J. Elem. s. 525–536 DOI: 10.5601/jelem.2012.17.3.14

REVEGETATION OF RECLAIMED SODA WASTE DUMPS: EFFECTS OF TOPSOIL PARAMETERS

Ewelina Zając[1], Jan Zarzycki[2]

[1]Chair of Land Reclamation and Peat-Bog Protection
[2]Chair of Ecology, Climatology and Air Protection
University of Agriculture in Krakow

Abstract

The paper presents the diversity of herbaceous vegetation developing in a complex of soda waste dumps in Krakow, which were reclaimed with a topsoil over 15 years ago (1995) and left without further treatment. A total of 132 plots were selected using the systematic method to determine some physical (texture composition, depth) and chemical parameters (pH, electrolytic conductivity, content of N, C, P, K, Mg, Ca, and C:N) of the topsoil. Plant species composition in each plot was determined using the Braun-Blanquet method. In total 133 plant species, predominantly ruderal and meadow ones, were found in the soda waste dumps. The areas dominated by ruderal species were characterized by greater depth of the topsoil and abundance in nitrogen and phosphorus, which increased the average plant height and plant cover. It was concluded that the reclamation method used for the soda waste dumps gave rise to communities with the predominance of ruderal species and halted the succession at this stage. Development of vegetation into meadow communities would require the use of a topsoil of low fertility and small depth. The species composition of the seed mixture intended for sowing on the reclaimed site should be ecologically matched to local conditions. For satisfactory reclamation effects, it is necessary to define the target characteristics of a plant community when determining the method of reclamation and land management.

Key words: soda waste dumps, reclamation, topsoil, vegetation.

dr inż. Ewelina Zając, Chair of Land Reclamation and Peat-Bog Protection, University of Agriculture in Krakow, al. Mickiewicza 24/28, 30-059 Kraków, e-mail: rmszatko@cyf-kr.edu.pl

ROZWÓJ ROŚLINNOŚCI NA ZREKULTYWOWANYCH OSADNIKACH POSODOWYCH: WPŁYW WŁAŚCIWOŚCI WARSTWY GLEBOWEJ

Abstrakt

W pracy przedstawiono zróżnicowanie roślinności zielnej rozwijającej się na kompleksie osadników posodowych w Krakowie zrekultywowanych przez pokrycie osadu warstwą nadkładu glebowego przed 15 laty (w 1995 r.), i pozostawionych bez dalszych zabiegów pielęgnacyjnych. W wyznaczonych metodą systematyczną 132 powierzchniach badawczych określono wybrane parametry fizyczne (skład granulometryczny, miąższość) i chemiczne (pH, przewodnictwo elektrolityczne, zawartość N, C, P, K, Mg, Ca i C:N) nadkładu glebowego. Skład gatunkowy roślinności na każdym poletku określono metodą Braun-Blanquetta. Na osadnikach stwierdzono występowanie 133 gatunków roślin, wśród których dominowały gatunki ruderalne i łąkowe. Powierzchnie z dominacją gatunków ruderalnych miały większą miąższość nadkładu glebowego i zawierały wiecej azotu i fosforu, co wpłynęło na większą średnią wysokość roślin i większe pokrycie powierzchni. Stwierdzono, że metoda rekultywacji zastosowana na osadnikach posodowych spowodowała wykształcanie się zbiorowisk roślinnych z przewagą gatunków ruderalnych i zatrzymanie się sukcesji na tym etapie. Ukierunkowanie rozwoju roślinności na zbiorowiska łąkowe wymagałoby zastosowania nadkładu glebowego o niskiej żyzności oraz niewielkiej miąższości. Skład gatunkowy mieszanki nasion przeznaczonej do wysiewu na rekultywowanym obiekcie powinien być ekologicznie dostosowany do lokalnych warunków. Aby uzyskać zadowalający efekt rekultywacji, konieczne jest określenie docelowych zbiorowisk roślinnych na etapie ustalania metody rekultywacji i zagospodarowania terenu.

