The vegetation on different top covers of an abandoned solid waste landfill

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Die Vegetation auf unterschiedlichen Abdeckschichten einer stillgelegten Hausmülldeponie

1. Introduction

Landfilling of municipal solid waste has been the most common measure in waste management during the past decades in Europe. Thus, many landfills exist that have to be recultivated and integrated into the landscape or are already re-colonised by vegetation.The plant cover on landfills is influenced by numerous variables, above all the surrounding vegetation, the climatic and weather conditions of the region, the seed bank in the deposited material, and the management of the landfill. Natural colonisation and succession depend not only on the age of the landfill, but also on the quantity and quality of the top covers (NEUMANN, 1976; KONOLD and ZELTNER, 1981). According to SCHLÜTER et al. (1996), especially the vitality of woody plants rooted in these covers can vary considerably. Furthermore, the specific gas situation of the landfill, in particular landfill gas production and emissions, plays an important role for the plant cover (HAIDER, 1991; BLUME et al., 1979). Landfill gas mainly consists of methane and carbon dioxide. Both gases are not directly toxic, but, due

Zusammenfassung

In den Jahren 2001/2002, zwölf Jahre nach Aufbringung verschiedener Abdeckungen, wurden auf einer stillgelegten Hausmülldeponie (Breitenau, Niederösterreich) folgende Parameter untersucht: aktuelle physikalisch-chemische Eigenschaften der Abdeckungen, Ausdehnung und Konzentration der Deponiegasaustritte, sowie die Vegetation auf den Abdeckungen der 3 Testzellen (bzw. 7 Versuchsfelder). Wir fanden gute Übereinstimmungen zwischen den physikalisch-chemischen Eigenschaften der Abdeckschichten und der Vegetation. In zwei Versuchsfeldern mit vergleichsweise dünner Abdeckung aus Kies waren Gasaustritte zu verzeichnen, die mit den Fehlstellen in der Vegetation übereinstimmten. Je dicker die (Kompost-)Abdeckung, desto mehr konkurrenzstarke, aber eher kurzlebige Ruderalarten wurden noch 12 Jahre nach Aufbringung der Abdeckung notiert, während über einer aus 1,3 m Kies bestehenden Abdeckung bereits eine Sukzession hin zu einem Halbtrockenrasen in Gang gekommen war.

Schlagworte: Vegetationssukkzession, phytosoziologische Aufnahmen, Deponieabdeckung, Kompost, Deponiegasemissionen.

Summary

In the years 2001/2002, twelve years after the placement of different top covers, an abandoned municipal solid waste landfill (Breitenau, Lower Austria) was investigated: recent physical and chemical soil properties, gas emissions and the vegetation on the top covers of the 3 test cells (comprising seven test fields) were assessed. We found good correlation between the current physical and chemical quality of the top covers and the vegetation. In two fields with thin covers of gravel, gas emissions were still evident also by vegetation gaps. The thicker the (compost) top layer, the more short lived but competitive ruderal species were found, whereas on a top cover with 1.3 m pure gravel a succession towards a dry/mesic turf has already started.

Key words: vegetation succession, phytosociological relevés, landfill cover properties, compost, landfill gas emissions.

to the replacement of air (in particular oxygen) in the top cover, damages of plant roots and the above ground vegetation may appear. The presence of toxic trace gases (< 1 % v/v in landfill gas), however, leads to direct damage of the plant tissues. Thus landfill gas emissions cause either a complete lack of vegetation or allow a plant cover that can tolerate the unfavourable conditions to a certain extent.

2. Materials and Methods

2.1 Landfill site

The investigations were carried out at the municipal solid waste (MSW) landfill at Breitenau, Lower Austria. This landfill is a typical bio-reactor landfill, which was constructed in 1986 as a test site to examine the impact of different construction designs, top covers and operating techniques (BINNER et al., 1997). Three different test cells have been installed with five different designs of the top cover (see Table 1). The top covers were applied in June 1989 (for details see Figure 1).

The climate of the landfill site is typically pannonian with an average annual precipitation about 550–600 mm, with a minimum in winter and a maximum in summer. Mean temperatures in July are approximately 19.5 °C, and in January –1.5 °C. The neighbouring vegetation are an afforestated *Pinus nigra* forest as well as ruderal and agricultural plant communities.

Table 2 shows some properties of the different top cover materials applied at the Breitenau landfill. Samples were taken in early summer 2002 at a depth of 0–30 cm beneath the surface. Chemical and physical analyses were carried out according to the Austrian standardised analytical methods for compost (ÖNORM S2023).

The compost cover on test cell III shows the highest organic content, the highest nitrogen supply and water content as well as the best supply and availability of phosphorus, obviously enhancing the growth and density of the plant cover on that test cell. The used gravel and silt were residues from a gravel washing plant. The silt was a fine and dense material, grain size < 75 mm, with a high sealing effect during the first years after application at the top of the landfill. The organic content of the silt was about 0.2–0.5 % (RIEHL-HERWISCH und LECHNER, 1995).

