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Regeneration of the European silver fir (*Abies alba* Mill.) in the Sudety Mountains on soils with different physico-chemical properties

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Abstract: The purpose of this study was to determine the basic physico-chemical properties of soil in silver fir stands with different stage of natural regeneration. The investigations were carried out in south-west part of Poland – in the Sudety Mountains. From 854 silver fir stands, 40 testing sites, varying in terms of habitat conditions and degree of natural regeneration, were selected. Soil samples were collected from litter (organic horizon – O) with a thickness of 7–15 cm and from mineral A horizon lying up to 20 cm below the organic horizon and were then analysed for pH, EC, C org., total N, exchangeable cations (Ca, Mg, K, Na, H and Al), soluble Mn, Fe, Zn and Pb as well as particle size distribution (samples from A horizon). The analysed soil samples are characterized by very high acidity and low content of bases. According to the performed statistical tests, none of the factors analysed within the samples tested has a significant impact on the natural regeneration of silver fir. The only dependence between potassium content in soil and the regeneration of silver fir in the Sudety Mountains is close to statistically significance.

Additional key words: silver fir silviculture, natural renewal, soil chemical properties, industrial soil pollutions

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Introduction

Amongst native conifers, silver fir has some of the most demanding requirements as regards the soil fertility. These demands grow as the species shifts from its optimum conditions towards the extremes of natural range (Zieliński 1952). According to Zarzycki (Jaworski and Zarzycki 1983) the described tree requires medium-fertile and fertile soils. Due to its existence in rather rich habitats and not a very quick or even slow growth in its youth and a deep and well-developed root system, this tree seldom suffers from a deficiency of macro- and microelements in the soil (Baule and Fricker 1973). More often, we observe symptoms of a surplus of some macro- and microelements, such as manganese (Rousseau 1960, Jaworski 1979a) or aluminium (Němec 1950), which has a toxic effect.

Similarly to other species, in certain conditions, the growth and health of silver fir depends strongly on the abundance of macro- and microelements in the soil, such as nitrogen (e.g. Fober 1983, Jaworski and Zarzycki 1983), calcium (e.g. Pancer-Kotejowa 1973, Jaworski 1979a, Jaworski and Zarzycki 1983), magnesium (e.g. Rehfuess 1968, Baran 1977, Jaworski and Zarzycki 1983, Fober 1983) and sometimes phosphorus, aluminium, manganese and iron (Rehfuess 1968, Houba 1972, Fober 1983, Rastovski 1997). However, the aforementioned impact depends largely on such factors as soil moisture and its particle size distribution and chemical properties. This is related to the fact, that some compounds considerably modify the uptake of other compounds, for instance, calcium modifies the uptake of manganese (Rousseau 1960, Jaworski 1979a).

Earlier studies on silver fir in the Sudety Mountains have pointed to a very poor regeneration of this tree and constantly decreasing share of silver fir in the tree stands of younger age classes (Jaworski 1979b, Bernadzki 1983, Boratyński and Filipiak 1997). It is commonly believed that, one of the main reasons for a lack of regeneration (not only in the Sudety) is the chemical composition of the surface soil horizons which is unfavourable for young silver firs and which is often related to the harmful effect of industrial pollution. According to the studies carried out, the process of silver fir declining has been significantly impeded over the past few years as a result of a significant reduction in emissions, particularly of sulphur dioxide (e.g. Filipiak 2002, Filipiak and Ufnalski 2004), nevertheless, there are still huge problems with the species' reproduction.

The aim of this study was to identify the basic physico-chemical properties of soil in silver fir stands which may throw some light on the issue of the poor regeneration of this species in the Sudety Mountains, despite a clear reduction in industrial emissions.

Material and methods

The research area is situated in south-west part of Poland, in the Sudety Mountains (Fig. 1). As a result of a field survey of 854 silver fir stands, 40 testing localities varying in terms of habitat conditions and degree of natural regeneration, were selected. The selection was actually random, although it was carried out separately for specific parts of the Sudety Mountains. Furthermore, the selection was limited to stands with a larger number of silver fir trees (at least a dozen or so). It was also assumed that at least 30% of tested localities should be characterised by good silver fir regeneration. In reality, only ca 5% of stands meet this requirement. Additionally, for comparison were tested soil samples taken in two stands in Świętokrzyskie Mountains (Zagnańsk Sub-district). In this region the silver fir is very common tree and good regenerate naturally.

The testing sites selected for the study are characterised by Cambisols, Luvisols and Podzols of different sub-types, formed from varied parent materials. The annual precipitation ranges from 640 to 1400 mm, and the average annual temperature from 0°C to 8°C.

Soil samples for physico-chemical analyses were taken in selected stands from the humose horizon characterised by organic level (O) (with a thickness of 7–15 cm) and from the mineral horizon (A) lying up to 20 cm below the organic horizon. The samples with a volume approximating 1 litre were dried, grinded (from horizon O) and sieved through a ϕ 2 mm sieve. Adequately prepared tests were used for determining: 1) particle size distribution – using the aerometric method, in accordance with PN-R-04032 (PKiN 1998). Sand fractions were separated wet on sieves. Soil texture classes were determined according to the Soil Survey Manual (Soil Survey Division Staff 1993); 2) soil reaction – potentiometrically (USDA 1996) using an Orion ionmetre (710A) in: a) redistilled water, using a 1:1 soil : solution ratio, b) extraction with 0.01 M $CaCl_2$, using a 1:2 soil : solution ratio, c) extraction with 1 M KCl, using a 1:1 soil : solution ratio; 3) electrical conductivity (EC_1, 25°C, mS $\times$ cm^{-1}) – conductometrically, using a 1:1 soil to solution ratio; 4) composition of exchangeable cations (Ca, Mg, K and Na) – determined by the Mehlich's method modified by Kociałkowski and Ratajczak (1984); 5) exchangeable acidity and exchangeable aluminium – determined by titration; 6) organic carbon content – determined using the Walkley-Black method (Nelson and Sommers 1982); 7) total nitrogen content – determined using the Kjeldahl method; 8) Mn, Fe, Zn and Pb concentrations – determined in 1 M of HCl using a 1:10 soil to solution ratio (IUNG 1985); 9) buffering curves for 8 tests.