Słowa kluczowe: osadniki posodowe, rekultywacja, nadkład glebowy, roślinność.

INTRODUCTION

One of the problems in many urban and industrial agglomerations is the reclamation and management of waste dumps of different origin e.g. industrial. In the past, they were located outside the city boundaries, but as the cities were growing, they were gradually incorporated into the urban structure. The soda waste dump in Krakow (Poland) occupies a large area, which is surrounded by developing housing estates. This should be preferably managed as an urban green area with recreational infrastructure, considering the shortage of such objects in the city. However, post-soda wastes represent extreme conditions for vegetation development. A very high $CaCO_3$ content and strongly alkaline reaction are not found in natural habitats. Other problems are high salinity, deficit of nitrogen and potassium as well as solidity of soda waste after sedimentation (Trzcińska-Tacik 1966, Boroń, Nagawiecka 1995, Siuta 2007). Such harsh conditions induce low floristic diversity and morfological deformations of spontaneously occurring plants (Trzcińska-Tacik 1966). Application of some reclamation measures to improve the habitat seems to be indispensable, e.g. the biological reclamation method worked out for soda waste dumps in Janików using sewage sludge (Siuta 2007).

The nature of derelict land determines the method of technical and biological reclamation, thus entailing further processes that occur in the developing ecosystem (BRADSHOW 2000). One of the reclamation procedures is to cover derelict land with a topsoil. This method enables the land to turn green rapidly by sowing conventional meadow grass seed mixtures (MARTÍNEZ-RUIZ, FERNÁNDEZ-SANTOS 2005, MARTÍNEZ-RUIZ, MARRS 2007). In such a situation, it is necessary to predetermine the target characteristics of the ecosystem and to adapt the reclamation process as well as possible cultivation measures (BLOOMFIELD et al. 1982) needed to form and maintain desired ecosystem types. Most sites can accommodate a variety of plant communities if provided sufficient topsoil (CARNELL, INSLEY 1982, BRADSHAW 1984 after ROBINSON, HANDEL 1995). However, the sites reclaimed by means of topsoil covering may create conditions that hinder the development of stable plant communities (ATHY et al. 2006). In the case of capped landfills soil degradation problems include compaction, decreased permeability, lack of organic material, diminished soil fauna, inappropriate soil texture (EWING 2002) and also shallow soil, water-logging and drought (DOBSON, MOFFAT 1993). The correlation between biomass and soil cover depth is confirmed by research conducted on different sites, e.g. a reclaimed waste dump (BOWEN et al. 2005).

After years, the reclamation of the soda waste dumps with the use of topsoil gave rise to a mosaic of vegetation patches with different species composition, plant cover and main biomass height. The technical reclamation combined with seed sowing initially produced a plant cover composed mainly of the meadow species commonly used in the reclamation of derelict land, but the abandonment of management measures caused changes in the species composition, i.e. spontaneous succession. In the case of depositional soils, it may be either primary succession, because it develops on a substratum that is not typical soil, or secondary succession, because it may contain plant propagules (REBELE 1992). That is why vegetation development on reclaimed soda waste dumps differs from succession in natural areas but also from succession taking place directly on the waste substratum, e.g. on an unreclaimed soda waste dump (ZARZYCKI, ZAJĄC 2001) or post-coal mining heaps (ROSTAŃSKI 2006).

The aim of this study was to evaluate the plant establishment pattern on soda waste dumps reclaimed by the topsoil method and to determine the effect of some physical and chemical properties of the soil cover used in the reclamation on species composition.

MATERIALS AND METHODS

The Krakow Soda Plant Solvay was in operation during 1901-1994. The basic products were raw soda, soda ash, and caustic soda, the manufacture of which generated huge amounts of waste deposited into sedimentation lagoons, called "white seas" (N 50°00′30″; E 19°56′26″). This waste consisted mainly of water, compounds of calcium, chloride and silicon dioxide (PAŁKA, SANECKI 1992) and was characterized by high alkalinity and salinity (BOROŃ et. al. 2000).