The diaspore content of the top covers was not assessed 12 years ago; therefore these data are not available. Due to the fact that the used silt and gravel were "non-natural" materials it can be assumed that no specific diaspore content was existing. Doubtlessly there were seeds of ruderals and other short-lived plants in the compost layer, but as the different top covers (compost, gravel, silt, ...) were of the same origin for all test cells and fields, fields with the same uppermost cover must have had the same conditions at the

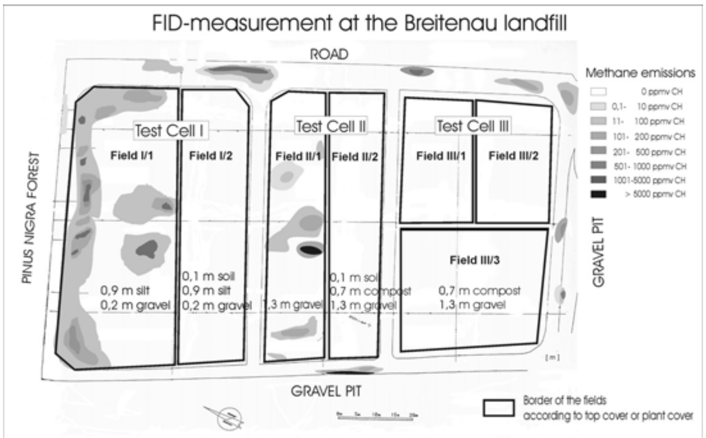

Figure 1: Test cells and fields at the Breitenau landfill including methane emissions mapping (FID-measurement) in October 2001. In dark grey and black areas (101– >5000 ppm v/v CH_4): Vegetation cover <5 %

Abbildung 1: Schematische Darstellung der Testfelder auf der Deponie Breitenau inklusive Methanemissions-Kartierung (FID-Messung) im Oktober 2001. In dunkelgrauen und schwarzen Bereichen (101 – >5000 ppm v/v CH_4): Vegetationsdeckung <5 %

Table 1: Volume and design of the top covers of the test cells at the Breitenau landfill. (MSW = municipal solid waste)

Tabelle 1: Verfüllvolumen und Gestaltung der Abdeckschichten auf den Versuchsflächen der Deponie Breitenau (MSW = Hausmüll)

	Test Cell				
	Cell I		Cell II		Cell III
Waste input	35,000 t MSW		25,600 t MSW		33,220 t MSW
Top cover	Field I/1	Field I/2	Field II/1	Field II/2	Field III/I–III/3
		0.1 m soil		0.1 m soil	
	0.9 m silt	0.9 m silt		0.7 m compost	0.7 m compost
	0.2 m gravel	0.2 m gravel	1.3 m gravel	1.3 m gravel	1.3 m gravel

Table 2: Characteristics of the top covers on the test fields at the Breitenau landfill (samples taken from a depth of 0–30 cm; DM = dry matter; WM = wet matter; CAL = CAL-extraction according to ÖNORM S2023

Tabelle 2: Kenndaten der Abdeckschichten auf den Versuchsflächen auf der Deponie Breitenau (Proben aus den obersten 0–30 cm; DM = Trockensubstanz; WM = Feuchtsubstanz; CAL = CAL-Extraktion gemäß ÖNORM S2023

Parameter		Field		Field		Field		
		I/1	I/2	II/1	II/2	III/1	III/2	III/3
pH – $CaCl_2$	–	7.7	7.6	7.6	7.6	7.5	7.6	7.6
conductivity	mS/cm	0.21	0.36	0.18	0.31	0.61	1.02	0.54
total N	% DM	0.06	0.27	0.07	0.35	1.1	0.74	0.72
NO_3	mg/kg DM	63	91	9	23	14	94	14
NH_4	mg/kg DM	1	3	1	2	1	1	2
Current Water content *	%w/w WM	9	16	7	9	19	25	26
organic content+)	% DM	3.4	7.0	2.9	7.6	24.1	20.8	18.6
organic Carbon	%DM	1.0	3.0	1.1	3.6	13.5	11.5	10.6
total P_2O_5	% DM	0.04	0.12	0.06	0.14	0.62	0.48	0.83
$P_2O_{5\text{-CAL}}$ (plant available)	% DM	0.004	0.003	0.002	0.01	0.04	0.02	0.05
Heavy metals (plant available)								
Cd		1.0	1.8	1.6	1.4	0.61		0.82
Cr		1	2	1	2	1		2
Cu	mg/kg DM	2	1	4	10	13		73
Ni		5	7	6	7	7		6
Pb		8	5	12	10	18		37
Zn		6	5	7	129	391		1,207

+) loss after ignition to 550°C); *sample taken in May 2002; +)Glühverlust bei 550 °C); * Probe vom Mai 2002

starting point. Yet the fact that one side of the landfill is bordering to a semi-natural forest may influence the seed rain in the more adjacent fields.

2.2 Gas emission measurement

Well operating bio-reactor landfills show a high gas production in the first 3–10 years and a continuously declining gas production over the following 10–30 years (Ehrig, 1991; Steinlechner et al., 1994). A similar behaviour was also observable at the Breitenau landfill (Riehl-Herwisch und Lechner, 1995; Binner et al., 1997). After the waste placement in 1987 gas extraction (collection) and gas quantity measuring systems were installed in spring 1989, showing gas collection rates of about 15–16 l methane per ton of waste and per day, and a steady decrease in gas production down to 2–3 l methane/t.d in 1991. Due to this immense decrease the gas collection system was switched off some years later (Riehl-Herwisch und Lechner, 1995).