The significance of differences between average data of localities with poor and good fir regeneration (tab. no 3) were tested by t-test and by logistic analysis with χ^2 test.

Results and discussion

The silver fir, within the investigated localities, occurs on soils differing significantly in terms of texture, which is related to diverse parent materials. The soil texture corresponds to four soil texture classes, namely, loamy sand, sandy loam, loam and silt with clay fraction content from 1 to 15% (Filipiak et al. 2003). The physico-chemical properties of investigated soils are presented in Tables 1 and 2. The average content of organic carbon in horizon A equalled 3.36% with fluctuations from 0.9 to 9.17%. Although these soils contain considerable quantities of organic carbon and clay fraction, they demonstrate very low saturation of the exchangeable complex with base cations; this is related to the domination of the exchangeable complex with aluminium and hydrogen cations. Because of the prevalence of aluminium and hydrogen cations among exchangeable cations, the soils demonstrate a very strongly acidic soil reaction, which many a time falls to pH 2.5 (in 1 M KCl). A low

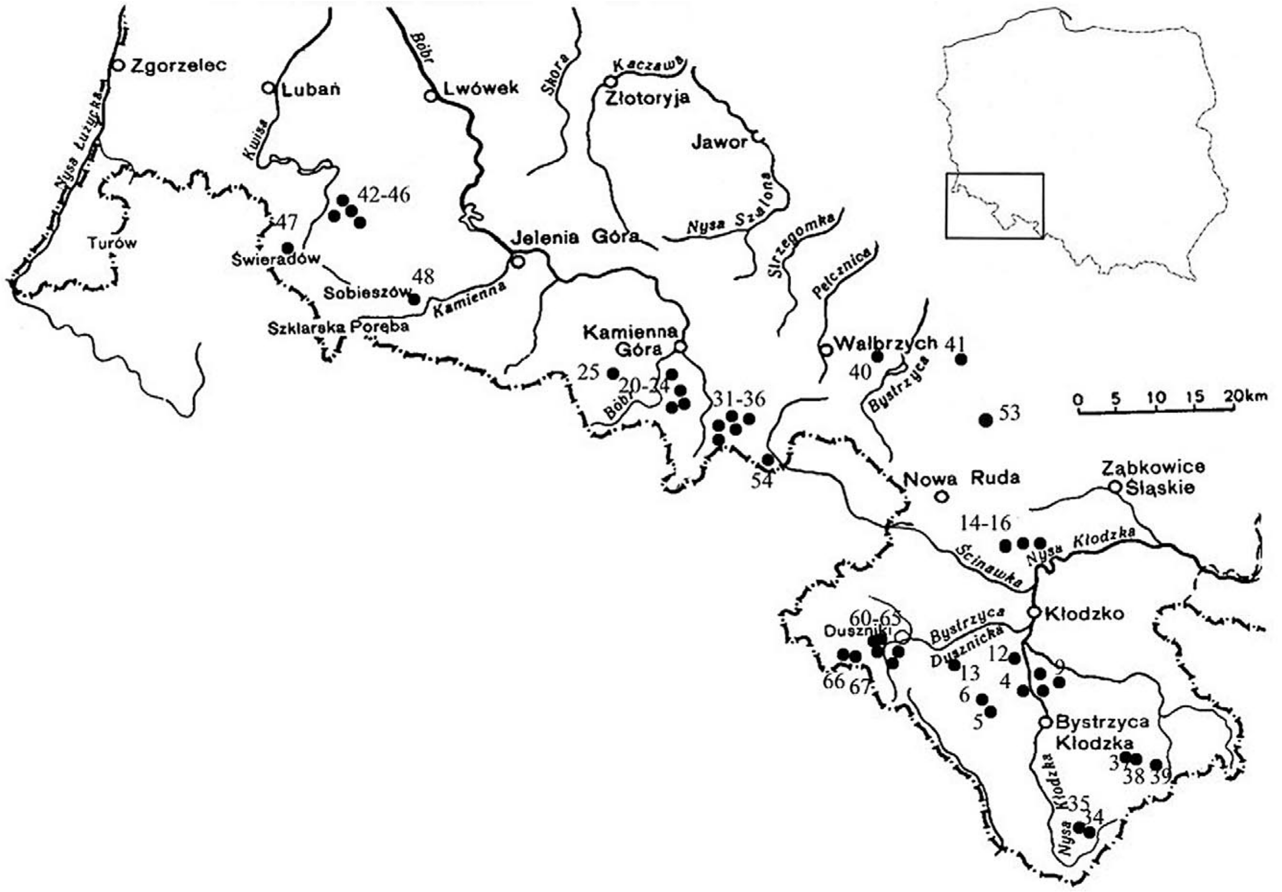

Fig. 1. Geographical distribution of examined European silver fir populations

content of exchangeable base cations and a high amount of aluminium and hydrogen cations cause the humus in horizons A and O to be strongly unsaturated, hence the samples tested demonstrate very low buffering capabilities, particularly in the acidic range (Fig. 2). Hydrogen, on the other hand, related to acidic groups with different potency and exchangeable aluminium is capable of neutralising a considerable amount of bases. Poor acid neutralisation capabilities are typical of forest soils containing even significant amounts of humus and clay fraction (Prusinkiewicz et al. 1992). Our observations show that a very strongly acidic reaction is not, however, a factor that restricts silver fir regeneration, since in areas where regeneration is considered good, pH ranged from 2.5 to 3.5. Probably this is related to the finer texture of endopedons, exhibiting greater abundance in nutrients and higher buffering abilities.