At the time of the plant's liquidation, the area of soda waste dumps in need of reclamation totalled 84.65 ha (MAŁECKI 1997). Reclamation work was carried out in the largest complex of soda waste dumps (17.43 ha). It involved levelling of the embankments, strengthening the scarps and covering with topsoil. Fertilizing and a grass and legume seed mixture were also applied, but no detailed information is available. The reclamation ended in 1995 and since then the soda waste dumps have been left untreated. At present, the area is overgrown with herbaceous plants and small clusters of trees. The only source of water for the vegetation is precipitation. In Krakow, the total annual precipitation usually varies between 650-700 mm. The sum of average monthly precipitation from May to September reaches 406 mm, with the maximum amount in July. The mean annual air temperature is 8.7°C. The coldest period of the year is between the second decade of January and the beginning of February, while the warmest period from the second half of July to the first decade of August. During the year, western winds prevail (about 25%), but also a very high frequency of calms (25.1%) is noted (MATUSZKO 2007).

The investigations were conducted in 2007-2009. A total of 132 plots, with an area of 25 m^2 each, were designated for characterizing the properties of the topsoil used for reclamation and the plant cover. The plots were laid out in a 30 by 30 m grid.

All plant species on each plot were recorded and the plant cover was estimated according to the Braun-Blanquet scale. Species were classified into meadow and ruderal ones according to ELLENBERG et al. (1992). Species constancy, i.e. the percentage of plots in which a species occurred, and cover coefficient (Cc), which describes the proportion of a species in plant cover, were calculated for each species. The cover coefficient was calculated according to Braun-Blanquet (1964), where Cc = 100 Σ cover of the species in all plots divided by number of plots.

Each of the 132 designated plots was measured for depth of the topsoil and soil samples (mixed from three sub-samples) were collected for laboratory analysis and tested for:

- grain-size distribution – Bouyoucos-Casagrande method modified by Prószyński;
- pH in H_2O and KCl (soil: water ratio 1:2,5);
- electrical conductivity (EC);
- organic carbon – Tiurin method;
- total nitrogen – Kjeldahl method;
- available phosphorus and potassium – Egner-Riehm method;
- total calcium and magnesium – ICP–AES method (samples were subjected to wet mineralization, then vaporized to dryness and dissolved in acid (ZAJĄC 2009).

Diversity of species composition and the effect of topsoil parameters were analysed by multivariate analysis. Detrended Correspondence Analysis (DCA) was performed in CANOCO ver. 4.5 (TER BRAAK, SMILAUER 2002) to order species, plots and topsoil parameters along the axis. Significance (percentage of explained variation) of each axis is expressed through eigenvalues. The gradient length, expressed in standard deviation units, is calculated by nonlinear scaling of each axis and expresses the exchange of species relative to the axis. Correlations between topsoil parameters, parameters of community structure and individual DCA axes were computed based on Pearson's correlation coefficient. For statistical analysis, the Braun-Blanquet scale was transformed into percentage scale. Square root transformation and downweighting of rare species were used. To meet the normal distribution assumption, the data were in some cases log-transformed prior to statistical analysis.