In autumn 2001 gas emission measurements were carried out at the landfill using a portable FlameIonisationDetector (FID), which is capable of detecting very small concentrations of hydrocarbons (CH) (0.5 ppm volume per volume (v/v) – 50,000 ppm v/v). The results of this detailed FID-measurement were verified by a second, partial and random measurement in early summer 2002. With a funnel shaped probe and a pump integrated in the FID it is possible to measure methane emissions directly at the surface of the top cover on landfills. CH_4-concentrations at the surface were detected in a close pattern (al least one measuring point per m^2), directly recorded by the FID, and the measuring points were mapped. These results were plotted on a map and after extrapolation of concentration isolines, a methane emission pattern of the investigated site was achieved (see Figure 1).

2.3 Vegetation ecology

The composition of the plant cover on the 3 test cells was estimated by phytosociological relevés using the method of Londo (1976). In this method, the cover percentage of a species is attributed to one of the following groups:

.1: > 1 % cover	1: 5–15 % cover	9: 85– 95 % cover
.2: 1–3 % cover	2: 15–25 % cover	10: 95–100 % cover
.4: 3–5 % cover	3: 25–35 % cover ...	

Phytosociological field work (relevés) was performed there in autumn 2001 and repeated in early summer 2002.

The test cells I and II could be divided optically into two fields each, as a consequence of different top covers and different neighbouring plant communities. Only test cell III with its very dense, but inhomogeneously composed plant cover was divided into 3 relevés oriented at the dominating species: 2 relevés were made in the „streetward" half of the cell, each covering approximately one quarter of the cell, whereas the third relevé was made in the remaining half of the whole cell.

The margins of the fields were excluded from the relevés in order to avoid border effects by the presence of plant species that were absent in the centre of the fields. The nomenclature of vascular species follows ADLER et al. (1994). Cryptogamic species were not noted, though small quantities of mosses were present in test cells I and II. The estimated cover of all vascular plant species was documented together with their ecological indicator values for nitrogen demand (N), temperature demand (T) and moisture demand (M) according to ELLENBERG et al. (1992), and their life forms according to RAUNKIAER (1910). These life forms often implicate the life span of a species.

The cumulative indicator values for N, T and M for the entire relevés were then calculated as sums of the species specific indicator values, and they depend on the cover percentage of every species. Furthermore, all species were attributed to one of the phytosociological classes according to MUCINA et al. (1993) and MUCINA (1993), respectively. For every field the diversity index (Shannon-Wiener index, see TREMP, 2005) was calculated. This index illustrates the degree of uncertainty to find a special taxon by random sampling.

3. Results

3.1 Gas emissions

During the FID-measurement the atmospheric pressure was 1017 mbar, the weather sunny and calm. On field I/1 (silt and gravel cover) the largest areas with methane emissions were detected (see Figure 1). The highest concentrations (> 5,000 ppm v/v CH) of surface methane emissions were detected on field II/1 (gravel cover). At these fields the emission spots were strongly correlated with bare spots in vegetation, which were clearly visible. Also at the surrounding area of the test cells high methane emissions were found due to lateral gas migration through cracks and fissures. On field I/2 (soil, silt and gravel cover), field II/2 (soil, compost and gravel cover) and on entire field III (compost and gravel cover) no methane emissions were measured.

3.2 Vegetation

Table 3 shows the recent species composition as well as total plant cover, total species number and the number of species with a cover of 5 % or more.

The vegetation in cell I and field II/1 shows large gaps; total percentage cover amounts to only 40 % and 80 %, respectively (Figure 2). Large parts of field I/1 and smaller patches of II/1 reveal unvegetated gravel on the surface exactly where highest gas emissions were measured (corresponding grey to black areas in Figure 1). Some pioneer trees and shrubs and few herbs with a low demand of nitrogen and moisture grow more distantly from gas emissions in field I/1; many of these individuals are crippled or abnormal. Nevertheless, this field comprises at least 40 species of vascular plants, among them *Sanguisorba minor* (Rosaceae) colonising even gravelly places close to gas emissions (Figure 2; Figure 3). Species diversity is also highest in fields II/1 and I/1, and the communities there comprise already high portions of the Festuco-Brometea class species.

