

Application of soil quality indexes for the habitat conditions variability assessment in the forestry rehabilitated former mining spoil banks

Marcin Pietrzykowski ✉, *Marek Pająk* and *Wojciech Krzaklewski*

University of Agriculture, Faculty of Forestry, Department of Forest Ecology, Al. 29 Listopada 46, 31-425 Kraków, Poland, phone: +48 12 4465302, fax: +48 12 4119715, e-mail: rlpietrz-cyf-kr.edu.pl

ABSTRACT

According to Polish law, all former mining areas, whether for coal or other minerals should be rehabilitated. This paper analyses the possibility of using of indexes of Soil Trophity (ITGL) and Site Soil (SIG) to describe variability in the “Bełchatów” Brown Coal Mine dumping grounds for mining subsidence, which have been reclaimed for forestry. Research was conducted in four substrate variants forming the soil bedrock being created of: nutrient-rich, sandy clay Quaternary (NWL on the inside spoil bank) and clay silt (NZL on the outside spoil bank), as well as poorer Quaternary sandy (NWG on the inside spoil bank) and acidic Miocene sands after neutralisation by bog lime (NZG on the outside spoil bank). Based on the values calculated for the tested indicators, a site assessment was carried out according to the scale drawn up for “natural” conditions. It was confirmed that concerning these two indicators tested on the mine’s spoil banks that the ITGL index reflected the soil variability better because the partial indicators valuation was based on the other soil properties and data transformation than the SIG. However, for a better description of the habitats which are forming in these conditions, it would be preferable to modify the partial indicators assessments described by these indexes based on the variability of post-mining soil properties.

KEY WORDS

forest habitat, post-mining lands, reclamation, Soil Site Index, Soil Trophism Index

INTRODUCTION

According to Polish law (Act on Agricultural and Forest Ground Protection, 1995/1997), all former mining lands, whether for coal or other minerals, must be graded to conform according to the appropriate regional topography, and they should receive reclamation treatments (e.g. receive some kind of lime, fertilizer, and plant regeneration, roads building and).

Open-cast lignite mining creates considerable soilless areas (spoil banks and excavations) which are currently required specific knowledge to reclamation. Forestry is the dominant among these, and is carried out on around 70% of post-mining areas in Poland. One very important issue for the reclamation to forest of these devastated areas is a proper assessment of the site conditions, which enables the reclamation to be properly planned and executed in such a way that the

work has a positive ecological effect of reforestation and the right public reception.

Each post-mining site, and sometimes even parts of its, requires a separate assessment of habitat conditions in order to set up a detailed biological reclamation operations (Knabe 1962; Greszta and Skawina 1965; Skawina 1969; Skawina and Trafas 1971; Strzyszczyk and Harabin 1976; Krzaklewski 1977; Siuta 1978; Gilewska 1991). The site assessment question using objective criteria is also crucial in terms to verify the initial diagnosis planning the reforestation or defectively growing tree stands with the target species composition.

The elements to be assessed in the standard description of the forest habitat are climate, geology, landform features and the soil formation in these conditions. The soil is the fundamental element in the forest site assessment (Brożek 2001), and the soil quality and production capability objective evaluation originally linked to agriculture are currently also an important issue in forest site studies. The soil eutrophication numerical description makes it possible to diagnose and to compare habitats objectives (Schoenholtz et al. 2000). The soil quality indexes are very useful tools for soil monitoring changes that occur in soils, as well as especially in case of eutrophication caused by the industry emission and even climatic changes. A quantitative assessment of "site fertility" is often incorrectly identified by "soil fertility". It may be conducted indirectly because the concept of fertility is associated not only with abundance, but with soil characteristics in general as well, and is its biological property (Puchalski and Prusinkiewicz 1975). The soil characteristics selection can be used as a direct eutrophication measures or as a soil quality indicators, which practise is still considered to be doubtfully (Burger and Kelting 1999; Schoenholtz et al. 2000; Brożek 2001, 2007).