RESULTS AND DISCUSSION

The basic chemical properties of the topsoil used to reclaim the soda waste dumps (Table 1) are not significantly different from those found in natural habitats. During the reclamation process, the soda waste dumps were covered with a topsoil (average depth 0.25 m) which was composed predominantly of the clay fraction. The soil cover has a low phosphorus content. On the other hand, the content of potassium and magnesium is very high, which may be associated with the dominant soil type and the fertilization carried out as part of the reclamation operations. Noteworthy is a very high total calcium content (an average of 18 251.4 mg kg^{-1} soil), which probably results from some components of the soda waste permeating into the soil cover, also with the participation of the soil fauna (POŚPIECH, SKALSKI 2006). This probably influences the pH, which is close to alkaline. For most samples, the C:N ratio ranges between 8:1 and 12:1, i.e. within the most common range found in the mineral soils of Poland (LITYŃSKI et al. 1976). The topsoil used in the reclamation of depositional sites is usually of low quality, often comes from deep building excavations (ROBINSON, HANDEL 1995), and sometimes contains contaminants of different origin. Also in the area of the investigated soda waste dumps, especially near the embankments, the reclamation material cover contained waste components (especially construction debris, building felt, etc.), which may influence both ecosystem development and the application of management measures (ZAJĄC 2009).

The development of vegetation in the analysed soda waste dumps showed considerable variation. Over 70% of the plots was characterized by an incomplete plant cover. The height of the main plant mass ranged from 10 cm to 130 cm. In total133 plant species were found in the investigated plots, including 47 meadow and 40 ruderal ones (Table 2). The other 46 were species of diverse habitat requirements.

Table 1

Characteristics of the topsoil

Parameter	Range	Mean value (standard deviation)	Median
Depth of topsoil (m)	0.10 - 0.68	0.25 (± 0.11)	0.22
Fraction (%):			
1.0 - 0.1 mm (sand)	13 - 68	29.70 (± 9.67)	27.00
0.1 - 0.02 mm (silt)	7 - 30	13.26 (± 3.82)	12.50
< 0.02 mm (clay)	22 - 78	57.33 (± 10.53)	59.50
pH KCl	6.75 - 7.56	7.14 (± 0.14)	7.13
pH_{H_2O}	6.75 - 7.97	7.61 (± 0.18)	7.63
EC (mS cm^{-1})	0.20 - 1.59	0.41 (± 0.20)	0.38
Organic C (g kg^{-1})	11.53 - 79.97	21.18 (± 7.64)	19.42
Total N (g kg^{-1})	1.01 - 4.82	2.14 (± 0.53)	2.06
C:N	4.68 - 27.77	9.96 (± 2.47)	9.81
P_2O_5 (mg kg^{-1} soil)	0.00 - 835.9	46.4 (± 120.9)	18.6
K_2O (mg kg^{-1} soil)	75.3 - 840.4	419.0 (± 98.2)	417.4
Ca (mg kg^{-1} soil)	3739.1 - 86332.3	18251.4 (± 11350.9)	16307.1
Mg (mg kg^{-1} soil)	1363.9 - 9539.3	4797.9 (± 1568.8)	4626.7

Although soils with a high content of clay fraction make a good insulation layer, they generally have unfavourable physical properties with poor aeration and permeability. Water-logging may occur in wet periods and excessive drying out of the topsoil in dry periods (Ewing 2002). The species composition in the dumps reflected the varying degrees of soil moisture. Some areas were colonized by species typical of dry habitats (e.g. *Campanula rapunculoides, Poa compressa, Filipendula vulgaris*) and others by species typical of wet habitats (e.g. *Lysimachia vulgaris, Phragmites australis*).

Over the past 15 years, the vegetation dominated by species that appear spontaneously has developed on the investigated area. Urban and industrial areas are often characterized by the occurrence of a relatively large number of species in a small area (Angold et al. 2006). Ruderal and meadow species predominate, but species from very diverse habitats are found. Occurrence of both ruderal and meadow species in the course of succession is typical of many areas of anthropogenic origin (Kutyna et al. 2007).

