Contemporary Problems of Management and Environmental Protection
Vol. 1, 2009. Soils of Chosen Landscapes: 153-163

Chapter IX

Marcin Pietrzykowski
Marek Pająk

The Application of the Forest Soil Trophism Index (FSTI) for Assessment of Site Condition Variability in Post-Mining Areas Reclaimed to Forestry

INTRODUCTION

The methods of site condition assessment used in the reclamation of post-mining areas in Poland are: the cartographic-soil method, the phytosociological-soil method and the soil method. However, most of the methods of classification of post-mining areas apply to the initial conditions and to the assessment of these soils' usefulness for reclamation [KNABE 1962, SKAWINA, TRAFAS 1971, KRZAKLEWSKI 1979, GOŁDA 2005]. Apart from preliminary estimation allowing for general classification of areas for reclamation purposes, what is essential is detailed assessment of sites at a given object. This constitutes the basis of forest management, including an appropriate choice of the species composition in afforested areas [KRZAKLEWSKI 2001]. Every post-mining object, and sometimes its parts, requires individual assessment of its site conditions in order to prepare biological reclamation measures to be taken [GRESZTA, SKAWINA 1965, SKAWINA 1969, SKAWINA, TRAFAS 1971, STRZYSZCZ, HARABIN 1976, KRZAKLEWSKI 1977; SIUTA 1978, GILEWSKA 1991]. The issue of site assessment according to objective criteria is significant for forest practice also in the aspect of verification of initial site diagnosis for the purpose of planning the reconstruction of ripening stands or stands with the target species composition but showing defective growth.

The elements assessed in the standard description of a forest site are: climate, geology, land relief and soil formed in these conditions. Soil is a basic element of forest site diagnosis [BROŻEK 2001]; and the issues of objective assessment of soil quality and production capabilities, initially connected with agriculture, are now also important for forest site science. Presentation of soil trophism in the form of numerical data allows for diagnosis and objective comparison of sites [SHOENHOLTZ et al. 2000]. Quantitative assessment of 'site fertility', often identified with 'soil fertility', may be performed indirectly because the concept of fertility is related not only to abundance but also to soil features in general and it is their biological resultant [PUCHALSKI, PRUSINKIEWICZ 1975]. The choice of soil features serving as direct measures of trophism or indices of soil quality is still controversial [BURGER, KELTING 1999; SCHOENHOLTZ et al. 2000; BROŻEK 2001, 2007].

For soil-less areas, it is already in the early 1970s that a scoring method of soil classification was elaborated in order to assess their capability to reclamation [SKAWINA, TRAFAS 1971]. The past and current practice of using this classification has confirmed its universality and usefulness in initial recognition of the conditions for biological reclamation of soil-less areas [KRZAKLEWSKI, WÓJCIK 2004]. Its usefulness has also been proved for assessment of the differentiation of site conditions at afforested objects belonging to I and II stand age classes [PIETRZYKOWSKI et al. 2009].

With regard to the forest practice in Polish conditions [BROŻEK 2001, BROŻEK, ZWYDAK 2003], the Soil Trophism Index (FSTI) has been proposed. It took into consideration the results of determination of soil physical and chemical properties which constitute soil trophism, i.e. the content of silt fractions and floatable particles, reaction, content of exchangeable alkaline cations and the C/N relation. The value of the index adopted is the sum of the indexes of individual features on a scale (from 1 to 10 points), where the values of the features are weighed according to the volume of levels. The value of the FSTI is reduced by the so-called index of soil skeleton parts (from 1 to 5 points). The fact that the values of individual features are determined according to a scale of points results from the variability of these features in the soils of Poland. The variability of the FSTI value in Polish soils allowed for determination of trophic groups of sites: from oligotrophic soils with the FSTI value < 10 points to hypertrophic soils with the FSTI value > 36 points and, consequently, for determination of respective units: from coniferous forests (C) to forests (F). Further studies showed that, in the classification of lowland and upland forest sites in Poland, there were four properties which clearly characterized the following site groups: coniferous forests (C), mixed coniferous forests (MC), mixed forests (MF) and forests (F). The properties were: the content of fractions 0.1-0.02 mm and <0.02 mm, pH in H_2O and the content of easily mineralized nitrogen [BROŻEK 2007]. The first attempt of applying FSTI to assess sites forming in post-mining areas was undertaken by PIETRZYKOWSKI AND KRZAKLEWSKI [2006], whose research concerned the working formed after the exploitation of filling sands.

