). Clinkers, combusting ashes, and dusts from boilers were generated at the amounts of 786.5 thousand Mg (including recycled 272.0 thousand Mg). Wastes from mining other fossils than metal ores were produced at the level of 1 333.9 thousand Mg (including recycled 1 045.4 thousand Mg). The quantity of clinker from metallurgical processes (blast furnace, steel works) amounted to 1 079.7 thousand Mg (including recycled 1 045.4 thousand Mg).

Other wastes from iron and steel metallurgy were generated at the amount of 525.8 thousand Mg (including recycled 524.8 thousand Mg). Iron and steel were collected as wastes at quantity of 360.4 thousand Mg (including recycled 172.9 thousand Mg).

In 1998, Silesian Province was ranked at the second place referring to the size of electric energy production – 20.2% of domestic production. The province has the longest heat network in the country – 16.4% of the total Polish network. Following power plants are the electricity supplying sources:

- 9 power plants and heat and power plants localized in central part of the province,
- 6 system power plants,
- 3 hydropower plants localized in southern part of the province.

Silesian Province produces 14.6% of Gross Domestic Product. Services are the main economy branch employing about 895.4 thousand people in Silesian Province. However, industry and construction also share vary high percentage

(431.5 thousand and 55.2 thousand employed people, respectively). The lowest number of employees work at agriculture and forestry.

Industry produces about 34% of GDP of the province. The most important branches are: mining, metallurgy, and electric energy production. Silesian Province mines 92% of hard coal in Poland, 83% cars, and 70% of raw steel. Agriculture and forestry are the poorest developed part of economy in the province. Small farms prevail. Average size of arable lands per a farm amounts to 6.53 ha. Agriculture produces 4% GDP, which is the lowest index among Polish provinces. A process of rural areas urbanization takes place in Silesian Province, which makes the percentage of typical rural areas decreased.

Rural areas occupy 4 784 km^2 (which makes up 38.9% of the province territory) and is inhabited by 6.9% of total inhabitants.

Rural communes of urbanized character form another group. They cover about 24% of the province area and are inhabited by 11.6% of Silesian Province inhabitants.

Almost 998 thousand people lives in rural areas of Silesian Province, which makes up over 21% of region and 6.8% of rural inhabitants of Poland.

Silesian Province is too often associated with only heavy industry and mining, meanwhile area of arable lands equal to 486 thousand hectares, makes up 39.4% of province area.

Mean size of a form is 6.53 ha, which in consequence makes that agriculture in Silesian Province is one of the most scattered in Poland (13 rank).

Częstochowa, then Rybnik sub-regions have the largest arable land areas, while in other sub-regions, the percentage of arable lands in the total area is similar.

Soil conditions within Silesian Province are very diverse. Difficult soil conditions are found in Bielsko-Biała sub-region, where poor soils along with mountains and foothills prevail. The conditions for agricultural production are not favoring in Częstochowa sub-region either. Light soils from low bonitation class dominate. Cereals, then potatoes, and root crops are most readily grown in the province. Despite of difficulties resulting from industry influences as well as scattering, some increase can be observed in all general directions of agricultural production.

Natural and soil conditions for agricultural production in Silesian Province are very diverse. The worst conditions are found in Żywiec, better, in Kłobuck, Zawiercie, Myszków, and Częstochowa, whereas the best in Racibórz county. Such differentiation results from the fact that mainly podzolic, rusty, lessive, and brown soil, but also chernozems, black soils, muds, and rendzinas occur in that area. Often conflicts referring to protecting the arable lands vs. investment needs arises on areas where large dense complexes of good-quality soils from bonitation classes IIIa and IIIb (Adrianek and Skowronek 2008).

Average area of individual farm with over 1 ha area of arable lands is 4.8 ha at Polish mean of 8.0 ha, which makes that agriculture in Silesian Province is one of the most scattered in the country. Harvest of general cereals with mixtures made up 2.5% of domestic production, that of rapeseed and agrimony 2.2%, potato 3.0%, and sugar beet 0.7%. In 2009, yield of sugar beets and potatoes from 1 ha were higher in Silesian Province than average in Poland. Yields of general cereals with mixtures as well as rapeseed and agrimony per 1 ha were lower than whole-Polish mean level (Report of WIOŚ 2009).

Status of natural environment in the region is a result of many-year industrial activity, developed transport networks with highly intensive traffic, and insufficient inputs for environment protection infrastructure.

As a consequence of activities undertaken to improve the natural environment status, the air contamination degree decreased in the province. However, as compared to other voivodeships, Silesian Province is still at the first place of the most contaminated regions in reference to air pollution. Waters in Silesian Province are of low quality and only a small part of them can be used in economic activity. Besides air contamination, quality of surface waters is also affected by improper waste dumping and disposal of municipal and industrial sewage to water reservoirs and flows.

The total area of devastated and degraded lands that require reclamation and management amounts to about 4 717 km^2.

According to statistical data, arable lands make up 51.9%, forests and trees 32.2%, waters 2.2%, transportation tracts and residential areas 11.4%, mining areas 0.2%, and wastelands 1.3% of Silesian Province area.

Silesian Province is one of the most anthropogenically transformed Polish region; however, many unique natural values, that are partially under various nature protection forms or intended to be protected, can be observed within the region.

3. SOIL ACIDIFICATION STATUS IN THE PROVINCE OF SILESIA

Soil reaction, expressed by a value of pH_{KCl}, is an indicator that permits objective estimation of acidification of soils. In Poland, soil reaction determinations are conducted based on a uniform methodology. Soil samples for the determinations are taken in accordance with a standard that provides for the determination of soil pH in 1 mol KCl dm^{-3} (Chwil *et al.* 2006).

Soil reaction estimation is made based on limit values – Table 1.

The reaction of soils of the Province of Silesia was determined analysing, in the years 2004-2009, 79202 samples of arable lands. The determinations were performed by the Regional Agro-Chemical Station in Gliwice. Detailed data concerning the status of soil acidification in the particular communes and towns of the province are given in Table 2.

Table 1. Estimation of soil reaction

pH	Estimation of soil acidification
<4.5	Highly acid soils
4.6 – 5.5	Acid soils
5.6 – 6.5	Lightly acid soils
6.6 – 7.2	Neutral soils
>7.2	Alkaline soils

The data indicate that in the Province of Silesia as much as 49% of the soils are soils with pH below 5.5, i.e. acid soils (29%) and highly acid soils (20%). If we add to that one half of the share of soils with lightly acid reaction, then the so-called index of negative valuation of soils, which is a measure of the liming requirements, will amount to 66% for the province (Jadczyszyn 2009).

Detail analysis of the presented values of soil reaction indicates that the highest acidification is found in the districts of Kłobuck, Częstochowa, Żywiec, Wodzisław, Zawiercie, as well as Lubliniec, Myszków and Mikołów. Analysis of soil reaction in the particular communes permits the statement that in as many as 13 of them acid soils alone account for 51% to 100% of the area. The data indicate also that in as many as 32 communes the sum of highly acid and acid soils exceeds 70% of the area of arable lands. Communes with the most acidified soils include, among others, Kruszyna, Lelów, Mykanów, Rędziny, Kłobuck, Lipie, Opatów, Popów, Przystajń, Inędza, Gilowice, Jeleśnia, Koszarawa, Łękawica, Rajcza and Węgierska Górka.

In towns with the status of township districts and communes notable areas of acid soils are found in Dąbrowa Górnicza, Ruda Śląska, Rybnik, Tychy and Żory (Tab. 2).

The status of acidification of soils is closely related with their particle size distribution, expressed in simplified form as the agronomical category of soils (Tab. 3) (Chwil *et al*. 2006, Filipek *et al*. 2006).

Most susceptible to acidification and very light and light soils that in Poland account for as much as 65% of the area of arable lands (very light soils – 32%, light soils – 33%) (Lipiński 2005). The high percentage of highly acid soils (21.2%) and acid soils (30%) on the scale of the country is attributable to the high share of light and very light soils.

Table 2. Soil reaction (pH_{KCl}) in the Silesian province (2004-2009)

Item.	Poviat	Municipality	Analysed area in ha	Number of samples collected	Reaction: very acid units/%		acid units/%		slightly acid units/%		neutral units/%		alkaline units/%		Negative validation
1	będziński	**total**	**14620**	**1113**	**41**	**4**	**117**	**10**	**280**	**25**	**374**	**34**	**301**	**27**	**26.5**
		Bobrowniki	2409	104	9	9	14	13	34	33	33	32	14	13	38.5
		city Będzin	1496	65	1	1	3	5	13	20	18	28	30	46	16
		city Czeladź	220	53	0	0	0	0	6	11	43	81	4	8	5.5
		city Sławków	760	77	2	3	0	0	7	9	35	45	33	43	7.5
		Mierzęcice	2827	211	25	12	46	22	76	36	47	22	17	8	52
		Psary	2705	222	2	1	15	7	68	31	70	31	67	30	23.5
		Siewierz	4058	309	2	1	39	12	74	24	114	37	80	26	25
		Wojkowice	144	72	0	0	0	0	2	3	14	19	56	78	1.5
2	bielski	**total**	**10857**	**2963**	**472**	**16**	**922**	**31**	**1180**	**40**	**321**	**11**	**68**	**2**	**67**
		Bestwina	4320	390	71	18	137	35	153	39	29	8	0	0	72.5
		Buczkowice	1.6	10	1	10	7	70	2	20	0	0	0	0	90

Table 2. Cont. Soil reaction (pH_{KCl}) in the Silesian province (2004-2009)

Item	Poviat	Municipality	Analysed area in ha	Number of samples collected	Reaction: very acid units/%		acid units/%		slightly acid units/%		neutral units/%		alkaline units/%		Negative validation
2	bielski	Czechowice-Dziedzice	1428	864	230	27	262	30	288	33	70	8	14	2	73.5
		Jasienica	1810	981	100	12	299	33	406	40	126	9	50	6	65
		Jaworze	402	304	34	11	96	32	111	37	62	20	1	0	61.5
		Kozy	90	48	7	14	21	44	20	42	0	0	0	0	79
		Porąbka	2168	65	11	17	25	38	20	31	7	11	2	3	70.5
		Wilamowice	637	301	18	6	75	25	180	60	27	9	1	0	61
		total	**6062**	**2971**	**577**	**19**	**974**	**33**	**892**	**30**	**417**	**14**	**111**	**4**	**67**
3	bieruńsko-lędziński	Bojszowy	754.2	548	130	24	239	43	148	27	27	5	4	1	80.5
		Chełm Śląski	367	214	44	21	86	40	68	32	14	6	2	1	77
		Lędziny	1722	1265	258	20	402	32	361	29	190	15	54	4	66.5
		city Bieruń	1612	836	139	19	223	29	274	34	156	15	44	3	65
		city Imielin	1606	108	6	6	24	22	41	38	30	28	7	6	47

4	cieszyński	**total**	**7821**	**2981**	**361**	**12**	**963**	**33**	**1022**	**34**	**451**	**15**	**184**	**6**	**62**
		Babice	1.3	4	0	0	1	25	1	25	2	50	0	0	37.5
		Brenna	102	29	1	3	4	14	6	21	12	41	6	21	27.5
		Chybie	454	166	8	5	55	33	68	41	20	12	15	9	58.5
		Dębowiec	1319	566	11	2	96	17	195	34	169	30	95	17	36
		Goleszów	625	233	6	3	40	17	68	29	77	33	42	18	34.5
		Hażlach	459	270	27	10	99	37	103	38	40	15	1	0	66
		Istebna	500	7	4	57	0	0	2	29	1	14	0	0	71.5
		city Cieszyn	86	30	1	3	3	10	6	20	14	47	6	20	23
		city Ustroń	64.4	37	3	8	16	43	16	43	2	6	0	0	72.5
		city Wisła	204	263	138	52	107	41	18	7	0	0	0	0	96.5
		Skoczów	388	193	13	7	69	36	69	36	35	18	7	3	61
		Strumień	874	545	61	11	205	38	221	40	47	9	11	2	69
		Zebrzydowice	2745	638	88	14	268	42	249	39	32	5	1	0	75.5

Table 2. Cont. Soil reaction (pH_{KCl}) in the Silesian province (2004-2009)

Item	Poviat	Municipality	Analysed area in ha	Number of samples collected	Reaction										
					very acid units/%		acid units/%		slightly acid units/%		neutral units/%		alkaline units/%		Negative validation
5	często-chowski	**total**	**51324**	**3218**	**1393**	**43**	**863**	**27**	**492**	**15**	**301**	**10**	**169**	**5**	**77.5**
		Blachownia	2.4	3	0	0	1	34	1	33	1	33	0	0	50.5
		Dąbrowa Zielona	10054	67	24	36	19	28	18	27	6	9	0	0	77.5
		Janów	529	229	88	38	41	18	29	12	18	8	53	23	62
		Kłomnice	989	611	168	27	231	38	105	17	85	14	22	4	73.5
		Koniecpol	11108	59	11	18	17	29	20	34	10	17	1	2	64
		Konopiska	8.3	8	0	0	4	51	3	37	1	12	0	0	69.5
		Kruszyna	1301	663	403	60	128	19	86	13	23	4	23	4	85.5
		Lelów	1034	425	197	46	117	28	62	15	39	9	10	2	81.5
		Mstów	191	108	8	8	21	19	19	18	21	19	39	36	36
		Mykanów	15542	847	432	51	218	26	114	14	73	8	10	1	84
		Olsztyn	9	10	3	30	1	10	5	50	1	10	0	0	65
		Poczesna	6310	89	16	18	40	45	20	23	11	12	2	2	74.5
		Przyrów	32.5	20	6	30	10	50	4	20	0	0	0	0	90

		Rędziny	4213	79	37	47	15	19	6	8	12	15	9	11	70
		total	**34292**	**8270**	**1331**	**16**	**2440**	**30**	**3515**	**42**	**819**	**10**	**165**	**2**	**67**
		Gierałtowice	1895	1252	138	11	452	36	491	39	134	11	37	3	66.5
		city Knurów	49.5	24	6	25	6	25	11	46	1	4	0	0	73
		city Pyskowice	325	206	61	30	81	39	50	24	12	6	2	1	81
6	gliwicki	Pilchowice	7658	558	7	1	172	31	323	58	50	9	6	1	61
		Rudziniec	13677	1623	47	3	388	24	936	58	216	13	36	2	56
		Sośnicowice	2555	1088	288	27	230	21	482	44	68	6	20	2	70
		Toszek	3859	1612	274	17	485	30	705	44	126	8	22	1	69
		Wielowieś	4274	1907	510	27	626	33	517	27	212	11	42	2	73.5
		total	**6889**	**4513**	**2063**	**46**	**1657**	**37**	**679**	**15**	**100**	**2**	**14**	**0**	**90.5**
		Kłobuck	697	445	210	47	147	33	75	17	10	2	3	1	88.5
		Krzepice	1263	783	316	41	314	40	135	17	17	2	1	0	89.5
7	kłobucki	Lipie	309	205	106	52	80	39	17	8	2	1	0	0	95
		Miedźno	47.2	30	12	40	13	43	3	10	2	7	0	0	88
		Opatów	520	321	167	52	103	32	41	13	10	3	0	0	90.5
		Panki	691	419	182	43	161	38	70	17	4	1	2	1	89.5

Table 2. Cont. Soil reaction (pH_{KCl}) in the Silesian province (2004-2009)

Item	Poviat	Municipality	Analysed area in ha	Number of samples collected	Reaction										
					very acid units/%		acid units/%		slightly acid units/%		neutral units/%		alkaline units/%		Negative validation
7	kłobucki	Popów	1169	751	394	53	247	33	94	12	15	2	1	0	92
		Przystajń	1893	1307	594	46	500	38	175	13	33	3	5	0	90.5
		Wręczyca Wielka	298	252	82	33	92	36	69	27	7	3	2	1	82.5
		total	**12780**	**6625**	**1508**	**23**	**2393**	**36**	**2188**	**33**	**466**	**7**	**70**	**1**	**75.5**
8	lubliniecki	Boronów	104.2	83	20	24	39	47	19	23	4	5	1	1	82.5
		Ciasna	5068	2565	553	21	932	36	942	37	122	5	16	1	75.5
		Herby	509	416	114	27	165	40	113	27	22	5	2	1	80.5
		Kochanowice	1434	716	168	24	232	32	259	36	43	6	14	2	74
		Koszęcin	1762	834	324	39	237	29	169	20	93	11	11	1	78
		city Lubliniec	546	274	31	11	78	29	132	48	30	11	3	1	64
		Pawonków	2158	1235	229	19	564	46	373	30	63	5	6	0	80
		Woźniki	1199	502	69	14	146	29	181	36	89	18	17	3	61
9	city Bielsko Biała	Bielsko-Biała	5.4	9	1	12	4	44	4	44	0	0	0	0	78
10	city Bytom	Bytom	121.6	96	2	2	21	22	32	33	27	28	14	15	40.5
11	City Chorzów	Chorzów	106.1	30	0	0	0	0	0	0	14	47	16	53	0

12	City Często-chowa	Częstochowa	404	115	9	8	45	39	54	47	6	5	1	1	70.5
13	City Dąbrowa Górnicza	Dąbrowa Górnicza	5.5	3	1	33	0	0	0	0	2	67	0	0	33
14	City Gliwice	Gliwice	3052	1431	180	13	272	19	609	42	281	20	89	6	53
15	City Jastrzębie Zdrój	Jastrzębie-Zdrój	5202	125	8	6	42	34	44	35	26	21	5	4	57.5
16	city Jaworzno	Jaworzno	669	225	5	2	50	22	63	28	94	42	13	6	38
17	city Katowice	Katowice	4.2	6	0	0	0	0	3	50	3	50	0	0	25
18	city Mysłowice	Mysłowice	377	220	26	12	69	31	78	36	40	18	7	3	61
19	city Piekary Śląskie	Piekary Śląskie	180	112	0	0	9	8	54	49	44	39	5	4	32.5
20	city Ruda Śląska	Ruda Śląska	55.5	63	2	3	32	51	25	40	3	5	1	1	74
21	city Rybnik	Rybnik	326	91	19	21	23	25	29	32	17	19	3	3	62
22	city Siemiano-wice Śląskie	Siemianowice Śląskie	46.9	30	0	0	7	23	7	23	13	44	3	10	34.5
23	city Sosnowiec	Sosnowiec	0.8	6	0	0	0	0	0	0	6	100	0	0	0

Table 2. Cont. Soil reaction (pH_{KCl}) in the Silesian province (2004-2009)

Item	Poviat	Municipality	Analysed area in ha	Number of samples collected	Reaction: very acid units/%		acid units/%		slightly acid units/%		neutral units/%		alkaline units/%		Negative validation
24	city Tychy	Tychy	1730	843	197	23	303	35	243	29	90	11	10	1	72.5
25	city Zabrze	Zabrze	54.2	131	0	0	0	0	25	19	72	55	34	26	9.5
26	city Żory	Żory	418	476	78	16	176	37	217	46	5	1	0	0	76
27	miko-łowski	**total**	**5268**	**1447**	**261**	**18**	**527**	**36**	**479**	**33**	**141**	**10**	**39**	**3**	**70.5**
		city Łaziska Górne	306	145	29	20	57	39	43	30	13	9	3	2	74
		city Mikołów	1153	649	42	6	185	29	298	46	94	14	30	5	58
		city Orzesze	581	424	115	27	194	46	99	23	16	4	0	0	84.5
		Ornontowice	1016	84	20	24	20	24	23	27	16	19	5	6	61.5
		Wyry	2211	145	55	38	71	49	16	11	2	1	1	1	92.5
28	mysz-kowski	**total**	**19197**	**2245**	**714**	**32**	**590**	**26**	**601**	**27**	**270**	**12**	**70**	**3**	**71.5**
		Koziegłowy	1293	771	157	20	257	33	234	30	120	16	3	1	68
		city Myszków	1020	478	15	3	94	20	247	52	84	17	38	8	49
		Niegowa	9160	921	522	57	218	23	101	11	55	6	25	3	85.5
		Poraj	2829	28	8	28	6	22	8	28	3	11	3	11	64
		Żarki	4894	47	12	26	15	32	11	23	8	17	1	2	69.5

29	pszczyński	**total**	**10364**	**6693**	**1112**	**17**	**2246**	**33**	**2492**	**37**	**720**	**11**	**123**	**2**	**68.5**
		Goczałkowice-Zdrój	211	156	15	10	58	37	55	35	23	15	5	3	64.5
		Kobiór	224.5	150	23	15	58	39	58	39	9	6	2	1	73.5
		Miedźna	1378.9	1127	122	11	362	32	472	42	165	15	6	0	64
		Pawłowice	3742.5	2176	608	28	835	28	609	28	104	5	20	1	70
		Pszczyna	2728.7	1693	135	8	405	24	776	46	316	19	61	3	55
		Suszec	2079	1391	209	15	528	38	522	38	103	7	29	2	72
30	raciborski	**total**	**28539**	**13452**	**665**	**5**	**2204**	**17**	**6610**	**49**	**3252**	**24**	**721**	**5**	**46.5**
		Kornowac	565	542	111	21	181	33	199	37	45	8	6	1	72.5
		Krzanowice	6166	2375	24	1	290	12	1222	52	688	29	151	6	39
		Krzyżanowice	4698	2073	97	5	316	15	1087	52	540	26	33	2	46
		Kuźnia Raciborska	860	728	105	15	224	31	301	41	88	12	10	1	66.5
		city Racibórz	3210	1868	83	4	294	16	732	39	575	31	184	10	39.5
		Nędza	1195	734	117	16	230	31	210	29	131	18	46	6	61.5
		Pietrowice Wielkie	3265	1853	47	2	334	18	863	47	400	22	209	11	43.5
		Rudnik	8580	3279	81	2	335	10	1996	61	785	24	82	3	42.5

Table 2. Cont. Soil reaction (pH_{KCl}) in the Silesian province (2004-2009)

Item	Poviat	Municipality	Analysed area in ha	Number of samples collected	Reaction										
					very acid units/%		acid units/%		slightly acid units/%		neutral units/%		alkaline units/%		Negative validation
31	rybnicki	**total**	**1643**	**617**	**94**	**15**	**183**	**30**	**295**	**48**	**36**	**6**	**9**	**1**	**69**
		Czerwionka-Leszczyny	956	370	92	25	149	40	107	29	14	4	8	2	79.5
		Lyski	615	186	0	0	13	7	150	81	22	12	1	0	47.5
		Świerklany	72.5	61	2	3	21	34	38	63	0	0	0	0	68.5
32	tarno-górski	**total**	**12243**	**6336**	**968**	**15**	**2023**	**32**	**2404**	**38**	**818**	**13**	**123**	**2**	**66**
		Krupski Młyn	350	188	27	14	61	33	86	46	14	7	0	0	70
		city Kalety	126	133	29	22	66	50	32	24	6	4	0	0	84
		city Miasteczko Śląskie	54.8	22	1	4	5	23	11	50	3	14	2	9	52
		city Radzionków	175	68	0	0	10	15	20	29	36	53	2	3	29.5
		city Tarnowskie Góry	656	382	111	29	100	26	95	25	72	19	4	1	67.5
		Ożarowice	262	220	32	15	78	35	71	32	35	16	4	2	66
		Świerklaniec	91	38	0	0	1	3	6	16	13	34	18	47	11
		Tworóg	1687	984	168	17	450	46	295	30	65	6	6	1	78
		Zbrosławice	8840	4301	600	14	1252	29	1788	42	574	13	87	2	64

33	wodzisła-wski	**total**	**3202**	**3188**	**852**	**27**	**1226**	**38**	**879**	**27**	**212**	**7**	**19**	**1**	**78.5**
		Godów	808	1100	330	30	454	41	255	23	56	5	5	1	82.5
		Gorzyce	656	556	172	31	221	40	130	23	30	5	3	1	82.5
		Lubomia	789	688	104	15	271	39	226	33	80	12	7	1	70.5
		city Pszów	56	36	2	5	9	25	23	64	1	3	1	3	62
		city Radlin	4	8	2	25	3	38	2	25	1	12	0	0	75.5
		city Rydułtowy	36.6	71	12	17	26	36	22	31	9	13	2	3	68.5
		city Wodzisław Śląski	157.6	95	6	6	35	37	44	46	10	11	0	0	66
		Marklowice	249	207	88	43	72	34	37	18	10	5	0	0	86
		Mszana	446	427	136	32	135	32	140	33	15	3	1	0	80.5
34	zawier-ciański	**total**	**70581**	**6919**	**2360**	**34**	**1962**	**29**	**1339**	**19**	**761**	**11**	**497**	**7**	**72.5**
		Irządze	6637	751	367	49	205	27	132	18	39	5	8	1	85
		Kroczyce	1030	393	168	43	83	21	48	12	58	15	36	9	70
		Łazy	6611	105	0	0	26	25	23	22	24	23	32	30	36
		city Poręba	244	111	4	4	31	28	58	52	16	14	2	2	58
		city Zawiercie	9141	214	4	2	23	11	75	35	71	33	41	19	30.5
		Ogrodzieniec	411	364	14	4	35	10	45	12	63	17	207	57	20
		Pilica	15314	2206	678	31	713	32	450	20	233	11	132	6	73
		Szczekociny	13449	1160	414	36	346	30	272	23	120	10	8	1	77.5

Table 2. Cont. Soil reaction (pH_{KCl}) in the Silesian province (2004-2009)

Item	Poviat	Municipality	Analysed area in ha	Number of samples collected	Reaction											
					very acid units/%		acid units/%		slightly acid units/%		neutral units/%		alkaline units/%	Negative validation	
34	zawier-ciański	Włodowice	4805	82	9	11	21	25	12	15	26	32	14	17	43.5
		Żarnowice	12939	1533	702	46	479	31	224	15	111	7	17	1	84.5
35	żywiecki	**total**	**7058**	**1639**	**588**	**36**	**627**	**38**	**352**	**22**	**70**	**4**	**2**	**0**	**85**
		Gilowice	1814	341	183	54	125	37	29	8	4	1	0	0	95
		Jeleśnia	1.7	5	3	60	2	40	0	0	0	0	0	0	100
		Koszarawa	9.7	24	19	80	4	16	1	4	0	0	0	0	98
		Lipowa	529	257	69	27	111	43	60	24	16	6	1	0	82
		Łękawica	7.1	3	2	67	0	0	1	33	0	0	0	0	83.5
		Łodygowice	462	646	194	30	280	43	139	22	32	5	1	0	84
		city Żywiec	10.7	17	5	29	2	12	9	53	1	6	0	0	67.5
		Milówka	0.1	1	0	0	0	0	0	0	1	100	0	0	0

		Radziechowy-Wieprz	4123	228	30	13	88	39	100	44	10	4	0	0	74
		Rajcza	4.2	14	14	100	0	0	0	0	0	0	0	0	100
		Ślemień	94.3	96	64	67	14	15	13	13	5	5	0	0	88.5
		Świnna	0.2	1	0	0	0	0	0	0	1	100	0	0	0
		Węgierska Górka	2.1	6	5	83	1	17	0	0	0	0	0	0	100
36	**Silesian Province**	**total**	**315498**	**79202**	**15888**	**20**	**22970**	**29**	**27186**	**34**	**10272**	**13**	**2886**	**4**	**66**

*This breakdown does not include, due to lack of data, the following municipalities: Szczyrk, Wilkowice, Kamienica Polska, Starcza, Gaszowice, Jejkowice, Czernichów, Ujsoły and Świętochłowice. The demand for lime fertilizers was estimated further in this paper (Tab. 14). As regards the Cieszyński poviat, the Babice municipality was additionally taken into account.