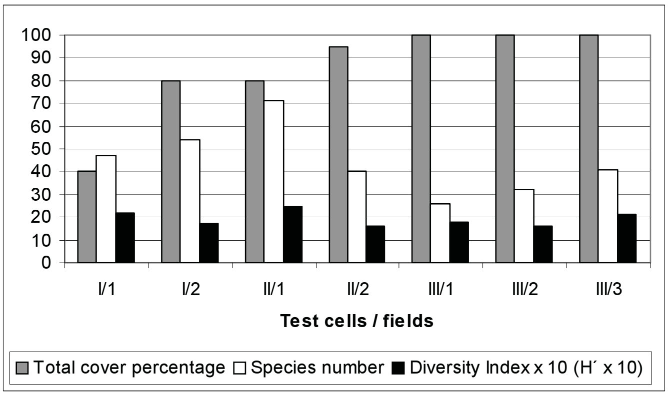

Figure 2: Comparison of total cover percentage, number of vascular species and Shannon-Wiener diversity index (10 x H´) in the 7 relevés at the waste landfill Breitenau 2001/2002

Abbildung 2: Vergleich von Gesamtdeckung, Anzahl der Gefäßpflanzen und Shannon-Wiener Diversitätsindex (10 x H´) in den 7 Aufnahmen auf der Mülldeponie Breitenau 2001/2002

The two fields with a top cover of 0.1 m soil upon 0.9 m silt and 0.2 m gravel (I/2) and upon 0.7 m compost and 1.3 m gravel (II/2) are dominated by grasses: I/2 by *Calamagrostis epigejos* and II/2 by *Elymus repens*, both very competitive perennials; species diversity and composition reflect this fact. Figure 4 reveals low nitrogen and moisture values for cell I as well as for II/1.

Field II/2 has not only an impressing total cover compared with its relatively moderate species number, but also

Table 3: Plant species composition and cover as well as species numbers in the seven fields of the three test cells (H = herbal layer; S = shrub layer)
Tabelle 3: Artenzusammensetzung, Artenzahlen und geschätzte Deckung in den sieben Feldern der drei Testzellen (H = Krautschicht; S = Strauchschicht)

	Species cover (LONDO, 1976)						
Test cell:	**I/1**	**I/2**	**II/1**	**II/2**	**III/1**	**III/2**	**III/3**
Species number, total:	47	54	71	40	26	32	41
Total cover (%):	40	80	80	95	100	100	100
Number of spp. with cover =/>1	2	3	3	5	5	3	5
Pinus sylvestris H	.1	.1					
Salix elaeagnos H	.1	.1					
Rubus fruticosus agg. H	.1	.1					
Pinus nigra S	.2	1	.2				
Pinus nigra H	.4	.2	.2				
Populus nigra S	0,5	1	.2				
Populus nigra H	.2	.2	.1				
Salix purpurea H	.1	.1	.1				
Salix purpurea S		.2	.2				
Populus tremula S		.1	.2				
Salix caprea S		.1	.1				
Rosa spec. S		.1	.1				
Salix elaeagnos S		.1	.1				
Pinus sylvestris S		.1					
Salix alba S		.1					
Clematis vitalba H		.1	.1				
Populus tremula H			.1				
Populus x *canescens* S			.1				
Populus alba S			.1				
Populus alba H			.1				
Salix caprea x? H			.1				
Malus domestica H			.1				
Cotoneaster horizontalis H			.1				
Salix alba H			.1				
Pyrus pyraster H				.1			
Rubus caesius H		.1		.1			
Sambucus nigra S				.1	1	2	1
Sambucus nigra H				.1		.2	
Setaria viridis	.1						
Hieracium bauhini	.1						
Pimpinella saxifraga	.1						
Agrimonia eupatoria	.1						
Potentilla cf. *canescens*	.1						
Tragopogon spec. (fasciated)	.1						
Epilobium angustifolium	.1						
Tussilago farfara	.1						
Bromus inermis	.1						
Solidago gigantea		.1					
Lathyrus pratensis		.1					
Humulus lupulus		.1					
Brachypodium pinnatum		.1					
Festuca pratensis		.1					
Fragaria vesca		.1					
Silene vulgaris	.1	.1	.1				
Fragaria viridis	.1	.1	.1				
Verbascum cf. lychnitis	.1	.1	.1				
Bromus erectus	.2	.2	3				
Centaurea jacea subjacea	.1	.1	.2				
Sanguisorba minor	1	.2	1				
Potentilla reptans	.1	.1	.2				
Achillea millefolium agg.	.1	.1	.2				
Echium vulgare	.1	.1	.1				
Daucus carota	.1	.1	.1				
Medicago lupulina	.1	.1	.1				
Galium verum	.1	.1	.1				
Thesium cf. *dollineri*	.1		.1				
Securigera varia	.1		.1				
Carlina vulgaris	.1		.1				
Lotus corniculatus	.1		.1				
Setaria pumila	.1		.1				
Leontodon saxatilis	.1		.1				
Trifolium pratense	.1		.1				
Poa compressa	.1		.1				
Arabis auriculata	.1		.1				
Hieracium umbellatum			.1				
Leucanthemum vulgare s.l.		.1	.1				
Plantago lanceolata		.1	.1				
Festuca cf. *rupicola*		.1	.1				
Hypericum perforatum		.1	.1				
Inula conyza		.1	.1				
Carex alba			.1				