According to the tests performed soils in stands with better regeneration contain more potassium, also this result is only close to statistically significance. (t-test, logistic analysis, $P=0.09$). Our results may support the opinion that silver fir has a bigger demand (several times bigger than spruce) for potassium (e.g., Jaworski and Zarzycki 1983). A relatively high content of potassium in the soil was indicated by well regenerating Carpathian firs studied by Adam-

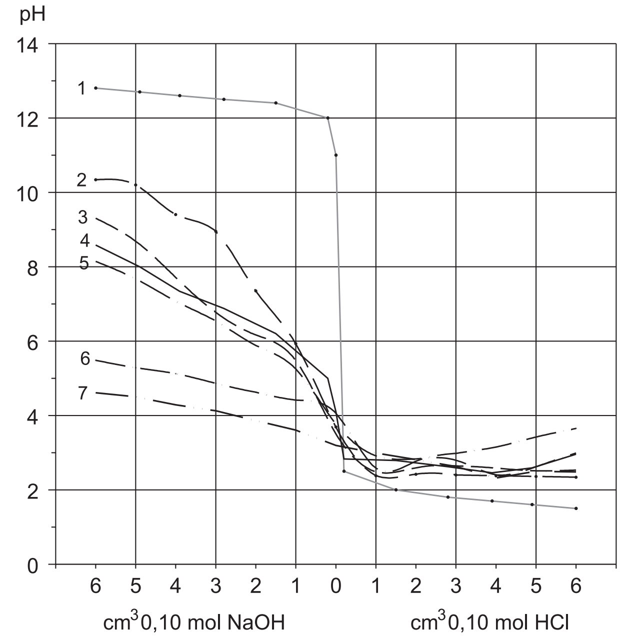

Fig. 2. Buffer curves for selected samples of soil from silver fir localities in Sudety Mts.: 1 – theoretical curve, 2 – sample No. 57 (A horizon), 3 – sample No. 51 – (A horizon), 4 – sample No. 37 (A horizon), 5 – sample 52 – (A horizon), 6 – sample No. 5 (O horizon), 7 – sample No. 26 (O horizon). The samples number – see tab. 1 and 2

Table. 1. Some chemical properties of soils from silver fir localities in Sudety Mts. 0 horizon. N. r. s. – Natural regeneration state: 1 – good. 0 – poor; EC – electrical conductivity; ECEC – effective cation exchangeable capacity