The aim of the present study is broader assessment of the usefulness of the Forest Soil Trophim Index (FSTI), [BROŻEK 2001] for diagnosis of forest sites forming in reclaimed and afforested post-mining areas.

MATERIAL AND METHODS

Research was conducted at four post-mining objects, reclaimed and afforested with Scotch pine belonging to I and II stand age classes. The objects were: the top of the external waste heap of the "Bełchatów" lignite coal mine (abbreviation: bel); the "Smolnica" central carbon waste spoil heap (abbrev.: smol); the floor of the quarry "Szczakowa" filling sand mine (abbrev.: szcz); the external waste heap of the "Piaseczno" open-pit sulphur mine (abbrev.: pias). Within each of the objects, two fertility variants (symbols: V1 and V2) were initially distinguished. The V1 one represented the potentially more fertile deposits at a given object, i.e. the ones with more advantageous graining, with a larger admixture of clay and silt fractions. The V2 one represented the potentially less fertile deposits at a given object, i.e. the barren ones with the graining of sand (the "Piaseczno" and the "Szczakowa") or the carbonized Miocene sands after neutralization (the "Bełchatów" waste heap). In the case of the "Smolnica" central Carboniferous waste heap, the potentially more fertile variant (V1) underwent mineral fertilization 30 years ago while the less fertile variant V2 did not undergo this measure. At this object, Scotch pine had been self-sown about 30 years ago on experimental plots set up in order to assess the growth of poplar [STRZYSZCZ, HARABIN 1976, STOLARSKA et al. 2006]. At each object, experimental plots were set up (squares of 100 m^2) in four replications. Four control plots were also set up on fresh mixed coniferous forest sites (FMCF) and fresh mixed forest sites (FMF) in managed forests (the collective symbol (K), distributed so that there was one in the vicinity of each post-mining object. On the experimental plots, 36 soil profiles were made: 32 soil pits for post-mining soils down to the depth of 110 cm and 4 soil pits for natural rusty and podzolic soils, down to the depth of 150 cm, on the control plots. On each plot, 5 additional drilling holes (in the envelope pattern) were made and mixed samples were taken from the layers: 0 – 8; 8 – 50 and 50 – 110 cm (post-mining soils) as well as from the distinguished soil horizons (natural soils). Under laboratory conditions, the standard methods (OSTROWSKA et al. 1991) were used to determine the following features: partick size distribution by means of the Prószyński method (the granulometric fractions and groups according to the PN-R-04033 standard); pH by means of the potentiometric metod in H_2O and 1 M KCl in the soil : solution proportion of 1 : 2.5 (in mineral horizons); and 1 : 5 (in organic horizons); the content of calcium carbonate ($CaCO_3$) by means of the Scheibler method; the content of organic carbon (Corg) and total nitrogen (N) by means of Leco CNS 2000 device (carbon in infrared, nitrogen in the diferential thermal conductivity detector); samples containing carbonates were, before the determination of Corg, treated in 10% HCl in order to remove carbonates. Additionally, for soils being formed on the Carboniferous spoil heap, carbon Corg was determined using the Tiurin method; the total of the alkalis (S_H) was calculated by totaling the exchangeable Ca^{2+}, Mg^{2+}, Na^+, K^+ cations determined in 1 M NH_4Ac with pH 7.0 by means of the AAS method.