On the soda waste dumps the group of meadow species included many species of high constancy (16 species with constancy above 30%). However, their cover coefficients were low (770 at most). Ruderal species occurred with much lower constancy (10 species with constancy above 30%), but of-

Table 2

Frequency F (%) and cover coefficient (Cc) of main plant species on soda waste dumps

Ruderal species n = 40			Meadow species n = 47			Other species n = 46		
Species	F	Cc	species	F	Cc	species	F	Cc
Artemisia vulgaris L.	78	307	*Vicia cracca* L.	87	516	*Calamagrostis epigejos* (L.) ROTH	77	1911
Tanacetum vulgare L.	58	535	*Crepis biennis* L.	76	770	*Trifolium medium* L.	36	1222
Melilotus officinalis (L.) PALL.	57	302	*Potentilla anserina* L.	64	80	*Campanula rapunculoides* L.	36	236
Cirsium arvense (L.) SCOP.	53	193	*Daucus carota* L.	63	186	*Ononis arvensis* L.	33	410
Agropyron repens (L.) P.BEAUV.	52	793	*Pastinaca sativa* L. S. STR.	60	200	*Senecio jakobea* L.	24	22
Medicago sativa L.	48	720	*Lathyrus pratensis* L.	52	381	*Coronilla varia* L.	23	191
Melilotus alba MEDIK	43	217	*Taraxacum officinale* F. H. WIGG	52	135	*Euphorbia esula* L.	20	23
Medicago lupulina L.	32	41	*Trifolium pratense* L.	48	317	*Vicia sepium* L.	12	20
Erigeron annuus L. (PERS.)	33	45	*Festuca rubra* L. S. STR.	47	519	*Odontites serotina* (LAM.) RCHB. S. STR.	12	9
Solidago gigantea AITON	30	71	*Arrhenatherum elatius* (L.) P. BEAUV. EX J. PRESL & C. PRESL	45	497	*Rubus caesius* L.	8	75
Lathyrus bulbosus L.	18	145	*Dactylis glomerata* L.	45	60	*Carex acutiformis* ERH.	8	80
Symphytum officinale E.	17	22	*Lotus corniculatus* L.	45	22	*Rubus plicatus* WEIHE & NEES	7	43
Equisetum arvense L.	15	27	*Festuca pratensis* HUDS.	39	87	*Populus tremula* L.	6	21
Poa compressa L.	15	31	*Centaurea jacea* L.	39	197	*Carex spicata* HUDS.	5	3
Hypericum perforatum L.	9	8	*Poa pratensis* L. S. STR.	33	138	*Mentha arvensis* L.	5	6
Oenothera biennis L. S. STR.	9	11	*Achillea millefolium* L. S. STR.	31	47	*Robinia pseudoacacia* L.	4	5

ten dominated in individual plots. The species widely distributed and often showing a high degree of plant cover was *Calamagrostis epigejos*. Except *Trifolium medium*, the other species occurred sporadically and were characterized by a low degree of plant cover.

Similarities in species composition between individual plots were relatively small, as confirmed by the results of Detrended Correspondence Analysis (DCA) – Table 3. The gradient length of the first three axes was similar (about 3 SD). The first two axes account for 13.6% of the total variation and the first four for 22.5%.

Table 3

Summary of the DCA analysis

	Axis			
	1	2	3	4
Lengths of the gradient (standard deviation)	3.110	3.043	3.059	2.528
Cumulative percentage variance of species data	8.1	13.6	18.7	22.5

The main gradient in species composition, illustrated by the first DCA axis, is associated with an increasing depth of the topsoil, nitrogen and phosphorus content. This axis correlates positively with the proportion of the sand fraction and negatively with the proportion of clay fraction. The first axis also correlates with the proportion of the area covered by ruderal species and negatively with the area covered by meadow species. None of the analysed factors was significantly correlated with the second DCA axis. The first axis also shows a strong positive correlation with height of the main plant mass and plant cover (Table 4).