Forest sub-district "Obręb"	Subcompartment	No.	N.r.s.	Tot. % N	Organic carbon %C	C:N	pH H_2O	pH KCl	pH $CaCl_2$	EC [dS m^{-1}]	Exchengeable cations						Acidity	ECEC	Soluble				Available			
											Ca	Na	K	Mg	Al	H			Mn	Fe	Zn	Pb	P_2O_5	Mg	K_2O	Ca
											cmol(+) kg^{-1}								mg/kg				mg/100g			
Bardo	148f	1	0	0.82	16.22	19.77	4.39	3.59	3.73	0.071	4.19	0.086	0.349	0.657	2.79	3.61	6.40	11.68	197.9	106.99	109.1	184.8	2.0	10.1	7.05	83.8
Bardo	256c	2	0	0.85	18.85	22.29	3.27	2.87	3.06	0.071	2.76	0.052	1.100	0.939	5.37	3.93	9.29	14.14	110.6	125.00	21.0	23.6	8.1	13.5	26.26	55.2
Bardo	257a	3	0	0.86	20.05	23.37	3.63	3.47	3.54	0.087	4.51	0.057	0.309	0.884	5.48	3.41	8.90	14.66	270.8	150.24	61.2	20.5	3.5	12.06	5.14	90.2
Bardo	6j	4	1	1.39	32.91	23.63	4.4	3.79	3.64	0.220	13.2	0.088	1.350	3.540	–	–	–	18.18	364.9	104.74	55.9	181.7	24.8	30.5	22.21	264.0
Bystrzyca	18g	5	0	0.94	30.66	32.50	4.44	3.64	3.9	0.122	10.95	0.048	0.766	2.039	1.29	1.83	3.12	16.92	111.6	127.25	40.8	171.2	14.9	21.8	17.13	219.0
Bystrzyca	19a	6	0	1.00	34.89	34.86	3.77	2.94	3.15	0.130	8.07	0.056	0.696	1.229	1.52	4.72	6.25	16.30	381.3	105.09	46.6	106.5	15.1	14.99	13.52	161.4
Bystrzyca	313a	7	0	0.91	36.15	39.93	4.42	3.7	3.83	0.114	13.64	0.040	0.599	2.345	1.38	0.93	2.31	18.93	488.5	101.07	46.1	52.7	7.8	23.03	8.49	272.8
Bystrzyca	315i	8	0	1.43	44.82	31.43	4.09	3.36	3.56	0.142	14.62	0.049	0.760	2.811	1.58	2.55	4.13	22.37	126.9	139.93	17.9	33.9	13.2	25.58	15.58	292.4
Bystrzyca	317j	9	0	1.04	26.61	25.69	4.64	4.02	4.19	0.146	11.45	0.058	0.780	2.995	0.58	1.21	1.78	17.07	23.1	83.40	14.7	13.2	13.1	26.08	12.31	229.0
Bystrzyca	304c	12	0	0.83	33.87	40.81	4.27	3.51	3.72	0.166	12.57	0.086	0.968	3.610	1.28	2.46	3.74	20.97	490.2	145.50	29.3	44.2	11.9	29.5	24.16	251.4
Pokrzywno	351c	13	1	1.92	30.42	15.86	4.33	3.49	3.92	0.18	8.51	0.094	1.023	1.456	3.93	0.86	4.79	15.87	440.7	129.98	82.2	78.4	7.9	16.95	20.95	170.2
Kłodzko	88c	14	0	1.86	24.20	13.00	4.83	3.98	4.35	0.15	8.71	0.027	0.98	2.117	1.50	0.19	1.69	13.53	72.5	123.10	15.3	25	16.5	22.4	19.18	174.2
Kłodzko	88a	15	1	2.31	39.01	16.89	4.43	3.57	3.98	0.215	12.08	0.034	1.086	2.22	1.39	0.31	1.69	17.11	18.2	105.60	31.5	115.2	27.5	25.4	20.93	241.6
Kłodzko	88b	16	0	1.41	15.60	11.07	4.37	3.41	3.75	0.067	2.29	0.036	0.309	0.556	4.82	1.35	6.17	9.36	112.8	105.92	21.6	21.2	4.6	9.56	6.05	45.8
Kłodzko	118c	17	1	1.52	46.26	33.04	3.51	2.67	2.87	0.126	6.13	0.078	0.925	0.896	2.94	4.53	7.47	15.50	392.3	132.46	79.7	95.1	18.3	15.49	5.70	122.6
Kłodzko	329d	18	0	2.37	27.84	11.77	4.06	3.46	3.55	0.215	1.18	0.052	0.631	0.385	9.42	5.24	14.66	16.91	341.2	140.76	29.5	22.1	3.6	6.25	12.92	23.6
Lubawka	334f	19	0	3.77	32.14	8.53	3.79	2.89	3.06	0.144	1.67	0.025	0.465	0.438	7.63	3.98	11.61	14.21	143.1	136.49	14.8	32.0	8.5	7.85	9.52	33.4
Lubawka	155p	20	0	1.17	37.00	31.54	3.3	2.64	2.7	0.091	2.3	0.030	0.634	0.588	7.50	6.26	13.76	17.31	61.3	119.31	75.2	269.1	8.0	8.2	12.66	46.0
Lubawka	155p	21	0	1.53	49.92	32.65	3.56	2.65	2.87	0.110	4.96	0.048	1.022	0.623	2.47	5.31	7.78	14.43	316.2	140.88	67.1	73.9	15.6	11.43	21.68	99.2
Lubawka	155r	22	1	3.37	36.65	10.86	3.63	2.8	3.05	0.136	5.47	0.067	0.469	0.7	7.42	3.16	10.58	17.29	88.8	144.43	34.3	150.3	25.3	11.2	9.60	109.4
Lubawka	142d	23	0	2.56	35.53	13.87	3.77	2.93	3.16	0.154	4.1	0.035	0.64	0.786	7.27	2.24	9.50	15.06	197.8	116.47	48.8	23.2	10.3	12.45	13.11	82.0
Lubawka	156a	24	0	0.86	25.32	29.47	3.91	3.09	3.26	0.071	5.93	0.056	0.397	2.982	4.19	4.06	8.26	17.62	135.3	131.52	20.1	21.9	5.1	25.92	8.25	118.6
Lubawka	174d	25	0	0.80	27.26	33.95	3.36	2.56	2.6	0.079	1.87	0.064	0.405	0.363	5.88	5.06	10.94	13.64	424.7	124.29	50.1	119.4	5.1	6.1	10.22	37.4
Lubawka	217c	26	1	2.25	43.55	19.32	3.87	2.88	3.14	0.123	5.42	0.04	0.702	0.601	4.36	2.60	6.96	13.72	322.9	138.15	15.3	16.1	7.6	11.2	15.22	108.4
Lubawka	217d	28	0	2.30	17.20	7.49	3.73	2.79	2.98	0.099	1.98	0.051	0.285	0.289	6.16	3.57	9.73	12.34	12.0	72.70	7.9	10.4	4.4	5.25	5.49	39.6
Lubawka	218a	29	1	2.03	38.78	19.10	3.82	2.9	3.15	0.163	6.15	0.027	0.648	0.64	5.03	2.31	7.35	14.81	26.0	98.50	12.3	18.9	10.0	10.45	14.05	123.0
Lubawka	218a2	30	0	1.57	18.50	11.80	3.62	2.87	3.06	0.133	1.58	0.031	0.323	0.301	7.53	2.15	9.68	11.92	16.4	104.27	15.7	23.9	4.5	6.75	7.00	31.6
Lubawka	208j	31	1	2.86	31.87	11.16	3.89	3.04	3.07	0.246	4.24	0.064	0.763	0.626	4.10	2.92	7.01	12.71	8.1	70.70	17.7	9.1	28.2	11.2	14.71	84.8
Międzylesie	27d	32	0	0.87	22.53	25.90	5.03	4.33	4.47	0.142	11.2	0.064	1.035	2.968	1.20	0.78	1.98	17.25	328.5	128.91	42.6	95.6	17.0	28.51	25.91	224.0
Międzylesie	31b	33	0	0.96	24.34	25.31	4.13	3.36	3.56	0.134	8.18	0.040	0.914	1.924	1.74	1.52	3.26	14.32	508.5	49.70	64.5	113.1	10.2	22.6	21.29	163.6
Międzylesie	110a	34	0	2.67	30.92	11.56	3.69	2.95	3.27	0.23	4.47	0.035	0.668	1.487	9.15	4.68	13.83	20.49	288.4	124.53	12.6	18.3	23.9	16.2	13.08	89.4

Table 1 cont.