The FSTI index applied was modified and adapted to post-mining soils. In comparison with the original version (BROŻEK 2001), the range of silt and clay fractions was changed by applying the division into the silt fraction from 0.05 to 0.002 and the clay fraction <0.002 according to PN-R-04033, rather than the division into groups and granulometric fractions according to the Polish Soil Society [1989]. The alkali total was calculated as the total of the exchangeable Ca^{2+}, Mg^{2+}, Na^+, K^+ cations determined in ammonium acetate, rather than according to the Kappen method. The Kappen method is not recommended for soils with pH below 4.0 (in such conditions the whole sorption complex is filled with H^+ ions) and for soils containing $CaCO_3$. Considerable variability of pH values in a broad spectrum is characteristic of post-mining soils. The alkali total was next converted into capacity with the use of volumetric density determined for particular deposits at given objects, rather than calculated on the basis of the formula covering variability for natural forest soils in Poland, as presented in the original work [BROŻEK 2001]. The index of the degree of organic matter decomposition C:N was calculated only for the initial organic-mineral horizons (AinCan, 0-8cm). For these reasons, and for the sake of clarity in the following part of the present study, the Soil Trophism Index (STI) is used, which is based on the FSTI (on the basis of the following studies: BROŻEK [2001], BROŻEK and ZWYDAK [2003]).

The STI values for each profile (representing an experimental plot) were calculated as a weighed mean of the thickness of soil horizons. The results obtained (the STI values) were elaborated statistically with the use of the Statistica programme (STATSOFT INC. 2007). The significance of differences of the mean values was verified by means of the t-student test for independent variables ($p<0.05$).

RESEARCH RESULTS

Soils in post-mining areas were, in accordance with *Klasyfikacja Gleb Leśnych Polski* {Classification of Forest Soils in Poland}, [2000], classified as anthropogenic urban soils with unformed profile (Urbic Anthrosol, according to FAO 1988), while natural soils were classified as podzolic soils (Albic Arenosol, according to FAO 1988) and podzolic proper (Haplic Podzol, according to FAO 1988). The selected physical and chemical properties of initial soils being formed at the post-mining objects under analysis are presented in Table 1.

Table 1

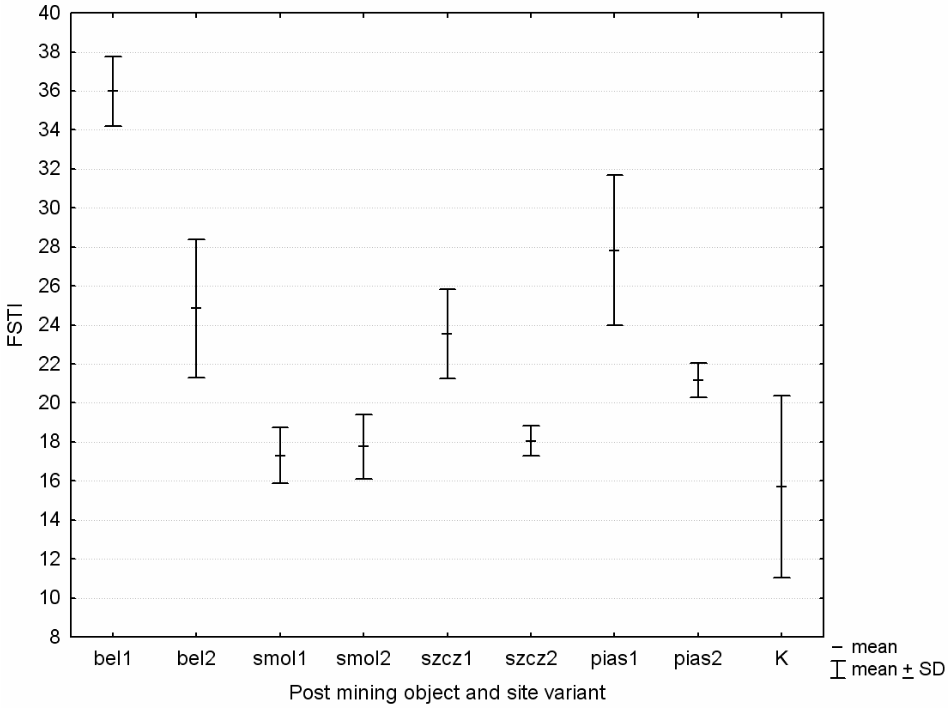
Selected properties of initial soils at four post-mining objects in relation to a fertility variant