As far back as the early 70-ties of the last century a point classification for ground assessment in terms of its usefulness for reclamation was drawn up regarding soilless areas (Skawina and Trafas 1971). The application of this practice until now has confirmed its universality and usefulness in initial biological reclamation conditions observations for soilless areas (Krzaklewski and Wójcik 2004). Its usefulness has also been shown in the habitat conditions assessment in areas with stands at the 1st and 2nd age classes (Pietrzykowski et al. 2009).

In Polish conditions, for forestry practice the Soil Trophism Index (ITGL) has been proposed (Brożek 2001; Brożek and Zwydak 2003), which covers the physical and chemical soil properties that contribute to their eutrophication, i.e. its dust and fines fraction, its pH and exchangeable basic cation content, and the C:N ratio. These features were numerically appropriately assessed then, separately for each of the soil horizons, and the final value was the sum of the partial indicators weighted by the soil horizon thickness, where it was crucial that the range of specific value features were on a point scale resulting from the natural variability in Polish soils. In the post-mining areas site conditions rehabilitated for forestry variation assessment, the usefulness of this indicator was positive, although it pointed to the modification necessity when there were being adapted to initial stages of post-mining soils (Pietrzykowski and Krzaklewski 2006; Pietrzykowski and Pająk 2009).

As a result of further studies (Brożek et al. 2008), a new concept for a numerical assessment method for soil characteristics was drawn up for the mapping of forest sites, known as the Site Soil Index (SIG). The proposed indicator allow for a several soil characteristics synthetic perspectives selected on the basis of statistical data base set on the podsolc and rusty soils variability range. Over 122 diagnostic positions for podsolc and rusty soils for one synthetic value allows for the ranking and grouping of forested sites in relation to plant communities and tree stands. The following soil characteristics are included: properties of fines (diameter < 0.02 mm), properties of basic cations (Mg^{2+} , Ca^{2+} , K^+ , Na^+), and acidity calculated as hydrogen ions on the basis of hydrolytic acidity per pedon (100×100×150 cm) and nitrogen calculated as N, or the percentage of total nitrogen in the soil's first mineral horizon divided by the C:N ratio at that horizon (Brożek et al. 2008). One important assumption in this method was, as in the original concept of ITGL (Brożek 2001), the transformation and standardization of features on an accepted numerical scale (from 1 to 10 for partial indicators referring to the listed soil features, i.e. the properties of fines index (W_{CZS}), the properties of base cations index (W_{SI}), the calculated acidity index (W_V) and the calculated nitrogen index (W_N)). The range of values for the soil features recalculated into the indices takes into account the variability of soils investigated in Poland. Furthermore,

it is also important that the features given are recalculated per pedon volume including the volume density.

These methods of sites assessing and distinguishing soil subtypes trophic varieties according to the ITGL and SIG have been already found as practical application in managed forest conditions in "natural" sites (Brożek and Zwydak 2003; Brożek et al. 2008). In these conditions, it has been noted that a diagnosis based on the SIG was more precise. In this work, the SIG appropriate value ranges of the investigated forest site types have been given to forestry practice.

The aim of this paper is to assess the usefulness of the soil quality indexes: Forest Soil Trophism Index (ITGL) (Brożek 2001) and the Site Soil Index (SIG) (Brożek et al. 2008) to describe the soil variability in the forested site conditions and characteristics of the reclaimed and forested terrain of the "Bełchatów" Lignite Mine spoil banks.

MATERIAL AND METHODS

The research work was conducted on reclaimed top sections of the spoil banks (1st forest class, up to 20 years) at the "Bełchatów" Lignite Mine, which are regenerated with Scots pine. Four substrate variants were chosen for the research. These were located on the peaks of the spoil banks (internal and external) and covered fragments constructed from better rock formations, i.e. Quaternary sandy-clay (variant on the internal spoil bank, marked NWL) and clay silt (variant on the external spoil bank, marked NZL), and worse, i.e. Quaternary barren sandy (variant on the internal spoil bank, marked NWG) and acidic Miocene sands after neutralisation (variant on the external spoil bank, marked NZG). For each separate variant, research plots were laid out in four repetitions (100 m² squares) in which soil samples were taken to a depth up to 150 cm. The soil morphology was described and samples of disturbed structure were taken from depths of 0–8 cm (initial organic-mineral AiCan horizon), 8–50, 50–110, and 110–150 cm (Can horizons). In order to discover the weight by volume, samples of undisturbed structure were also taken from each horizon in 250 cm³ cylinders (with three repetitions per horizon).