Forest sub-district "Obręb"	Subcompartment	No.	N.r.s.	Tot. % N	Organic carbon %C	C:N	pH H_2O	pH KCl	pH $CaCl_2$	EC [dS m^{-1}]	Exchengeable cations Ca	Na	K	Mg	Al	H	Acidity	ECEC	Soluble Mn	Fe	Zn	Pb	Available P_2O_5	Mg	K_2O	Ca
											cmol$_{(+)}$ kg^{-1}								mg/kg				mg/100g			
Międzylesie	110b	35	1	1.87	34.25	18.29	3.56	2.84	3.25	0.150	3.28	0.033	0.469	1.046	16.80	2.54	19.33	24.16	372.3	115.64	47.4	150.3	3.2	13.8	9.41	65.6
Międzygórze	239c	37	0	1.81	45.14	24.94	4.45	3.56	3.95	0.15	9.13	0.025	0.713	1.775	2.14	1.08	3.22	14.86	377.6	141.71	18.2	103.5	21.4	18.4	13.96	182.6
Międzygórze	172j	38	0	3.43	42.42	12.36	4.85	3.42	3.84	0.113	3.33	0.034	1.04	2.65	2.30	1.34	3.64	10.69	156.3	109.20	33.0	96.9	5.2	25.4	20.36	66.6
Międzygórze	238a	39	0	2.13	48.20	22.63	3.7	2.85	3.16	0.226	12.03	0.059	1.173	2.085	2.12	1.88	3.99	19.34	309.8	98.34	78.2	22.7	1.6	21.46	22.96	240.6
Świdnica	220c	40	0	3.30	34.74	10.51	3.95	3.19	3.48	0.21	7.36	0.081	0.868	1.44	5.07	3.00	8.07	17.82	31.9	103.79	32.2	52.3	6.8	18.45	17.78	147.2
Bielawa	154j	41	0	3.00	24.78	8.27	4.44	3.48	3.84	0.14	8.51	0.035	0.75	1.52	4.16	1.51	5.67	16.48	269.6	119.55	22.0	22.9	6.9	18.9	4.77	170.2
Świeradów	29c	42	0	4.23	44.00	10.41	4.47	3.57	3.98	0.335	11.05	0.161	1.19	1.849	1.33	1.54	2.87	17.12	83.0	120.97	22.4	36.1	38.6	22.1	24.37	221.0
Świeradów	28b	43	0	3.74	30.78	8.24	4.01	3.17	3.4	0.137	0.4	0.073	0.036	0.25	4.96	2.65	7.60	8.36	268.4	128.79	24.1	82.4	16.0	4.2	0.76	8.0
Świeradów	29 c2	44	0	2.39	45.82	19.14	5.37	4.76	5.23	0.58	25.2	0.139	1.26	2.69	1.19	1.43	2.63	31.92	131.4	132.11	26.8	113.1	57.3	26.5	26.56	504.0
Świeradów	19b2	45	0	5.25	39.91	7.60	3.69	3.02	3.13	0.164	4.81	0.087	0.525	0.561	10.75	4.26	15.01	20.99	287.5	99.76	35.0	94.8	18.7	8.51	11.07	96.2
Świeradów	18 i	46	0	4.16	45.08	10.84	4.4	3.75	4.11	0.468	15.27	0.233	1.3	2.48	1.74	2.66	4.40	23.68	561.3	118.72	46.8	141.4	57.6	24.6	27.40	305.4
Świeradów	31i	47	0	0.80	19.86	22.29	3.64	3.03	3.21	0.079	2.18	0.059	0.421	0.492	7.72	4.12	11.84	14.99	80.3	127.61	31.4	196.9	4.5	7.3	9.22	43.6
Zagnańsk	390c	48	0	3.04	38.45	12.66	3.78	2.99	3.24	0.252	3.53	0.044	0.929	1.188	4.31	4.90	9.21	14.90	7.5	107.20	19.6	13.0	17.9	13.89	17.91	70.6
Wałbrzych	104g	49	0	0.61	21.37	35.21	3.42	2.88	2.9	0.063	0.89	0.061	0.234	0.350	8.80	5.80	14.60	16.14	389.0	54.20	44.7	20.1	2.5	6.39	3.04	17.8
Wałbrzych	115d	50	0	1.39	37.82	27.24	3.58	2.66	2.8	0.126	3.94	0.060	0.756	0.839	–	–	–	5.60	513.9	128.44	95.8	69.3	7.5	13.09	16.95	78.8
Wałbrzych	26a	51	0	1.46	28.98	19.90	3.33	2.51	2.89	0.103	1.95	0.060	0.482	0.559	11.67	9.16	20.83	23.88	156.4	123.34	38.4	119.4	6.6	8.6	7.88	39.0
Gluszyca	127d	52	1	1.51	31.93	22.40	3.3	2.62	2.83	0.134	2.8	0.070	0.547	0.556	9.38	6.92	16.30	20.27	11.0	104.98	15.6	16.4	6.1	7.42	7.46	56.0
Gluszyca	127d	53	0	0.68	15.89	23.25	3.68	3.11	3.19	0.073	1.69	0.039	0.281	0.520	10.08	4.33	14.41	16.94	557.3	133.77	65.6	56.9	4.7	9.05	4.29	33.8
Gluszyca	374i	54	0	1.11	25.69	25.05	3.56	2.51	3.26	0.083	1.61	0.420	0.383	0.222	7.96	5.53	13.48	16.12	12.1	129.98	14.9	16.4	2.0	3.25	7.03	32.2
Zagnańsk	5d	55	1	1.81	40.97	22.69	3.92	3.09	3.35	0.149	8.04	0.106	0.737	0.726	4.94	1.69	6.63	16.24	520.9	106.64	53.3	82.4	10.0	13.61	20.01	160.8
Zagnańsk	20a	56	1	2.07	42.40	20.46	4.1	3.28	3.56	0.187	11.67	0.136	0.923	1.37	2.98	1.96	4.94	19.03	75.0	142.89	68.3	92.5	13.3	19.25	1.00	233.4
Duszniki	235p	57	1	2.95	38.27	12.96	3.41	2.53	2.78	0.176	3.34	0.085	0.572	0.633	6.83	4.83	11.66	16.29	192.8	133.06	37.1	88.6	14.4	8.25	16.70	66.8
Duszniki	235f	58	1	4.72	49.32	10.45	4.31	3.65	3.95	0.324	2.72	0.054	0.136	0.197	1.17	2.00	3.17	6.28	33.3	134.00	36.6	124.6	33.1	3.7	2.87	54.4
Duszniki	235h	59	1	3.95	31.16	7.89	4.16	3.19	3.51	0.119	11.42	0.044	0.75	1.378	1.92	1.04	2.96	16.55	448.7	135.19	59.3	89.7	13.6	15.1	15.81	228.4
Duszniki	235f	60	1	1.04	49.49	47.81	3.08	2.92	3.14	0.166	9.41	0.136	1.650	1.570	0.76	3.77	4.53	17.30	451.8	101.66	85.7	178.0	20.5	21.4	32.34	188.2
Duszniki	325a	61	1	1.08	36.37	33.87	4.19	3.47	3.67	0.158	12.85	0.103	1.450	2.130	2.89	2.43	5.33	21.86	43.4	134.60	18.3	25.5	14.0	18.51	25.90	257.0
Duszniki	325b	62	1	1.16	40.73	35.08	3.25	2.48	2.64	0.181	3.85	0.055	0.614	0.523	5.93	7.66	13.58	18.63	431.1	14.10	32.2	10.07	11.7	11.58	15.88	77.0
Duszniki	325a	63	1	0.60	18.90	31.72	4.15	3.49	3.64	0.118	6.03	0.067	0.823	0.884	3.17	2.80	5.97	13.77	9.5	23.50	14.2	26.1	9.0	13.85	7.30	120.6
Duszniki	119b	65	0	1.73	43.71	26.48	3.58	2.72	2.9	0.126	5.32	0.093	1.100	0.967	2.95	4.33	7.28	14.76	61.6	106.28	33.4	84.6	19.1	16.25	25.18	106.4
Duszniki	121d	66	1	5.01	44.62	8.90	3.9	3.1	3.36	0.683	8.31	0.449	1.19	2.19	2.75	2.42	5.17	17.31	78.8	149.29	20.9	28.0	52.7	24.6	14.91	166.2
Duszniki	379k	67	0	2.63	43.31	16.48	3.54	2.72	2.97	0.327	5.7	0.385	0.84	1.042	7.57	6.21	13.77	21.74	48.2	131.75	36.2	134.0	17.3	12.5	23.65	114.0