Data presented in Table 4 show that among the 79202 arable land soil samples tested, taken in the territory of the province of Silesia, very light soils constitute only 1%, and light soils – 12%. Dominant in the province are medium heavy soils (51.5%) and heavy soils (35.5%), characterised by strong buffering properties, which makes them resistant to acidification. For comparison, in a gross sample comprising approximately 90000 soil samples collected from arable lands for the purpose of determination of agronomical soil categories on the scale of the country, the share of very light soils was 5.14%, light soils – 39.1%, medium heavy soils – 41.5%, and that of heavy soils – only 13.9%. The values indicate that the share of light and very light soils in the province of Silesia is ca. 3.4 – fold lower compared to their in Poland as a whole. In spite of such notable differences in the agronomical category of soils, the relative share of highly acid and acid soils on the scale of the province of Silesia and on that of the country is very similar. This clearly indicates that in the province of Silesia the acidification of soils caused by natural factors is strongly augmented by anthropogenic factors, and by the emissions of SO_2 and NO_x in particular (section. 4.3.) (Kaczor and Kozłowska 2000).

Table 3. Agronomic categories and granulometric soil subgroups

Soil category	Granulometric categories (division units)		% of particles with ϕ of up to 0.02 mm
very light	loose sand	ls	0-10
	loamy sand	ls	
	sandy silt	ss	
light	light loamy sand	lls	11-20
	heavy loamy sand	hls	
	silt	s	
medium	slightly sandy soil	sss	21-35
	light soil	ls	
	loamy silt	ls	
heavy	medium soil	ms	more than 35
	heavy soil	hs	
	very heavy soil	vhs	
	silty loam	sl	
	loam, loamy silt	l, ls	

Table 4. The share of soil under analysis in the Silesian province in agronomic categories

Item	Poviat	Municipality	Analysed area in ha	Number of samples collected	Agronomic category of soil									
					v. light unit / %		light unit / %		medium unit / %		heavy unit / %		organic unit / %	
1	Będziński	**total**	**14620**	**1113**	**85**	**8**	**623**	**56**	**381**	**34**	**24**	**2**	**0**	**0**
		Bobrowniki	2409	104	9	9	62	60	32	31	1	1	0	0
		city Będzin	1496	65	19	29	40	62	6	9	0	0	0	0
		city Czeladź	220	53	0	0	14	26	37	70	2	4	0	0
		city Sławków	761	77	0	0	6	8	71	92	0	0	0	0
		Mierzęcice	2827	211	22	10	151	72	38	18	0	0	0	0
		Psary	2705	222	17	8	150	68	55	25	0	0	0	0
		Siewierz	4058	309	18	6	160	52	110	36	21	7	0	0
		Wojkowice	144	72	0	0	40	56	32	44	0	0	0	0
2	bielski	**total**	**10857**	**2963**	**0**	**0**	**13**	**0**	**500**	**17**	**2450**	**83**	**0**	**0**
		Bestwina	4320	390	0	0	4	1	23	6	363	93	0	0
		Buczkowice	1.6	10	0	0	0	0	4	40	6	60	0	0
		Czechowice-Dziedzice	1428	864	0	0	0	0	194	22	670	78	0	0

Table 4. Cont. The share of soil under analysis in the Silesian province in agronomic categories

Item	Poviat	Municipality	Analysed area in ha	Number of samples collected	Agronomic category of soil									
					v. light unit / %		light unit / %		medium unit / %		heavy unit / %		organic unit / %	
2	bielski	Jasienica	1810	981	0	0	9	1	138	14	834	85	0	0
		Jaworze	402	304	0	0	0	0	122	40	182	60	0	0
		Kozy	90	48	0	0	0	0	0	0	48	100	0	0
		Porąbka	2168	65	0	0	0	0	2	3	63	97	0	0
		Wilamowice	637	301	0	0	0	0	17	6	284	94	0	0
3	bieruńsko -lędziński	**total**	**6062**	**2971**	**4**	**0**	**258**	**9**	**2408**	**81**	**301**	**10**	**0**	**0**
		Bojszowy	754	548	0	0	50	9	393	72	105	19	0	0
		Chełm Śląski	367	214	0	0	4	2	198	93	12	6	0	0
		Lędziny	1723	1265	0	0	74	6	1121	89	70	6	0	0
		city Bieruń	1612	836	4	0	57	7	661	79	114	14	0	0
		city Imielin	1606	108	0	0	73	68	35	32	0	0	0	0
		total	**7821**	**2981**	**0**	**0**	**1**	**0**	**787**	**26**	**2193**	**74**	**0**	**0**
		Babice	1.3	4	0	0	1	25	3	75	0	0	0	0
		Brenna	102	29	0	0	0	0	0	0	29	100	0	0

4	cieszyński	Chybie	454	166	0	0	0	0	36	22	130	78	0	0
		Dębowiec	1319	566	0	0	0	0	52	9	514	91	0	0
		Goleszów	625	233	0	0	0	0	13	6	220	94	0	0
		Hażlach	459	270	0	0	0	0	60	22	210	78	0	0
		Istebna	500	7	0	0	0	0	0	0	7	100	0	0
		city Cieszyn	86.1	30	0	0	0	0	2	7	28	93	0	0
		city Ustroń	64.4	37	0	0	0	0	1	3	36	97	0	0
		city Wisła	204	263	0	0	0	0	0	0	263	100	0	0
		Skoczów	388	193	0	0	0	0	72	37	121	63	0	0
		Strumień	874	545	0	0	0	0	178	33	367	67	0	0
		Zebrzydowice	2745	638	0	0	0	0	370	58	268	42	0	0
5	częstochowski	**total**	**51324**	**3218**	**67**	**2**	**250**	**8**	**2258**	**70**	**643**	**20**	**0**	**0**
		Blachownia	2.4	3	0	0	0	0	3	100	0	0	0	0
		Dąbrowa Zielona	10054	67	0	0	27	40	25	37	15	22	0	0
		Janów	530	229	20	9	102	45	86	38	21	9	0	0
		Kłomnice	989	611	0	0	0	0	397	65	214	35	0	0
		Koniecpol	11108	59	2	3	24	41	30	51	3	5	0	0

Table 4. Cont. The share of soil under analysis in the Silesian province in agronomic categories

Item	Poviat	Municipality	Analysed area in ha	Number of samples collected	Agronomic category of soil									
					v. light unit / %		light unit / %		medium unit / %		heavy unit / %		organic unit / %	
5	częstochowski	Konopiska	8.3	8	0	0	0	0	8	100	0	0	0	0
		Kruszyna	1301	663	0	0	3	0	624	94	36	5	0	0
		Lelów	1034	425	0	0	35	8	150	35	240	56	0	0
		Mstów	190.9	108	0	0	19	18	79	73	10	9	0	0
		Mykanów	15542	847	17	2	15	2	758	89	57	7	0	0
		Olsztyn	9	10	0	0	0	0	10	100	0	0	0	0
		Poczesna	6310	89	21	24	13	15	41	46	14	16	0	0
		Przyrów	32.5	20	0	0	0	0	20	100	0	0	0	0
		Rędziny	4213	79	7	9	12	15	27	34	33	42	0	0
6	gliwicki	**total**	**34292**	**8270**	**72**	**1**	**2323**	**28**	**5260**	**64**	**615**	**7**	**0**	**0**
		Gierałtowice	1895	1252	0	0	43	3	1027	82	182	15	0	0
		city Knurów	49.5	24	0	0	2	8	22	92	0	0	0	0
		city Pyskowice	325	206	2	1	73	35	119	58	12	6	0	0
		Pilchowice	7658	558	0	0	8	1	452	81	98	18	0	0
		Rudziniec	13677	1623	4	0	461	28	932	57	226	14	0	0

		Sośnicowice	2555	1088	0	0	13	1	1054	97	21	2	0	0
		Toszek	3859	1612	24	1	614	38	925	57	49	3	0	0
		Wielowieś	4274	1907	42	2	1109	58	729	38	27	1	0	0
7	kłobucki	**total**	**6889**	**4513**	**0**	**0**	**11**	**0**	**4437**	**98**	**65**	**1**	**0**	**0**
		Kłobuck	697	445	0	0	0	0	445	100	0	0	0	0
		Krzepice	1263	783	0	0	3	0	780	100	0	0	0	0
		Lipie	309	205	0	0	0	0	170	83	35	17	0	0
		Miedźno	47.2	30	0	0	0	0	30	100	0	0	0	0
		Opatów	520	321	0	0	0	0	321	100	0	0	0	0
		Panki	691	419	0	0	0	0	403	96	16	4	0	0
		Popów	1169	751	0	0	2	0	749	100	0	0	0	0
		Przystajń	1893	1307	0	0	6	0	1290	99	11	1	0	0
		Wręczyca Wielka	299	252	0	0	0	0	249	99	3	1	0	0
8	lubliniecki	**total**	**12780**	**6625**	**33**	**0**	**934**	**14**	**4843**	**73**	**815**	**12**	**0**	**0**
		Boronów	104.2	83	1	1	45	54	31	37	6	7	0	0
		Ciasna	5068	2565	0	0	2	0	2197	86	366	14	0	0
		Herby	509	416	0	0	0	0	407	98	9	2	0	0

Table 4. Cont. The share of soil under analysis in the Silesian province in agronomic categories

Item	Poviat	Municipality	Analysed area in ha	Number of samples collected	Agronomic category of soil: v. light unit	%	light unit	%	medium unit	%	heavy unit	%	organic unit	%
8	lubliniecki	Kochanowice	1434	716	10	1	256	36	326	46	124	17	0	0
		Koszęcin	1762	834	7	1	381	46	357	43	89	11	0	0
		city Lubliniec	546	274	6	2	130	47	116	42	22	8	0	0
		Pawonków	2158	1235	0	0	7	1	1219	99	9	1	0	0
		Woźniki	1199	502	9	2	113	23	190	38	190	38	0	0
9	city Bielsko Biała	Bielsko-Biała	5.4	9	0	0	0	0	3	33	6	67	0	0
10	city Bytom	Bytom	122	96	0	0	52	54	41	43	3	3	0	0
11	city Chorzów	Chorzów	106	30	0	0	0	0	30	100	0	0	0	0
12	city Częstochowa	Częstochowa	404	115	0	0	29	25	86	75	0	0	0	0
13	city Dąbrowa Górnicza	Dąbrowa Górnicza	5.5	3	0	0	0	0	3	100	0	0	0	0
14	city Gliwice	Gliwice	3052	1431	101	7	325	23	448	31	556	39	1	0
15	city Jastrzębie Zdrój	Jastrzębie-Zdrój	5202	125	0	0	7	6	112	90	6	5	0	0
16	city Jaworzno	Jaworzno	669	225	37	16	118	52	67	30	1	0	2	1
17	city Katowice	Katowice	4.2	6	0	0	6	100	0	0	0	0	0	0

18	city Mysłowice	Mysłowice	377	220	0	0	37	17	171	78	12	5	0	0
19	city Piekary Śląskie	Piekary Śląskie	180	112	0	0	1	1	100	89	11	10	0	0
20	city Ruda Śląska	Ruda Śląska	55.5	63	0	0	7	11	56	89	0	0	0	0
21	city Rybnik	Rybnik	326	91	0	0	0	0	91	100	0	0	0	0
22	city Siemianowice Śląskie	Siemianowice Śląskie	46.9	30	0	0	0	0	30	100	0	0	0	0
23	city Sosnowiec	Sosnowiec	0.8	6	0	0	4	67	2	33	0	0	0	0
24	city Tychy	Tychy	1730	843	0	0	36	4	753	89	54	6	0	0
25	city Zabrze	Zabrze	54.2	131	0	0	112	85	15	11	4	3	0	0
26	city Żory	city Żory	418	476	0	0	14	3	343	72	119	25	0	0
27	mikołowski	**total**	**5268**	**1447**	**2**	**0**	**50**	**3**	**1361**	**94**	**34**	**2**	**0**	**0**
		city Łaziska Górne	306	145	0	0	7	5	137	94	1	1	0	0
		city Mikołów	1153	649	0	0	14	2	623	96	12	2	0	0
		city Orzesze	581	424	2	0	12	3	398	94	12	3	0	0
		Ornontowice	1016	84	0	0	4	5	78	93	2	2	0	0
		Wyry	2211	145	0	0	13	9	125	86	7	5	0	0

Table 4. Cont. The share of soil under analysis in the Silesian province in agronomic categories

Item	Poviat	Municipality	Analysed area in ha	Number of samples collected	Agronomic category of soil									
					v. light unit / %		light unit / %		medium unit / %		heavy unit / %		organic unit / %	
28	myszkowski	**total**	**19197**	**2245**	**17**	**1**	**363**	**16**	**662**	**29**	**1200**	**53**	**3**	**0**
		Koziegłowy	1293	771	1	0	244	32	316	41	207	27	3	0
		city Myszków	1020	478	0	0	28	6	150	31	300	63	0	0
		Niegowa	9160	921	1	0	46	5	184	20	690	75	0	0
		Poraj	2829	28	6	21	13	46	6	21	3	11	0	0
		Żarki	4894	47	9	19	32	68	6	13	0	0	0	0
29	pszczyński	**total**	**10364**	**6693**	**0**	**0**	**163**	**2**	**5558**	**83**	**972**	**15**	**0**	**0**
		Goczałkowice-Zdrój	210.8	156	0	0	1	1	150	96	5	3	0	0
		Kobiór	224	150	0	0	8	5	139	93	3	2	0	0
		Miedźna	1379	1127	0	0	26	2	827	73	274	24	0	0
		Pawłowice	3742	2176	0	0	7	0	1602	74	567	26	0	0
		Pszczyna	2729	1693	0	0	32	2	1579	93	82	5	0	0
		Suszec	2079	1391	0	0	89	6	1261	91	41	3	0	0

30	raciborski	**total**	**28539**	**13452**	**0**	**0**	**141**	**1**	**1251**	**9**	**12060**	**90**	**0**	**0**
		Kornowac	565	542	0	0	1	0	508	94	33	6	0	0
		Krzanowice	6166	2375	0	0	0	0	0	0	2375	100	0	0
		Krzyżanowice	4698	2073	0	0	0	0	39	2	2034	98	0	0
		Kuźnia Raciborska	860	728	0	0	113	16	332	46	283	39	0	0
		city Racibórz	3210	1868	0	0	2	0	100	5	1766	95	0	0
		Nędza	1195	734	0	0	25	3	266	36	443	60	0	0
		Pietrowice Wielkie	3265	1853	0	0	0	0	6	0	1847	100	0	0
		Rudnik	8580	3279	0	0	0	0	0	0	3279	100	0	0
31	rybnicki	**total**	**1643**	**617**	**0**	**0**	**17**	**3**	**537**	**87**	**63**	**10**	**0**	**0**
		Czerwionka-Leszczyny	955	370	0	0	9	2	351	95	10	3	0	0
		Lyski	615	186	0	0	0	0	186	100	0	0	0	0
		Świerklany	72.5	61	0	0	8	13	0	0	53	87	0	0
32	tarnogórski	**total**	**12242**	**6336**	**134**	**2**	**1552**	**24**	**4080**	**64**	**570**	**9**	**0**	**0**
		Krupski Młyn	350	188	0	0	68	36	96	51	24	13	0	0
		city Kalety	126	133	4	3	121	91	5	4	3	2	0	0
		city Miasteczko Śląskie	54.8	22	0	0	20	91	2	9	0	0	0	0

Table 4. Cont. The share of soil under analysis in the Silesian province in agronomic categories

Item	Poviat	Municipality	Analysed area in ha	Number of samples collected	Agronomic category of soil									
					v. light unit / %		light unit / %		medium unit / %		heavy unit / %		organic unit / %	
32	tarnogórski	city Radzionków	175	68	0	0	1	1	52	76	15	22	0	0
		city Tarnowskie Góry	656	382	0	0	168	44	200	52	14	4	0	0
		Ożarowice	262	220	76	35	135	61	8	4	1	0	0	0
		Świerklaniec	91	38	0	0	4	11	14	37	20	53	0	0
		Tworóg	1686	984	45	5	538	55	362	37	39	4	0	0
		Zbrosławice	8840	4301	9	0	497	12	3341	78	454	11	0	0
33	wodzisławski	**total**	**3202**	**3188**	**0**	**0**	**194**	**6**	**1971**	**62**	**1023**	**32**	**0**	**0**
		Godów	808	1100	0	0	170	15	874	79	56	5	0	0
		Gorzyce	656	556	0	0	8	1	269	48	279	50	0	0
		Lubomia	788	688	0	0	8	1	285	41	395	57	0	0
		city Pszów	56	36	0	0	0	0	2	6	34	94	0	0
		city Radlin	4	8	0	0	2	25	6	75	0	0	0	0
		city Rydułtowy	37	71	0	0	3	4	63	89	5	7	0	0
		city Wodzisław Śląski	158	95	0	0	3	3	1	1	91	96	0	0

		Marklowice	249	207	0	0	0	0	179	86	28	14	0	0
		Mszana	446	427	0	0	0	0	292	68	135	32	0	0
34	zawierciański	**total**	**70581**	**6919**	**37**	**1**	**1749**	**25**	**2204**	**32**	**2897**	**42**	**32**	**0**
		Irządze	6637	751	0	0	16	2	46	6	689	92	0	0
		Kroczyce	1030	393	0	0	173	44	120	31	100	25	0	0
		Łazy	6611	105	2	2	36	34	29	28	38	36	0	0
		city Poręba	244	111	0	0	0	0	10	9	101	91	0	0
		city Zawiercie	9141	214	0	0	49	23	155	72	10	5	0	0
		Ogrodzieniec	411	364	4	1	160	44	160	44	40	11	0	0
		Pilica	15314	2206	2	0	575	26	673	31	956	43	0	0
		Szczekociny	13449	1160	3	0	409	35	483	42	250	22	15	1
		Włodowice	4805	82	8	10	41	50	29	35	4	5	0	0
		Żarnowiec	12939	1533	18	1	290	19	499	33	709	46	17	1
35	żywiecki	**total**	**7059**	**1639**	**0**	**0**	**0**	**0**	**10**	**1**	**1629**	**99**	**0**	**0**
		Gilowice	1814	341	0	0	0	0	0	0	341	100	0	0
		Jeleśnia	1.7	5	0	0	0	0	0	0	5	100	0	0
		Koszarawa	9.7	24	0	0	0	0	0	0	24	100	0	0

Table 4. Cont. The share of soil under analysis in the Silesian province in agronomic categories

Item	Poviat	Municipality	Analysed area in ha	Number of samples collected	Agronomic category of soil									
					v. light unit / %		light unit / %		medium unit / %		heavy unit / %		organic unit / %	
35	żywiecki	Lipowa	529	257	0	0	0	0	0	0	257	100	0	0
		Łękawica	7.1	3	0	0	0	0	0	0	3	100	0	0
		Łodygowice	462	646	0	0	0	0	0	0	646	100	0	0
		city Żywiec	10.7	17	0	0	0	0	0	0	17	100	0	0
		Milówka	0.1	1	0	0	0	0	0	0	1	100	0	0
		Radziechowy -Wieprz	4123	228	0	0	0	0	0	0	228	100	0	0
		Rajcza	4.2	14	0	0	0	0	0	0	14	100	0	0
		Ślemień	94.3	96	0	0	0	0	10	10	86	90	0	0
		Świnna	0.2	1	0	0	0	0	0	0	1	100	0	0
		Węgierska Górka	2.1	6	0	0	0	0	0	0	6	100	0	0
36	**Silesian Province**	**total**	**315498**	**79202**	**589**	**1**	**9390**	**12**	**40859**	**52**	**28326**	**36**	**38**	**0**

*This breakdown, due to the lack of data, does not include the following municipalites: Szczyrk, Wilkowice, Kamienica Polska, Starcza, Gaszowice, Jejkowice, Czernichów, Ujsoły and Świętochłowice. The demand for lime fertilizers in these municipalities was estimated further in this paper (table 14). As regards the Cieszyński poviat, the Babice municipality was additionally taken into account.

4. CAUSES OF SOIL ACIDIFICATION IN THE PROVINCE OF SILESIA

As follows from Chapter 3, in the Province of Silesia as much as 20% of the soils are characterised by highly acid reaction (pH < 4.50), 29% by acid reaction (pH 4.6-5.5) and 34% by lightly acid reaction (5.6-6.5). Only 13% of the soils have neutral reaction (pH 6.6-7.2) and 4% alkaline reaction (>7.2). These data indicate that acid soils occur on large areas in the region. Another cause for concern is the fact that a large part of the acid soils are characterised by considerable density (heavy and medium heavy soils). Such soils get acidified more slowly, but also it requires much more time and effort to bring them to an optimum reaction (Badora *et al*. 2003, Kaniuczak 2007, Wójcikowska-Kapusta and Martyn 1996).

The acidification of soils is determined by a group of natural and anthropogenic factors.

4.1. Natural causes

High, stable and good quality crop yields can be obtained mainly through maintaining in top efficiency the farmer's workshop – the soil. Within the farming production space the soils are particularly sensitive to various forms of transformation, as they constitute a permanent and, basically, non-replaceable component of the natural environment (Dechnik *et al*. 1990, Józefaciuk and Szatanik-Kloc 2002).

Soil acidification is a result of natural physicochemical, chemical and biological processes taking place in the soil environment. The most important natural causes of soil acidification include the following:

- prevalence of precipitation over evaporation and leaching of alkaline cations,
- increased concentration of CO_2 in the gaseous phase of the soil,
- microbiological transformations related with the processes of oxidation,
- hydrolysis of salts of aluminium,
- organic acids formed during the decomposition of organic matter,
- exchangeable aluminium ions occurring in the soil.

Soil acidification is a result of physicochemical, chemical and biochemical processes that become intensified at the moment of appearance of living organisms in the environment. The respiration of organisms and the mineralisation of organic matter result in the formation of CO_2, which leads to the formation of H_2CO_3 and to increased solubility of $MgCO_3$ and $CaCO_3$. The leaching of alkali causes an increase in the concentration of H^+ ions in the soil.

Organic acids, phenols and polyphenols formed during the decomposition of organic matter, and acid secretions of plant roots and soil microorganisms lead to a lowering of the pH of soil solution. All oxidation processes taking place under aerobic conditions lead to an increase of acidification (Lipiński 2005).

4.2. Anthropogenic causes

The anthropogenic factors that have a high importance for soil acidification include fertilisation and industrial atmospheric pollution with acid character. The participation of those factors in soil acidification is highly varied in the various regions of the country (Filipek *et al*. 2006, Gorlach 1995, Kabata-Pendias *et al*. 1986, Kulisz 1988).