	Species cover (LONDO, 1976)						
Test cell:	**I/1**	**I/2**	**II/1**	**II/2**	**III/1**	**III/2**	**III/3**
Species number, total:	47	54	71	40	26	32	41
Total cover (%):	40	80	80	95	100	100	100
Number of spp. with cover =/>1	2	3	3	5	5	3	5
Cerastium glutinosum			.1				
Seseli cf. *annuum*			.1				
Potentilla pusilla			.1				
Salvia pratensis			.1				
Potentilla cf. *arenaria*			.1				
Aster. novi-belgii s.l.			.1				
Centaurea stoebe			.1				
Melica ciliata			.1	.1			
Oenothera biennis s.l.		.1		.1			
Euphorbia esula agg.		.1	.2	.1			
Galium album		.1	.4	.2			
Solidago canadensis	.1	.2	.2	.1			
Trifolium campestre	.1	.1	.1	.1			
Linaria vulgaris	.1	.1	.1				.1
Cirsium vulgare		.1	.1		.4	.1	.2
Calamagrostis epigejos	1	5	1	1	.2	.2	.1
Dactylis glomerata	.1	.1	.1	.1	.1	.1	.1
Artemisia vulgaris	.1	.1	.1	1	.2	.2	.1
Cirsium arvense		.1	.1	.1	.1	.2	.1
Poa angustifolia	.1	.1	.2	.1	.1	.1	.1
Silene latifolia ssp. alba	.1	.1	.1	.1	.1	.1	.1
Taraxacum officinale s.l.		.1	.1		.1	.1	.1
Arrhenatherum elatius	.1	.2	.2	.2	.2	.1	.1
Erigeron annuus	.1	.1	.2		.1		.1
Conyza canadensis		.1					.1
Picris hieracioides		.1	.1				.1
Elymus repens			.2	6	1	.2	.2
Festuca rubra			.1				.1
Carduus acanthoides			.1	.1	.1	.2	.2
Centaurea scabiosa			.2	.2			.1
Viola arvensis				.1			
Euphorbia virgata				.1			
Anthriscus cf. *caucalis*				.1			
Arctium lappa				.1			
Heracleum sphondylium				.1			
Cichorium intybus				.1			
Ballota nigra				.1			
Onopordon acanthium				.1			
Rumex obtusifolius				.1	.1	.1	
Sonchus oleraceus				.1		.1	
Cardaria draba				.1	.1		.2
Cynoglossum creticum				.1		.1	.1
Lactuca serriola				.1		.2	.2
Echinops sphaerocephalus				1	1		3
Urtica dioica				1	5	2	3
Sisymbrium loeselii				.1	.1	.4	.1
Galium aparine				.1	.4	.2	.2
Atriplex oblongifolia				.2	.1	.2	.2
Mercurialis annua				.1			.1
Trisetum flavescens				.1			.1
Geranium pusillum					.2	.1	1
Chelidonium majus					1	5	2
Stellaria media agg.					.2	.2	.2
Erysimum cheiranthoides					.1		.1
Sinapis arvensis					.1		
Amaranthus retroflexus					.1		
Plantago major						.1	
Lolium perenne						.1	
Poa trivialis						.1	
Sisymbrium orientale						.1	
Chenopodium album						.1	
Descurainia sophia						.1	.1
Alliaria petiolata						.1	.1
Mentha verticillata agg.						.1	.1
Ajuga reptans							.1
Malva pusilla							.1
Capsella bursa-pastoris							.1
Camelina microcarpa							.1
Arenaria serpyllifolia							.1
Tripleurospermum inodorum							.1

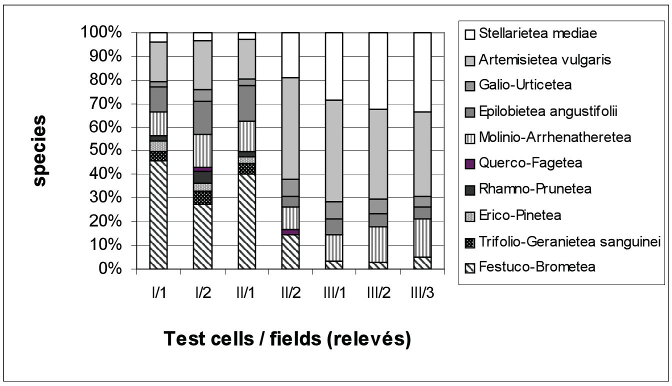

Figure 3: Relative portion of phytosociological classes in the species composition of the 7 relevés at the landfill Breitenau 2001/2002

Abbildung 3: Relativer Anteil der phytosoziologischen Klassen an der Artenzusammensetzung der Aufnahmeflächen der Deponie Breitenau 2001/2002

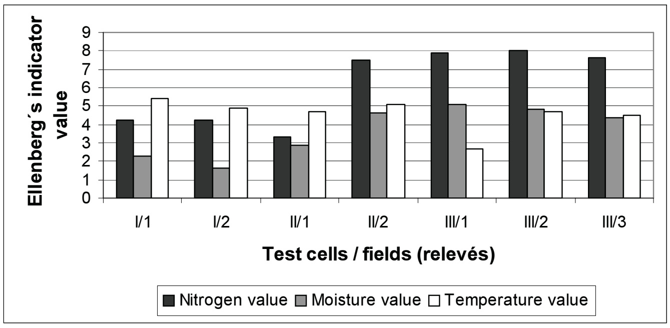

Figure 4: Breitenau landfill 2001/2002: ELLENBERG et al.'s (1992) indicator values (for nitrogen, moisture, and temperature) calculated for every relevé (Note that the respective dominant species in the field I/2 is indifferent with regard to site moisture, and in III/1 with regard to temperature)

Abbildung 4: Mülldeponie Breitenau 2001/2002: Zeigerwerte nach ELLENBERG et al. (1992) für Stickstoff, Feuchte und Temperatur, errechnet für jede Aufnahme (Zu beachten: Die jeweils dominante Art in den Feldern I/2 und III/1 ist gegenüber einem ökologischen Faktor (I/2: Feuchte, III/1: Temperatur) indifferent)

a high cumulative indicator value for nitrogen demand (N-value). A low diversity index and high percentages of Stellarietea and Artemisietea species (short-lived and perennial ruderals) can explain this.