In the laboratory, the following characteristics were estimated for air-dried samples: particle size distribu-

tion using aerometric method (fractions as in standard PN-R-04033); additionally using the sieve-weight method for sand fractions; pH using the potentiometric method in H₂O and 1 M KCl maintaining soil proportion: solution 1:2.5; calcium carbonate content (CaCO₃) using Scheibler's method; organic carbon (C_{org}), total nitrogen (N_{org}) and total sulfur (S_{org}) content in a Leco CNS 2000 analyzer (carbon and sulfur in the infrared, nitrogen in the thermal conductivity detector); samples containing carbonates were treated with 10% HCl to remove them before testing for C_{org}; total alkalinity (S_H) calculated by summing the exchangeable cations Ca²⁺, Mg²⁺, Na⁺, K⁺ marked in an extract of 1N CH₃COONH₄ with pH 7.0 using the AAS method, hydrolytic acidity (H_h) using Kappen's method (extractor 1 N Ca(CH₃COO)₂) (Ostrowska et al. 1991).

The ITGL and SIG values obtained were statistically drawn up using the Statistica application (StatSoft Inc. 2008). For testing the significance of the differences in mean ITGL values, the RIR-Tukey test was used (because the variable takes values in a constant range), preceded by a variance homogeneity test, and for the SIG the non-parametric Kruskal-Wallis test (because the variable takes integer values).

RESULTS AND DISCUSSION

Soils in post-mining terrain are classified as an anthropogenic urban soils with an unformed profile (Forest Soils Classification in Poland 2000), and as Urbic Anthrosols according to the FAO classification (1988). The distinguished variants were mostly differentiated in the fraction of fines in the granulometric content (silt and loam sized fraction), as well as pH value and conductivity (PEW), indicating the variable content of plant nutrition in the soil solution and the cation exchange capacity (S_H).

In particular, the soils formed on the sandy Miocene formations differed considerably in respect to these features from the remaining soils. The selected initial soils properties created on the post-mining investigated objects are presented in Tab. 1.

The highest content of fines occurred in the NZL variant soils on the external spoil bank (on average over 41% silt and 13% loam), and then in the NWL variant (respectively 15% and 6%). There was a considerably

Tab. 1. Selected properties of the initial post-mining soils formed in different horizons on reclaimed spoil banks at the "Belchatów" Brown Coal Mine

Characteristics	Horizon (depth cm)	Object and variant			
		External spoil bank		Internal spoil bank	
		NZL	NZG	NWL	NWG
Silt 0.05–0.002 mm (%)	AiCan (0–8)	41(9)	4(1)	15(2)	5(2)
Clay > 0.002 mm (%)		13(1)	9(1)	6(1)	4(1)
Silt 0.05–0.002 mm (%)	Can (8–150)	47(16)	5(2)	8(4)	1(1)
Clay > 0,002 mm (%)		11(2)	7(3)	6(2)	4(1)
pH KCl	AiCan (0–8)	7.5(0.2)	5.2(1.9)	7.4(0.5)	8.3(0.2)
	Can (8–150)	8.0(0.2)	5.0(2.7)	8.3(0.2)	8.2(0.7)
N _{og} (%)	AiCan (0–8)	0.050 (0.010)	0.032(0.002)	0.038(0.008)	0.023(0.002)
C _{org} (%)		0.81(0.16)	0.73(0.37)	0.61(1.15)	0.16(0.13)
C _{org} (%)	Can (8–150)	0.13(0.02)	0.81(0.82)	0.11(0.07)	0.05(0.05)
S _{og} (%)	AiCan (0–8)	0.016(0.00)	0.018(0.01)	0.014(0.007)	0.009(0.001)
	Can (8–150)	0.020(0.006)	0.050(0.040)	0.009(0.001)	0.007(0.001)
EC ($\mu\text{S}\cdot\text{cm}^{-1}$)	AiCan (0–8)	136(11)	32(19)	89.0(14.2)	56.5(7.6)
	Can (8–150)	95(25)	203(242)	66(15)	38(15)
S _H ($\text{cmol}(+)\cdot\text{kg}^{-1}$)	AiCan (0–8)	18.6(5.9)	3.2(1.0)	11.9(4.3)	10.1(7.9)
	Can (8–150)	25.3(5.8)	7.3(6.2)	16.2(5.1)	4.3(2.9)
H _h ($\text{cmol}(+)\cdot\text{kg}^{-1}$)	AiCan (0–8)	0.6(0.1)	3.3(2.0)	0.5(0.3)	0.3(0.0)
	Can (8–150)	0.4(0.1)	5.0(3.8)	0.4(0.1)	0.3(0.1)