4.2.1. Fertilisation

Mineral fertilisers are a basic means of production in agriculture. They determine to the greatest extent the level and quality of crop yields. However, one should be aware of the fact that the application of most nitrogen fertilisers contributes to the acidification of soils. Those are so-called physiological acid fertilisers, among which we include ammonium sulphate, ammonium nitrate and urea. The mechanism of soil acidification by those fertilisers consists in that as ammonium ions (NH_4^+) are taken up by plants, equivalent amounts of hydrogen ions (H^+) are released to the rhizosphere. It should be noted that certain nitrogen fertilisers have practically no effect on soil reaction (nitro-chalks), while others (soda saltpetre, lime saltpetre) have an alkalifying effect.

Using the values of acid equivalents one can calculate that 1 kg of nitrogen applied in the form of ammonium sulphate is a source of 110 moles of H^+. In the case of urea and ammonium nitrate the values are equal at 36 moles of H^+ .

In typically agricultural provinces (Wielkopolskie, Kujawsko-Pomorskie), both in the past (1975-1989) and at present that anthropogenic factor plays a significant role in soil acidification. This results from the highest use of mineral fertilisers in those regions and from a low effect of acid atmospheric emissions (GUS 2008).

In Poland, the mean use of mineral fertilisers was the highest in the period of 1975-89, when the rate of application was 185 kg NPK ha^{-1}, including 73 kg N, 50 kg P_2O_5 and 62 kg K_2O. Once the subsidies for fertilisers ceased, their prices increased, as a result of which the level of their application in 1992 dropped ca. 3-fold to 62.1 kg NPK ha^{-1}. In subsequent years the use of mineral fertilisers in Poland showed an increasing trend and in the economic year 2007/2008 it reached the level of 132.6 kg NPK ha^{-1}, including 70.7 kg N ha^{-1}.

In the province of Silesia the use of mineral fertilisers is notably lower than the national average. In 2007/2008 it was 117.3 kg NPK ha^{-1}, in which nitrogen accounted for 62.4 kg ha^{-1}. Taking into account the structure of nitrogen fertiliser use one can assume that 1 kg of nitrogen applied within the area of the province was the source of ca. 30 moles of H^+. With the dose of 62.4 kg that value will be 1872 moles of H^+ . Assuming that 1 mole of CaO neutralises 2 moles of hydrogen, the neutralisation of 1872 moles of H^+ will require 936 moles of calcium oxide, i.e. ca. 52 kg CaO ha^{-1} $year^{-1}$. With the assumption that liming is applied every 4 years, the neutralisation of acidification resulting from the se of nitrogen fertilisers will oscillate around the level of 208 kg CaO, i.e. ca. 0.2 t CaO ha^{-1}/4 years (GUS Statistical Yearbook 2008 and 2009).

4.2.2. Industrial pollution of the atmosphere

Sulphur dioxide and nitrogen oxides are the basic material for the generation of acid rain and constitute – next to nitrogen fertilisation – a fundamental anthropogenic factor causing the acidification of the soil environment. The basic sources of those gases are electric power generation and industry, and in the case of nitrogen oxides also road transport – Table 5.

In Poland and in the Central and East European countries the problem of emissions and atmospheric pollution with sulphur and nitrogen oxides is particularly serious. High levels of concentration and deposition of those pollutants have caused, in many regions, significant environmental damage. Poland, despite a reduction of atmospheric pollution, especially with sulphur oxides, is still characterised by a high level of acid emissions – Table 6. The main contributor to those is the sector of industrial power generation whose power and heat-and-power generating plants are based almost solely on hard coal and lignite burning (Radomski 2003) – Table 7.

In the structure of total emissions from the area of the province of Silesia, the emission resulting from industrial activity, comprising point sources – power generation, industrial power generation and production processes, accounts for 86% of SO_2 emission and 63% of NO_X. The remaining 14% of SO_2 comes from the living sector. In the case of nitrogen oxides, 27% of the province emission comes from transport, and 7% from the living sector.

Table 5. Total emission* of sulfur (IV) oxide and nitrogen oxides in Poland (according to contamination sources) (data from GUS 2009)

Source	2000	2005	2006	2007	2008
	thousand tons				
			SO_2		
Total	1511	1145	1222	1131	999
Utility power plants	805	673	717	668	448
Industrial power plants	265	102	110	88	192
Industrial technologies	91	56	56	57	24
Other stationary sources	309	312	337	316	333
Mobile sources	41	2	2	2	2
			NO_X		
Total	844	875	921	885	831
Utility power plants	237	246	253	249	226
Industrial power plants	99	93	102	101	84
Industrial technologies	75	54	67	73	48
Other stationary sources	120	116	122	113	122
Mobile sources	313	366	377	349	350

*Data estimated on a base of fuels utilization as well as technological indices.

Table 6. Total emission of sulfur (IV) oxide and nitrogen oxides in Poland in 1980-2008 (data from GUS 1981-2010)

Years	SO_2** (thousand tons)	NO_X** (recalculated onto NO_2) (thousand tons)
1980	4132	378
1985	3978	1353
1990	3210	1280
1995	2376	1120
1996	2368	1154
1997	2181	1114
1998	1897	991
1999	1719	951
2000	1511	844
2001	1564	805
2002	1456	796
2003	1375	808
2004	1241	804
2005	1145	875
2006	1222	921
2007	1216	860
2008	999	831

**Data estimated on a base of fuels utilization as well as technological indices.

Table 7. Domestic utilization of basic fuels within national economy (data after GUS 2009)

Type	2000	2005	2006	2007	2008
	thousand tons				
Hard coal	83372	78722	83693	84605	80415
Brown coal	59487	61589	60801	57528	59371
Petroleum	18080	18165	20045	20113	20803
High-methane natural gas	10509	12694	12841	12727	13036
High-nitrogen natural gas	3114	3514	3441	3535	3386
Gasoline*	5174	4065	4158	4144	4416
Diesel oil	6000	7489	8527	9623	10509

*excluding aviation and jet fuels.

In the area of the province of Silesia there are 361 plants that are particularly noxious to air cleanliness. Emissions from those plants are among the highest in the country. The greatest sources of SO_2 emission include the power generating plants “Rybnik”, “Jaworzno III”, “Łagisza”, “Łaziska” and “Halemba”, heat-and-power plants Chorzów “Elcho” and “Będzin”, and the Arcelor Mitkal Poland SA plant in Dąbrowa Górnicza. Those plants contribute 75% of SO_2 emission in the province.

The greatest sources of industrial emission of NO_X are the power plants “Rybnik”, “Jaworzno III”, “Łaziska”, “Łagisza”, Arcelor Mitkal Poland SA Plant in Dąbrowa Górnicza, and the heat-and-power plant “E C Nowa” in Dąbrowa Górnicza. NO_X emissions from those plants contribute 70% of the province emissions (WIOŚ Report 2009).

Sulphur dioxide and nitrogen oxides emitted to the atmosphere may, after some time, return to the substrate (soil, plant cover, water reservoirs) in an unchanged form as so-called dry precipitation. A part of those oxides gets oxidised in the atmosphere to the respective acids and reaches the substrate with rain or other precipitation (snow, hail, fog). This is so-called wet deposition and in such a case we deal with classic acid rain.

Calculations show that in 208 in the area of the province of Silesia precipitation waters deposited:

- 20.42 kg SO_4^{2-} ha^{-1},
- 9.34 kg Cl^- ha^{-1},
- 3.61 N ha^{-1} (nitrates (III) and (V)),
- 5.43 kg N ha^{-1} (ammonium nitrogen),

- 14.66 N ha^{-1} (total nitrogen),
- 0.0541 kg H^+ ha^{-1}.

The results of a ten-year study conducted by WIOŚ Katowice showed that in the years 1999-2007 the amounts of substances deposited with precipitations on the area of the province of Silesia were, on average, 17.7% greater than in 2008.

In 2008, the deposition of atmospheric pollution brought by precipitations on the area of the province of Silesia, in spite of the observed decreasing trends of many components over the period of 1999-2007, still negatively affects the condition of the natural environment of the region.

The migration of nitrogen compounds, and especially of those of sulphur, over long distances causes that their deposition (imission) on the territory of a given country (province) frequently differs from indigenous emissions. Unfortunately, the province of Silesia is one of those regions that receive the greatest influx of trans-boundary air pollution. The greatest contributors to that are the Czech Republic, Hungary and Germany.

Acid falls in the form of dry and wet precipitation negatively affect vegetation, both directly and indirectly. The direct effect of acid pollutions causes various damage to plants (physiological damage, chloroses, necroses) and disturbs the cationic-anionic balance in their chemical composition.

The indirect effect of acid pollutions on plants takes place via the soil. It is expressed by a load of hydrogen protons reaching the soil through the deposition (imission) of sulphur dioxide and nitrogen oxides previously emitted to the atmosphere.

When calculating the load of hydrogen resulting from industrial emissions of SO_2 and NO_X it is most frequently assumed that the emission of those compounds equal their imission. Apart from that, in the calculations, in accordance with GUS data, the emission of nitrogen oxides is given as converted to NO_2.

The method of calculation of the load of protons (H^+) reaching the soil as a result of emission of industrial pollutions of acid character (SO_2, NO_2) for the province of Silesia in 2007 is as follows:

The total emission of sulphur dioxide in the province of Silesia in 2007 was 153 000 tons, and that of nitrogen dioxide 145 000 tons. Assuming that the emission of those gases is equal to their deposition, and that the deposition is uniform over the whole areas, the deposit of those compounds will equal 124 kg SO_2 ha^{-1} and 117 kg NO_2 ha^{-1}, respectively.

153 thousand tons SO_2 = 153 000 000 kg

145 thousand tons NO_2 = 145 000 000 kg

The area of the province of Silesia is 12344 km^2 = 1234400 ha

Deposit of SO_2 = 153 000 000 kg : 1234400 ha = ≈124 kg SO_2 ha^{-1}

Deposit of NO_2 = 145 000 000 kg : 1234400 ha = ≈ 117 kg NO_2 ha^{-1}

When reaching the soil in the form of dry or wet precipitation, both SO_2 and NO_2 undergo transformations. The end products of those transformations are acids H_2SO_4 and HNO_3 which are a source of hydrogen protons (H^+).

$2\ SO_2 + 2\ H_2O + O_2 \rightarrow 2H_2SO_4$

$2\ NO_2 + H_2O \rightarrow HNO_3 + HNO_2$

One mole of SO_2 generates 2 moles of H^+, and one mole of NO_2 1 mole of H^+:

124 kg =124000 g SO_2 : 64 (molar weight of SO_2) = 1937.5 moles of SO_2 which generate 1937.5 · 2 = 3875 moles of H^+ ha^{-1} $year^{-1}$

117 kg = 117000g NO_2 : 46 (molar weight of NO_2) = 2543 moles of NO_2 which generate 2543 moles of H^+ ha^{-1} $year^{-1}$

Assuming that 1 mole of Ca (56 g) neutralises 2 moles of H^+ we can calculate that to neutralise hydrogen protons related with SO_2 emission we have to use 108.5 kg CaO ha^{-1} $year^{-1}$, and those related with NO_2 emission – 71 kg CaO ha^{-1} $year^{-1}$.

$CaO + 2\ HCl \rightarrow CaCl_2 + H_2O$

3875 : 2 = 1937.5 moles CaO = 1937.5 · 56 g = 108500 g CaO =

108.5 kg CaO ha^{-1} $year^{-1}$

2543 : 2 = 1271.5 moles CaO = 1271.5 · 56 g = 71204 g CaO

= ≈ 71 kg CaO ha^{-1} $year^{-1}$

Assuming that soil liming is performed every 4 years, the dose of lime required to eliminate acidification caused by sulphur dioxide emission in the area of the province of Silesia will be 0.434 t CaO/ha/4 years, and by nitrogen oxides emission 0.284 t CaO/ha/4 years. Altogether, the additional soil liming related with the effect of acid industrial emissions in the province will amount to 0.718 t CaO/ha/4 years.

4.3. Participation of industrial pollution of the atmosphere in soil acidification in the Province of Silesia

Analysing the changes in the reaction of the soils of Poland over the last 40 years one can find that on the scale of the country the soil reaction is determined to the greatest extent by the parent rock, the climate and the biocenosis. In the literature it is emphasised that the effect of anthropogenic factors becomes more observable when smaller administrative units are analysed (Filipek 2006, Kabata-Pendias *et al*. 1986).

In the province of Silesia, in the analysed year 2007, sulphur dioxide emission was 3.4 – fold higher than the national average. In the case of emission of nitrogen oxides, that excess was more than 4 – fold (4, 12). In the context of the quoted values and taking into account long-term studies, one can conclude that the participation of industrial air pollutions (SO_2, NO_X) in overall soil acidification in the province amounts to ca. 50%.

The calculations presented in subsections 4.2.1 and 4.2.2 show that the amount of hydrogen ions generated as a result of fertilisation is 1871 moles H^+ ha^{-1}, from the deposition of SO_2 – 3875 mole H^+ ha^{-1}, and from the deposition of NO_X 2543 moles H^+ ha^{-1}. These data permit the calculation of the share of those factors in soil acidification caused by anthropogenic pressure:

amount of H^+ ions of anthropogenic origin (mole H^+ ha^{-1}) = 1972 + 3875 + 2543 = 8290 moles H^+ ha^{-1},

% share of fertilisation in soil acidification = 22.6,

% share of SO_2 in soil acidification = 46.7,

% share of NO_X in soil acidification = 30.7.

Calculations show that among the anthropogenic factors the strongest effect on soil acidification is exerted by emission of SO_2 (46.7%), slightly lower by emission of NO_X (30.7%) and the lowest is that of fertilisation (22.6%). The combined participation of industrial pollution of air in soil acidification of anthropogenic origin in the province of Silesia amounts to 77.4%.

5. EFFECTS OF SOIL ACIDIFICATION IN THE PROVINCE OF SILESIA

Soil acidification is unfavourable both from the viewpoints of agriculture and ecology. This results from the fact that in an acid environment there is intensified leaching of certain nutrients, including potassium, and magnesium and calcium in particular. Other components, and especially phosphorus, are transformed into forms unavailable to plants. On the other hand, in an acid environment there is increased availability of heavy metals. On strongly acidified soils the growth and development of plants is inhibited, and the agricultural produce obtained is of low quality (Jackowska 1997, Kaczor 1992, Kaczor 1998).

5.1. Levels of basic nutrients in the soils

The richness of the soils of the province of Silesia in available forms of phosphorus, potassium and magnesium is presented in Tables 8, 9 and 10. These assays – like those of soil reaction – were performed by the Regional Agro-Chemical Station in Gliwice. Soil samples for the analyses were taken from arable lands of the particular communes of the province in the years 2004-2009 in the amount of 79202 (phosphorus) and 79143 (potassium, magnesium). Determinations of the levels of phosphorus and potassium were made with the method of Egner-Riehm, and of available magnesium – with the method of Schachtschabel. Estimations of soil richness in the components analysed were made based on the valid limit values (Adrianek and Skowronek 2008).

Data presented in Table 8 show that in the province of Silesia 16% of soils are characterised by very low, and 24% by low richness in available phosphorus. Soils with medium richness constitute 20%, with high richness 15%, and with very high richness 25%. The index of negative valuation, covering soils with very low and low richness and one half of those with medium richness, has the value of 50.2% for the province. This indicates that a half of the soils analysed requires systematic fertilisation with phosphorus.

Detail analysis of the richness of the soils in available phosphorus shows that in the area of 45 rural communes, 7 town-village communes and 3 township communes one half of the soils are characterised by very low and low richness in available phosphorus. The poorest soils in that element are found in the districts of Bielsko (communes Kozy, Buczkowice, Jawone, Jaziemica, Czechowice-Dziedzice, Porębka), Cieszyn (towns Wisła and Ustroń, Skonów, Zebrzydowice), Częstochowa (Janów, Kruszyna, Lalów, Mykanów, Olsztyn, Poczesna), Kłobuck (Lipie, Panki), Myszków (all communes), Wodzisław (all village communes), Zawiercie (all communes except Szczekocin and Włodowic) and Żywiec (whole district except communes Milówka, Radziechowy-Wieprz and Świnna).

Soils with very low richness in potassium constitute 29% in the province of Silesia, and those with low richness 25%. Among the analysed soils, 29% are characterised by medium richness, 10% by high richness, and only 7% by very high richness. The index of negative valuation for available potassium has the value of 68.5% for the province of Silesia (Tab. 9).

Table 8. Soil abundance in available phosphorus in the Silesian province (2004-2009)

Item	Poviat	Municipality	Analyse area in ha	Number of samples collected	Phosphorus										Negative validation
					very low unit/%		low unit/%		medium unit/%		high unit/%		very high unit/%		
1	będziński	**total**	**14620**	**1113**	**186**	**17**	**242**	**22**	**215**	**19**	**177**	**16**	**293**	**26**	**48.1**
		Bobrowniki	2409	104	29	28	19	18	17	16	16	15	23	22	54.3
		city Będzin	1496	65	19	29	8	12	9	14	9	14	20	31	48.5
		city Czeladź	220	53	1	2	2	4	3	6	11	21	36	68	8.5
		city Sławków	760	77	8	10	13	17	7	9	13	17	36	47	31.8
		Mierzęcice	2827	211	50	24	68	32	48	23	21	10	24	11	67.3
		Psary	2705	222	17	8	33	15	49	22	55	25	68	31	33.6
		Siewierz	4058	309	52	17	83	27	63	20	43	14	68	22	53.9
		Wojkowice	144	72	10	14	16	22	19	26	9	13	18	25	49.3
2	bielski	**total**	**10857**	**2963**	**891**	**30**	**642**	**22**	**463**	**16**	**330**	**11**	**637**	**21**	**59.6**
		Bestwina	4320	390	78	20	78	20	71	18	45	12	118	30	49.1
		Buczkowice	1.6	10	4	40	2	20	1	10	2	20	1	10	65.0
		Czechowice-Dziedzice	1428	864	303	35	210	24	138	16	84	10	129	15	67.4
		Jasienica	1810	981	321	33	183	19	111	11	137	14	229	23	57.0

		Jaworze	402	304	109	36	63	21	61	20	16	5	55	18	66.6
		Kozy	90	48	31	65	10	21	4	8	1	2	2	4	89.6
		Porąbka	2168	65	20	31	18	28	6	9	3	5	18	28	63.1
		Wilamowice	637	301	25	8	78	26	71	24	42	14	85	28	46.0
3	bieruńsko - lędziński	**total**	**6062**	**2971**	**490**	**16**	**630**	**21**	**652**	**22**	**449**	**15**	**750**	**25**	**48.7**
		Bojszowy	754	548	73	13	126	23	106	19	106	19	137	25	46.0
		Chełm Śląski	367	214	64	30	46	21	46	21	25	12	33	15	62.1
		Lędziny	1723	1265	193	15	278	22	298	24	173	14	323	26	49.0
		city Bieruń	1612	836	150	18	161	19	181	22	125	15	219	26	48.0
		city Imielin	1606	108	10	9	19	18	21	19	20	19	38	35	36.6
4	cieszyński	**total**	**7821**	**2981**	**718**	**24**	**552**	**19**	**460**	**15**	**299**	**10**	**952**	**32**	**50.3**
		Brenna	102	29	1	3	3	10	3	10	3	10	19	66	19.0
		Chybie	454	166	7	4	14	8	18	11	16	10	111	67	18.1
		Dębowiec	1319	566	34	6	71	13	75	13	41	7	345	61	25.2
		Goleszów	625	233	32	14	35	15	35	15	30	13	101	43	36.3
		Hażlach	459	270	83	31	52	19	49	18	19	7	67	25	59.1
		Istebna	500	7	1	14	3	43	0	0	1	14	2	29	57.1
		city Cieszyn	86.1	30	6	20	6	20	4	13	2	7	12	40	46.7

Table 8. Cont. Soil abundance in available phosphorus in the Silesian province (2004-2009)

Item	Poviat	Municipality	Analyse area in ha	Number of samples collected	Phosphorus very low unit/%		low unit/%		medium unit/%		high unit/%		very high unit/%		Negative validation
4	cieszyński	city Ustroń	64.4	37	16	43	13	35	4	11	0	0	4	11	83.8
		city Wisła	204	263	213	81	26	10	13	5	3	1	8	3	93.3
		Skoczów	388	193	58	30	46	24	36	19	25	13	28	15	63.2
		Strumień	874	545	52	10	107	20	128	23	102	19	156	29	40.9
		Zebrzydowice	2745	638	214	34	173	27	95	15	57	9	99	16	68.1
5	często-chowski	**total**	**51324**	**3218**	**682**	**21**	**1137**	**35**	**631**	**20**	**325**	**10**	**443**	**14**	**66.3**
		Blachownia	2.4	3	0	0	2	67	1	33	0	0	0	0	83.3
		Dąbrowa Zielona	10054	67	7	10	16	24	15	22	11	16	18	27	45.5
		Janów	529	229	47	21	86	38	31	14	32	14	33	14	64.8
		Kłomnice	989	611	79	13	178	29	161	26	78	13	115	19	55.2
		Koniecpol	11108	59	4	7	18	31	22	37	9	15	6	10	55.9
		Konopiska	8.3	8	1	13	1	13	0	0	2	25	4	50	25.0
		Kruszyna	1301	663	160	24	277	42	100	15	53	8	73	11	73.5

		Lelów	1034	425	101	24	168	40	91	21	34	8	31	7	74.0
		Mstów	191	108	15	14	25	23	21	19	16	15	31	29	46.8
		Mykanów	15542	847	229	27	298	35	152	18	62	7	106	13	71.2
		Olsztyn	9	10	3	30	4	40	1	10	2	20	0	0	75.0
		Poczesna	6310	89	28	31	33	37	16	18	4	4	8	9	77.5
		Przyrów	32.5	20	3	15	10	50	5	25	1	5	1	5	77.5
		Rędziny	4213	79	5	6	21	27	15	19	21	27	17	22	42.4
		total	**34292**	**8270**	**725**	**9**	**1688**	**20**	**2085**	**25**	**1654**	**20**	**2118**	**26**	**41.8**
		Gierałtowice	1895	1252	184	15	379	30	256	20	167	13	266	21	55.2
		city Knurów	49.5	24	5	21	3	13	6	25	2	8	8	33	45.8
		city Pyskowice	325	206	14	7	54	26	51	25	35	17	52	25	45.4
6	gliwicki	Pilchowice	7658	558	22	4	148	27	158	28	120	22	110	20	44.6
		Rudziniec	13677	1623	48	3	166	10	395	24	411	25	603	37	25.4
		Sośnicowice	2555	1088	43	4	97	9	258	24	346	32	344	32	24.7
		Toszek	3859	1612	192	12	412	26	456	28	255	16	297	18	51.6
		Wielowieś	4274	1907	217	11	429	22	505	26	318	17	438	23	47.1

Table 8. Cont. Soil abundance in available phosphorus in the Silesian province (2004-2009)

Item	Poviat	Municipality	Analyse area in ha	Number of samples collected	Phosphorus										Negative validation
					very low unit/%		low unit/%		medium unit/%		high unit/%		very high unit/%		
7	kłobucki	**total**	**6889**	**4513**	**578**	**13**	**1271**	**28**	**1306**	**29**	**686**	**15**	**672**	**15**	**55.4**
		Kłobuck	697	445	50	11	166	37	136	31	49	11	44	10	63.8
		Krzepice	1263	783	114	15	205	26	250	32	117	15	97	12	56.7
		Lipie	309	205	30	15	70	34	54	26	35	17	16	8	62.0
		Miedźno	47.2	30	2	7	19	63	5	17	4	13	0	0	78.3
		Opatów	520	321	39	12	93	29	109	34	50	16	30	9	58.1
		Panki	691	419	84	20	128	31	110	26	49	12	48	11	63.7
		Popów	1169	751	92	12	219	29	205	27	110	15	125	17	55.1
		Przystajń	1893	1307	145	11	332	25	364	28	220	17	246	19	50.4
		Wręczyca Wielka	298	252	22	9	39	15	73	29	52	21	66	26	38.7
8	lubliniecki	**total**	**12780**	**6625**	**899**	**14**	**1353**	**20**	**1485**	**22**	**1158**	**17**	**1730**	**26**	**45.2**
		Boronów	104.2	83	22	27	17	20	19	23	14	17	11	13	58.4
		Ciasna	5068	2565	272	11	397	15	568	22	560	22	768	30	37.2
		Herby	509	416	49	12	107	26	122	29	71	17	67	16	52.2

		Kochanowice	1434	716	145	20	205	29	126	18	113	16	127	18	57.7
		Koszęcin	1762	834	139	17	210	25	160	19	91	11	234	28	51.4
		city Lubliniec	546	274	19	7	39	14	53	19	60	22	103	38	30.8
		Pawonków	2158	1235	120	10	246	20	337	27	202	16	330	27	43.3
		Woźniki	1199	502	133	26	132	26	100	20	47	9	90	18	62.7
9	city Bielsko Biała	Bielsko-Biała	5.4	9	4	44	1	11	3	33	1	11	0	0	72.2
10	city Bytom	Bytom	122	96	18	19	19	20	9	9	7	7	43	45	43.2
11	city Chorzów	Chorzów	106	30	0	0	0	0	0	0	0	0	30	100	0.0
12	City Często-chowa	Częstochowa	404	115	9	8	79	69	15	13	6	5	6	5	83.0
13	city Dąbrowa Górnicza	Dąbrowa Górnicza	5.5	3	0	0	1	33	1	33	1	33	0	0	50.0
14	city Gliwice	Gliwice	3052	1431	156	11	335	23	349	24	226	16	365	26	46.5
15	city Jastrzębie Zdrój	Jastrzębie-Zdrój	5202	125	22	18	27	22	21	17	10	8	45	36	47.6
16	city Jaworzno	Jaworzno	669	225	59	26	73	32	44	20	25	11	24	11	68.4
17	city Katowice	Katowice	4.2	6	0	0	1	17	1	17	0	0	4	67	25.0