The highest total cover percentages, but low species numbers are found in test cell III. The vegetation consists of few but very competitive ruderals which form a dense multi-storey layer. The highest nitrogen demand (N-value) of all test cells is located here. The moisture demand (M-value) of the species here is also markedly higher than that of species dominating in cell I or field II/1. The temperature demand (T-value) for field III/3 (see Figure 4) is markedly lower than in III/2 or III/3. The prevailing species here, *Urtica dioica*, has no specific moisture demands; this is true also for *Calamagrostis epigejos* dominating in field I/2, explaining the rather low M-values in the two fields. The three fields in test cell 3 reveal similarly high portions of Stellarietea mediae- and Artemisietea species, but very few of the Festuco-Brometea class. Compared with data provided by WALTER (1992) who studied the same landfill in the vegetation period of 1990, the amount of perennial species did not increase drastically in cell III (Figure 5): In 2002, the number of perennials here is only slightly higher than it was 12 years earlier. But in cell II perennial species are now doubled, and in cell I almost threefold compared with 1990. On the other hand, the number of therophytes/ short-lived „weed" species was about 3 times higher in 1990 than in 2002. Both studies, WALTER's of 1990 and ours of 2002, show that the highest portion of therophytes (mostly Stellarietea mediae species) is bound to the compost surface of test cell III. Yet we found only one short-lived species with a cover of more than 5 %, the annual (-biennial) therophytic *Geranium pusillum*, in field III/3 (Table 3). The substrates of test cell I are not only scarcely vegetated but have – and had – the lowest number of therophytic species. In 1990, Walter found the lowest amount of perennials in cell I as well.

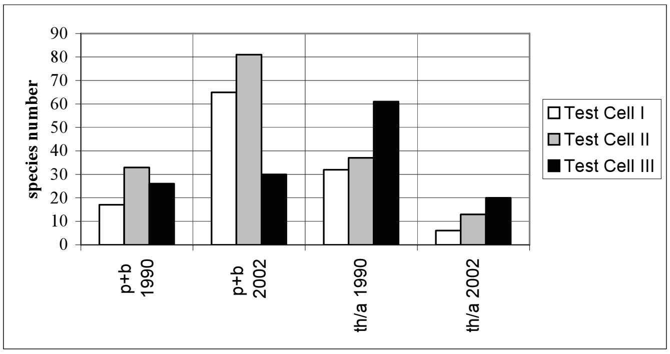

Figure 5: Breitenau landfill: Comparison of life form spectra published by WALTER (1992) and recent life form spectra (2001/2002) in the 3 test cells
p+b: Perennial and biennial species; th/a: therophytes/ annuals

Abbildung 5: Mülldeponie Breitenau: Vergleich der Lebensformspektren erhoben von WALTER (1992) und aktuelle Lebensformspektren (2001/2002) in den 3 Testzellen
p+b: Ausdauernde und zweijährige Arten; th/a: Therophyten/Annuelle

4. Discussion

The origin of the different cover materials for all cells was identical, thus it can be assumed that the diaspore reserves in the fields with compost top cover were comparable, and also the fields with soil or gravel as top cover had starting conditions comparable to each other. Nevertheless, the seed input by seed rain favoured different successions on equal top covers, and these top covers with their different permeability for gas emissions and capacity for methane oxidation supported the diversification of the plant covers on the 7 fields.

Our findings confirm results formerly published by other authors, especially as to the physiological hazards for plants by landfill gas emissions (WEDEMEYER VON, 1982; KONOLD and ZELTNER, 1981). Beside the replacement of oxygen by methane and CO_2, locations with landfill gas emissions are also said to be extremely dry (GOMISCEK, 1999). This fact may be responsible for the relatively high cover percentage of *Sanguisorba minor*, a plant well adapted to dry sites, near gas emissions.