Table. 2. Some physico-chemical properties of soils from silver fir localities in Sudety Mts, A horizon. N. r. s. – Natural regeneration state: 1 – good, 0 – poor; EC – electrical conductivity; ECEC – effective cation exchangeable capacity

Forests ub-district “Obręb”	Subcompartment	No.	N.r.s.	Tot. % N	Organic carbon % C	C:N	pH H_2O	pH KCl	pH $CaCl_2$	EC [dS m^{-1}]	Exchengable cations: Ca	Na	K	Mg	Al	H	Acidity	ECEC	Soluble: Mn	Fe	Zn	Pb	Available: P_2O_5	Mg	K_2O	Ca	Clay content	Soil Texture
											cmol$_{(+)}$ kg^{-1}								mg/kg				mg/100g					
Bardo	148s	1	0	0.25	3.29	13.35	4.35	3.48	3.85	0.149	1.00	0.050	0.224	0.224	1.90	2.73	4.63	6.13	518.5	109.72	32.6	85.1	1.1	3.45	5.99	20.0	5	csl
Bardo	256c	2	0	0.13	2.13	16.54	4.32	3.23	3.71	0.087	1.26	0.053	0.138	0.202	3.90	1.62	5.52	7.17	434.1	130.45	44.5	103.5	0.5	2.95	3.16	25.2	5	sil
Bardo	257a	3	0	0.10	2.45	24.06	3.74	3.01	3.33	0.134	0.49	0.040	0.029	0.126	6.59	1.87	8.45	9.14	393.7	124.29	38.5	40.8	5.2	1.95	0.66	9.8	7	fsl
Bystrzyca	6j	4	1	0.30	1.30	43.93	3.56	2.79	3.07	0.134	1.09	0.070	0.119	0.325	7.37	2.77	10.14	11.75	195.6	119.31	44.6	169.1	5.8	6.70	2.02	21.8	2	vfsl
Pokrzywno	18g	5	0	0.09	1.80	18.95	4.36	3.15	3.65	0.071	1.12	0.069	0.055	0.168	4.06	1.54	5.60	7.02	207.4	118.48	32.7	78.4	1.1	2.58	3.12	22.4	7	fsl
Bystrzyca	313a	7	0	0.25	7.98	32.32	3.59	2.85	3.22	0.189	1.14	0.049	0.145	0.328	6.07	2.35	8.42	10.08	43.0	102.25	34.3	78.8	1.8	5.26	2.81	22.8	1	fsl
Bystrzyca	315i	8	0	0.20	4.20	20.63	3.80	2.90	3.23	0.158	1.88	0.039	0.097	0.324	5.69	1.83	7.52	9.86	210.0	106.16	41.1	106.2	5.2	4.03	3.42	37.6	11	sl
Bystrzyca	317j	9	0	0.15	2.74	18.67	3.59	2.96	3.45	0.051	1.46	0.046	0.051	0.370	5.70	1.87	7.57	9.50	130.3	100.59	20.1	23.5	4.0	5.80	1.24	29.2	10	sl
Bystrzyca	99a	10	0	0.13	2.73	20.82	3.37	2.61	2.85	0.150	0.54	0.040	0.029	0.190	5.95	2.13	8.08	8.88	210.8	118.72	40.3	126.2	2.2	3.10	0.70	10.8	6	fsl
Bystrzyca	99a	11	0	0.29	4.97	17.39	3.72	3.12	3.29	0.103	0.65	0.051	0.041	0.135	8.74	2.91	11.66	12.53	259.8	130.69	38.4	65.3	1.0	2.38	3.05	13.0	1	fsl
Bystrzyca	304c	12	0	0.10	1.58	15.07	4.16	3.24	3.60	0.103	0.77	0.058	0.040	0.219	4.37	0.98	5.36	6.44	39.6	127.61	26.7	101.3	1.2	4.23	1.13	15.4	6	sl
Pokrzywno	351c	13	1	0.25	4.06	16.12	4.15	3.18	3.64	0.202	0.51	0.048	0.189	0.298	10.14	2.17	12.32	13.36	539.9	132.94	53.9	31.8	2.2	4.51	3.87	10.2	15	l
Wojborz	88c	14	0	0.56	5.21	9.30	4.55	3.58	4.01	0.095	0.57	0.027	0.106	0.100	7.17	1.69	8.86	9.66	341.6	114.10	25.3	16.2	1.8	1.35	2.07	11.4		