Table 8. Cont. Soil abundance in available phosphorus in the Silesian province (2004-2009)

Item	Poviat	Municipality	Analyse area in ha	Number of samples collected	Phosphorus										Negative validation
					very low unit/%		low unit/%		medium unit/%		high unit/%		very high unit/%		
18	city Mysłowice	Mysłowice	377	220	41	19	36	16	29	13	22	10	92	42	41.6
19	city Piekary Śląskie	Piekary Śląskie	179	112	2	2	14	13	17	15	27	24	52	46	21.9
20	city Ruda Śląska	Ruda Śląska	55.5	63	0	0	12	19	12	19	16	25	23	37	28.6
21	city Rybnik	Rybnik	326	91	5	5	14	15	21	23	16	18	35	38	32.4
22	city Siemiano-wice Śląskie	Siemianowice Śląskie	47	30	0	0	3	10	7	23	10	33	10	33	21.7
23	city Sosnowiec	Sosnowiec	0.8	6	0	0	0	0	0	0	1	17	5	83	0.0
24	city Tychy	Tychy	1730	843	80	9	174	21	158	19	133	16	298	35	39.5
25	city Zabrze	Zabrze	54.2	131	0	0	20	15	0	0	3	2	108	82	15.3
26	city Żory	city Żory	418	476	67	14	116	24	90	19	63	13	140	29	47.9
27	mikołowski	**total**	**5268**	**1447**	**246**	**17**	**247**	**17**	**289**	**20**	**230**	**16**	**435**	**30**	**44.1**
		city Łaziska Górne	306	145	25	17	32	22	24	17	13	9	51	35	47.6
		city Mikołów	1153	649	100	15	85	13	126	19	116	18	222	34	38.2
		city Orzesze	581	424	60	14	77	18	99	23	76	18	112	26	44.0
		Ornontowice	1016	84	12	14	16	19	14	17	15	18	27	32	41.7

		Wyry	2211	145	49	34	37	26	26	18	10	7	23	16	68.3
28	myszkowski	**total**	**19197**	**2245**	**704**	**31**	**721**	**32**	**406**	**18**	**209**	**9**	**205**	**9**	**72.5**
		Koziegłowy	1293	771	320	42	228	30	105	14	62	8	56	7	77.9
		city Myszków	1020	478	67	14	153	32	132	28	63	13	63	13	59.8
		Niegowa	9160	921	302	33	314	34	153	17	78	8	74	8	75.2
		Poraj	2829	28	7	25	10	36	4	14	3	11	4	14	67.9
		Żarki	4894	47	8	17	16	34	12	26	3	6	8	17	63.8
29	pszczyński	**total**	**10364**	**6693**	**690**	**10**	**1086**	**16**	**1241**	**19**	**1010**	**15**	**2666**	**40**	**35.8**
		Goczałkowice-Zdrój	211	156	11	7	33	21	30	19	30	19	52	33	37.8
		Kobiór	224	150	19	13	17	11	21	14	10	7	83	55	31.0
		Miedźna	1379	1127	122	11	237	21	217	19	175	16	376	33	41.5
		Pawłowice	3742	2176	348	16	492	23	515	24	346	16	475	22	50.4
		Pszczyna	2729	1693	52	3	140	8	250	15	274	16	977	58	18.7
		Suszec	2079	1391	138	10	167	12	208	15	175	13	703	51	29.4
30	raciborski	**total**	**28539**	**13452**	**1041**	**8**	**2702**	**20**	**2981**	**22**	**2311**	**17**	**4417**	**33**	**38.9**
		Kornowac	565	542	90	17	148	27	112	21	61	11	131	24	54.2
		Krzanowice	6165.7	2375	109	5	424	18	499	21	421	18	922	39	32.9

Table 8. Cont. Soil abundance in available phosphorus in the Silesian province (2004-2009)

Item	Poviat	Municipality	Analyse area in ha	Number of samples collected	Phosphorus very low unit	/%	low unit	/%	medium unit	/%	high unit	/%	very high unit	/%	Negative validation
30	raciborski	Krzyżanowice	4698.3	2073	139	7	387	19	550	27	408	20	589	28	38.6
		Kuźnia Raciborska	859.6	728	132	18	190	26	147	20	89	12	170	23	54.3
		city Racibórz	3210.3	1868	119	6	308	16	353	19	241	13	847	45	32.3
		Nędza	1194.7	734	114	16	171	23	166	23	130	18	153	21	50.1
		Pietrowice Wielkie	3265.4	1853	133	7	328	18	387	21	357	19	648	35	35.3
		Rudnik	8580	3279	205	6	746	23	767	23	604	18	957	29	40.7
31	rybnicki	**total**	**1643**	**617**	**45**	**7**	**148**	**24**	**185**	**30**	**125**	**20**	**114**	**18**	**46.3**
		Czerwionka-Leszczyny	956	370	39	11	107	29	84	23	57	15	83	22	50.8
		Lyski	615	186	4	2	34	18	72	39	50	27	26	14	39.8
		Świerklany	72.5	61	2	3	7	11	29	48	18	30	5	8	38.5
32	tarnogórski	**total**	**12242**	**6336**	**667**	**11**	**1652**	**26**	**1713**	**27**	**1069**	**17**	**1235**	**19**	**50.1**
		Krupski Młyn	350	188	29	15	41	22	50	27	41	22	27	14	50.5
		city Kalety	126	133	34	26	33	25	28	21	12	9	26	20	60.9
		city Miasteczko Śląskie	55	22	4	18	5	23	2	9	5	23	6	27	45.5

		city Radzionków	175	68	3	4	7	10	23	34	9	13	26	38	31.6
		city Tarnowskie Góry	656	382	7	2	58	15	149	39	87	23	81	21	36.5
		Ożarowice	262	220	40	18	58	26	43	20	28	13	51	23	54.3
		Świerklaniec	91	38	1	3	5	13	7	18	9	24	16	42	25.0
		Tworóg	1687	984	108	11	235	24	222	23	179	18	240	24	46.1
		Zbrosławice	8840	4301	441	10	1210	28	1189	28	699	16	762	18	52.2
33	wodzisławski	**total**	**3202**	**3188**	**788**	**25**	**996**	**31**	**633**	**20**	**321**	**10**	**450**	**14**	**65.9**
		Godów	808	1100	321	29	342	31	227	21	111	10	99	9	70.6
		Gorzyce	656	556	152	27	166	30	121	22	53	10	64	12	68.1
		Lubomia	788	688	184	27	235	34	110	16	66	10	93	14	68.9
		city Pszów	56	36	5	14	20	56	9	25	0	0	2	6	81.9
		city Radlin	4	8	2	25	4	50	1	13	0	0	1	13	81.3
		city Rydułtowy	36.6	71	17	24	14	20	15	21	4	6	21	30	54.2
		city Wodzisław Śląski	158	95	3	3	14	15	18	19	18	19	42	44	27.4
		Marklowice	249	207	54	26	89	43	29	14	17	8	18	9	76.1
		Mszana	446	427	50	12	112	26	103	24	52	12	110	26	50.0

Table 8. Cont. Soil abundance in available phosphorus in the Silesian province (2004-2009)

Item	Poviat	Municipality	Analyse area in ha	Number of samples collected	Phosphorus										Negative validation
					very low unit/%		low unit/%		medium unit/%		high unit/%		very high unit/%		
34	zawierciański	**total**	**70581**	**6919**	**2131**	**31**	**2319**	**34**	**1128**	**16**	**510**	**7**	**831**	**12**	**72.5**
		Irządze	6637	751	293	39	226	30	107	14	38	5	87	12	76.2
		Kroczyce	1030	393	88	22	124	32	102	26	52	13	27	7	66.9
		Łazy	6611	105	28	27	26	25	18	17	11	10	22	21	60.0
		city Poręba	244	111	47	42	45	41	14	13	3	3	2	2	89.2
		city Zawiercie	9141	214	49	23	82	38	36	17	24	11	23	11	69.6
		Ogrodzieniec	411	364	77	21	98	27	83	23	48	13	58	16	59.5
		Pilica	15314	2206	955	43	749	34	298	14	105	5	99	4	84.0
		Szczekociny	13449	1160	166	14	365	31	168	14	115	10	346	30	53.0
		Włodowice	4805	82	8	10	14	17	21	26	13	16	26	32	39.6
		Żarnowiec	12939	1533	420	27	590	38	281	18	101	7	141	9	75.0
		total	**7058**	**1639**	**672**	**41**	**368**	**22**	**214**	**13**	**151**	**9**	**234**	**14**	**70.0**
		Gilowice	1814	341	207	61	73	21	32	9	16	5	13	4	86.8
		Jeleśnia	1.7	5	2	40	2	40	1	20	0	0	0	0	90.0
		Koszarawa	9.7	24	16	67	3	13	3	13	0	0	2	8	85.4

35	żywiecki	Lipowa	529	257	90	35	54	21	40	16	36	14	37	14	63.8
		Łękawica	7.1	3	2	67	1	33	0	0	0	0	0	0	100.0
		Łodygowice	462	646	269	42	172	27	74	11	44	7	87	13	74.0
		city Żywiec	10.7	17	8	47	3	18	1	6	0	0	5	29	67.6
		Milówka	0.1	1	0	0	0	0	0	0	0	0	1	100	0.0
		Radziechowy-Wieprz	4123	228	15	7	40	18	46	20	46	20	81	36	34.2
		Rajcza	4.2	14	9	64	2	14	2	14	0	0	1	7	85.7
		Ślemień	94.3	96	50	52	17	18	14	15	9	9	6	6	77.1
		Świnna	0.2	1	0	0	0	0	0	0	0	0	1	100	0.0
		Węgierska Górka	2.1	6	4	67	1	17	1	17	0	0	0	0	91.7
36	**Silesian Province**	**total**	**315498**	**79202**	**12616**	**16**	**18679**	**24**	**16864**	**21**	**11581**	**15**	**19462**	**25**	**50.2**

*This breakdown, does not include, due to the lack of data, the following municipalities: Szczyrk, Wilkowice, Kamienica Polska, Starcza, Gaszowice, Jejkowice, Czernichów, Ujsoły and Świętochłowice.

Table 9. Soil abundance in available potassium in the Silesian province (2004-2009)

Item	Poviat	Municipality	Analysed area in ha	Number of samples collected	Potassium										Negative validation
					very low unit/%		low unit/%		medium unit/%		high unit/%		very high unit/%		
1	będziński	**total**	**14620**	**1113**	**321**	**29**	**283**	**25**	**210**	**19**	**143**	**13**	**156**	**14**	**63.7**
		Bobrowniki	2409	104	23	22	22	21	20	19	16	15	23	22	52.9
		city Będzin	1496	65	15	23	19	29	17	26	4	6	10	15	65.4
		city Czeladź	220	53	8	15	13	25	11	21	4	8	17	32	50.0
		city Sławków	760	77	45	58	18	23	10	13	3	4	1	1	88.3
		Mierzęcice	2827	211	80	38	58	27	38	18	22	10	13	6	74.4
		Psary	2705	222	9	4	38	17	39	18	67	30	69	31	30.0
		Siewierz	4058	309	133	43	93	30	55	18	18	6	10	3	82.0
		Wojkowice	144	72	8	11	22	31	20	28	9	13	13	18	55.6
2	bielski	**total**	**10857**	**2963**	**695**	**23**	**589**	**20**	**1206**	**41**	**213**	**7**	**260**	**9**	**63.7**
		Bestwina	4320	390	60	15	79	20	210	54	14	4	27	7	62.6
		Buczkowice	1.6	10	1	10	2	20	2	20	3	30	2	20	40.0
		Czechowice-Dziedzice	1428	864	279	32	161	19	274	32	58	7	92	11	66.8
		Jasienica	1810	981	215	22	214	22	391	40	96	10	65	7	63.7

		Jaworze	402	304	83	27	54	18	80	26	24	8	63	21	58.2
		Kozy	90	48	32	67	9	19	7	15	0	0	0	0	92.7
		Porąbka	2168	65	7	11	18	28	36	55	3	5	1	2	66.2
		Wilamowice	637	301	18	6	52	17	206	68	15	5	10	3	57.5
3	bieruńsko - lędziński	**total**	**6062**	**2971**	**1105**	**37**	**819**	**28**	**649**	**22**	**250**	**8**	**148**	**5**	**75.7**
		Bojszowy	754	548	249	45	153	28	100	18	28	5	18	3	82.5
		Chełm Śląski	367	214	93	43	59	28	42	20	12	6	8	4	80.8
		Lędziny	1723	1265	488	39	357	28	227	18	129	10	64	5	75.8
		city Bieruń	1612	836	245	29	208	25	247	30	78	9	58	7	69.0
		city Imielin	1606	108	30	28	42	39	33	31	3	3	0	0	81.9
4	cieszyński	**total**	**7821**	**2981**	**604**	**20**	**587**	**20**	**1306**	**44**	**268**	**9**	**216**	**7**	**61.9**
		Brenna	102	29	4	14	5	17	20	69	0	0	0	0	65.5
		Chybie	454	166	51	31	22	13	70	42	11	7	12	7	65.1
		Dębowiec	1319	566	69	12	102	18	285	50	31	5	79	14	55.4
		Goleszów	625	233	24	10	68	29	107	46	13	6	21	9	62.4
		Hażlach	4589	270	50	19	48	18	102	38	29	11	41	15	55.2
		Istebna	500	7	4	57	0	0	3	43	0	0	0	0	78.6
		city Cieszyn	86	30	3	10	4	13	21	70	1	3	1	3	58.3

Table 9. Cont. Soil abundance in available potassium in the Silesian province (2004-2009)

Item	Povitat	Municipality	Analysed area in ha	Number of samples collected	Potassium										Negative validation
					very low unit/%		low unit/%		medium unit/%		high unit/%		very high unit/%		
4	cieszyński	city Ustroń	64	37	24	65	6	16	5	14	1	3	1	3	87.8
		city Wisła	204	263	161	61	30	11	42	16	5	2	25	10	80.6
		Skoczów	388	193	55	28	50	26	74	38	6	3	8	4	73.6
		Strumień	874	545	57	10	133	24	289	53	44	8	22	4	61.4
		Zebrzydowice	2745	638	99	16	118	18	288	45	127	20	6	1	56.6
5	częstochowski	**total**	**51324**	**3218**	**1500**	**47**	**855**	**27**	**500**	**16**	**187**	**6**	**176**	**5**	**81.0**
		Blachownia	2.4	3	1	33	1	33	1	33	0	0	0	0	83.3
		Dąbrowa Zielona	10054	67	30	45	18	27	8	12	8	12	3	4	77.6
		Janów	530	229	123	54	68	30	24	10	8	3	6	3	88.6
		Kłomnice	989	611	205	34	129	21	142	23	51	8	84	14	66.3
		Koniecpol	11108	59	35	59	11	19	4	7	8	14	1	2	81.4
		Konopiska	8.3	8	4	50	3	38	1	13	0	0	0	0	93.8

		Kruszyna	1301	663	384	58	153	23	69	10	24	4	33	5	86.2
		Lelów	1034	425	185	44	141	33	56	13	17	4	26	6	83.3
		Mstów	191	108	26	24	19	18	28	26	33	31	2	2	54.6
		Mykanów	15542	847	437	52	237	28	127	15	31	4	15	2	87.1
		Olsztyn	9	10	8	80	1	10	1	10	0	0	0	0	95.0
		Poczesna	6310	89	43	48	28	31	12	13	4	4	2	2	86.5
		Przyrów	32.5	20	9	45	6	30	3	15	1	5	1	5	82.5
		Rędziny	4213	79	10	13	40	51	24	30	2	3	3	4	78.5
		total	**34292**	**8270**	**1424**	**17**	**2387**	**29**	**2780**	**34**	**1199**	**14**	**480**	**6**	**62.9**
		Gierałtowice	1895	1252	206	16	283	23	457	37	259	21	47	4	57.3
		city Knurów	49.5	24	22	92	2	8	0	0	0	0	0	0	100.0
		city Pyskowice	325	206	31	15	61	30	65	32	32	16	17	8	60.4
6	gliwicki	Pilchowice	7658	558	122	22	213	38	178	32	40	7	5	1	76.0
		Rudziniec	13677	1623	124	8	485	30	666	41	232	14	116	7	58.0
		Sośnicowice	2555	1088	316	29	261	24	363	33	115	11	33	3	69.7
		Toszek	3859	1612	247	15	489	30	499	31	285	18	92	6	61.1
		Wielowieś	4274	1907	356	19	593	31	552	29	236	12	170	9	64.2

Table 9. Cont. Soil abundance in available potassium in the Silesian province (2004-2009)

Item	Poviat	Municipality	Analysed area in ha	Number of samples collected	Potassium										Negative validation
					very low unit/%		low unit/%		medium unit/%		high unit/%		very high unit/%		
7	kłobucki	**total**	**6889**	**4513**	**3114**	**69**	**871**	**19**	**375**	**8**	**101**	**2**	**52**	**1**	**92.5**
		Kłobuck	697	445	336	76	75	17	21	5	8	2	5	1	94.7
		Krzepice	1263	783	381	49	227	29	121	15	24	3	30	4	85.4
		Lipie	309	205	154	75	36	18	11	5	3	1	1	0	95.4
		Miedźno	47.2	30	20	67	4	13	4	13	1	3	1	3	86.7
		Opatów	520	321	209	65	74	23	32	10	6	2	0	0	93.1
		Panki	691	419	309	74	66	16	26	6	15	4	3	1	92.6
		Popów	1169	751	522	70	151	20	57	8	17	2	4	1	93.4
		Przystajń	1893	1307	1045	80	161	12	75	6	19	1	7	1	95.1
		Wręczyca Wielka	298	252	138	55	77	31	28	11	8	3	1	0	90.9
8	lubliniecki	**total**	**12780**	**6617**	**2769**	**42**	**1784**	**27**	**1340**	**20**	**483**	**7**	**241**	**4**	**78.9**
		Boronów	104.2	83	35	42	32	39	14	17	2	2	0	0	89.2
		Ciasna	5068	2565	1382	54	677	26	369	14	71	3	66	3	87.5
		Herby	509	416	243	58	117	28	47	11	3	1	6	1	92.2

		Kochanowice	1434	716	203	28	194	27	207	29	74	10	38	5	69.9
		Koszęcin	1762	834	312	37	203	24	198	24	66	8	55	7	73.6
		city Lubliniec	546	270	38	14	79	29	77	29	38	14	38	14	57.6
		Pawonków	2158	1231	461	37	302	25	270	22	178	14	20	2	72.9
		Woźniki	1199	502	95	19	180	36	158	31	51	10	18	4	70.5
9	city Bielsko Biała	Bielsko-Biała	5.4	9	1	11	1	11	7	78	0	0	0	0	61.1
10	city Bytom	Bytom	122	96	39	41	29	30	16	17	9	9	3	3	79.2
11	city Chorzów	Chorzów	106	30	0	0	1	3	3	10	10	33	16	53	8.3
12	city Częstochowa	Częstochowa	404	115	2	2	50	43	56	49	6	5	1	1	69.6
13	city Dąbrowa Górnicza	Dąbrowa Górnicza	5.5	3	1	33	0	0	0	0	1	33	1	33	33.3
14	city Gliwice	Gliwice	3052	1390	205	15	399	29	569	41	139	10	78	6	63.9
15	city. Jastrzębie Zdrój	Jastrzębie-Zdrój	5202	125	18	14	28	22	28	22	31	25	20	16	48.0
16	city Jaworzno	Jaworzno	669	225	40	18	92	41	55	24	22	10	16	7	70.9
17	city Katowice	Katowice	4.2	6	0	0	0	0	2	33	3	50	1	17	16.7
18	city Mysłowice	Mysłowice	377	217	66	30	57	26	55	25	26	12	13	6	69.4

Table 9. Cont. Soil abundance in available potassium in the Silesian province (2004-2009)

Item	Poviat	Municipality	Analysed area in ha	Number of samples collected	Potassium										Negative validation
					very low unit/%		low unit/%		medium unit/%		high unit/%		very high unit/%		
19	city Piekary Śląskie	Piekary Śląskie	179	112	16	14	21	19	35	31	32	29	8	7	48.7
20	city Ruda Śląska	Ruda Śląska	55.5	63	5	8	12	19	29	46	15	24	2	3	50.0
21	city Rybnik	Rybnik	326	91	22	24	21	23	27	30	7	8	14	15	62.1
22	city Siemianowice Śląskie	Siemianowice Śląskie	47	30	6	20	17	57	7	23	0	0	0	0	88.3
23	city Sosnowiec	Sosnowiec	0.8	6	1	17	4	67	0	0	1	17	0	0	83.3
24	city Tychy	Tychy	1730	843	195	23	164	19	188	22	116	14	180	21	53.7
25	city Zabrze	Zabrze	54.2	131	3	2	24	18	47	36	31	24	26	20	38.5
26	city Żory	city Żory	418	476	102	21	111	23	143	30	59	12	61	13	59.8
27	mikołowski	**total**	**5268**	**1447**	**482**	**33**	**351**	**24**	**425**	**29**	**111**	**8**	**78**	**5**	**72.3**
		city Łaziska Górne	306	145	30	21	37	26	42	29	15	10	21	14	60.7
		city Mikołów	1153	649	180	28	156	24	225	35	61	9	27	4	69.1
		city Orzesze	581	424	187	44	107	25	93	22	17	4	20	5	80.3

		Ornontowice	1016	84	22	26	20	24	34	40	5	6	3	4	70.2
		Wyry	2211	145	63	43	31	21	31	21	13	9	7	5	75.5
		total	**19197**	**2245**	**1031**	**46**	**545**	**24**	**442**	**20**	**97**	**4**	**130**	**6**	**80.0**
		Koziegłowy	1293	771	305	40	202	26	156	20	38	5	70	9	75.9
		city Myszków	1020	478	124	26	155	32	161	34	26	5	12	3	75.2
28	myszkowski	Niegowa	9160	921	555	60	171	19	116	13	31	3	48	5	85.1
		Poraj	2829	28	16	57	5	18	5	18	2	7	0	0	83.9
		Żarki	4894	47	31	66	12	26	4	9	0	0	0	0	95.7
		total	**10364**	**6693**	**1243**	**19**	**1483**	**22**	**2082**	**31**	**1410**	**21**	**475**	**7**	**56.3**
		Goczałkowice-Zdrój	211	156	22	14	33	21	34	22	51	33	16	10	46.2
		Kobiór	224	150	54	36	36	24	34	23	20	13	6	4	71.3
29	pszczyński	Miedźna	1379	1127	230	20	258	23	339	30	219	19	81	7	58.3
		Pawłowice	3742	2176	386	18	517	24	730	34	276	13	267	12	58.3
		Pszczyna	2729	1693	197	12	327	19	545	32	593	35	31	2	47.0
		Suszec	2079	1391	354	25	312	22	400	29	251	18	74	5	62.3

Table 9. Cont. Soil abundance in available potassium in the Silesian province (2004-2009)

Item	Poviat	Municipality	Analysed area in ha	Number of samples collected	Potassium										Negative validation
					very low unit/%		low unit/%		medium unit/%		high unit/%		very high unit/%		
30	raciborski	**total**	**28539**	**13452**	**2192**	**16**	**3340**	**25**	**5867**	**44**	**1105**	**8**	**948**	**7**	**62.9**
		Kornowac	565	542	127	23	119	22	145	27	151	28	0	0	58.8
		Krzanowice	6166	2375	450	19	635	27	1037	44	129	5	124	5	67.5
		Krzyżanowice	4698	2073	242	12	522	25	811	39	202	10	296	14	56.4
		Kuźnia Raciborska	860	728	114	16	167	23	325	45	103	14	19	3	60.9
		city Racibórz	3210	1868	296	16	450	24	819	44	200	11	103	6	61.9
		Nędza	1195	734	117	16	131	18	350	48	93	13	43	6	57.6
		Pietrowice Wielkie	3265	1853	409	22	408	22	859	46	72	4	105	6	67.3
		Rudnik	8580	3279	437	13	908	28	1521	46	155	5	258	8	64.2
31	rybnicki	**total**	**1643**	**617**	**162**	**26**	**182**	**29**	**203**	**33**	**46**	**7**	**24**	**4**	**72.2**
		Czerwionka-Leszczyny	955	370	114	31	104	28	115	31	21	6	16	4	74.5
		Lyski	615	186	46	25	70	38	62	33	8	4	0	0	79.0
		Świerklany	72.5	61	2	3	8	13	26	43	17	28	8	13	37.7