smaller ratio of fines in the NZG soils on the internal spoil bank of the sandy Miocene formations (respectively 4% silt and 9% loam), and in the NWG variant of the Quaternary sands (respectively 5% and 4%). Furthermore, the NZG soils in the Miocene sands were characterized by acidity (pH in KCl with average value 5.0–5.2) and the highest hydrolytic acidity values (averaging from 3.32 in the AiCan horizons to 4.98 $\text{cmol}(+)\cdot\text{kg}^{-1}$ in the deeper Can horizons).

The remaining soils were weakly alkaline (pH KCl from 7.4 do 8.3). The NZG soils were also characterized by the highest total sulfur (S_{og}) content, which was observed as average from 0.018 up to 0.05% (Tab. 1). The soils characterised by the better formations in the NZL and NWL variants were characterised by a greater total alkalinity (S_H respectively 18.6 and 11.9 $\text{cmol}\cdot\text{kg}^{-1}$) in comparison to the variants of the poorer formations (respectively NZG 3.2 to 7.2 $\text{cmol}\cdot\text{kg}^{-1}$ and NWG averaging from 4.3 to 10.1 $\text{cmol}(+)\cdot\text{kg}^{-1}$).

Similarly as in the case of the total nitrogen (N_{og}) and organic carbon (C_{org}) content, a higher value oc-

curred in the soils of the better formations variants (respectively N_{og} in the AiCan horizon from 0.023% for NWG to 0.032% for NZG and C_{org} from 0.16% for NWG and 0.73% for NZG) (Table 1). However, it was notable that in the deeper Can levels the carbon content was relatively high, particularly in the case of soils in the Miocene formations (C_{org} on average 0.81%) (Table 1). This is related to the origin of these formations, which contains considerable quantities of geogenic carbon, and also, as previously mentioned higher sulphur content. For this reason, it means that soils formed on the contaminated with carbon spoil banks which is accompanied with lignite mining are known as "sulphurous soils" (Katzur and Haubold-Rosar 1996).

The calculated ITGL values for the post-mining soils in the distinguished variants were varied within a range from 20.0 (in the NZG variant) to 37.1 (in the NZL variant) (Fig. 1).

The highest ITGL values were recorded in the Quaternary clay silt soils on the external spoil bank (NZL),

whereas the lowest were in the acidic sandy soils post neutralisation (NZG). The differences between these variants were statistically significant (Tab. 2). In the case of the internal spoil banks soils, the mean ITGLs was varied statistically significantly and their values were estimated in the range from 23.0 to 27.6 in the NWG variant and from 30.4 to 32.2 in the NZL variant. The ITGL values for soils on this spoil banks were considerably less differentiated than on the external bank.