Feature	Level	Bełchatów				Smolnica				Szczakowa				Piaseczno			
		V1	V2	V1	V2	V1	V2	V1	V2	V1	V2	V1	V2	V1	V2	V1	V2
Fractions		$\bar{x}$		SD		$\bar{x}$		SD		$\bar{x}$		SD		$\bar{x}$		SD	
Skeleton > 2mm	AiCan. Can	a.	a.	a.	a.	70	70	a.	a.	a.	a.	a.	a.	a.	5.0	a.	5.8
Silt 0.05-0.002		32	8	11	2	36	37	2	7	8	5	3	1	11	4	6	2
Clay < 0.002		3	3	3	2	24	21	2	3	4	1	1	1	9	4	2	1
pH KCl	AiCan	7.4	5.0	0.2	1.7	3.4	3.5	0.2	0.6	4.2	5.9	0.1	2.1	5.6	5.4	1.4	1.6
	Can	7.5	4.7	0.1	1.5	3.6	3.1	0.4	0.2	4.6	6.2	0.2	1.6	6.4	6.3	0.8	0.9
EC [µS/cm]	AiCan	126.3	52.8	34.0	32.5	74.8	94.3	11.5	62.1	14.5	34.8	3.1	30.4	95.8	65.8	43.9	59.3
	Can	108.8	88.6	16.0	31.5	342.4	289.8	83.8	105.9	12.0	18.8	1.6	12.8	189.3	98.3	146.3	45.9
Explanations: a. – absent; EC – Electrical Conductivity (EC); SD – standard deviation, V1 – variant representing potentially more fertile deposits, V2 – variant representing potentially less fertile deposits																	

Generally, the fertility variants distinguished differed as to the share of silt and clay fractions, pH values and Electrical Conductivity (EC), indicating a varied content of of nutrients in the soil solution. A relatively lowest differentiation between the variants was noted at the "Smolnica" Carboniferous spoil heap. Soils at this waste heap were also distinguished by a considerable share of the skeleton (70% of the volume).

The STI values obtained for soils at the four post-mining objects under analysis were largely differentiated, both within a given object and between the adopted fertility variants. The smallest differentiation of the STI values between the variants and of the basic chemical soil properties occurred at the "Smolnica" Carboniferous spoil heap.

In both variants, i.e. the fertilized one (V1) and the non-fertilized one (V2), the STI values ranged from 15.7 to 19.4; the mean values were: 17.3 for V1 and 17.8 for V2. A relatively small variability of STI values was also noted in the V2 poorer variant consisting of sand deposits at the "Szczakowa" quarry (from 17.3 to 19.1, mean value 18.1) as well as in the V2 poorer variant consisting of sands at the "Piaseczno" waste heap (from 20.1 to 22.2, mean value 21.2), (Fig. 1). In the remaining cases a higher variability of the STI values was noted within particular variants, including seemingly uniform fragments of the workings and waste heaps. In variant V1 of the "Szczakowa" quarry, on more fertile deposits, i.e. sands with addition of clay, the STI value ranged from 20.9 to 26.4 (average value 23.5) whereas in variant V1 of the "Piaseczno" waste heap, i.e. on sands with clay admixture, this value ranged from 24.0 to 31.7 (average value 27.8). At the top of the external waste heap of the "Bełchatów" lignite coal mine, on potentially more fertile plots (V1) consisting of sand-clay deposits, the STI value amounted to 33.8 up to 37.6 (on average 36.0) while on potentially less fertile plots (V2), located on Tertiary sands, the value in question was between 19.7 and 27.2 (on average 24.9).