32	tarnogórski	**total**	**12242**	**6329**	**1005**	**16**	**1596**	**25**	**2228**	**35**	**926**	**15**	**574**	**9**	**58.7**
		Krupski Młyn	350	188	5	3	55	29	94	50	31	16	3	2	56.9
		city Kalety	126	131	49	37	41	31	20	15	11	8	10	8	76.3
		city Miasteczko Śląskie	54.8	20	13	65	4	20	2	10	1	5	0	0	90.0
		city Radzionków	175	68	10	15	17	25	19	28	10	15	12	18	53.7
		city Tarnowskie Góry	656	382	51	13	148	39	99	26	38	10	46	12	65.1
		Ożarowice	262	220	52	24	96	44	39	18	16	7	17	8	76.1
		Świerklaniec	91	38	3	8	9	24	21	55	1	3	4	11	59.2
		Tworóg	1687	981	232	24	338	34	262	27	102	10	47	5	71.5
		Zbrosławice	8840	4301	590	14	888	21	1672	39	716	17	435	10	53.8
33	wodzisławski	**total**	**3202**	**3188**	**517**	**16**	**872**	**27**	**1124**	**35**	**395**	**12**	**280**	**9**	**61.2**
		Godów	808	1100	206	19	324	29	321	29	136	12	113	10	62.8
		Gorzyce	656	556	57	10	120	22	223	40	68	12	88	16	51.9
		Lubomia	788	688	57	8	217	32	321	47	86	13	7	1	63.2
		city Pszów	56	36	0	0	2	6	16	44	13	36	5	14	27.8
		city Radlin	4	8	2	25	0	0	1	13	3	38	2	25	31.3
		city Rydułtowy	36.6	71	11	15	14	20	25	35	8	11	13	18	52.8

Table 9. Cont. Soil abundance in available potassium in the Silesian province (2004-2009)

Item	Poviat	Municipality	Analysed area in ha	Number of samples collected	Potassium										Negative validatio n
					very low unit/%		low unit/%		medium unit/%		high unit/%		very high unit/%		
33	wodzisławski	city Wodzisław Śląski	158	95	10	11	17	18	42	44	12	13	14	15	50.5
		Marklowice	249	207	61	29	49	24	59	29	17	8	21	10	67.4
		Mszana	446	427	113	26	129	30	116	27	52	12	17	4	70.3
34	zawierciański	**total**	**70581**	**6919**	**3284**	**47**	**1765**	**26**	**1178**	**17**	**338**	**5**	**354**	**5**	**81.5**
		Irządze	6637.2	751	297	40	201	27	189	25	21	3	43	6	78.9
		Kroczyce	1029.6	393	238	61	107	27	39	10	9	2	0	0	92.7
		Łazy	6611	105	22	21	33	31	29	28	17	16	4	4	66.2
		city Poręba	244	111	10	9	21	19	54	49	9	8	17	15	52.3
		city Zawiercie	9141	214	22	10	55	26	83	39	46	21	8	4	55.4
		Ogrodzieniec	411	364	125	34	119	33	69	19	29	8	22	6	76.5
		Pilica	15314	2206	1329	60	525	24	235	11	57	3	60	3	89.4
		Szczekociny	13449	1160	348	30	318	27	260	22	110	9	124	11	68.6
		Włodowice	4805	82	31	38	25	30	17	21	6	7	3	4	78.7
		Żarnowiec	12939	1533	862	56	361	24	203	13	34	2	73	5	86.4

35	żywiecki	**total**	**7058**	**1639**	**518**	**32**	**302**	**18**	**559**	**34**	**97**	**6**	**163**	**10**	**67.1**
		Gilowice	1814	341	121	35	71	21	142	42	6	2	1	0	77.1
		Jeleśnia	1.7	5	4	80	0	0	1	20	0	0	0	0	90.0
		Koszarawa	9.7	24	16	67	1	4	5	21	1	4	1	4	81.3
		Lipowa	529	257	69	27	42	16	101	39	13	5	32	12	62.8
		Łękawica	7.1	3	3	100	0	0	0	0	0	0	0	0	100.0
		Łodygowice	462	646	188	29	112	17	194	30	60	9	92	14	61.5
		city Żywiec	10.7	17	7	41	5	29	4	24	0	0	1	6	82.4
		Milówka	0.1	1	0	0	0	0	1	100	0	0	0	0	50.0
		Radziechowy -Wieprz	4123	228	50	22	56	25	71	31	16	7	35	15	62.1
		Rajcza	4.2	14	10	71	2	14	2	14	0	0	0	0	92.9
		Ślemień	94.3	96	45	47	13	14	36	38	1	1	1	1	79.2
		Świnna	0.2	1	0	0	0	0	1	100	0	0	0	0	50.0
		Węgierska Górka	2.1	6	5	83	0	0	1	17	0	0	0	0	91.7
36	**Silesian Province**	**total**	**315498**	**79143**	**22688**	**29**	**19642**	**25**	**23741**	**30**	**7877**	**10**	**5195**	**7**	**68.5**

*This breakdown, does not include, due to the lack of data, the following municipalities: Szczyrk, Wilkowice, Kamienica Polska, Starcza, Gaszowice, Jejkowice, Czernichów, Ujsoły and Świętochłowice.
Silesian Province

Table 10. Soil abundance in available magnesium in the Silesian province (2004-2009)

Item	Poviat	Municipality	Analysed area in ha	Number of samples collected	Magnesium										Negative validation
					very low unit / %		low unit / %		medium unit / %		high unit / %		very high unit / %		
1	będziński	**total**	**14620**	**1113**	**40**	**4**	**99**	**9**	**241**	**22**	**193**	**17**	**540**	**49**	**23.3**
		Bobrowniki	2409	104	5	5	10	10	25	24	13	13	51	49	26.4
		city Będzin	1496	65	2	3	3	5	5	8	11	17	44	68	11.5
		city Czeladź	220	53	0	0	3	6	6	11	4	8	40	75	11.3
		city Sławków	760	77	1	1	7	9	9	12	8	10	52	68	16.2
		Mierzęcice	2827	211	18	9	30	14	69	33	37	18	57	27	39.1
		Psary	2705	222	0	0	11	5	55	25	57	26	99	45	17.3
		Siewierz	4058	309	10	3	28	9	55	18	46	15	170	55	21.2
		Wojkowice	144	72	4	6	7	10	17	24	17	24	27	38	27.1
2	bielski	**total**	**10857**	**2963**	**159**	**5**	**629**	**21**	**1192**	**40**	**537**	**18**	**446**	**15**	**46.7**
		Bestwina	4320	390	20	5	118	30	172	44	60	15	20	5	57.4
		Buczkowice	1.6	10	1	10	5	50	3	30	0	0	1	10	75.0
		Czechowice-Dziedzice	1428	864	25	3	132	15	348	40	184	21	175	20	38.3

		Jasienica	1810	981	63	6	203	21	385	39	184	19	146	15	46.7
		Jaworze	402	304	11	4	48	16	114	38	56	18	75	25	38.2
		Kozy	90	48	2	4	8	17	16	33	15	31	7	15	37.5
		Porąbka	2168	65	4	6	13	20	31	48	8	12	9	14	50.0
		Wilamowice	637	301	33	11	102	34	123	41	30	10	13	4	65.3
3	bieruńsko - lędziński	**total**	**6062**	**2971**	**433**	**15**	**468**	**16**	**489**	**16**	**409**	**14**	**1172**	**39**	**38.6**
		Bojszowy	754	548	73	13	80	15	100	18	89	16	206	38	37.0
		Chełm Śląski	367	214	59	28	39	18	31	14	14	7	71	33	53.0
		Lędziny	1723	1265	189	15	208	16	200	16	179	14	489	39	39.3
		city Bieruń	1612	836	105	13	125	15	137	16	108	13	361	43	35.7
		city Imielin	1606	108	7	6	16	15	21	19	19	18	45	42	31.0
4	cieszyński	**total**	**7821**	**2981**	**197**	**7**	**538**	**18**	**985**	**33**	**591**	**20**	**670**	**22**	**41.2**
		Brenna	102	29	5	17	4	14	15	52	3	10	2	7	56.9
		Chybie	454	166	18	11	45	27	59	36	24	14	20	12	55.7
		Dębowiec	1319	566	21	4	146	26	258	46	106	19	35	6	52.3
		Goleszów	625	233	17	7	42	18	80	34	74	32	20	9	42.5
		Hażlach	459	270	12	4	65	24	103	38	34	13	56	21	47.6

Table 10. Cont. Soil abundance in available magnesium in the Silesian province (2004-2009)

Item	Poviat	Municipality	Analysed area in ha	Number of samples collected	Magnesium										Negative validation
					very low unit / %		low unit / %		medium unit / %		high unit / %		very high unit / %		
4	cieszyński	Istebna	500	7	2	29	0	0	1	14	3	43	1	14	35.7
		city Cieszyn	86.1	30	0	0	4	13	16	53	6	20	4	13	40.0
		city Ustroń	64.4	37	0	0	0	0	15	41	12	32	10	27	20.3
		city Wisła	204	263	68	26	75	29	88	33	25	10	7	3	71.1
		Skoczów	388	193	17	9	40	21	68	35	20	10	48	25	47.2
		Strumień	874	545	30	6	83	15	171	31	161	30	100	18	36.4
		Zebrzydowice	2745	638	7	1	34	5	111	17	121	19	365	57	15.1
		total	**51324**	**3218**	**1683**	**52**	**691**	**21**	**419**	**13**	**201**	**6**	**224**	**7**	**80.3**
5	często-chowski	Blachownia	2.4	3	1	33	2	67	0	0	0	0	0	0	100.0
		Dąbrowa Zielona	10054	67	32	48	9	13	16	24	3	4	7	10	73.1
		Janów	529	229	103	45	76	33	34	15	10	4	6	3	85.6
		Kłomnice	989	611	349	57	151	25	81	13	21	3	9	1	88.5
		Koniecpol	11108	59	25	42	10	17	11	19	9	15	4	7	68.6
		Konopiska	8.3	8	1	13	2	25	2	25	1	13	2	25	50.0

		Kruszyna	1301	663	421	63	100	15	56	8	30	5	56	8	82.8
		Lelów	1034	425	168	40	113	27	93	22	31	7	20	5	77.1
		Mstów	191	108	39	36	44	41	16	15	8	7	1	1	84.3
		Mykanów	15542	847	486	57	134	16	88	10	56	7	83	10	78.4
		Olsztyn	9	10	7	70	2	20	1	10	0	0	0	0	95.0
		Poczesna	6310	89	9	10	14	16	10	11	29	33	27	30	31.5
		Przyrów	32.5	20	10	50	7	35	1	5	1	5	1	5	87.5
		Rędziny	4213	79	32	41	27	34	10	13	2	3	8	10	81.0
		total	**34292**	**8270**	**1631**	**20**	**1821**	**22**	**2159**	**26**	**1322**	**16**	**1337**	**16**	**54.8**
		Gierałtowice	1895	1252	216	17	211	17	310	25	222	18	293	23	46.5
		city Knurów	49.5	24	7	29	5	21	3	13	4	17	5	21	56.3
		city Pyskowice	325	206	21	10	33	16	48	23	41	20	63	31	37.9
6	gliwicki	Pilchowice	7658	558	83	15	253	45	154	28	50	9	18	3	74.0
		Rudziniec	13677	1623	203	13	464	29	534	33	257	16	165	10	57.5
		Sośnicowice	2555	1088	340	31	185	17	236	22	150	14	177	16	59.1
		Toszek	3859	1612	286	18	366	23	442	27	255	16	263	16	54.2
		Wielowieś	4274	1907	475	25	304	16	432	23	343	18	353	19	52.2

Table 10. Cont. Soil abundance in available magnesium in the Silesian province (2004-2009)

Item	Poviat	Municipality	Analysed area in ha	Number of samples collected	Magnesium										Negative validation
					very low unit / %		low unit / %		medium unit / %		high unit / %		very high unit / %		
7	kłobucki	**total**	**6889**	**4513**	**2066**	**46**	**974**	**22**	**623**	**14**	**338**	**7**	**512**	**11**	**74.3**
		Kłobuck	697	445	238	53	82	18	55	12	26	6	44	10	78.1
		Krzepice	1263	783	280	36	177	23	129	16	75	10	122	16	66.6
		Lipie	309	205	114	56	47	23	30	15	8	4	6	3	85.9
		Miedźno	47.2	30	13	43	6	20	8	27	3	10	0	0	76.7
		Opatów	520	321	186	58	66	21	34	11	11	3	24	7	83.8
		Panki	691	419	180	43	86	21	52	12	43	10	58	14	69.7
		Popów	1169	751	459	61	163	22	64	9	33	4	32	4	87.1
		Przystajń	1893	1307	517	40	287	22	192	15	120	9	191	15	68.9
		Wręczyca Wielka	298	252	79	31	60	24	59	23	19	8	35	14	66.9
		total	**12780**	**6617**	**1561**	**24**	**1185**	**18**	**1368**	**21**	**987**	**15**	**1516**	**23**	**51.8**
		Boronów	104.2	83	9	11	19	23	29	35	8	10	18	22	51.2
		Ciasna	5068	2565	737	29	478	19	540	21	350	14	460	18	57.9

8	lubliniecki	Herby	509	416	125	30	78	19	71	17	54	13	88	21	57.3
		Kochanowice	1434	716	133	19	87	12	198	28	134	19	164	23	44.6
		Koszęcin	1762	834	207	25	83	10	122	15	127	15	295	35	42.1
		city Lubliniec	546	270	14	5	18	7	56	21	58	21	124	46	22.2
		Pawonków	2158	1231	290	24	349	28	219	18	155	13	218	18	60.8
		Woźniki	1199	502	46	9	73	15	133	26	101	20	149	30	37.0
9	city Bielsko Biała	Bielsko-Biała	5.4	9	0	0	1	11	3	33	2	22	3	33	27.8
10	city Bytom	Bytom	122	96	1	1	0	0	24	25	46	48	25	26	13.5
11	city Chorzów	Chorzów	106	30	0	0	0	0	0	0	1	3	29	97	0.0
12	city Częstochowa	Częstochowa	404	115	18	16	38	33	34	30	14	12	11	10	63.5
13	city Dąbrowa Górnicza	Dąbrowa Górnicza	5.5	3	0	0	1	33	0	0	0	0	2	67	33.3
14	city Gliwice	Gliwice	3052	1390	150	11	180	13	422	30	301	22	337	24	38.9
15	city. Jastrzębie Zdrój	Jastrzębie-Zdrój	5202	125	2	2	7	6	12	10	18	14	86	69	12.0
16	city Jaworzno	Jaworzno	669	225	6	3	20	9	17	8	27	12	155	69	15.3
17	city Katowice	Katowice	4.2	6	0	0	0	0	0	0	0	0	6	100	0.0

Table 10. Cont. Soil abundance in available magnesium in the Silesian province (2004-2009)

Item	Poviat	Municipality	Analysed area in ha	Number of samples collected	Magnesium										Negative validation
					very low unit / %		low unit / %		medium unit / %		high unit / %		very high unit / %		
18	city Mysłowice	Mysłowice	377	217	28	13	32	15	37	17	38	18	82	38	36.2
19	city Piekary Śląskie	Piekary Śląskie	179	112	1	1	2	2	8	7	15	13	86	77	6.3
20	city Ruda Śląska	Ruda Śląska	55.5	63	4	6	15	24	15	24	9	14	20	32	42.1
21	city Rybnik	Rybnik	326	91	20	22	26	29	16	18	6	7	23	25	59.3
22	city Siemianowice Śląskie	Siemianowice Śląskie	46.9	30	0	0	7	23	13	43	3	10	7	23	45.0
23	city Sosnowiec	Sosnowiec	0.8	6	0	0	0	0	4	67	0	0	2	33	33.3
24	city Tychy	Tychy	1730	843	75	9	108	13	154	18	129	15	377	45	30.8
25	city Zabrze	Zabrze	54.2	131	0	0	0	0	11	8	15	11	105	80	4.2
26	city Żory	city Żory	418	476	59	12	61	13	88	18	91	19	177	37	34.5
27	mikołowski	**total**	**5268**	**1447**	**262**	**18**	**307**	**21**	**280**	**19**	**193**	**13**	**405**	**28**	**49.0**
		city Łaziska Górne	306	145	15	10	18	12	22	15	17	12	73	50	30.3
		city Mikołów	1153	649	102	16	143	22	136	21	88	14	180	28	48.2

		city Orzesze	581	424	81	19	103	24	78	18	56	13	106	25	52.6
		Ornontowice	1016	84	16	19	15	18	19	23	13	15	21	25	48.2
		Wyry	2211	145	48	33	28	19	25	17	19	13	25	17	61.0
28	myszkowski	**total**	**19197**	**2245**	**616**	**27**	**397**	**18**	**554**	**25**	**334**	**15**	**344**	**15**	**57.5**
		Koziegłowy	1293	771	178	23	143	19	178	23	116	15	156	20	53.2
		city Myszków	1020	478	72	15	36	8	119	25	132	28	119	25	35.0
		Niegowa	9160	921	340	37	203	22	243	26	79	9	56	6	72.1
		Poraj	2829	28	9	32	4	14	4	14	0	0	11	39	53.6
		Żarki	4894	47	17	36	11	23	10	21	7	15	2	4	70.2
29	pszczyński	**total**	**10364**	**6693**	**694**	**10**	**1329**	**20**	**1622**	**24**	**1125**	**17**	**1923**	**29**	**42.3**
		Goczałkowice-Zdrój	211	156	20	13	54	35	34	22	27	17	21	13	58.3
		Kobiór	224	150	19	13	32	21	20	13	25	17	54	36	40.7
		Miedźna	1379	1127	102	9	227	20	327	29	207	18	264	23	43.7
		Pawłowice	3742	2176	162	7	319	15	536	25	353	16	806	37	34.4
		Pszczyna	2729	1693	143	8	325	19	417	25	321	19	487	29	40.0
		Suszec	2079	1391	248	18	372	27	288	21	192	14	291	21	54.9

Table 10. Cont. Soil abundance in available magnesium in the Silesian province (2004-2009)

Item	Poviat	Municipality	Analysed area in ha	Number of samples collected	Magnesium										Negative validation
					very low unit / %		low unit / %		medium unit / %		high unit / %		very high unit / %		
30	raciborski	**total**	**28539**	**13452**	**689**	**5**	**2433**	**18**	**5579**	**41**	**2719**	**20**	**2032**	**15**	**43.9**
		Kornowac	565	542	45	8	94	17	108	20	110	20	185	34	35.6
		Krzanowice	6166	2375	49	2	417	18	1144	48	495	21	270	11	43.7
		Krzyżanowice	4698	2073	73	4	285	14	929	45	451	22	335	16	39.7
		Kuźnia Raciborska	860	728	45	6	66	9	124	17	172	24	321	44	23.8
		city Racibórz	3210	1868	73	4	326	17	727	39	460	25	282	15	40.8
		Nędza	1195	734	90	12	65	9	115	16	136	19	328	45	29.0
		Pietrowice Wielkie	3265	1853	56	3	279	15	837	45	502	27	179	10	40.7
		Rudnik	8580	3279	258	8	901	27	1595	49	393	12	132	4	59.7
31	rybnicki	**total**	**1643**	**617**	**112**	**18**	**141**	**23**	**143**	**23**	**108**	**18**	**113**	**18**	**52.6**
		Czerwionka-Leszczyny	955	370	107	29	113	31	74	20	36	10	40	11	69.5
		Lyski	615	186	2	1	19	10	42	23	52	28	71	38	22.6
		Świerklany	72.5	61	3	5	9	15	27	44	20	33	2	3	41.8

32	tarnogórski	**total**	**12242**	**6329**	**961**	**15**	**951**	**15**	**1486**	**23**	**1141**	**18**	**1790**	**28**	**41.9**
		Krupski Młyn	350	188	2	1	12	6	67	36	54	29	53	28	25.3
		city Kalety	126	131	13	10	11	8	31	24	29	22	47	36	30.2
		city Miasteczko Śląskie	54.8	20	2	10	1	5	6	30	3	15	8	40	30.0
		city Radzionków	174.9	68	0	0	11	16	16	24	7	10	34	50	27.9
		city Tarnowskie Góry	656	382	112	29	42	11	45	12	46	12	137	36	46.2
		Ożarowice	262	220	26	12	18	8	48	22	27	12	101	46	30.9
		Świerklaniec	91	38	16	42	14	37	3	8	3	8	2	5	82.9
		Tworóg	1687	981	200	20	189	19	238	24	150	15	204	21	51.8
		Zbrosławice	8840	4301	590	14	653	15	1032	24	822	19	1204	28	40.9
33	wodzisławski	**total**	**3202**	**3188**	**409**	**13**	**454**	**14**	**575**	**18**	**549**	**17**	**1201**	**38**	**36.1**
		Godów	808	1100	235	21	178	16	215	20	141	13	331	30	47.3
		Gorzyce	656	556	84	15	62	11	82	15	90	16	238	43	33.6
		Lubomia	788	688	18	3	65	9	86	13	141	20	378	55	18.3

Table 10. Cont. Soil abundance in available magnesium in the Silesian province (2004-2009)

Item	Poviat	Municipality	Analysed area in ha	Number of samples collected	Magnesium										Negative validation
					very low unit / %		low unit / %		medium unit / %		high unit / %		very high unit / %		
33	wodzisławski	city Pszów	56	36	1	3	0	0	11	31	20	56	4	11	18.1
		city Radlin	4	8	0	0	2	25	0	0	0	0	6	75	25.0
		city Rydułtowy	36.6	71	3	4	8	11	9	13	13	18	38	54	21.8
		city Wodzisław Śląski	158	95	17	18	13	14	25	26	26	27	14	15	44.7
		Marklowice	249	207	16	8	62	30	41	20	32	15	56	27	47.6
		Mszana	446	427	35	8	64	15	106	25	86	20	136	32	35.6
34	zawierciański	**total**	**70581**	**6919**	**2651**	**38**	**1613**	**23**	**1521**	**22**	**607**	**9**	**527**	**8**	**72.6**
		Irządze	6637	751	172	23	186	25	282	38	87	12	24	3	66.4
		Kroczyce	1030	393	209	53	97	25	58	15	19	5	10	3	85.2
		Łazy	6611	105	16	15	41	39	28	27	7	7	13	12	67.6
		city Poręba	244	111	12	11	8	7	35	32	31	28	25	23	33.8
		city Zawiercie	9141	214	39	18	23	11	27	13	28	13	97	45	35.3

		Ogrodzieniec	411	364	171	47	102	28	62	17	17	5	12	3	83.5
		Pilica	15314	2206	946	43	499	23	434	20	180	8	147	7	75.3
		Szczekociny	13449	1160	423	36	267	23	252	22	119	10	99	9	70.3
		Włodowice	4805	82	29	35	26	32	15	18	7	9	5	6	76.2
		Żarnowiec	12939	1533	634	41	364	24	328	21	112	7	95	6	75.8
35	żywiecki	**total**	**7058**	**1639**	**195**	**12**	**323**	**20**	**552**	**34**	**291**	**18**	**278**	**17**	**48.4**
		Gilowice	1814	341	63	18	79	23	114	33	49	14	36	11	58.4
		Jeleśnia	1.7	5	0	0	1	20	3	60	0	0	1	20	50.0
		Koszarawa	9.7	24	3	13	4	17	8	33	3	13	6	25	45.8
		Lipowa	529	257	14	5	32	12	103	40	52	20	56	22	37.9
		Łękawica	7.1	3	2	67	0	0	0	0	1	33	0	0	66.7
		Łodygowice	462	646	56	9	107	17	192	30	139	22	152	24	40.1
		city Żywiec	10.7	17	1	6	1	6	5	29	5	29	5	29	26.5
		Milówka	0.1	1	0	0	0	0	0	0	0	0	1	100	0.0
		Radziechowy-Wieprz	4123	228	23	10	68	30	89	39	33	14	15	7	59.4

Table 10. Cont. Soil abundance in available magnesium in the Silesian province (2004-2009)

Item	Poviat	Municipality	Analysed area in ha	Number of samples collected	Magnesium										Negative validation
					very low unit / %		low unit / %		medium unit / %		high unit / %		very high unit / %		
35	żywiecki	Rajcza	4.2	14	2	14	4	29	7	50	1	7	0	0	67.9
		Ślemień	94.3	96	31	32	24	25	29	30	8	8	4	4	72.4
		Świnna	0.2	1	0	0	0	0	0	0	0	0	1	100	0.0
		Węgierska Górka	2.1	6	0	0	3	50	2	33	0	0	1	17	66.7
36	**Silesian Province**	**total**	**315498**	**79143**	**14723**	**19**	**14851**	**19**	**20646**	**26**	**12360**	**16**	**16563**	**21**	**50.4**

*This breakdown, does not include, due to the lack of data, the following municipalities: Szczyrk, Wilkowice, Kamienica Polska, Starcza, Gaszowice, Jejkowice, Czernichów, Ujsoły and Świętochłowice.

Detail analysis of the values presented in Table 9 indicates that in as many as 67 rural communes, 13 town-village communes and 5 township communes over 50% of soils are soil with very low and low richness in available potassium. The most soils poor in that component are found in the districts of Będzin, Bieruń-Lędzin, Częstochowa, Kłobuck, Lubliniec, Mikołów, Myszków, Rybnik, Zawiercie, Żywiec and Cieszyn. Communes in which most soils are characterised by very low levels of that element include Kozy, Istebna, Janów, Koniecpol, Kruszyna, Mykanów, Olsztyn, all communes of the district of Kłobuck, as well as Ciasna, Herby, Niegowa, Poraj Żarki, and also Pilica, Żarnowiec, Jeleśnia, Koszarawa, Łękawica, Rajcza and Węgierska Górka (Adrianek and Skowronek 2008).