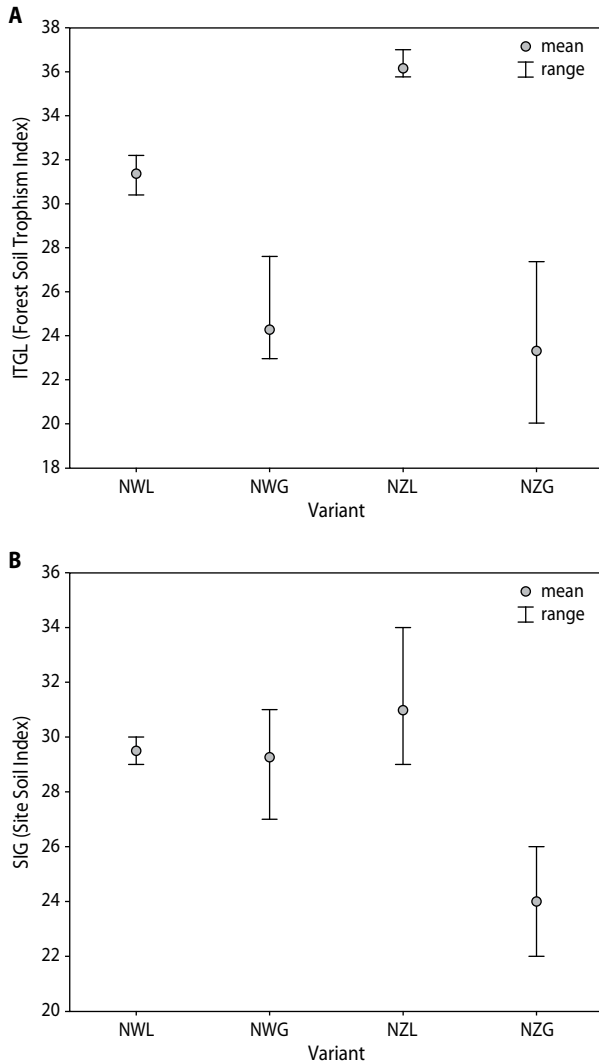


Fig. 1. Variability in the Site Soil Index (SIG) and the Forest Soil Trophism Index (ITGL) in the initial soils on spoil banks at the “Belchatów” Brown Coal Mine reclaimed for forestry

According to the assessment scale proposed in the original paper (Brożek 2001; Brożek and Zwydak

2003), referring to forested sites, the ITGL values in the range were confirmed for the NZL variant (the best) would be correspond to forest habitats. The soils in the weakest variant (NZG) on acidic sandy Miocene neutralised formations would be classified as mixed forest sites.

Tab. 2. Statistical differences in the Forest Soil Trophism Index (ITGL) for the soils investigated at the different substrates in spoil banks at the “Belchatów” Brown Coal Mine (RIR-Tukey test, $p < 0.05$)

Substrate variant and type of spoil bank	{1} M = 31.37	{2} M = 24.29	{3} M = 36.17	{4} M = 23.31
NWL {1}	–	0.002366*	0.031398*	0.000920*
NWG {2}	0.002366*	–	0.000209*	0.909993
NZL {3}	0.031398*	0.000209*	–	0.000202*
NZG {4}	0.000920*	0.909993	0.000202*	–

* Statistically significant differences at $p < 0.05$.

Tab. 3. Statistical differences in Site Soil Index (SIG) for the soils investigated at the different substrates on spoil banks at the “Belchatów” Brown Coal Mine (Kruskal-Wallis test, $p < 0.05$)

Substrate variant and type of spoil bank	NWL – R: 9.5000	NWG – R: 9.6250	NZL – R: 12.375	NZG – R: 2.5000
NWL	–	1.000000	1.000000	0.225533
NWG	1.000000	–	1.000000	0.205844
NZL	1.000000	1.000000	–	0.020122*
NZG	0.225533	0.205844	0.020122*	–

$df = 3, N = 16, H = 9,731735; p = 0.0210; *$ statistically significant differences at $p < 0.05$.

The calculated SIG values for the post-mining soils in the distinguished variants were ranged from 22 (in the NZG variant) to 34 (in the NZL variant). The highest SIG values (34, with average 31) were recorded in the Quaternary clay silt soils on the external spoil bank (NZL), whereas the lowest were in the acidic sandy soils post neutralisation (NZG) (SIG 22, with average 24) (Fig. 1). The differences between these variants were statistically significant (Tab. 3). In the case of the soils of the external spoil bank, the mean SIG values did not

differ statistically for the NWL and NWG variants and fell in a range, respectively, of 29–30 and 27–31, while the SIG values for soils of these spoil banks were considerably less differentiated than on the external spoil bank. In fact, this is also in the case of the basic soil properties variability (Tab. 1).