Explanations: belv1, belv2, smolv1, smolv2, szczv1, szczv2, piasv1 i piasv2 - Post-mining object and its variant, K - Control plots

Fig. 1. Variablility of the Soil Trophism Index (STI) for the adopted fertility variants within the examined parts of post-mining objects.

The STI values made a statistically significant distinction ($p<0.05$) between the initially adopted fertility variants V1 and V2 on the waste heaps of the "Bełchatów" and the "Piaseczno" and on the "Szczakowa" quarry (Table 2). In these cases, the soil variants differed as to their species (the share of silt and clay parts). The "Bełchatów" and the "Piaseczno" also differed as to the kind (origin) of their soils: the "Bełchatów" waste heap has Quaternary sands with clays and Tertiary sands after neutralization with bog lime, while the "Piaseczno" has Quaternary sands and Tertiary sands with clays. At the "Smolnica" spoil heap, whose soil variants had different mineral fertilization performed in the biological reclamation stage, the STI values did not differ significantly.

Table 2

Comparison of the mean values of the Soil Trophism Index (STI) occurring at the examined objects in relation to a fertility variant (V1 and V2) (the result of the t-student test for independent samples).

Object	STI mean for variant		t-Statystics value	p-level	Standard deviation for variant		Quotient Variance ratio	p-level (F)
	V1	V2			V1	V2		
Bełchatów	35.98	24.85	5.615542	0.001361*	1.76	3.55	4.049317	0.280785
Smolnica	17.30	17.75	-0.410649	0.695592	1.43	1.66	1.354575	0.808990
Szczakowa	23.53	18.05	4.536648	0.003947*	2.29	0.77	8.763966	0.107801
Piaseczno	27.83	21.18	3.377659	0.014901*	3.84	0.87	19.33443	0.036477

*statistically significant difference for $p<0.05$; V1 and V2 variants are described in Methods

In the case of soils being formed out of carbonized Carboniferous deposits at the "Smolnica" spoil heap, where a large part of the carbon is of geological origin, in order to calculate the $I_{C:N}$ partial index it was necessary to consider the Corg determined by means of the Tiurin method (as opposed to the other cases of soils, where C was determined by means of burning and infrared detection on the LECO CNS 2000 analyzer). Using this method, much lower (several times lower carbon contents were obtained in soil levels; and eventually, the $I_{C:N}$ index assumed the maximum values, i.e. 10 points. However, even with this assumption, the final STI value did not increase more than by 0.7 of a unit because of the share of this feature in the mean weighed with the volume of the initial organic-mineral level. A decrease in the final STI value for the soils at the "Smolnica" spoil heap was largely influenced by the value of the skeleton index I_{sk}, ranging from 70 to 90%. At objects of this type, a very large variability of the pH value even on a small surface may be an unfavourable factor for plants. This was noted in particular at one of the plots in the non-fertilized variant, where the pH value deep in the profile amounted to 3 and the final STI value was much lower than on the other plots representing this variant (<16). On the basis of this case one may consider introducing a modification in soil quality assessment, e.g. in the form of the index of pH variability, which should be subtracted from the final value of the index. In this way the unfavourable effect of a large variability of pH in the soil profile on tree species would be taken into consideration.

In the case of soils forming on Tertiary sands after neutralization (the V2 variant) at the "Bełchatów" waste heap, an increase in the value of soil assessment on the basis of the STI was largely influenced by very advantageous properties of bog lime applied in these fragments as a neutralizer, including high pH values and a considerable abundance in Ca^{2+} i Mg^{2+} cations.