Data given in 10 indicate that 25% of soils in the province of Silesia are characterised by medium levels of available magnesium, and soils with very low and low levels of that component constitute 19% each. The remaining 37% of soils fall in the group of soils with high (16%) and very high (21%) levels of potassium. The value of the index of negative valuation is similar to that for phosphorus and amounts to 50.4%. The lowest levels of available magnesium are characteristic of soils in the districts of Częstochowa, Kłobuck and Zawiercie. In 39 communes, mainly from those districts, over one half of soils are soils with very low and low levels of that element (WIOŚ Report 2009).

Analysis of the soils of the province of Silesia in terms of the levels of available forms of phosphorus, potassium and magnesium permits the conclusion that in a majority of cases the soils that are the poorest in those components and the most acidified soils. This relation is very visible, especially in the case of potassium and phosphorus. A strong relation between the levels of the basic nutrients and soil reaction is indicated, among others, by studies performed at the IUNG – BIP. Those studies show that highly acid soils in over 50% have at the same time very low and low levels of available phosphorus. Whereas, in soils with adjusted reaction the share of soils with very low and low levels of phosphorus does not exceed 15%. The cited studies indicate also a strong relation between soil reaction and the levels of potassium and magnesium (Chwil *et al.* 2006).

Overall, it can be concluded that with progressing acidification of soils there appears impoverishment of the soils in the basic nutrients, which notably reduces the effectiveness and profitability of fertilisation.

5.2. Soil acidification and bioavailability of heavy metals

Every substance appearing at a higher elemental concentration relative to its occurrence at natural level constitutes a potential soil contamination hazard (Ruszkowska *et al*. 1996, Szatanik-Kloc 2004). In industrial regions, the primary source of heavy metals is the deposition of dusts, the main metals in the dust being cadmium, zinc and lead. Environmental problems related with the presence of metals in soil result from their mobility, form, and the conditions prevailing in the environment. Their behaviour is regulated primarily by the reaction of the soil (Brodowska and Kaczor 2008, Jackowska and Piotrowski 2001, Kaczor *et al*. 2009).

Increased levels of mobile forms of cadmium, zinc, lead and other metals are the cause of their inclusion by plants in the nutrition chain, which may constitute a hazard to living organisms. Cadmium is particularly dangerous to humans, while zinc, aluminium and manganese to plants. The negative effect of toxic elements on the soil and on plant, animal and human organisms results from the fact that those elements are subject to biological accumulation. This is especially dangerous in an environment with permanent pressure of a toxic factor.

Cadmium is highly mobile in soils with pH 4.5-5.5. The high mobility of cadmium is the cause of its rapid inclusion in the nutrition chain. Plants easily uptake that element, but under certain conditions a limiting effect of calcium is observed. That element constitutes a particular risk to man and animals, as it is easily absorbed, relatively long retained in tissues, and accumulates in organs with vital functions in the organism. It causes disturbance in the functioning of kidneys, chronic hypertensive disease, neoplastic changes, disturbed metabolism of calcium, and reproductive functions.

The occurrence of lead in the surface horizons of soils is largely related with the effect of anthropogenic factors. As a rule, its levels are higher relative to the natural content. Due to the global character of lead atmospheric pollution, anthropogenic accumulation of lead takes place in a majority of soils. Even if the levels of lead are acceptable from the viewpoint of ecotoxicity or phytotoxicity, an increased content of lead in soil may constitute a hazard to man. Lead introduced in soil accumulates mainly in the surface horizons. This is the cause of considerable concentration of the element, both as a result of one-time deposition and of low-level but long-term pollution. The highest threat to ecosystems is lead contamination of light acid soils. Long-term noxious effect of that metal causes also the degradation of resistant soils.

Significant emission of lead is generated by the non-ferrous metals metallurgy and casting industry. Locally, also the combustion of various kinds of coal in power generation plants may cause increased deposition of lead on the surface of the ground. Although the reach of atmospheric pollution is global, the strongest contamination is always observed in the regions of direct effect of the sources of the pollution. In such areas all the components of the natural environment – soil, water, flora and fauna – have increased levels of lead (Gorlach 1995).

The intensity of Pb uptake by plants depends primarily on the soil reaction. Soil liming may inhibit lead uptake by plants.

Almost all lead introduced in the human organism migrates to the blood and binds with the plasma proteins. A part of it is also deposited in the bones and in the soft tissues. Organs most exposed to the risk of lead poisoning include the liver, kidneys, bone marrow and the brain (Jackowska 2002, Radomski 2002, Wójcikowska-Kapusta and Martyn 1998).

The main source of excessive zinc levels for plants are the industrial emissions, both directly through the deposition of dusts on leaf blades, and indirectly through soil contamination. All forms of easily soluble zinc are available to plants. Zinc absorption by plants is determined primarily by the soil reaction.

Zinc is not highly toxic to animals and humans. The most sensitive to the metal are the ruminants that may suffer zinc poisoning after eating plants containing approximately 1000 mg Zn kg^{-1} d.m. The toxicity of zinc is related primarily with secondary deficit of copper. However, excessive levels of zinc in animal organisms is considered to the a cause of neoplastic diseases (Kaczor 1998).

Table 11 presents data on the levels of heavy metals in soils on the province of Silesia. The determinations were performed by the Agro-Chemical Station in Gliwice in the years 2004-2007.

Table 11. Content of heavy metals in soils of the province of Silesia (2003-2007)

Metal	Number of samples analysed	Lowest content (mg kg^{-1} d.m.)	Highest content (mg kg^{-1} d.m.)	Permissible value	Number of points with excessive levels of heavy metals
Lead	1208	0.94	2299.94	100	416
Cadmium	1289	0.1	171.7	4	348
Zinc	946	12.5	13488	300	402
Chromium	531	0.45	147.05	150	0
Nickel	576	<0.06	54.36	100	0
Copper	300	1	60.4	150	0
Mercury	285	0	5.907	2	1

As follows from the data given in the Table, the soils of the province of Silesia are the most contaminated with zinc, lead and cadmium. Among 946 soil samples analysed for the content of zinc, in as many as 402 cases the levels determined exceeded the permissible value (42.5%). In the case of lead, excessive levels were found in 416 samples (34.4%), and cadmium in 348 (27%). Generally, it can be stated that high levels of those metals occur on more than a third of the soils of the province of Silesia.

Detailed data indicate that the highest levels of zinc, frequently exceeding the permissible value by a factor of 5-7, occur in the soils of communes in the following districts:

- Będzin (communes Będzin, Czeladź, Wojkowice, Bobrowniki, Mierzęcice, Psary, Siewierz, Sławków);
- Gliwice (communes Rudziniec, Pyskowice);
- Mikołów (commune Łaziska Górne);
- Bieruń–Lędziny (comune Imielin);
- Dąbrowa Górnicza;
- Jaworzno;
- Żory;
- Tychy.

The highest levels of lead, considerably exceeding the permissible values, were recorded in the following communes:

- Będzin district (communes Będzin, Czeladź, Wojkowice, Bobrowniki, Mierzęcice, Psary Siewierz, Sławków),
- Częstochowa district (communes Poczesna, Rędziny),
- Gliwice district (communes Pyskowice, Rudziniec),
- Mikołów district (commune Łaziska Górne),
- Myszków district (commune Poraj),
- Bieruń-Lędziny district (commune Imielin),
- Zawiercie district (commune Zawiercie),
- Dąbrowa Górnicza,
- Jaworzno,
- Rybnik.

Cadmium levels considerably exceeding the permissible values were found in the soils of the following communes:

- Będzin district (communes Będzin, Czeladź, Wojkowice, Bobrowniki, Mierzęcice, Psary, Siewierz, Sławków),
- Częstochowa district (communes Dąbrowa Zielona, Koniecpol),

- Gliwice district (commune Rudziniec),
- Zawiercie district (commune Zawiercie),
- Dąbrowa Górnicza,
- Jaworzno,
- Tychy.

Analysis of the content of heavy metals and the reaction of the soils permits the conclusion that in many cases high levels of zinc, lead and cadmium are accompanied by acid reaction of the soils. Such a relation occurs in the communes Poczesna and Rędziny (district of Częstochowa), Łaziskah Górne (district of Mikołów), Dąbrowa Zielona and Koniecpol (district of Częstochowa), and also in Żory, Tychy and Rybnik. However, no such regularity was found in the soils of the district of Będzin. In many communes of that district most soils are characterised by pH values close to the optimum, and at the same time they are strongly contaminated with zinc, lead and cadmium. This can be attributed to very high imission of dusts in that area, containing large amounts of those metals.

Summing up, we should emphasise that as a result of anthropogenic effects (industrial dusts) the soils of the province of Silesia are contaminated with heavy metals in the highest degree. As mentioned before, the bioavailability of heavy metals in the soils inhibits the regulation of their reaction to the optimum to the greatest extent. In the context of this situation, regular liming of the soils in the province of Silesia is a necessary treatment, as on the one hand it will protect the soils from further degradation, and on the other it will make them safer in food and fodder production, and thus will contribute to an improvement of the health status of humans and animals.

5.3. Chemical composition of soils and plant yielding

High yields of crop plants can be obtained on soils with regulated reaction. Every crop plant species can develop within a fairly broad range of pH values, yet the maximum yields are obtained at optimum values of soil reaction for particular crop plant species – Table 12.

The ionic composition of strongly acid soils diverges considerably from the nutritional requirements of plants. In spite of considerable abilities of plants to regulate, within their mass, the distribution and concentration of ions, in a majority of cases there is a relatively strong correlation between the ionic composition of soils and the ionic composition of plants. As a result, plants growing under the conditions of acid soils absorb excessive amounts of ions characteristic of acid environments (aluminium, manganese, sulphur, heavy metals), and such components as magnesium, calcium, phosphorus and molybdenum are usually absorbed in insufficient quantities.

Table 12. Optimum ranges of pH for crop plants

Sensitivity of crop plants to acid reaction of soil	Crop plant species	Optimum pH of soil
Little sensitive plants	lupine, Ornithopus, flax, rye, grasses	5.1-5.5
Medium sensitive plants	oat, potato, cereal mixes, fodder mixes	5.6-6.0
Sensitive plants	wheat, rapeseed, broad bean, white lupine, faba bean, triticale	6.1-6.5
Highly sensitive plants	beets, maize, lucerne, clover, soybean, barley	6.6-7.0

Commonly accepted as the key factors of the status of acidification are high levels of active aluminium in the soil and, in some cases, also of manganese. With lowering pH values there is an increase in the concentration of hydrogen and aluminium ions in the soil solution, the result of which is uptake of alkaline ions by plants. Active aluminium causes also a reduction in the uptake of phosphorus and molybdenum by plants.

With an acute deficit or high excess of components, characteristic changes begin to appear on plant organs, informing about disturbances in the mineral composition of plants.

Characteristic symptoms of excessive levels of aluminium appear on plant roots. The roots, due to inhibition of their elongation, become shorter, thicker and twisted. At high levels of aluminium in the soil solution, the meristems of the main root, and then those of the side roots tend to brown and then decay. The whole root system becomes weak and brittle, and it is no longer able to provide the plant with sufficient amount of water and nutrients.

The conclusion of a toxic effect of aluminium on aboveground parts of plants is arrived at indirectly. That effect is manifested by changes characteristic of a deficit of magnesium, phosphorus and calcium (Kaczor 1998, Kaczor and Kozłowska 2000).

Opposite to aluminium, manganese is easily transported from the rots to the shoots, and therefore the symptoms of toxicity of that element can be observed on the aboveground parts of plants. Specific symptoms of excessive levels of manganese appear most frequently in the form of brown spots on older organs of plants (Józefaciuk and Szatanik-Kloc 2002).

Summing up, it should be stated that plants growing in an acid environment are frequently characterised by a deficit of components necessary for human and animal nutrition, and by an excess of components that may be the cause of various diseases. Apart from the questionable quality of the obtained agricultural produce, acid reaction of soils causes also a notable reduction in the level of crop yields.

It is estimated that in Poland, after the regulation of soil reaction, the yields of crop plants would increase by at least 12-15% compared to the yields obtained at present. Whereas, it is impossible to estimate the losses resulting from the activation of many toxic elements that, in acid soils, are subject to intensified leaching together with the basic biogens (Wujec 2006).

6. SOIL LIMING REQUIREMENTS IN THE PROVINCE OF SILESIA

6.1. Ranges of soil liming requirements, doses and principles of the use of fertilisers for de-acidification of soils

The Polish system of agrochemical evaluation of soils discerns 5 ranges of soil liming requirements - necessary, needed, recommended, limited and not required – Table 13. The ranges are related to the agronomical category of soils. As follows from the Table, the optimum range of pH for very light soils is 5.1-5.5 pH, for medium-heavy soils 6.1-6.5 pH, and for heavy soils 6.6-7.0. This differentiation is related with the buffering properties of soils, i.e. their ability to counteract sudden changes in reaction. The differentiation of the ranges of pH values with relation to the agronomical category of soils results also from the fact that on lighter soils crop rotations are dominated by plants with lower requirements concerning the soil reaction (rye, oats, potato), while on heavier soils species with stronger response to liming dominate (beets, maize, wheat, barley, rapeseed) (Chwil *et al*. 2006, Fotyma and Zięba 1989).

Table 13. Liming needs – ranges

Agronomic soil category	pH for the range of liming needs				
	necessary	needed	recommended	limited	superfluous
Very Light	up to 4.0	4.1-4.5	4.6-5.0	5.1-5.5	from 5.6
Light	up to 4.5	4.6-5.0	5.1-5.5	5.6-6.0	from 6.1
Medium	up to 5.0	5.1-5.5	5.6-6.0	6.1-6.5	from 6.6
Heavy	up to 5.5	5.6-6.0	6.1-6.5	6.6-7.0	from 7.1
Grassland	up to 5.0	5.1-5.5	5.6-6.0	–	–

Optimum pH range

Table 14 presents data concerning the soil liming requirements in communes within the territory of rural districts and towns with the status of township districts and township communes.

As follows from the data given in those Tables, in the whole province of Silesia 35% of arable soils require liming as a necessary treatment, 17% fall in the range of “liming needed”, and in the case of 19% of the soils liming is “recommended”. The area of soils on which liming should be limited is 15%, and the treatment is not required on 14% of the area of arable soils. Liming requirements expressed for the scale of the province by the index of negative valuation (sum of soils in the ranges “necessary” and “needed” and one half of soils in the range “recommended”) amount to 61.5%. The relative share of soils in the particular groups of liming requirements is a resultant of the reaction and the particle size distribution of the soils. As a result of these relations – in spite of the similarity of the shares of acid and highly soils in Poland and in the province of Silesia – liming requirements in the province under analysis are approximately 4% higher.

Detail analysis of the data given in Table 14 permits the conclusion that in 66 rural communes, 9 village-town communes and 3 township communes more than a half of the soils under study qualify for the ranges in which liming is either necessary or needed. The greatest liming requirements appear in the districts of Kłobuck (all communes), Żywiec (11 communes), Wodzisław (communes Gorzyce, Marklowice, Mszana), and also in a majority of communes in the districts of Bielsko

Table 14. Soil liming needs in the Silesian province

Item	Poviat	Municipality	Analysed area in ha	Number of samples collected	Liming needs										Negative validation
					necessary unit / %		needed unit / %		recommended unit / %		limited unit / %		superfluous unit / %		
1	będziński	**total**	**14620**	**1113**	**42**	**4**	**57**	**5**	**78**	**7**	**128**	**11**	**808**	**73**	**12.5**
		Bobrowniki	2409	104	8	8	7	7	10	9	20	19	59	57	19.5
		city Będzin	1496	65	2	3	1	1	2	3	3	5	57	88	5.5
		city Czeladź	220	53	0	0	0	0	3	6	4	7	46	87	3
		city Sławków	760	77	2	3	0	0	0	0	7	9	68	88	3
		Mierzęcice	2827	211	21	10	27	13	25	12	31	14	107	51	29
		Psary	2705	222	3	1	3	1	10	5	31	14	175	79	4.5
		Siewierz	4058	309	6	2	19	6	28	9	30	10	226	73	12.5
		Wojkowice	144	72	0	0	0	0	0	0	2	3	70	97	0
2	bielski	**total**	**10857**	**2963**	**1187**	**40**	**617**	**21**	**607**	**20**	**288**	**10**	**264**	**9**	**71**
		Bestwina	4320	390	204	52	84	22	69	18	21	5	12	3	83
		Buczkowice	1.6	10	7	70	2	20	1	10	0	0	0	0	95
		Czechowice-Dziedzice	1428	864	428	50	160	19	147	17	82	9	47	5	77.5
		Jasienica	1810	981	334	37	206	20	195	20	108	9	138	14	67

Table 14. Cont. Soil liming needs in the Silesian province

Item	Poviat	Municipality	Analysed area in ha	Number of samples collected	Liming needs										Negative validation
					necessary unit / %		needed unit / %		recommended unit / %		limited unit / %		superfluous unit / %		
2	bielski	Jaworze	402	304	60	20	79	26	65	21	42	14	58	19	56.5
		Kozy	90	48	28	58	10	21	8	17	2	4	0	0	87.5
		Porąbka	2169	65	36	56	6	9	13	20	6	9	4	6	75
		Wilamowice	637	301	90	30	70	23	109	36	27	9	5	2	71
		total	**6062**	**2971**	**1022**	**34**	**493**	**17**	**459**	**15**	**446**	**15**	**551**	**19**	**58.5**
3	bieruńsko - lędziński	Bojszowy	754	548	254	46	109	20	85	16	65	12	35	6	74
		Chełm Śląski	367	214	84	39	41	19	39	18	33	16	17	8	67
		Lędziny	1723	1265	429	34	210	17	187	15	182	14	257	20	58.5
		city Bieruń	1612	836	247	34	119	14	138	18	140	17	192	17	57
		city Imielin	1606	108	8	7	14	13	10	9	26	24	50	47	24.5
		total	**7821**	**2981**	**1023**	**34**	**593**	**20**	**518**	**17**	**417**	**14**	**430**	**15**	**62.5**
		Babice	1.3	4	0	0	1	25	0	0	1	25	2	50	25
		Brenna	102	29	5	17	4	14	2	7	9	31	9	31	34.5
		Chybie	454	166	59	35	28	17	32	19	26	16	21	13	61.5

4	cieszyński	Dębowiec	1319	566	95	17	72	13	99	17	110	19	190	34	38.5
		Goleszów	625	233	36	15	26	11	34	15	60	26	77	33	33.5
		Hażlach	459	270	96	35	64	24	42	16	43	16	25	9	67
		Istebna	500	7	4	57	0	0	2	29	1	14	0	0	71.5
		city Cieszyn	86.1	30	2	7	3	10	3	10	4	13	18	60	22
		city Ustroń	64.4	37	19	51	10	27	5	14	2	5	1	3	85
		city Wisła	204	263	174	66	53	20	25	10	9	3	2	1	91
		Skoczów	388	193	58	30	34	18	42	22	27	14	32	16	59
		Strumień	874	545	211	39	152	28	110	20	46	8	26	5	77
		Zebrzydowice	2745	638	264	42	146	23	122	19	79	12	27	4	74.5
5	częstochowski	**total**	**51324**	**3218**	**1886**	**59**	**381**	**12**	**252**	**7**	**257**	**8**	**442**	**14**	**74.5**
		Blachownia	2.4	3	0	0	1	34	0	0	1	33	1	33	34
		Dąbrowa Zielona	10054	67	34	51	10	15	5	8	7	10	11	16	70
		Janów	529	229	94	41	26	12	16	7	11	4	82	36	56.5
		Kłomnice	989	611	312	51	109	18	57	9	67	11	66	11	73.5
		Koniecpol	11108	59	14	24	14	24	7	12	11	18	13	22	54
		Konopiska	8.3	8	2	25	2	25	1	13	2	25	1	12	56.5

Table 14. Cont. Soil liming needs in the Silesian province

Item	Poviat	Municipality	Analysed area in ha	Number of samples collected	Liming needs										Negative validation
					necessary unit / %		needed unit / %		recommended unit / %		limited unit / %		superfluous unit / %		
5	częstochowski	Kruszyna	1301	663	479	72	52	8	39	6	45	7	48	7	83
		Lelów	1034	425	286	67	48	11	23	5	28	7	40	10	80.5
		Mstów	191	108	21	20	8	7	8	7	11	10	60	56	30.5
		Mykanów	15542	847	557	66	80	9	72	9	52	6	86	10	79.5
		Olsztyn	9	10	4	40	0	0	4	40	1	10	1	10	60
		Poczesna	6310	89	26	29	20	22	15	17	13	15	15	17	59.5
		Przyrów	32.5	20	12	60	4	20	4	20	0	0	0	0	90
		Rędziny	4213	79	45	57	7	9	1	1	8	10	18	23	66.5
6	gliwicki	**total**	**34292**	**8270**	**1996**	**24**	**1460**	**18**	**1916**	**23**	**1644**	**20**	**1254**	**15**	**53.5**
		Gierałtowice	1895	1252	343	27	255	20	282	23	234	19	138	11	58.5
		city Knurów	49.5	24	6	25	6	25	5	21	4	17	3	12	60.5
		city Pyskowice	325	206	94	46	38	19	34	16	21	10	19	9	73
		Pilchowice	7658	558	69	12	159	28	199	36	77	14	54	10	58
		Rudziniec	13677	1623	140	9	272	17	461	28	420	26	330	20	40

		Sośnicowice	2555	1088	366	34	172	16	256	23	202	19	92	8	61.5
		Toszek	3859	1612	374	23	275	17	335	21	399	25	229	14	50.5
		Wielowieś	4274	1907	604	32	283	15	344	18	287	15	389	20	56
7	kłobucki	**total**	**6889**	**4513**	**3014**	**67**	**691**	**15**	**429**	**9**	**255**	**6**	**124**	**3**	**86.5**
		Kłobuck	697	445	297	67	60	13	44	10	28	6	16	4	85
		Krzepice	1263	783	482	62	138	18	80	10	63	8	20	2	85
		Lipie	309	205	151	74	36	18	9	4	7	3	2	1	94
		Miedźno	47.2	30	19	63	6	20	2	7	1	3	2	7	86.5
		Opatów	520	321	234	73	35	11	30	9	12	4	10	3	88.5
		Panki	691	419	275	66	70	17	44	10	24	6	6	1	88
		Popów	1169	751	555	74	86	12	63	8	31	4	16	2	90
		Przystajń	1893	1307	878	67	210	16	118	9	60	5	41	3	87.5
		Wręczyca Wielka	298	252	123	49	50	20	39	15	29	12	11	4	76.5
8	lubliniecki	**total**	**12780**	**6625**	**2558**	**39**	**1304**	**20**	**1341**	**20**	**869**	**13**	**553**	**8**	**69**
		Boronów	104.2	83	24	29	22	26	18	22	9	11	10	12	66
		Ciasna	5068	2565	1021	40	523	20	579	23	334	13	108	4	71.5
		Herby	509	416	184	44	89	21	65	16	50	12	28	7	73

Table 14. Cont. Soil liming needs in the Silesian province

Item	Poviat	Municipality	Analysed area in ha	Number of samples collected	Liming needs										Negative validation
					necessary unit / %		needed unit / %		recommended unit / %		limited unit / %		superfluous unit / %		
8	lubliniecki	Kochanowice	1434	716	226	32	146	20	162	23	88	12	94	13	63.5
		Koszęcin	1762	834	400	48	133	16	112	14	87	10	102	12	71
		city Lubliniec	546	274	41	15	44	16	63	23	64	23	62	23	42.5
		Pawonków	2158	1235	529	43	254	20	247	20	132	11	73	6	73
		Woźniki	1199	502	133	26	93	19	95	19	105	21	76	15	54.5
9	city Bielsko Biała	Bielsko-Biała	5.4	9	5	56	2	22	2	22	0	0	0	0	89
10	city Bytom	Bytom	122	96	7	7	16	17	10	10	13	14	50	52	29
11	city Chorzów	Chorzów	106.1	30	0	0	0	0	0	0	0	0	30	100	0
12	city Częstochowa	Częstochowa	404	115	17	15	34	30	36	31	21	18	7	6	60.5
13	city Dąbrowa Górnicza	Dąbrowa Górnicza	5.5	3	1	33	0	0	0	0	0	0	2	67	33
14	city Gliwice	Gliwice	3052	1431	299	21	183	13	309	21	315	22	325	23	44.5
15	city Jastrzębie Zdrój	Jastrzębie-Zdrój	5202	125	31	25	20	16	25	20	18	14	31	25	51
16	city Jaworzno	Jaworzno	669	225	7	3	21	9	27	12	32	14	138	62	18