According to the proposed scale (Brożek et al 2006) for forested sites, the SIG values in the range was confirmed for the NZL variant (the best) correspond to mixed forest sites. The SIG values for the NWL and NWG variants would also correspond to a mixed forest assessment. Therefore, the assessment scale following SIG values for natural sites would not allow for the differentiation of the sites on the spoil banks between variants NWL, NWG, and NZL. The SIG values for the soils in the weakest variant (NZG) on acidic sandy Miocene formations would classify the sites as mixed forests.

Very important issue connected with habitat condition evaluation on post-mining sites are soil-plant relationships (Pietrzykowski et al. 2010). Based on this the soil-phytosociological methods of site diagnosis described by Krzaklewski (1977) there were recommended for post-mining object as a background of biological reclamation (Krzaklewski and Pietrzykowski 2007). In some part of investigated internal spoil heap KWB “Bełchatów” (variant NWG and NWL) the site diagnosis were proceed by Krzaklewski et al. (2000) with using soil-phytosociological method. Based on results of phytosociological surveys by Braun-Blanquette method and soil study: the cover abundance of plant communities (in percentage %), dominant vascular plant species and soil particle size distribution the prognosis of habitat unit groups and appropriate biological reclamation treatments were recommended. According to this on part of the spoil represents of NWL variant the fresh mixed forest sites with domination of *Calamagrostis epigejos* L. at above 50% cover abundance were prognosed and fresh coniferous forest with domination of *Corispermum leptopterum* Asch. at below 25% cover abundance on part of NWG variant. Comparing these results with site-evaluation by SIG and ITGL indexes the conclusions are as follows 1) soil-phytosociological method used approximately 10 years earlier shows lower (less trophy) of the site units, and 2) plant-soil relationships on post-mining sites are still dynamic.

CONCLUSIONS

When evaluating soil fertility in post-mining terrain it must be noted that soil is only in the beginning stage to form on spoil banks, therefore the indicators should be treated for forecasting only (Krzaklewski and Pietrzykowski 2007). Undoubtedly, in order to draw up the ITGL and SIG indicators for natural forest soils, characteristics that significantly differentiate them were selected, such as reserves of fines, sum of the bases, pH value, acidity, or nitrogen content in the mineral horizon. It can be concluded that the research carried out in the event of using the SIG indicator those characteristics did not significantly differentiate between soils forming on spoil banks from Quaternary sandy, clay sandy and clay silt formations. The ITGL indicator was better at capturing the differences in forming soils as it includes more characteristics of the investigated soils (which seems to be very important for forming urban soils). In turn, for soils forming on Miocene formations, the factors affecting the lower values of the analysed indicators were mostly the pH value and hydrolytic acidity (H_b). In the literature (Katzur and Haubold-Rosar 1996), they are referred to as “sulphurous soils” and they are characterised by very high acidity. However, neutralisation using bog lime influenced the improvement in soil properties, including sum of the bases increase (this was particularly influenced by the content of Ca^{2+} and Mg^{2+} , which are abundant in bog lime) and lowered acidity (Krzaklewski et al. 1997). However, it should be noted that for those formations even after the neutralisation process they may present a very dynamic system, especially in sulphide oxidation (Katzur and Haubold-Rosar 1996).

Comparing results of site-evaluation by SIG and ITGL indexes with phytosociological method of habitat diagnosis proceed 10 years earlier on this part of internal spoil heap (NWL and NWG variants) the conclusion is that plant-soil relationships on post-mining sites are still dynamic and soil quality indexes show different and higher trophy conditions.

Based on the research and earlier studies (Pietrzykowski and Pająk 2009) it can be stated that of the two indicators tested under the conditions of the “Bełchatów” Lignite Mine spoil banks, ITLG better reflects the variability in soils under investigation. However, in order to better site description forming un-

der those conditions, one should be modified the valuation of partial indicators based on the knowledge of other soil properties and the predisposition for habitat formation on post-mining sites (Krzaklewski and Pietrzykowski 2007; Pietrzykowski et al. 2009), as well as the properties of plant communities formed on the reclaimed terrains under discussion.

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