The STI values calculated, ranging from 16.0 to 26.0, would allow for classification of sites located at post-mining objects mostly as mezotrophic mixed forests (MF) (Table 3). To a smaller extent, where the STI values exceeded 26.0, the sites could be classified as eutrophic and in the case of the bel-1 plot with the STI value over 36 even as hypertrophic sites.

In these cases, there may appear sites similar to forest ones (F). Soils in natural conditions, whose STI index ranges from 16.1 to 26.0, are diagnosed as appropriate for oak stands with a small admixture of pine. In these conditions, natural soils are: fresh and relatively moist rusty soils proper, less fertile acid brown soils or, more seldom, podzolic soils. They are formed out of sands, mainly outwash and glacier sands, often with more fertile layers on deeper levels, and out of loamy sands and clays. Mixed forest sites are formed here; and the potential communities are: pine and oal forests (*Querco roboris-Pinetum*), acidophilous oak forests (*Calamagrostio-Quercetum petraeae*) and acid beech forests (*Luzulo-pilosae-Fagetum*). Natural soils, whose FSTI value exceeds 26, are mainly brown soils proper. Fertile forest sites are formed on them. Potential communities appropriate for these soils are central-European dry-ground forests, subcontinental dry-ground forests and marshy meadows. The soils on these sites are usually rich in calcium carbonate, and often include the most fertile limestone soil, black earth, brown soils as well as deluvial and alluvial soils [BROŻEK, ZWYDAK 2003].

At the "Smolnica" waste heap in the non-fertilized variant (V2) on one of the experimental plots, the STI value indicated the oligotrophic site of mixed coniferous forest (MC). In the natural conditions the FSTI values ranging from 10.1 to 16.0 are characteristic of podzolic soils, rusty soils proper, podzolized soils and sometimes arenosols. These are mixed coniferous forest sites with fresh moistening, where the potential flora is constituted by richer variants of coniferous forests (*Leucobryo-Pinetum* and *Peucedano-Pinetum* with *Oxalis acetosella*) and poorer variants of mixed coniferous forests with sessile oak (*Quercetum petraeae-Pinetum*). On moister soils poorer forms of moist mixed coniferous forest may be formed (*Querco roboris - Pinetum molinietosum*) [BROŻEK, ZWYDAK 2003].

The STI (i.e. the modified FSTI) for natural soils on control sites ranged from 12.9 for podzolic rusty soil in its ground-glia variety on the bel-9 plot, to 13.5 for podzolic rusty soil on the szczak-27 plot, to 13.7 for podzolic soil proper in its ground-glia variety on the pias-36 plot, and to 22.7 for rusty podzolic soil on the smol-18 plot. The highest STI value (for soil on the smol-18 control plot) was mainly due to a larger share of silty parts in the granulometric composition; that is why the value of the silt index (I_{silt}) significantly affected the increase in the STI value. On most of the control plots (3 cases), the STI values indicated the sites of oligotrophic mixed coniferous forests (MC); and on one control plot in the vicinity of the "Smolnica" object the STI indicated a mesotrophic site of mixed forests (MF).

SUMMARY AND CONCLUSIONS

The results obtained show that the Soil Trophism Index (STI), i.e. the modified Forest Soil Trophism Index (FSTI), may be of use in the assessment of differentiation of site conditions at post-mining objects, where it may be applied as a supplementary measure. This concerns chiefly objects formed out of deposits which differ in grain size (the share of silt and clay) and origin (geological features of rocks which constitute substratum for soils that form on them), as in the case of the examined fragments of the top of the waste heap of the "Bełchatów" lignite coal mine, the "Piaseczno" waste heap and "Szczakowa" sand mine quarry. In these cases, the mean values of the Forest Soil Trophism Index (FSTI) differentiated significantly ($p<0.05$) between fertility variants (parts of workings and waste heaps).