17	city Katowice	Katowice	4.2	6	0	0	0	0	0	0	2	33	4	67	0
18	city Mysłowice	Mysłowice	377	220	54	25	34	15	31	14	39	18	62	28	47
19	city Piekary Śląskie	Piekary Śląskie	180	112	4	4	5	4	25	22	31	28	47	42	19
20	city Ruda Śląska	Ruda Śląska	55.5	63	8	13	26	41	19	30	4	6	6	10	69
21	city Rybnik	Rybnik	326	91	34	37	8	9	20	22	8	9	21	23	57
22	city Siemianowice Śląskie	Siemianowice Śląskie	46.9	30	1	3	6	20	3	10	4	13	16	54	28
23	city Sosnowiec	Sosnowiec	0.8	6	0	0	0	0	0	0	0	0	6	100	0
24	city Tychy	Tychy	1730	843	340	40	148	18	145	17	110	13	100	12	66.5
25	city Zabrze	Zabrze	54.2	131	0	0	1	1	7	5	10	8	113	86	3.5
26	city Żory	city Żory	418	476	168	35	129	27	108	23	60	13	11	2	73.5
27	mikołowski	**total**	**5268**	**1447**	**482**	**33**	**265**	**19**	**254**	**18**	**252**	**17**	**194**	**13**	**61**
		city Łaziska Górne	306	145	52	36	30	21	26	18	21	14	16	11	66
		city Mikołów	1153	649	119	18	90	14	131	20	177	28	132	20	42
		city Orzesze	581	424	186	44	110	26	73	17	35	8	20	5	78.5
		Ornontowice	1016	84	33	39	7	8	11	13	10	12	23	28	53.5
		Wyry	2211	145	92	64	28	19	13	9	9	6	3	2	87.5

Table 14. Cont. Soil liming needs in the Silesian province

Item	Poviat	Municipality	Analysed area in ha	Number of samples collected	Liming needs										Negative validation
					necessary unit / %		needed unit / %		recommended unit / %		limited unit / %		superfluous unit / %		
28	myszkowski	**total**	**19197**	**2245**	**1043**	**46**	**305**	**14**	**344**	**15**	**258**	**12**	**295**	**13**	**67.5**
		Koziegłowy	1293	771	243	31	143	19	141	18	115	15	129	17	59
		city Myszków	1020	478	72	15	86	18	136	29	102	21	82	17	47.5
		Niegowa	9160	921	707	77	65	7	59	6	33	4	57	6	87
		Poraj	2829	28	8	28	3	11	3	11	5	18	9	32	44.5
		Żarki	4894	47	13	28	8	17	5	11	3	6	18	38	50.5
29	pszczyński	**total**	**10364**	**6693**	**2181**	**33**	**1265**	**19**	**1298**	**19**	**1137**	**17**	**812**	**12**	**61.5**
		Goczałkowice-Zdrój	211	156	38	24	34	22	24	16	30	19	30	19	54
		Kobiór	224	150	50	34	21	14	41	27	21	14	17	11	61.5
		Miedźna	1379	1127	341	30	177	16	229	20	235	232	145	13	56
		Pawłowice	3742	2176	1034	48	483	22	381	17	189	9	89	4	78.5
		Pszczyna	2729	1693	300	18	245	15	343	20	430	25	375	22	43
		Suszec	2079	1391	418	30	305	22	280	20	232	17	156	11	62

30	raciborski	**total**	**28539**	**13452**	**2552**	**19**	**2556**	**19**	**4117**	**31**	**2764**	**20**	**1463**	**11**	**53.5**
		Kornowac	565	542	206	38	94	17	122	23	70	13	50	9	66.5
		Krzanowice	6166	2375	314	13	450	19	764	32	549	23	298	13	48
		Krzyżanowice	4698	2073	401	19	435	21	655	32	482	23	100	5	56
		Kuźnia Raciborska	860	728	217	30	142	20	178	24	115	16	76	10	62
		city Racibórz	3210	1868	346	19	326	17	420	22	422	23	354	19	47
		Nędza	1195	734	272	37	114	15	119	16	122	17	107	15	60
		Pietrowice Wielkie	3265	1853	380	20	349	19	510	28	315	17	299	16	53
		Rudnik	8580	3279	416	13	646	20	1349	41	689	21	179	5	53.5
31	rybnicki	**total**	**1643**	**617**	**182**	**30**	**107**	**17**	**173**	**28**	**107**	**17**	**48**	**8**	**61**
		Czerwionka-Leszczyny	955	370	160	43	77	21	91	25	17	4	25	7	76.5
		Lyski	615	186	3	2	9	5	63	34	88	47	23	12	24
		Świerklany	72.5	61	19	31	21	35	19	31	2	3	0	0	81.5
32	tarnogórski	**total**	**12242**	**6336**	**1510**	**24**	**1219**	**19**	**1339**	**21**	**1196**	**19**	**1072**	**17**	**53.5**
		Krupski Młyn	350	188	59	31	20	11	34	18	56	30	19	10	51
		city Kalety	126	133	32	24	31	23	33	25	20	15	17	13	59.5

Table 14. Cont. Soil liming needs in the Silesian province

Item	Poviat	Municipality	Analysed area in ha	Number of samples collected	Liming needs: necessary unit	/ %	needed unit	/ %	recommended unit	/ %	limited unit	/ %	superfluous unit	/ %	Negative validation
		city Miasteczko Śląskie	54.8	22	1	5	2	9	4	18	4	18	11	50	23
		city Radzionków	175	68	6	9	5	7	8	12	15	22	34	50	22
32	tarnogórski	city Tarnowskie Góry	656	382	139	37	58	15	39	10	58	15	88	23	57
		Ożarowice	262	220	20	9	44	20	38	17	37	17	81	37	37.5
		Świerklaniec	91	38	1	3	0	0	4	10	5	13	28	74	8
		Tworóg	1687	984	229	27	227	23	232	24	152	15	144	15	62
		Zbrosławice	8840	4301	1023	24	832	19	947	22	849	20	650	15	54
		total	**3202**	**3188**	**1656**	**52**	**556**	**18**	**480**	**15**	**324**	**10**	**172**	**5**	**77.5**
		Godów	808	1100	548	50	205	19	153	14	124	11	70	6	76
		Gorzyce	656	556	344	62	78	14	77	14	33	6	24	4	83
33	wodzisławski	Lubomia	788	688	330	48	118	17	108	16	92	13	40	6	73
		city Pszów	56	36	11	31	17	47	6	17	0	0	2	5	86.5
		city Radlin	4	8	3	38	1	12	1	12	2	26	1	12	56

		city Rydułtowy	36.6	71	25	35	15	21	10	14	8	11	13	19	63
		city Wodzisław Śląski	158	95	39	41	27	28	19	20	9	10	1	1	79
		Marklowice	249	207	126	61	37	18	29	14	5	2	10	5	86
		Mszana	446	427	230	54	58	14	77	18	51	12	11	2	77
34	zawierciański	**total**	**70581**	**6919**	**3528**	**51**	**818**	**12**	**727**	**11**	**569**	**8**	**1277**	**18**	**68.5**
		Irządze	6637	751	566	75	56	8	69	9	31	4	29	4	87.5
		Kroczyce	1030	393	203	52	42	10	23	6	32	8	93	24	65
		Łazy	6611	105	9	9	10	10	16	15	17	16	53	50	26.5
		city Poręba	244	111	34	31	28	25	28	25	12	11	9	8	68.5
		city Zawiercie	9141	214	15	7	10	5	26	12	47	22	116	54	18
		Ogrodzieniec	410.6	364	28	8	14	4	19	5	22	6	281	77	14.5
		Pilica	15314	2206	1117	51	322	15	248	11	160	7	359	16	71.5
		Szczekociny	13449	1160	549	47	148	13	149	13	132	11	182	16	66.5
		Włodowice	4805	82	10	12	8	10	12	15	4	5	48	58	29.5
		Żarnowice	12939	1533	997	65	180	12	137	9	112	7	107	7	81.5
35	żywiecki	**total**	**7058**	**1639**	**1068**	**65**	**252**	**15**	**173**	**11**	**89**	**5**	**57**	**4**	**85.5**
		Gilowice	1814	341	249	73	47	14	32	9	7	2	6	2	91.5

Table 14. Cont. Soil liming needs in the Silesian province

Item	Poviat	Municipality	Analysed area in ha	Number of samples collected	Liming needs										Negative validation
					necessary unit / %		needed unit / %		recommended unit / %		limited unit / %		superfluous unit / %		
35	żywiecki	Jeleśnia	1.7	5	4	80	1	20	0	0	0	0	0	0	100
		Koszarawa	9.7	24	23	96	1	4	0	0	0	0	0	0	100
		Lipowa	529	257	163	63	40	15	25	10	17	7	12	5	83
		Łękawica	7.1	3	2	67	1	33	0	0	0	0	0	0	100
		Łodygowice	462	646	426	66	97	15	68	10	32	5	23	4	86
		city Żywiec	10.7	17	6	35	2	12	7	41	2	12	0	0	67.5
		Milówka	0.1	1	0	0	0	0	0	0	0	0	1	100	0
		Radziechowy-Wieprz	4123	228	98	43	55	24	37	16	26	12	12	5	75
		Rajcza	4.2	14	14	100	0	0	0	0	0	0	0	0	100
		Ślemień	94.3	96	77	80	8	9	4	4	4	4	3	3	91
		Świnna	0.2	1	0	0	0	0	0	0	1	100	0	0	0
		Węgierska Górka	2.1	6	6	100	0	0	0	0	0	0	0	0	100
36	**Silesian Province**	**total**	**315498**	**79202**	**27906**	**35**	**13572**	**17**	**15272**	**19**	**11667**	**15**	**10785**	**14**	**61.5**

*This breakdown, due to the lack of data, does not include the following municipalites : Szczyrk, Wilkowice, Kamienica Polska, Starcza, Gaszowice, Jejkowice, Czernichów, Ujsoły and Świętochłowice. The demand for lime fertilizers in these municipalities was estimated further in this paper (table 14). As regards the Cieszyński poviat, the Babice municipality was additionally taken into account..

Biała,Częstochowa, Lubliniec, Zawiercie and Mikołów. In those districts, in as many as 43 communes the need for soil liming applies to from 51 to 100% of the area of arable lands.

Knowledge of soil reaction (pH_{KCl}) and its agronomical category permits the identification of the liming requirements and determination of the dose of calcium fertiliser to be applied – Table 15. As can be seen from the Table, the level of liming dose, expressed in t CaO ha^{-1} with relation to the value of pH_{KCl} (liming requirement range) and agronomical category varies within the range from 1 to 6 t CaO ha^{-1}.

Table 15. Optimum lime fertilizer doses recommended in Poland, in t CaO per 1 ha

Agronomic soil category	Range of liming needs			
	necessary	needed	recommended	limted
Very Light	3.0	2.0	1.0	–
Light	3.5	2.5	1.5	–
Medium	4.5	3.0	1.7	1.0
Heavy	6.0	3.0	2.0	1.0

In terms of chemical composition, fertilisers for the de-acidification of soils are classified as calcium fertilisers, calcium-magnesium fertilisers and calcium-silicate – magnesium fertilisers. Calcium fertilisers contain only calcium, in the form of oxides and carbonates, calcium-magnesium fertilisers are composed of calcium or magnesium oxides or both of those elements in carbonate forms, while the composition of calcium-silicate-magnesium fertilisers includes calcium and magnesium in the form of oxides and silicates – Tables 16 and 17.

From the viewpoint of agriculture, the division of that group of fertilisers into fast and low acting is highly important. Fertilisers that rapidly de-acidify the soil include oxide and hydroxide forms, and the slow acting ones are carbonates and silicates. Fast acting fertilisers should be applied on heavy soils with high buffering capacity. Whereas, carbonate and silicate forms are recommended for use on light soils. Application of oxide fertilisers on light soils may cause too violent a change of the soil reaction, which may have an unfavourable effect on the growth and yielding of plants.

Table 16. Assortment of lime fertilizers manufactured in Poland (after Chwil *et al*. 2006)

Fertilizer name	Group of fertilizers Chemical composition	Alkalinity (content of active component) (kg CaO t^{-1})	Physical form Other components and compounds (kg t^{-1})	Source of fertilizer achievement
Calcium oxide fertilizer	Calcium oxide CaO	I – about 800 II– about 700 III – about 600	amorphous white powder	Heating $CaCO_3$, worse kinds of quicklime achieved during producing the lime for building industry
Post-carbide lime	Hydroxide $Ca(OH)_2$	650-700	–	By-product at acetylene production
Ordinary calcium carbonate fertilizer	Carbonate $CaCO_3$	about 450	dusty, up to 50 H_2O	Crushing the lime rocks
Chalk calcium carbonate fertilizer	Carbonate $CaCO_3$	about 450	loose, white	Crushing the chalk lime
Calcium carbonate fertilizer – Chalk	Carbonate $CaCO_3$	400 - 450	amorphous, wet (up to 300 H_2O)	Natural beds of meadow or lake lime

Fertilizer name	Group of fertilizers Chemical composition	Alkalinity (content of active component) (kg CaO t^{-1})	Physical form Other components and compounds (kg t^{-1})	Source of fertilizer achievement
Post-cellulose lime	Carbonate $CaCO_3$	about 400	Wet (up to 250 H_2O) do 50 Cl, up to 15 S	Waste in cellulose-paper industry
Post-sodium lime	Carbonate $CaCO_3$	400-500	amorphous powder up to 100 H_2O, up to 25 Cl	Waste in sodium industry
Post-flotation lime	Carbonate $CaCO_3$	about 400	wet (up to 250 H_2O) up to 15 S	Waste at sulfur enriching process by means of flotation
Defecation lime	Carbonate $CaCO_3$	150-300	wet 1-4 N; 5-22 P; 0.4-4 K; microelements	Waste product from sugar plant

Table 17. Assortment of lime-magnesium fertilizers manufactured in Poland (after Chwil *et al.* 2006)

Fertilizer name	Group of fertilizers Chemical composition	Content of active component (kg CaO, MgO t^{-1})	Alkalinity (kg CaO t^{-1})	Physical form Other components	Source of fertilizer achievement
Magnesium oxide lime	Oxide CaO + MgO	550 CaO, 100 MgO	690	fine, additives of Zn, Cu, and Co	Dolomite heating
Magvit T	Oxide CaO + MgO	600-00 CaO, 100-200 MgO	740-896	dusty, small quantities of N, P, K, Zn, Mn, and Fe	Heating and crushing of dolomitized lime
Magnesium oxide lime 50%	Oxide CaO + MgO	300-400 CaO, 100-200 MgO	440-680	dusty, up to 3 kg Pb t^{-1} and additives of Zn, Mn, and Co	Waste product from zinc smelter plant
Magnesium carbonate lime	Carbonate $CaCO_3 \cdot MgCO_3 + CaCO_3$	460 CaO, 90 MgO	586	dusty	Mixture of crushed dolomite and lime at 1:1 ratio
Dolovit	Carbonate $CaCO_3 \cdot MgCO_3$	300 CaO, 190 MgO	566	dusty, contains Zn, Cu, B, Mo, Mn, and Fe	Crushed dolomite of particle diameter 0-3 mm

Fertilizer name	Group of fertilizers Chemical composition	Content of active component (kg CaO, MgO t^{-1})	Alkalinity (kg CaO t^{-1})	Physical form Other components	Source of fertilizer achievement
Magvit W	Carbonate $CaCO_3 \cdot MgCO_3$	420 CaO, 80 MgO	532	dusty, contains N, P, K, Zn, Mn, and Fe	Crushing of dolomitized lime
Magnesium carbonate lime	Carbonate $CaCO_3 \cdot MgCO_3$	400 CaO, 100-200 MgO	540-680	loose, fine, contains Zn, Cu, and Pb	Waste from zinc, copper, and lead ores flotation
Magnesium silicate lime	Mixed CaO + MgO $CaSiO_3 + MgSiO_3$	300-380 CaO, 70-150 MgO	398-590	dusty	Waste from ironworks

Liming has a favourable effect on soil properties, and consequently also on the yielding of plants, over several years. The frequency of application of the treatment depends on the sensitivity of the crops grown to acid reaction of soil, but the typical frequency of application of liming is every 4-5 years. Calcium fertilisers should be mixed with the soil, therefore they are applied on the stubble prior to post-harvest tillage or in autumn, before the pre-winter ploughing. When choosing fertilisers for the de-acidification of soils, those that include magnesium should be applied first on soils with low levels of that element.

On grasslands, liming is best applied in a non-vegetation period, e.g. in late autumn. Less frequently liming is applied in early spring, before the start of vegetation.

6.2. Use of and requirements for calcium fertilisers

The status of soil acidification is related with the use of calcium fertilisers. In Poland, in 1980, that use amounted to 160 kg CaO ha^{-1}, and in 1990 – 182 kg CaO ha^{-1}. In the period of 2000-2005 – relative to the year 1990 – the use of calcium fertilisers decreased by half and fell within the range of 91-95 kg CaO ha^{-1} – Table 13. In recent years there has been a further decrease in the use of fertilisers for the de-acidification of soils. In 2008 the average use of calcium fertilisers in the country was only 38.5 kg CaO ha^{-1} (GUS Yearbook 2009).

In the province of Silesia, in the years 2000-2001 the use of calcium fertilisers was nearly 70% higher that the national average and amounted to ca. 160 kg CaO ha^{-1}. In subsequent years – as in the whole Poland – the amounts of calcium fertilisers applied decreased significantly and in 2008 oscillated around the level of 36.5 kg CaO ha^{-1} – Table 18. A drastic drop in the level of use of calcium fertilisers, both at the scale of the country and in the province of Silesia, has been observed since 2007. The immediate cause of the several-fold decrease in the use of calcium fertilisers was the elimination of subsidies for soil liming, and burdening the farmers with the whole costs of the treatment. As a result of this the province of Silesia has been placed in an especially uncomfortable situation, as in that province the pressure of acidification, caused by the effect of industrial pollutions (SO_2, NO_X), is almost 4-fold higher than the national average, and 7-8-fold greater compared to provinces situated far from centres of industry. The rapidly progressing acidification of soils in the province of Silesia is evidenced by the fact that as recently as 2004 the share of highly acid soils, with pH below 4.50, was 15.7%, and now those soils constitute as much as 20% (Fotyma and Zięba 1989).

Table 18. Use of lime fertilizers in Poland and in the Silesian province in the years 2000-2008

Years	Poland	Silesian province
	(kg CaO ha^{-1})	
2000	95.1	164.4
2001	94.2	157.8
2002	94.1	98.0
2003	94.6	118.2
2004	93.5	100.2
2005	91.5	80.5
2006	54.8	86.8
2007	37.4	31.0
2008	38.5	36.5

Table 19 present values concerning the total area of arable lands and the area qualified for liming (ha), the requirements for calcium fertilisers (t CaO 100%), and costs taking into account the price of the fertilisers and transport to the farmer (thousands PLN). The calculations were made separately for al. the communes of the province of Silesia – Table 19.

The values of total area of arable lands for the particular administrative units of the province were taken from the Bank of Regional Data (Bureau of Statistics in Katowice, update of 1st April, 2008). The determinations of the area of arable lands qualified for liming were made taking into account all those soils for which the treatment is *necessary*, *needed* and *recommended* – Table 14. When calculating the requirement for the fertilisers the doses to be applied were determined taking into account the range of liming requirements and the agronomical category of the soils – Tables 4, 14, 15. The price of 1 ton of calcium fertiliser (t CaO 100%) including transport to the farmer was set at 120 PLN. The price was set taking into account the fact that deposits of minerals containing calcium and magnesium are located almost solely in the south of the country.

Table 19. Total demand for lime fertilizers and soil liming costs in the municipalities of the Silesian province

Item	Rural poviat	Towns and municipalities	Total arable land (ha)	Arable land intended for liming (ha)	Demand for lime fertilizers (t CaO)	Liming costs in thousand PLN
1.	będziński	Będzin	1713	120	256	31
2.		Czeladź	717	43	72	9
3.		Wojkowice	756	0	0	0
4.		Bobrowniki	3273	785	2038	244
5.		Mierzęcice	3536	1328	3325	399
6.		Psary	3279	229	453	54
7.		Siewierz	6244	1061	2987	358
8.		Sławków	1356	41	182	22
∑		**Poviat będziński**	**20874**	**3607**	**9313**	**1117**
1.	bielski	Szczyrk*	764	650	2340	281
2.		Bestwina	2444	2248	9649	1158
3.		Buczkowice	1378	1378	6292	755
4.		Czechowice-Dziedzice	3458	2974	12909	1549
5.		Jasienica	5541	4266	17301	2076
6.		Jaworze	795	533	1793	215
7.		Kozy	1000	960	4450	534
8.		Porąbka	2142	1821	8575	1029
9.		Wilamowice	4092	3642	12998	1560

10.		Wilkowice*	1032	772	2701	324
∑		**Poviat bielski**	**22646**	**19244**	**79008**	**9481**
1.	cieszyński	Cieszyn	1613	435	1467	176
2.		Ustroń	2112	1943	8713	1046
3.		Wisła	1970	1891	9376	1125
4.		Brenna	2322	882	3667	440
5.		Chybie	1742	1237	4993	600
6.		Dębowiec	3077	1446	5299	636
7.		Goleszów	4652	1907	3500	420
8.		Hażlach	3492	2619	10524	1263
9.		Istebna	3168	2724	12670	1520
10.		Skoczów	3576	2503	9257	1111
11.		Strumień	4109	3575	13836	1660
12.		Zebrzydowice	2296	1929	7329	880
∑		**Poviat cieszyński**	**34129**	**23091**	**90631**	**10876**
1.	częstochowski	Blachownia	2241	762	2286	274
2.		Dąbrowa Zielona	6010	4447	16912	2029
3.		Janów	6415	3849	13457	1615
4.		Kamienica Polska*	2257	1466	4398	528
5.		Kłomnice	10593	8262	34586	4150
6.		Koniecpol	8142	4885	15028	1803

Table 19. Cont. Total demand for lime fertilizers and soil liming costs in the municipalities of the Silesian province

Item	Rural poviat	Towns and municipalities	Total arable land (ha)	Arable land intended for liming (ha)	Demand for lime fertilizers (t CaO)	Liming costs in thousand PLN
7.	częstochowski	Konopiska	4669	2941	9785	1174
8.		Kruszyna	4708	4049	17123	2055
9.		Lelów	7802	6476	30703	3684
10.		Mstów	9369	3185	11364	1364
11.		Mykanów	11387	9565	39019	4682
12.		Olsztyn	4978	3982	12344	1481
13.		Poczesna	3962	2694	8244	989
14.		Przyrów	4887	4887	17789	2135
15.		Rędziny	3138	2102	9531	144
16.		Starcza*	1612	1048	3459	415
∑		**Poviat częstochowski**	**92170**	**64600**	**246028**	**29523**
1.	gliwicki	Knurów	750	532	1401	168
2.		Pyskowice	1859	1506	6292	755
3.		Gierałtowice	2805	1963	6350	762
4.		Pilchowice	3932	2988	7982	958
5.		Rudziniec	7445	4020	9680	1162
6.		Sośnicowice	4039	2948	9690	1163
7.		Toszek	7168	4372	18249	2190

8.		Wielowieś	7577	4925	14492	1739
∑		**Poviat gliwicki**	**35575**	**23254**	**74136**	**8896**
1.	kłobucki	Kłobuck	7716	6944	27682	3322
2.		Krzepice	6358	5722	22335	2680
3.		Lipie	6146	5900	25375	3045
4.		Miedźno	5405	4864	19209	2305
5.		Opatów	6264	5825	23883	2866
6.		Panki	3182	2959	11740	1409
7.		Popów	6448	6061	24667	2960
8.		Przystajń	5308	4883	19416	2330
9.		Wręczyca Wielka	8330	6997	25554	3066
∑		**Poviat kłobucki**	**55157**	**50155**	**199861**	**23983**
1.	lubliniecki	Lubliniec	1385	748	1932	232
2.		Boronów	1503	1157	3365	404
3.		Ciasna	6754	5606	19486	2338
4.		Herby	2150	1741	6224	747
5.		Kochanowice	3894	2920	9145	1097
6.		Koszęcin	4930	3845	13181	1582
7.		Pawonków	5565	4619	16334	1960
8.		Woźniki	7418	4747	15836	1900
∑		**Poviat lubliniecki**	**33599**	**25383**	**85503**	**10260**

Table 19. Cont. Total demand for lime fertilizers and soil liming costs in the municipalities of the Silesian province

Item	Rural poviat	Towns and municipalities	Total arable land (ha)	Arable land intended for liming (ha)	Demand for lime fertilizers (t CaO)	Liming costs in thousand PLN
1.	mikołowski	Łaziska Górne	929	697	2302	276
2.		Mikołów	4274	2222	6644	797
3.		Orzesze	2991	2602	9127	1095
4.		Ornontowice	972	583	2145	257
5.		Wyry	1905	1753	6770	812
∑		**Poviat mikołowski**	**11071**	**7857**	**26988**	**3239**
1.	myszkowski	Myszków	4059	2516	7433	892
2.		Koziegłowy	11532	7842	26177	3141
3.		Niegowa	6820	6138	31479	3777
4.		Poraj	2674	1337	4117	494
5.		Żarki	5786	3240	9376	1125
∑		**Poviat myszkowski**	**30871**	**21073**	**78582**	**9430**
1.	pszczyński	Goczałkowice Zdrój	874	542	1766	212
2.		Kobiór	440	330	1056	127
3.		Miedźna	3167	2090	7245	869
4.		Pawłowice	5329	4636	14059	1687
5.		Pszczyna	9487	5028	15272	1833
6.		Suszec	3989	2872	9328	1119
∑		**Poviat pszczyński**	**23286**	**15498**	**48726**	**5847**