Methane emissions were mainly detected in the fields with only organic-poor cover material (gravel and silt cover on fields I/1, II/1; see Figure 1). As soon as the landfill is topped by soil or compost, gas emissions are reduced or stopped. This is probably due to the microbial methane oxidation process. Specific microorganisms, namely methanotrophic bacteria, are capable of converting methane to carbon dioxide, water and microbial biomass. This process is well known and takes place in many natural systems like wetlands and swamps (WHITTENBURY et al., 1970), and also in suitable top covers on landfills (WHALEN et al., 1990; BERGMANN et al., 1993; KIGHTLEY et al., 1995; BÖRJESSON et al., 1998; HUMER und LECHNER, 1999; HUBER-HUMER und LECHNER, 2002). In particular, high methane oxidation capacity could be found in porous, coarse and organic-rich substrates. Thus, the compost and soil covers on field I/2, field II/2 and field III may have enhanced methane oxidation and mitigated methane emissions. On the other hand, plant establishment and growth can profit from the nutrients and probably also seeds, bulbs and rhizomes applied with the toppings: Even in cell II, the comparatively higher amount of organic matter in field II/2 favours the species *Elymus* (= *Agropyron*) *repens*, an N-demanding species (HOLZNER, 1981), to form a ruderal semi-dry meadow. According to BRANDES (1980, 1982, 1986) *Elymus repens* prefers warmer and drier ruderal sites than *Calamagrostis epigejos*. The poorer, but in deeper layers probably moister substrate in field I/2 is dominated by the latter species, a pioneer grass also growing in sand and other poor soils (FORSTNER, 1983). The low amount of perennials in cell I in 1990 (WALTER, 1992) and the relatively many therophytic species in cell III in 2002 indicate that only a few perennial species are well established, but these are very competitive in the fields with most organic matter in the top cover. According to HOLZNER (1981, 1994) their presence can hamper further succession at least for several years. The plant cover of cell II/1 with well-established *Bromus erectus* and more than 25 other Festuco-Brometea species as well as some *Pinus nigra* has already undergone first steps of a succession towards a dry/mesic turf or even towards a *Pinus nigra* forest, well adapted to the summer-dry and warm pannonian climate. Provided that the gas emissions will stop within the next decades, also cell I will probably follow this successional pattern some day.

From the point-of-view of nature conservation, this development may offer a chance for those species with low nutrient and moisture demand that have suffered from a loss of their habitats by intensification in agriculture (BERNHARDT, 1996). On the other hand, taking into account that the deposition of solid waste will occupy future generations even more than today and that methane emissions can be controlled effectively by compost covers, compost covers may provide benefits not only for human society, but also for "weed" communities that have as well decreased rapidly by man who tends to keep the landscape "neat and clean".

References

ADLER, W., K. OSWALD and R. FISCHER (1994): Exkursionsflora von Österreich. Verlag E. Ulmer, Stuttgart and Wien.

BERGMAN H., A. JACOBSSON and A. LAGERKVIST (1993): Investigations regarding biofilters for methane oxidation in landfill top covers. Proceedings Sardinia 93, Fourth International Landfill Symposium, S. Margherita di Pula, Cagliari, Italy, 11–15 October 1993, CISA, 717–727.

BERNHARDT, K.-G. (1996): Die Pflanzengesellschaften des Fürstentums Liechtenstein. III. Halbtrockenrasen. Ber. Bot.-Zool. Ges. Liechtenstein-Sargans-Werdenberg 23, 225–237.

BINNER, E., P. LECHNER, C. ZIEGLER and G. RIEHL-HERWISCH (1997): Breitenau landfill – water balance, emissions and a look into the landfill body. Proceedings Sardinia 97, Sixth International Landfill Symposium, Cagliari, Italy, CISA, October 1997, Vol. I, 301–310.

BLUME, H. B., R. BORNKAMM and H. SUKOPP (1979): Vegetationsschäden und Bodenveränderungen in der Umgebung einer Mülldeponie. Z. Kulturtechnik und Flurbereinigung 20, 65–79.

BÖRJESSON G., I. SUNDH, A. TUNLID and B. H. SVENSSON (1998): Methane oxidation in landfill cover soils as revealed by potential oxidation measurements and phospholipid fatty acid analyses, Soil Biol. Biochem. 30 (10/11), 423–433.

BRANDES, D. (1980): Ruderalgesellschaften des Verbandes Arction Tx. 1937 im östlichen Niedersachsen. Braunschw. Naturk. Schr. 1 (1), 77–104.

BRANDES, D. (1982): Notiz zur Flora der Stadt Salzgitter. Braunschw. Naturk. Schr. 1 (3), 565–570.

BRANDES, D. (1986): Ruderale Halbtrockenrasen des Verbandes Convolvulo-Agropyrion Görs 1966 im östlichen Niedersachsen. Braunschw. Naturk. Schr. 2 (3), 547–564.

CROFT, B. and R. EMBERTON (1989): Landfill gas and the Oxidation of methane in soil. The Technical Aspects of Controlled Waste Management, Department of the Environment, Wastes Technical Division, Research Report No. CWM 049/89.

ELLENBERG, H., H. E. WEBER, R. DÜLL, V. WIRTH, W. WERNER and D. PAULIßEN (1992): Zeigerwerte von Pflanzen in Mitteleuropa. Scripta Geobotanica 18, 2nd ed., Verlag Goltze, Göttingen.

EHRIG, H.-J. (1991): Gasprognose bei Restmülldeponien. In: RETTENBERGER, G. and R. STEGMANN (Hrsg.): Deponiegasnutzung. Trierer Berichte zur Abfallwirtschaft, Band 2. Economica Verlag, Bonn.

FORSTNER, W. (1983): Ruderale Vegetation in Ost-Österreich. Wissenschaftliche Mitt. Niederösterr. Landesmuseum 2, 19–133.