The statistical analysis showed that the proportion of the meadow and ruderal species in plant cover was related to differences in topsoil properties. The share of ruderal species increases with growing depth of topsoil and abundance of nitrogen and phosphorus (Figure 1a). According to PRACH (2003), the most important factors that influence succession towards ruderal communities are fertile substratum with high pH and location in urbanized areas, which is the case in the investigated soda waste dumps. Ruderal species (characteristic for class *Artemisietea, Agropyretea, Stellarietea*) grew more vigorously, showed higher plant cover and achieved greater biomass. Clonal species that reproduce by means of stolons, such as *Agropyron repens* and *Calamagrostis epigejos* developed particularly strongly. Especially the latter species show good tolerance to low soil depth and strong expansion on anthropogenic land (KIRNER, MACHN 2001, PRACH, PYSEK 2001).

Meadow species are relatively strongly represented in the soda waste dumps. Rather than forming typical plant communities, they occur in assemblages with ruderal and other species. The occurrence of meadow spe-

Table 4

Correlation between vegetation composition (DCA1 and DCA2 factor scores), site characteristics and vegetation characteristic. Correlation coefficient, statistically significant ($p<0.01$) are in bold

Parameter	DCA axis 1	DCA axis 2
Depth of topsoil	**0.40**	0.10
Sand	**0.29**	0.04
Silt	0.00	0.10
Clay	**-0.29**	-0.07
pH H_2O	-0.04	-0.09
pH KCl	0.05	-0.06
EC	0.06	0.01
Organic C	0.13	-0.01
Total N	**0.32**	-0.01
C:N	-0.11	-0.12
P_2O_5	**0.25**	-0.13
K_2O	0.10	-0.03
Ca	0.03	-0.01
Mg	-0.13	-0.10
Ruderal species	**0.60**	**0.39**
Meadow species	**-0.38**	0.08
Vegetation cover	**0.58**	0.06
Height of main plant mass	**0.45**	0.12

cies was associated with lower fertility and lower depth of the topsoil and higher content of clay fraction (Figure 1b). Increasing soil fertility causes high biomass production, which in turn reduces the number of species. That dependence is commonly observed in grasslands (Janssens et al. 1998, Marrs 1993). Another reason why they developed less well in the investigated dumps, if no mowing is done, is the strong competition from ruderal species. This is reflected in a lower plant cover and main biomass height on the plots dominated by meadow species. Unlike ruderal communities, meadow communities usually show greater biocenotic diversity and have better aesthetic value (Prach, Hobbs 2008), which is important in the case of sites located in urbanized areas.

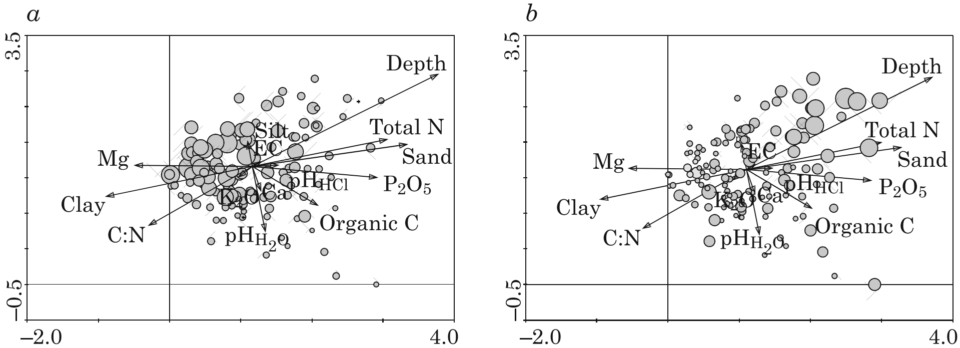

Fig. 1. DCA ordination diagram of plots displaying the major variation in species composition. The share of *a* – meadow species and *b* – ruderal species is visualised by the size of circles. The topsoil parameters were used as passive ones

CONCLUSIONS

1. The topsoil reclamation method applied in the soda waste dumps resulted in their revegetation, but due to the lack of further maintenance, communities with predominance of ruderal species have developed.