1.	raciborski	Racibórz	4970	2883	10301	1236
2.		Kornowac	2129	1661	5645	677
3.		Krzanowice	4208	2693	8372	1005
4.		Krzyżanowice	5469	3938	12918	1550
5.		Kuźnia Raciborska	2230	1650	5589	671
6.		Nędza	2101	1429	5737	688
7.		Pietrowice Wielkie	5933	3975	13825	1659
8.		Rudnik	6305	4666	13870	1664
∑		**Poviat raciborski**	**33345**	**22895**	**76257**	**9151**
1.	rybnicki	Czerwionka-Leszczyny	5039	4485	16986	2038
2.		Gaszowice*	1603	813	2439	293
3.		Jejkowice*	465	249	747	90
4.		Lyski	2941	1206	2405	289
5.		Świerklany	1460	1416	4942	593
∑		**Poviat rybnicki**	**11508**	**8169**	**27519**	**3302**
1.	tarnogórski	Kalety	752	541	1361	163
2.		Miasteczko Śląskie	487	156	243	29
3.		Radzionków	687	192	588	71
4.		Tarnowskie Góry	3056	1895	6430	772
5.		Krupski Młyn	178	107	285	34

Table 19. Cont. Total demand for lime fertilizers and soil liming costs in the municipalities of the Silesian province

Item	Rural poviat	Towns and municipalities	Total arable land (ha)	Arable land intended for liming (ha)	Demand for lime fertilizers (t CaO)	Liming costs in thousand PLN
6.	tarnogórski	Ożarowice	2899	1333	2891	347
7.		Świerklaniec	1147	149	260	31
8.		Tworóg	2762	2044	5660	679
9.		Zbrosławice	10424	6776	21152	2538
∑		**Poviat tarnogórski**	**22392**	**13193**	**38870**	**4664**
1.	bieruńsko-lędziński	Bieruń	2353	1553	5422	651
2.		Imielin	1368	397	1035	124
3.		Lędziny	1855	1224	4266	512
4.		Bojszowy	2056	1686	6228	747
5.		Chełm Śląski	1629	1238	4341	521
∑		**Poviat bieruńsko-lędziński**	**9261**	**6098**	**21292**	**2555**
1.	wodzisławski	Pszów	1279	1215	4575	549
2.		Radlin	605	375	1289	155
3.		Rydułtowy	908	636	2236	268
4.		Wodzisław Śląski	3050	2714	11653	1398
5.		Godów	2595	2154	7796	935
6.		Gorzyce	4016	3614	15769	1892
7.		Lubomia	2422	1962	8171	980

8.		Marklowice	1059	985	3873	465
9.		Mszana	2402	2066	8246	989
∑		**Poviat wodzisławski**	**18336**	**15721**	**63608**	**7633**
1.		Poręba	1898	1537	5811	697
2.		Zawiercie	4893	1174	3186	382
3.		Irządze	4895	4503	23648	2838
4.		Kroczyce	7016	4771	18840	2261
5.		Łazy	6122	2081	5878	705
6.	zawierciański	Ogrodzieniec	3904	664	2080	250
7.		Pilica	9738	7498	30346	3641
8.		Szczekociny	8943	6528	24212	2905
9.		Włodowice	4563	1688	4416	530
10.		Żarnowiec	9052	7785	33874	4065
∑		**Poviat zawierciański**	**61024**	**38229**	**152291**	**18275**
1.		Żywiec	1810	1593	5936	712
2.		Czernichów*	1098	990	4950	594
3.		Gilowice	1648	1582	8206	985
4.	żywiecki	Jeleśnia	6030	6030	32562	3907
5.		Koszarawa	1471	1471	8650	1038
6.		Lipowa	2298	2252	10638	1277
7.		Łękawica	1153	1153	5777	693

Table 19. Cont. Total demand for lime fertilizers and soil liming costs in the municipalities of the Silesian province

Item	Rural poviat	Towns and municipalities	Total arable land (ha)	Arable land intended for liming (ha)	Demand for lime fertilizers (t CaO)	Liming costs in thousand PLN
8.	żywiecki	Łodygowice	1808	1645	8333	1000
9.		Milówka	3414	0	0	0
10.		Radziechowy-Wieprz	3389	2813	12266	1472
11.		Rajcza	2752	2752	16512	1981
12.		Ślemień	1500	1395	7542	905
13.		Świnna	2190	0	0	0
14.		Ujsoły*	2609	2229	11145	1337
15.		Węgierska Górka	3002	3002	18012	2161
∑		**Poviat żywiecki**	**36172**	**28907**	**150529**	**18063**
1.		Bielsko-Biała	3022	3022	12574	1509
2.		Bytom	1567	533	1394	167
3.		Chorzów	532	0	0	0
4.		Częstochowa	6957	5287	13992	1679
5.		Dąbrowa Górnicza	7378	2582	11618	1394
6.		Gliwice	6698	3684	11557	1387
7.		Jastrzębie Zdrój	5125	3126	9983	1198
8.		Jaworzno	5532	1328	2871	344
9.		Katowice	2380	0	0	0

10.	Mysłowice	2282	1232	4045	485
11.	Piekary Śląskie	1916	575	1376	165
12.	Ruda Śląska	1857	1560	4236	508
13.	Rybnik	3366	2289	7773	933
14.	Siemianowice Śląskie	899	297	815	98
15.	Sosnowiec	2041	0	0	0
16.	Świętochłowice*	152	58	174	21
17.	Tychy	2881	2161	7625	915
18.	Zabrze	1792	107	184	22
19.	Żory	3374	2868	9809	1177
	Total Silesian Province	**611167**	**417683**	**1569168**	**188300**

*estimated data.

The data given in Table 19 show that out of the total area of arable lands of 611167 ha, as much as 417683 ha (68.3%) were qualified for liming. As mentioned before, there is no simple relation between the area of arable lands to be treated and the requirement of fertilisers. This results from the fact that the soils in the particular communes differ in the degree of acidification and in the level of compactness. The average doses of calcium fertilisers, relative to those features, vary from 1.97 t CaO ha^{-1} in Psary (prevalence of light soils, liming mostly *recommended*) to 6 t CaO ha^{-1} in Rajcza (heavy soils, liming *necessary*).

The total requirement for calcium fertilisers in the province of Silesia is 1569168 t CaO. This quantity of lime is necessary for the regulation of soil reaction of the arable lands. With the adopted assumptions (price of 1 t CaO incl. transport – 120 PLN), the cost of the treatment will be 188.3 million PLN. Analysis of the costs reveals that out of the 160 communes in which soils have been qualified for liming, in 86 communes the costs of the treatment will not exceed 1 million PLN, in 46 the costs will be in the range of 1-2 million, and in 17 communes within 2-3 million PLN. The cost level of 3-4 million PLN applies to 8 communes (Lelów, Kłobuck, Lipie, Wręczyca Wielka, Koziegłowy, Niegowa, Pilica, Jeleśnia), and costs within 4-5 million PLN – 3 communes (Mykanów, Kłomnice, Żarnowiec).

The costs that have to be borne to optimise the soil reaction cannot burden the farmers alone. Firstly, the financial burden would be to great for them, and secondly, they are not the ones who are responsible for the high level of soil acidification in the province.

7. RECOMMENDATIONS FOR THE SOLUTION OF THE PROBLEM OF SOIL ACIDIFICATION IN THE PROVINCE OF SILESIA CAUSED BY ANTHROPOGENIC TRANSFORMATIONS

Optimisation of the reaction of acidified soils is a long process. In the case of the province of Silesia the process of de-acidification will be relatively slow, as in that region medium-heavy and heavy soils predominate. As mentioned before, such soils are relatively resistant to acidification, but also their de-acidification is so much more difficult. The optimisation of the reaction of the soils in the region will be also delayed as a result of the effect of natural acidifying factors, and of anthropogenic factors with permanent character in particular. On the other hand it should be emphasised that overly intensive liming is less effective, as it involves considerable leaching of calcium and magnesium ions to the deeper horizons of the soils. When planning the time-scale for the optimisation of the soil reaction one should also take into account the duration of the effects of liming, and secure suitable financing. The strongest effects of liming are obtained in the second and third years after the treatment. However, research results indicate that even 8 years after the application of liming yield increases resulting from the treatment may bring notable profits.

Taking all those factors into account, as well as the ever-present objective obstacles and difficulties, we suggest that the process of optimisation of soil reaction in the province of Silesia should be planned for a period of 6-8 years. If such a period of implementation is adopted, the mean use of calcium fertilisers on arable lands qualified for liming will be from 470 to 626 kg CaO ha^{-1}. The total annual requirement for calcium fertilisers in the 6-year variant would be 261528 t CaO, and in the 8-year variant – 196146 t. The annual costs of the treatment at current prices would be at the level from 23537.5 thousand PLN to 31383.4 thousand PLN (Adrianek and Skowronek 2008, Fotyma and Zięba 1989, Village Revitalisation Program 2006-2010, Wujec 2006).

The realisation of the project requires that a soil liming schedule be developed for every commune. Detailed liming schedules should also be prepared for the farms.

Such liming schedules should be developed based on the following principles:

- liming should be planned first for soils with the highest level of acidification (*necessary* liming range);
- doses of calcium fertilisers should be determined in accordance with the rules, taking into account the reaction and agronomical category of the soils;
- fast acting oxide fertilisers should be applied on heavy soils, and on light soils – the carbonate forms of fertilisers;
- calcium-magnesium fertilisers should be applied on acidified soils with low levels of available magnesium;
- liming should be performed in the system of post-harvest tillage (preferably after the harvest of cereals) or in autumn prior to the pre-winter ploughing. On grasslands, the treatment is best applied in late autumn;
- it is advisable that the liming schedules be developed with the help of an officer of the commune and an representative of the Agro-Chemical Station in Gliwice.

After the 6-8-year period of so-called melioration liming the soils should reach reaction values within the range of 5.1-7.0 pH. Maintenance of those values requires regular application of calcium fertilisers in subsequent years, when so-called conservation liming should be applied, characterised by small doses that permit the soil reaction to be maintained at the correct level.

8. DISCUSSION

Analysis of nearly 80000 soil samples, performed in the years 2004-2009, indicates that in the province of Silesia highly acid soils constitute 20%, acid soils – 29%, lightly acid soils – 34%, and soils with alkaline reaction only 4% of the total area of arable lands. The highest level of soil acidification is observed in the districts of Kłobuck, Częstochowa, Żywiec, Wodzisław, Zawiercie, and also Lublinie, Myszków and Mikołów. In 32 communes of the province the area of acid and highly acid soils is above 70% of arable lands (Adrianek and Skowronek 2008).

The status of soil acidification in a given region is determined by the agronomical category of the soils, natural and anthropogenic factors contributing to acidification, and the use of calcium fertilisers. In the province of Silesia there is a dominance of medium-heavy and heavy soils (86% of the analysed soils) that are relatively resistant to changes in reaction. Acidification of heavy soils to pH below 4.5 indicates their chemical degradation. The process described at the beginning of this work usually takes place when there is a strong pressure of an acidifying anthropogenic factor. This is supported by the fact that in typically agricultural provinces, where soils under arable use are far from large industrial plants, the occurrence of strong acidification of heavy soils is extremely rare. Such large areas of acid and highly acid soils (49%) classified in the category of medium-heavy or heavy soils indicate clearly that in the province of Silesia the dominant factor in soil acidification is an anthropogenic factor. In Chapter 4 we demonstrated that the factor is emission of SO_2 and NO_X. Detailed calculations show that among the anthropogenic factors studied the percentage share of SO_2 in soil acidification is 46.7%, that of NO_X – 30.7%, and of fertilisation – 22.6%. The combined participation of industrial pollutions of the air in anthropogenic acidification of soils is 77.4%. Neutralisation of acidification resulting from the emissions of those gases requires soil liming applied every 4 years at the dose of 0.718 t CaO ha^{-1}. The dominant share of industrial gases in soil acidification results from their emission which, in the area of the province of Silesia in the year under analysis, was 3.4-fold, and in the case of NO_2 – 4.12-fold greater than the national average (Kaczor and Brodowska 2008).

Next to anthropogenic factors, other contributors to soil acidification include also natural factors related with the climate (prevalence of precipitations over evaporation), and microbiological transformations. In typically agricultural regions their participation in soil acidification is significant. Taking into account the specific character of the province of Silesia and the results of research on the subject one can conclude with certainty that in that region the share of industrial pollutions in total acidification of soils is at least 60% (WIOŚ Report 2009).

As mentioned before, the status of acidification soils is also determined by the level of liming applied. In the recent period (2008) the use of calcium fertilisers in Poland and in the province of Silesia is dramatically low and oscillates at the level of 36-38 kg CaO ha^{-1}. For the whole country, compared to the year 2000 the decrease in the use of such fertilisers is 2.5-fold, and for the province of Silesia 4.5-fold (GUS Statistical Yearbook 2009).

It should be stated with full emphasis that the quantities of calcium fertilisers applied at present do not suffice even to maintain the current soil reaction values. In the province of Silesia this is best evidenced by the fact that over the period of 2004 -2009 the share of highly acid soils increased by nearly 5% (Kaczor 2002).

In every case the acidification of soils reduces their levels of basic nutrients. This causes a reduction in the level and quality of crop yields, which in turn has a negative impact on the level of income for the farmers (Kaczor 1998, Józefaciuk and Szatanik-Kloc 2002).

In the province of Silesia the acidification of the soil, environment is particularly dangerous as it causes increased bioavailability of heavy metals. Research shows that on more than 1/3 of the area of arable lands there are excessive levels of zinc, lead and cadmium. Frequently the levels of those metals are several-fold higher in relation to the permitted values. In this context one can only hope that the relevant authorities, institutions and the farmers themselves will have sufficient determination to solve the problem of soil acidification in the region.

The calculated total requirement for calcium fertilisers in the province of Silesia is almost 1570 thousand tons of CaO. The calculation was made taking into account the soils for which liming is considered as *necessary*, *needed* and *recommended*. The qualification for liming of all soils from the range "*recommended*" is aimed at their protection against further acidification, and thus at preventing further increase in the share of acid and highly acid soils.

The costs of liming – taking into account the prices of the fertilisers and their transport – were calculated at 188.3 million PLN. The price of 1 t of CaO including transport to the farmer, adopted in the calculations at the level of 120 PLN, is ca. 50 PLN lower than that adopted for the estimation of costs of liming elsewhere in Poland. However, it is a realistic price, taking into account that the situation of deposits of minerals containing calcium and magnesium – mainly in the south of the country – considerably reduces the costs of transport. It should be added that the calculated amount does not include the cost of the actual application of the fertilisers, which is estimated at the level of 60 PLN per hectare.

Detailed analysis of the structure of the costs of soil liming, presented in Chapter 6, indicates that in 132 communes the costs do not exceed 2 million PLN, and in 11 communes are within the range of 3-5 million (Village Revitalisation Program 2006-2010).

On the one hand, soil liming is a basic factor I agricultural production, and on the other it is a factor ensuring the equilibrium of agricultural and forest ecosystems and the production of healthy food and fodders of good quality. Therefore, the treatment constitutes an important element of sustainable agriculture, food economy and environmental protection. In this context the problem of optimisation of the reaction of acidified soils cannot be the responsibility of the farmer or the agriculture alone, as neither the farmers nor the agriculture as a branch of the economy are capable of bearing the costs involved. This is supported by data showing the dramatically low current use of calcium fertilisers in Poland. On the other hand, the causes of acidification of soils are largely not on the part of the farmers and the farmers should not be left alone with the problem (GUS Yearbook 2008, Wujec 2006).

In the case of the province of Silesia – as demonstrated in the successive chapters of this work – the share of industrial emissions in the process of acidification of soils in unquestionable dominant. Therefore, participation in the financing of the undertaking aimed at the optimisation of the soils of the region, e.g. by the environmental protection and water economy funds appears to be highly justified. It should be added here that the reclamation of overly acidified soils through liming will improve their productivity, but first of all will make them safer from the ecological point of view. Indirectly, such activity will also significantly contribute to considerable limitation of the migration of the basic biogens and heavy metals to the ground and surface waters (Jackowska and Piotrowski 2001).

The solution of the problem of acidification of soils over a period of 6-8 years, as proposed in Chapter 7, requires a lot of effort and determination, but we are convinced that both from the viewpoints of agriculture and ecology that will be the best investment for the region.

9. CONCLUSIONS

1. The province of Silesia is a region of Poland with one of the highest degrees of anthropogenic transformation. Within its territory there are 361 industrial plants that are particularly noxious to air purity, which constitutes 21% of plants of this type on the scale of the whole country.

2. In the province of Silesia highly acid soils constitute 20%, acid soils – 29%, and lightly acid soils 34% of the arable lands. Therefore, *necessary* liming applies to 35% of the soils, *needed* – to 17%, and *recommended* to 19% of the total area of arable lands.

3. The participation of industrial atmospheric pollution (SO_2, NO_X) in the anthropogenic acidification of soils is dominant and accounts for 77.4% of that acidification. Neutralisation of soil acidification resulting from the emission of those gases requires the application of liming at 4 year intervals at the dose of 0.718 t CaO ha^{-1}.

4. In the province of Silesia dominant are medium-heavy and heavy soils, relatively resistant to acidification. Acidification of heavy soils to a reaction value below 4.5 indicates their chemical degradation and usually occurs under the conditions of a strong pressure of anthropogenic factors.

5. Acidification of soils reduces their level of basic nutrients (P, K, Mg) and increases the bioavailability of heavy metals in the environment. In the province of Silesia the permissible levels of zinc, cadmium and lead in the soil are exceeded on over 1/3 of the area of arable lands.

6. The use of calcium fertilisers at the current level of 36-38 kg CaO ha^{-1} $year^{-1}$ is too low even to maintain the present values of the soil reaction. This results in an increase in the share of acid and highly acid soils.

7. Optimisation of soil reaction in the province of Silesia requires the application of nearly 1.57 million tons of CaO. The costs of such an undertaking, covering the price of the fertilisers and transport, will amount to ca. 188.3 million PLN. In 132 communes the costs will be below 2 million PLN, and in 11 communes they will be within the range of 3-5 million PLN.

8. The optimisation of the soils should be conducted over a period of 6-8 years. The first to be limed should be the most acidified soils (range – liming *necessary*) in communes with the highest levels of heavy metals in the soils.

9. Comprehensive solution of the problem of acidification of soils in the province of Silesia requires the development of liming schedules for the communes and for the individual farms, covering a period of 6-8 years. When deter-

mining the doses and forms of calcium fertilisers it is necessary to take into account the reaction and the agronomical category of the soils, and their levels of nutrients, magnesium in particular.

10. Acidification is a continuous process. Once their reaction is optimised, regular liming should be applied in subsequent years, at doses that will ensure the mainternance of the correct range of pH values.

11. Soil liming is an important element of sustainable agriculture, food economy and environmental protection. Therefore, the costs of the treatment should not burden the farmers alone.

12. The specific character of the province of Silesia – characterised by dominant participation of industrial gaseous emissions in the acidification of soils – justifies financial support for the undertaking related with the optimisation of the reaction of the soils from the environmental protection and the water economy funds.

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11. SUMMARY

The work presents the status of acidification of soils in the province of Silesia, taking into account the causes and effects of the process. Further the work presents the total requirement for calcium fertilisers and the costs of soil liming in the particular communes of the province. Analysis of nearly 80000 soil samples, performed in the years 2004-2009, indicates that in the province of Silesia highly acid and acid soils constitute 49% of the area of arable lands. The highest acidification of soils is found in the districts of Kłobuck, Częstochowa, Żywiec, Wodzisław, Zawiercie, and also Lubliniec, Myszków and Mikołów. In 32 communes of the province the area of such soils exceeds 70% of the area of arable lands. The high share of soils with pH below 5.50, classified in the category of medium-heavy and heavy soils, indicates that in the region under analysis the dominant factor in the acidification of soils is the anthropogenic factor. Among the anthropogenic factors considered, the strongest effect on soil acidification was that of the emission of SO_2 (46.7%), smaller the emission of NO_X (30.7%), and the least - fertilisation (22.6%). Neutralisation of soil acidification attributable to industrial gas emissions alone (SO_2, NO_X) requires the application of 0.718 t CaO ha^{-1} at 4-year intervals. The dominant share of acid industrial pollutions in soil acidification results from their emission which, in the area of the province of Silesia in the year 2007, in the case of SO_2 was 3.4-fold, and in the case of NO_2 – 4.12-fold greater than the national average. The quantities of calcium fertilisers applied within the recent years are not enough even to maintain the current values of soil reaction. As a result, in the period of 2004-2009 in the region under analysis the share of highly acid soils increased by nearly 5%. Acidification of soils reduces their level of basic nutrients and increases the bioavailability of heavy metals, which causes a decrease of the level and reduced quality of crop yields. The total requirement for calcium fertilisers in the province of Silesia is 1.57 million tons of CaO. The costs of liming, covering the price of the fertiliser and transport, have been calculated at 188.3 million PLN. In 132 communes those costs do not exceed 2 million PLN, and in 11 communes the costs are within the range of 3-5 million PLN. Comprehensive solution of the problem of acidification of soils requires the development of liming schedules for the communes and for the individual farms, covering a period of 6-8 years. When calculating the doses and forms of calcium fertilisers it is necessary to take into account the reaction and the agronomical category of the soils, and their level of available magnesium. Optimisation of the reaction of the soils of the province of Silesia will largely improve their productivity and significantly reduce the migration of the basic nutrients and heavy metals to the ground and surface waters.

Keywords: province of Silesia, soil acidification, liming

12. STRESZCZENIE

KOMPLEKSOWE ROZWIĄZANIE PROBLEMU ZAKWASZENIA GLEB WOJEWÓDZTWA ŚLĄSKIEGO SPOWODOWANEGO PRZEKSZTAŁCENIAMI ANTROPOGENICZNYMI

W pracy przedstawiono stan zakwaszenia gleb w województwie śląskim z uwzględnieniem przyczyn i skutków tego procesu. W dalszej części opracowania zamieszczono całkowite zapotrzebowanie na nawozy wapniowe oraz koszty wapnowania gleb w poszczególnych gminach województwa. Analiza niemal 80000 prób glebowych wykonana w latach 2004-2009 wskazuje, że w województwie śląskim gleby bardzo kwaśne i kwaśne stanowią 49% powierzchni użytków rolnych. Największe zakwaszenie gleb występuje w powiatach: kłobuckim, częstochowskim, żywieckim, wodzisławskim, zawierciańskim, a także lublinieckim myszkowskim i mikołowskim. W 32 gminach województwa powierzchnia tych gleb przekracza 70% użytków rolnych. Duży udział gleb o pH poniżej 5,50 należących do kategorii średnich lub ciężkich wskazuje, że w analizowanym regionie czynnikiem dominującym w zakwaszeniu jest czynnik antropogeniczny. W obrębie rozpatrywanych czynników antropogenicznych największy wpływ na zakwa-

szenie gleb wywarła emisja SO_2 (46,7%), mniejszy emisja NO_X (30,7%), a najmniejszy nawożenie (22,6%). Zneutralizowanie zakwaszenia pochodzącego tylko z emisji gazów przemysłowych (SO_2, NO_X) wymaga stosowania co 4 lata 0,718 t $CaO \cdot ha^{-1}$. Dominujący udział kwaśnych zanieczyszczeń przemysłowych w zakwaszeniu gleb wynika z ich emisji, która na terenie województwa śląskiego w przypadku SO_2 w 2007 roku była 3,4- krotnie, a NO_2- 4,12-krotnie wyższa w stosunku do średniej krajowej. Ilości wnoszonych nawozów wapniowych w ostatnim okresie nie wystarczają nawet do utrzymania aktualnego odczynu gleb. W efekcie w analizowanym regionie w latach 2004-2009 udział gleb bardzo kwaśnych zwiększył się prawie o 5%. Zakwaszenie gleb obniża ich zasobność w składniki pokarmowe i zwiększa biodostępność metali ciężkich co wpływa na spadek wysokości i jakości plonów. Sumaryczne zapotrzebowanie na nawozy wapniowe w województwie śląskim wynosi 1,57 mln ton CaO. Koszty wapnowania obejmujące cenę wapna z transportem wyliczono na kwotę 188,3 mln zł. Koszty te w 132 gminach nie przekraczają 2 mln zł, a w 11 zamykają się w przedziale 3-5 mln zł. Kompleksowe rozwiązanie problemu zakwaszenia gleb wymaga sporządzenia w gminach i w gospodarstwach rolnych harmonogramów wapnowania na okres 6-8 lat. Przy obliczaniu dawek i form nawozów wapniowych należy brać pod uwagę odczyn, kategorię agronomiczną gleb oraz ich zasobność w magnez przyswajalny. Doprowadzenie odczynu gleb do optymalnego w województwie śląskim zwiększy ich produkcyjność oraz w dużym stopniu ograniczy migrację podstawowych składników pokarmowych i metali ciężkich do wód gruntowych i powierzchniowych.

Słowa kluczowe: województwo śląskie, zakwaszenie gleb, wapnowanie

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