GOMISCEK, T. (1999): Rekultivierung von Deponien mit abfallbürtigen Substraten und Energiepflanzen in Hinblick auf Wasserhaushalt und Biomasseertrag, Ph.D. Thesis, Universität für Bodenkultur.

HAIDER, I. (1991): Ökologisch-vegetationskundliche Veränderungen auf der Mülldeponie Köglerweg/Graz seit der Rekultivierung im Jahre 1981. Diploma Thesis, Karl Franzens-Universität, Graz.

HOLZNER, W. (1981): Acker-Unkräuter. Bestimmung, Verbreitung, Biologie und Ökologie. Verlag Stocker, Graz.

HOLZNER, W. (1994): Unkräuter, Begleiter und Freunde des Menschen. Grüne Reihe des Bundesministeriums für Umwelt, Jugend und Familie 4, 15–39.

HUBER-HUMER, M. and P. LECHNER (2002): Proper biocovers to enhance methane oxidation – findings from a two year field trial. Proceedings from the Solid Waste Association of North America's 25th Annual landfill Gas Symposium, Monterey, CA, March 2002, 101– 114.

HUMER, M. and P. LECHNER (1999): Methane Oxidation in Compost Cover Layers on Landfills. Proceedings Sardinia 1999, Volume III, Seventh International Waste Management and Landfill Symposium, Cagliari, Italy, CISA, 403–410.

KIGHTLEY, D., D. B. NEDWELL and M. COOPER (1995): Capacity for methane oxidation in landfill cover soils measured in laboratory-scale soil microcosms, Applied and Environmental Microbiology 61 (2), 592–601.

KONOLD, W. and G. H. ZELTNER (1981): Untersuchungen zur Vegetation abgedeckter Mülldeponien. Beihefte Veröff. Naturschutz Landschaftspflege Bad.-Württ. 24, 7–83.

LONDO, G. (1976): The decimal scale for relevés of permanent quadrats. Vegetatio 33, 61–64.

MUCINA, L., G. GRABHERR and T. ELLMAUER (eds.) (1993): Die Pflanzengesellschaften Österreichs. I. Anthropogene Vegetation. G. Fischer, Jena, Stuttgart, New York.

MUCINA, L. (ed.) (1993): Die Pflanzengesellschaften Österreichs. III. Wälder und Gebüsche. G. Fischer, Jena, Stuttgart, New York.

NEUMANN, U. (1976): Untersuchungen über die Begrünung und Entwicklung von Vegetationsdecken auf Mülldeponien. Ph. D. Thesis, Technical University Berlin, Germany.

ÖNORM S2023 (1993): Untersuchungsmethoden und Güteüberwachung von Komposten (Analytical methods and quality control of compost), Österreichisches Normungsinstitut, Fachnormenausschuss 199 – Kompostierung, Wien, November 1993.

RAUCHECKER, M. (2001): Ökologische Aspekte bei der Schließung und Rekultivierung von Deponien und Abfallflächen mit diversen Pflanzenarten und unterschiedlichen Kultursubstraten zur Produktion von Biomasse und Reduktion des Sickerwasseranfalls. Ph.D. Thesis, Universität für Bodenkultur Wien, Austria.

RIEHL-HERWISCH, G. and P. LECHNER (1995): Hausmüllversuchsanlage Breitenau, Untersuchungen zum quantitativen und qualitativen Wasserhaushalt (1986–1991); Abschlussbericht. Bundesministerium für Land- und Forstwirtschaft (Hrsg.): Wasserwirtschaftskataster, Wien.

SCHLÜTER, U., A. BARTH and H. HEBBELMANN (1996): Rekultivierung von Hausmülldeponien. Naturschutz und Landschaftsplanung 28 (9), 280–286.

STEINLECHNER, E., H. BERGHOLD, F. CATE, G. JUNGMEIER,

J. SPITZER and Ch. WUTZL (1994): Möglichkeiten der Vermeidung und Nutzung anthropogener Methanemissionen. Institut für Umweltgeologie und Ökosystemforschung, Joanneum Research, Graz.

TREMP, H. (2005): Aufnahme und Analyse vegetationsökologischer Arten. Eugen Ulmer, Stuttgart.

WALTER, J. (1992): Flora und Sukzessionsverhältnisse auf Mülldeponien in verschiedenen Gebieten Österreichs. Dipl. Thesis, University of Vienna, Austria.

WEDEMEYER, H.-C. VON (1982): Schäden am Rand einer Mülldeponie. Schriftenreihe HBLS, Sonderreihe Beispiele der agraren Taxation. Heft B 53. Verlag Pflug und Feder, Bonn.

WHALEN, S. C., W. REEBURGH and K. SANDBECK (1990): Rapid Methane Oxidation in a Landfill Cover Soil. Applied and Environmental Microbiology, 3405–3411.

WHITTENBURY, R., K. C. PHILLIPS and J. F. WILKINSON (1970): Enrichment, isolation and some properties of methane-utilising Bacteria. Journal of General Microbiology 61, 205–218.

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Eingelangt am 12. November 2003
Angenommen am 19. Juli 2005