The STI seems to be useless on waste heaps built out of Carboniferous deposits connected with deep mining of hard coal, such as the examined "Smolnica" waste heap. In this case, a large share of the skeleton and low pH values of the analysed soils would currently allow for classification of the examined parts of waste heaps as mesotrophic sites, and even as oligotrophic ones, despite potentially large abundance and possibility to produce fertile soils, which was described in literature [STRZYSZCZ 2004].

It may also be noted that, in the case of soils forming on Tertiary sands after neutralization (V2 variant) at the "Bełchatów" waste heap, an increase in the STI value was significantly influenced by very favourable properties of bog lime used as a neutralizer, and in particular by high pH values and the abundance of Ca^{2+} and Mg^{2+} cations.

The results obtained allow for proposing the following modification of the range of the STI values for the purpose of soil assessment and classification of potential sites in afforested post-mining areas, as adapted to their specific character:

- For the STI values ranging from 15 to 20 points: possibility of formation of coniferous forest sites (C);

- For the STI values ranging from 20.1 to 25.0 points: possibility of formation of mixed coniferous forest sites (MC);
- For the STI values ranging from 25.0 to 35 points: possibility of formation of mixed forest sites (MF);
- For the STI values > 35 points: possibility of formation of forest sites (F);

The application of the above method may be treated as a supplementary measure in complex diagnosis of sites located at post-mining areas which have been reclaimed for forestry; its further verification relative to other objects is undoubtedly recommended.

REFERENCES

BROŻEK S. 2001. *Indeks trofizmu gleb leśnych*. Act. Agr..et Silv. Ser. Silv. 39: 15-33.

BROŻEK, S. 2007. *Liczbowa wycena „jakości" gleb – narzędzie w diagnozowaniu siedlisk leśnych.* Sylwan 2: 35-42.

BROŻEK S., ZWYDAK M. 2003. *Atlas gleb leśnych Polski.* CILP, Warszawa.

BROŻEK S., ZWYDAK M., LASOTA J. 2006. *Soil properties applied in forest site classification of lowlands and uplands in Poland.* Mitt. Österr. Bodenkundl. Ges., Heft 73: 87-95.

BURGER, J.A., KELTING, D.L., 1999. *Using soil quality indicators to assess forest stand management.* For. Ecol. Manage. 122: 155-156.

FAO-UNESCO, 1988. *Soil Map of the World*. Revised Legend, Food and Agriculture Organization of the United Nations, Roma.

GILEWSKA M. 1991. *Rekultywacja biologiczna gruntów pogórniczych na przykładzie KWB „Konin".* Roczniki Akademii Rolniczej w Poznaniu,. 211. Poznań.

GOŁDA T. 2005. *Rekultywacja*. Skrypty AGH.

GRESZTA J., SKAWINA T. 1965. *Zasady klasyfikacji wyrobisk górnictwa piasku podsadzkowego dla celów rekultywacji.* Biuletyn nr 5 Zakład Badań Naukowych GOP PAN w Zabrzu, Materiały Międzynarodowego Sympozjum Rekultywacji Terenów Poprzemysłowych, Katowice.

Klasyfikacja gleb leśnych Polski. 2000. Warszawa.

KNABE W. 1962. *Methods and results of strip-mine reclamation in Germany*. Strip-mine Symposium held at the Ohio Agricultural Experiment Station. August 13/14, USA.

KRZAKLEWSKI W. 1977. *Roślinność spontaniczna jako wskaźnik warunków siedliskowych oraz podstawa do zalesienia skarp zwałowiska na przykładzie Kopalni Węgla Brunatnego „Adamów"*, MS., praca doktorska AR w Krakowie.

KRZAKLEWSKI W. 1979. *Fitosocjologiczna metoda oceny warunków rekultywacji i zagospodarowani leśnego nieużytków na przykładzie skarp zwałowiska kopalni Węgla Brunatnego "Adamów".* Arch. Ochr. Środ. 3/4: 121-165

KRZAKLEWSKI W. 2001. *Rekultywacja obszarów pogórniczych i poprzemysłowych. W: Przemiany środowiska naturalnego a ekorozwój*, red. Maciej J. Kotarba. Wydawnictwo TBPŚ Geosfera, Kraków: 85-104.