Wojborz	88a	15	1	0.15	1.40	9.31	4.23	3.28	3.73	0.077	0.63	0.033	0.129	0.098	7.09	1.31	8.40	9.29	556.9	89.20	31.6	20.8	1.3	1.35	2.49	12.6	5	fsl
Lubawka	320d	18	0	0.29	1.88	6.50	3.55	2.71	3.04	0.130	0.14	0.026	0.104	0.05	4.27	1.17	5.43	5.75	182.1	118.72	35.2	23.5	1.1	1.01	2.13	2.8	5	fsl
Lubawka	334f	19	0	0.37	3.20	8.72	3.93	3.25	3.46	0.100	0.14	0.021	0.147	0.033	6.35	1.00	7.35	7.69	252.1	132.11	31.2	49.4	3.9	0.54	3.01	2.8	4	sil
Lubawka	155p	21	0	0.18	4.47	24.19	3.41	2.87	3.01	0.103	0.57	0.042	0.128	0.150	7.00	3.06	10.06	10.95	537.9	79.20	53.1	56.2	5.2	2.85	2.93	11.4	2	sil
Lubawka	142d	23	0	0.31	3.78	12.38	3.71	3.04	3.27	0.136	0.12	0.021	0.095	0.040	6.18	1.40	7.58	7.85	48.2	109.80	14.4	33.4	6.1	0.85	2.06	2.4	3	fsl
Lubawka	217c	26	1	0.32	2.57	8.02	3.51	2.89	3.27	0.165	0.17	0.024	0.064	0.068	4.91	1.76	6.67	7.00	167.4	139.93	16.1	25.3	0.6	1.15	1.23	3.4	5	lfs
Lubawka	318a	27	1	0.18	2.02	11.24	3.51	2.95	3.15	0.162	0.21	0.054	0.061	0.068	2.40	0.97	3.37	3.76	113.1	135.31	17.5	31.6	1.3	1.31	1.19	4.2		
Lubawka	318a	29	1	0.34	8.90	25.84	3.60	2.90	3.24	0.300	0.26	0.026	0.066	0.060	3.95	1.26	5.21	5.62	160.0	139.81	19.6	66.0	0.3	1.25	1.43	5.2	4	fsl
Międzylesie	27a	32	0	0.40	9.17	22.91	3.80	3.07	3.35	0.118	1.61	0.084	0.208	0.345	7.87	2.05	9.92	12.17	13.6	126.90	25.6	63.1	1.4	5.65	4.04	32.2	5	vfsl
Międzylesie	31b	33	0	0.12	0.90	7.50	3.60	2.93	3.08	0.095	0.62	0.026	0.081	0.206	8.75	3.53	12.28	13.21	81.6	99.64	46.9	131.9	0.9	4.90	3.14	12.4	2	vfsl
Międzylesie	110b	36	1	0.37	6.85	36.17	3.06	2.54	2.64	0.142	1.08	0.055	0.263	0.249	11.82	3.39	15.21	16.86	463.4	120.26	66.4	55.2	0.7	4.25	15.98	21.6	13	sil
Bielawa	154j	41	0	0.18	1.59	8.84	4.29	3.07	3.76	0.108	0.47	0.031	0.24	0.060	4.91	2.20	7.11	7.91	31.8	142.18	16.9	25.5	0.4	1.05	12.54	9.4	4	fsl
Świeradów	29c	42	0	0.29	2.43	8.37	3.51	2.75	3.17	0.188	0.31	0.035	0.068	0.057	0.96	0.50	1.46	1.93	294.9	130.21	42.8	65.0	0.3	1.25	1.39	6.2	11	sil
Świeradów	28b	43	0	0.46	5.10	11.04	3.39	2.48	3.04	0.213	0.16	0.063	0.091	0.149	6.76	3.72	10.48	10.94	555.9	139.22	62.9	70.7	7.0	2.15	1.86	3.2	4	fsl
Wałbrzych	104g	49	0	0.17	4.36	25.32	3.82	3.41	3.61	0.110	0.38	0.034	0.012	0.085	6.06	1.70	7.76	8.27	71.5	111.02	22.3	30.0	0.1	2.50	0.52	7.6	1	lcs
Wałbrzych	115d	50	0	0.11	1.97	17.71	3.29	2.28	2.51	0.221	0.58	0.056	0.073	0.145	7.33	2.93	10.26	11.11	156.2	42.00	38.5	83.4	1.1	2.50	1.86	11.6	11	csl
Gluszyca	126h	51	0	0.11	1.75	15.63	3.23	2.33	2.61	0.166	0.41	0.037	0.075	0.100	10.55	2.64	13.18	13.81	436.4	131.28	124.5	64.7	1.4	1.95	1.79	8.2	15	l

Table 2 cont.