2. For satisfactory reclamation effects, it is necessary to define the target characteristics of a plant community when determining the method of reclamation and land management. This makes it possible to adapt technical reclamation procedures, topsoil conditioning, and plan possible management measures.

3. Development of vegetation into meadow communities, which are considered naturally and aesthetically more valuable, would require the use of a topsoil of low fertility and small depth. The species composition of the seed mixture intended for sowing on the reclaimed site should be ecologically matched to local conditions. Species typical of dry meadows (*Festuco-Brometea*) should be considered in the seed mixture for sites reliant on precipitation water and species typical of wet meadows (*Mollinietalia*) in constantly or periodically water-logged areas. Mowing is a necessary practice to hinder the development of highly competitive ruderal species.

REFERENCES

Angold P.G., Sadler J.P., Hill M.O., Pullin A., Rushton S., Austin K., Small E., Wood B., Wadsworth R., Sanderson R., Thompson K. 2006. *Biodiversity in urban habitat patches*. Sci. Total Environ, 360:196-204.

ATHY E.R., KEIFFER C.H., STEVENS M.H. 2006. *Effects of mulch on seedlings and soil on a closed landfill.* Restor. Ecol., 14: 233-241.

BLOOMFIELD H.E., HANDLEY J.F., BRADSHAW A.D. 1982. *Nutrient deficiencies and the aftercare of reclaimed derelict land*. J. Appl. Ecol., 19: 151-158.

BOROŃ K., ZAJĄC E., KLATKA S. 2000. *Reclamation of waste dumps of the KSP "Solvay" in Krakow*. Inż. Ekol., 1: 58-64. (in Polish)

BOROŃ K. J., NAGAWIECKA H. 1995. *The possibility of biological reclamation of soda waste reservoirs "White Seas" in Krakow, Poland*. Proc. of the Symposium Green'93., Balkema, Rotterdam, 523-526.

BOWEN C.K., SCHUMAN G.E., OLSON R.A., INGRAM L.J. 2005. *Influence of topsoil depth on plant and soil attributes of 24-year old reclaimed mined lands*. Arid Land Res. Manag., 19: 267-284.

BRADSHAW A. 2000. *The use of natural processes in reclamation - advantages and difficulties*, Landsc. Urb. Plann., 51: 89-100.

BRAUN-BLANQUET J. 1964. *Plant sociology*. 3 Aufl. Springer Verl. Wien (in German).

CARNELL R., INSELY H. 1982. *The influence of depth and type of cover material on tree establishment on a domestic refuse landfill site*. Reclam. Reveg. Res., 1: 225-230.

DOBSON M.C., MOFFAT A.J. 1993. *The potential for woodland establishment on landfill sites*. Department of the Environment HMSO, London.

ELLENBERG H., WEBER H.E., DÜLL R., WIRTH V., WERNER W., PAULIßEN D. 1992. *Indicator values of plants in Central Europe*. Scripta Geobot., 18: 1-258. (in German)

EWING K. 2002. *Mounding as a technique for restoration of Prairie on a capped landfill in the Puget Sound Lowlands*. Rest. Ecol., 10: 289-296.

JANSSENS F., PEETERS A., TALLOWIN J.R.B., BAKKER J.P., BEKKER R.M., FILLAT F., OOMES M.J.M. 1998. *Relationship between soil chemical factors and grassland diversity*. Plant Soil, 202: 69-78.

KIRMER A., MAHN E.-G. 2001. *Spontaneous and initiated succession on unvegetated slopes in the abandoned lignite-mining area of Goitsche Germany*. Appl. Veg. Sci., 4: 19-27.

KUTYNA I., NIED•WIECKI E., MALINOWSKI R. 2007. *Pioneer plant communities on newly formed sand bottom sediments within the Ostrów Grabowski dumping area in Szczecin*. Folia Universitatis Agriculturae Stetinensis Agricultura, 1 (253): 53-64 (in Polish).