KRZAKLEWSKI W., WÓJCIK J. 2004. *Wstępna ocena przydatności rekultywacyjnej utworów nadkładu odkrywki „Szczerców" w KWB „Bełchatów"*. Materiały sympozjum naukowego Warsztaty Górnicze z cyklu „Zagrożenia naturalne w górnictwie". Bełchatów 2-4 czerwca 2004. Wydawnictwo IGSMiE PAN, Kraków: 201-205.

OSTROWSKA A., GAWLIŃSKI S., SZCZEBIAŁKA Z. 1991. *Metody analizy i oceny właściwości gleb i roślin.* Warszawa.

PIETRZYKOWSKI M., KRZAKLEWSKI W. 2006. *Functionality assessment of soil quality index (ITGL) and vascular plant ecological indicator for site quality diagnosis in a sand mine excavation.* Acta Sci. Pol. Silv. Colendar. Rat. Ind. Lignar. 5(1), 47-56.

PIETRZYKOWSKI M., PAJĄK M., KRZAKLEWSKI W. 2009. *Ocena możliwości zastosowania liczby bonitacyjnej (LB) w diagnozie siedlisk leśnych kształtujących się na wybranych obiektach pogórniczych zrekultywowanych dla leśnictwa*. Ochr. Środ. i Zas. Nat. 38: 298-307

PUCHALSKI T., PRUSINKIEWICZ Z. 1975. *Ekologiczne podstawy siedliskoznawstwa leśnego*. PWRiL Warszawa.

SCHOENHOLTZ, S.H., VAN MIEGROET, H., BURGER, J.A., 2000. *A review of chemical and physical properties as indicators of forest soil quality: challenges and opportunities*. For. Ecol. and Manage. 138: 335-356.

SIUTA J. 1978. *Ochrona i rekultywacja gleb*. PWRiL Warszawa.

SKAWINA T. 1969. *Rezultaty badań nad modelem rekultywacji terenów pogórniczych w Polsce.* Zeszyty Naukowe AGH Kraków, 212, Geodezja. 12: 115-136.

SKAWINA T., TRAFAS M. 1971. *Zakres wykorzystania i sposób interpretacji wyników badań geologicznych dla potrzeb rekultywacji.* Ochrona Terenów Górniczych. 16: 3-10.

STOLARSKA M., STOLARSKI R., HARABIN Z., KRZAKLEWSKI W., PIETRZYKOWSKI M. 2006. *Sosna zwyczajna (Pinus Sylvestris L.) z sukcesji na centralnym zwałowisku odpadów górnictwa węgla kamiennego.* Rocz. Glebozn. 57(1/2): 183-191.

STRZYSZCZ Z., HARABIN Z. 1976. *Wytyczne leśnego oraz zadrzewieniowego zagospodarowania zwałowisk towarzyszących górnictwu węgla, kamiennego*. Naczelny Zarząd Lasów Państwowych i Instytut Podstaw Inżynierii Środowiska PAN w Zabrzu. Warszawa.

STRZYSZCZ Z. 2004. *Ocena przydatności i zasady stosowania różnorodnych odpadów do rekultywacji zwałowisk oraz terenów zdegradowanych działalnością przemysłową*. Instytut Podstaw Inżynierii Środowiska PAN w Zabrzu.

Acknowledgement: Research financed out of means for scientific purposes in the years 2007-2009 as a research project being part of Grant N 309 013 32 /2076 of the Ministry for Science and Higher Education of the Republic of Poland.

Marcin Pietrzykowski, Marek Pająk
Department of Forest Ecology
Hugo Kołłątaj University of Agriculture in Cracow
Al. 29 Listopada 46, 31-425 Kraków
e-mail: rlpietrz@cyf-kr.edu.pl