Forests ub-district "Obręb"	Subcom-partment	No.	N.r.s.	Tot. % N	Or-ganic carbon % C	C:N	pH H_2O	pH KCl	pH $CaCl_2$	EC [dS m^{-1}]	Exchangable cations Ca	Na	K	Mg	Al	H	Acidity	ECEC	Soluble Mn	Fe	Zn	Pb	P_2O_5	Available Mg	K_2O	Ca	Clay con-tent	Soil Tex-ture
											cmol$_{(+)}$ kg^{-1}								mg/kg					mg/100g				
Gluszyca	127d	52	1	0.19	3.67	18.93	3.76	3.05	3.22	0.095	0.48	0.041	0.096	0.117	5.74	1.32	7.06	7.79	32.6	113.98	27.9	98.6	1.6	1.95	20.06	9.6	5	fsl
Gluszyca	127d	53	0	0.21	2.91	13.56	4.35	3.71	3.87	0.054	0.61	0.043	0.010	0.088	3.95	1.01	4.96	5.71	133.0	137.91	32.6	24.3	2.3	1.75	0.23	12.2	6	vfsl
Gluszyca	374i	54	0	0.11	2.36	21.06	3.49	2.69	2.91	0.150	1.01	0.071	0.104	0.182	5.32	2.46	7.78	9.15	161.4	125.59	53.3	41.4	4.0	2.50	2.41	20.2	12	l
Zagnańsk	20a	55	1	0.13	2.56	19.86	3.43	2.54	2.93	0.144	0.65	0.088	0.046	0.072	1.43	0.93	2.36	3.22	141.1	126.54	28.4	88.2	0.7	0.68	4.10	13.0	3	fsl
Duszniki	235p	57	1	0.17	1.80	10.61	3.31	2.46	2.88	0.209	0.20	0.038	0.081	0.074	2.49	1.28	3.77	4.17	194.2	140.52	28.8	94.9	3.5	1.25	11.37	4.0	4	vfsl
Duszniki	325a	61	1	0.14	2.07	14.33	3.36	2.47	2.87	0.134	0.70	0.036	0.076	0.148	6.22	1.98	8.20	9.16	531.6	136.37	67.2	63.4	1.4	2.48	2.02	14.0	4	sl
Duszniki	325 e	62	1	0.13	3.02	23.18	3.19	2.50	2.79	0.197	0.59	0.044	0.043	0.100	4.09	1.71	5.79	6.57	343.2	121.21	34.9	14.1	4.4	1.85	0.42	11.8	7	fsl
Duszniki	140f	64	1	0.16	2.60	15.95	3.81	3.12	3.30	0.110	0.66	0.039	0.051	0.120	5.37	1.78	7.15	8.02	480.5	95.38	60.5	69.7	0.6	1.85	1.17	13.2	5	fsl

Table 3. Average values of studied soil proprieties on localities with poor and good fir regeneration. EC – electrical conductivity; ECEC – effective cation exchangeable capacity

Hori-zon	Natural regen-eration state	Total % N	Or-ganic carbon %C	C:N	pH H_2O	pH KCl	pH $CaCl_2$	EC [dS m^{-1}]	Exchengeable cations Ca	Na	K	Mg	Al	H	Acidity	ECEC	Soluble Mn	Fe	Zn	Pb	Available P_2O_5	Mg	K_2O	Ca
									cmol$_{(+)}$ kg^{-1}								mg/kg				mg/100 g			
0	poor	2.260	37.83	21.33	3.83	3.06	3.29	0.197	6.990	0.095	0.828	1.140	9.86	3.13	12.83	16.62	226.96	111.29	41.38	76.93	17.04	14.63	14.31	139.83
0	good	1.980	32.37	20.80	4.00	3.21	3.46	0.163	6.610	0.079	0.727	1.408	7.10	3.27	10.29	16.61	217.90	116.58	37.33	74.08	13.59	15.84	14.93	132.15
A	poor	0.219	3.38	16.69	3.77	2.97	3.30	0.130	0.715	0.044	0.094	0.160	5.79	2.02	7.81	8.82	234.17	116.54	38.83	61.61	2.49	2.70	2.60*	14.30
A	good	0.226	3.32	19.19	3.61	2.84	3.16	0.157	0.553	0.046	0.103	0.141	5.75	1.74	7.49	8.33	298.02	124.13	38.54	67.88	1.66	2.39	5.58*	11.06

czyk and Januszek (Jaworski and Zarzycki 1983) and Baran (1977).

When analysing metal content (Mn, Zn, Pb and Fe) in horizon A of the areas investigated one must conclude that it differs significantly in terms of quantity, however, the concentration of metals does not differ considerably from the standards adopted. Only the content of lead in the case of a dozen or so of stands investigated exceeds the standards for arable soils. The group of stands with higher lead content include also sites where a better than average regeneration of silver fir was identified, for instance, the comparative forest stand from Zagnańsk considered to be an optimum of regeneration. It is suggested that, in this particular case, the level of lead contamination did not play a role in inhibiting the regeneration of the silver fir.

Worth mentioning is also a relatively high content of manganese in the soils of certain stands. The field descriptions of samples where a higher content of this metal was identified, often contained annotations about the high content of dead fir needles, hence, the suggestion that manganese originates mainly from fallen needles which contain relatively large amounts thereof (Rousseau 1960). The described situation applies, for example, to litter samples taken under canopy of dens thicket or underwood. According to Rousseau (1960) high manganese content, especially in mull-type humus in rain-free periods, can have a toxic effect on young seedlings. Lack of seedlings was observed under the canopy of a dens thicket and a young stand with a high share of silver fir, but it can results from the fact that is very dark in there. In other stands in the Sudety Mountains, the toxic effect of manganese from fallen needles on the regeneration of the described species has a rather marginal significance due to the generally low share of silver fir in the tree stand. There are also few silver fir stands with typical mull-type humus.

Table 3 presents average values of studied soil proprieties taking into consideration division on localities with poor and good fir regeneration. The differences (among average) are not statistically significant. Presented data suggested, that silver fir can well regenerate on soils with diverse chemical composition. It corresponded to Korpel's (1975) opinion, that for fir more important are moisture conditions than chemistry of soils.

Conclusions

According to the studies performed, none of the factors analysed within the samples tested has a definite impact on the natural regeneration of silver fir. The only dependence between potassium content in soil and the regeneration of silver fir in the Sudety Mountains is close to statistically significance. It must be clearly emphasised here that natural regeneration of silver fir in southern Poland depends on a number of other factors. Surely, in some cases a specific chemical composition together with other factors, such as moisture or light, can have a significant modifying effect on the regeneration of silver fir. On the basis of the studies performed we can also risk a statement that presently the soil contamination factor is not the main reason for unsatisfactory regeneration of silver fir in the Sudety Mountains.

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