LITYŃSKI T., JURKOWSKA H., GORLACH E. 1976. *Agro-chemical soil analysis. Guidelines for soil and fertilizers analysis.* PWN, Warszawa. (in Polish)

MAŁECKI Z. 1997. *Restructure-Liquidation-Management of CSE "Solvay "* [in~~w~~:] Problemy Sozologiczne Aglomeracji Miejsko-Przemysłowych. Komitet Inżynierii Środowiska PAN, Kraków. (in Polish)

MATUSZKO D. (ed.). 2007. *Cracow's climate in the 20th century*. Inst. Geografii i Gospodarki Przestrzennej UJ, Kraków. (in Polish)

MARRS R.H. 1993. *Soil fertility and nature conservation in Europe: theoretical considerations and practical management solutions.* Adv. Ecol. Res., 24: 241-300.

MARTÍNEZ-RUIZ C., B. FERNÁNDEZ-SANTOS. 2005. *Natural revegetation on topsoiled mining spoils according to the exposure*. Acta Oecol., 28: 231-238.

MARTINEZ-RUIZ C., MARRS R.H. 2007. *Some factors affecting successional change on uranium mine wastes: Insights for ecological restoration*. Ecol. Eng., 30: 286-294.

PAŁKA J., SANECKI L. 1992. *The Kracow Soda Plant „Solvay" Current state report.* DDJM – Biuro Architektoniczne, Kraków. (in Polish)

POŚPIECH N., SKALSKI T. 2006. *Factors influencing earthworm communities in post-industrial areas of Krakow Soda Works*. Europ. J. Soil Biol., 42 (Suppl. 1): 278-283.

PRACH K. 2003. *Spontaneous succession in central-European man-made habitats: What information can be used in restoration practice?* Appl. Veg. Sci., 6: 125-129.

PRACH K., PYŠEK P. 2001. *Using spontaneous succession for restoration of human disturbed habitats: Experience from Central Europe*. Appl. Veg. Sci., 4: 111-114.

PRACH K., HOBBS R. J. 2008. *Spontaneous succession versus technical reclamation in the restoration of disturbed sites.* Restor. Ecol., 16: 363-366.

REBELE F. 1992. *Colonization and early succession on anthropogenic soils*. J. Veg. Sci., 3: 201-208.

ROBINSON G.R., HANDEL S.N. 1995. *Woody plant roots fail to penetrate a clay- lined landfill: Management implications.* Environ. Manage., 19 (1): 57-64.

ROSTAŃSKI A. 2006. *Spontaneous plant cover on colliery spoil heaps in Upper Silesia (Southern Poland).* Wyd. Uniw. Śląskiego, ser. Pr. Nauk. Uniw. Śląskiego, 2410. (in Polish)

SIUTA J. 2007. *System of plant cultivation and composting with the use of sewage sludge on the post-soda waste landfill at Janików.* Inż. Ekol., 19: 38-58. (in Polish)

TER BRAAK C.J.F., SMILAUER P. 2002. *CANOCO Reference manual and CanoDraw for Windows user«s guide: Software for Canonical Community Ordination (version 4.5),* Microcomputer Power (Ithaca NY USA).

TRZCIŃSKA-TACIK H. 1966. *Flora and vegetation of the spoil mounds of the Cracow Soda Factory.* Fragm. Florist. Geobot., 12(3): 342-306. (in Polish)

ZAJĄC E. 2009. *Analysis of physical and chemical properties of topsoil on reclaimed soda waste decanters of former Kracow Soda Plant Solvay.* Ochr. Środ. i Zas. Natur., 38: 388--395. (in Polish)

ZARZYCKI J., ZAJĄC E. 2001. *Vegetation development on the unreclaimed soda waste decanter of the former Krakow Soda Plant „Solvay”* Zesz. Nauk. AR w Krakowie, 390: 37-46. (in Polish)