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CASE STUDY OF LANDFILL RECLAMATION AT CZECH LANDFILL SITE

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Abstract

The landfill reclamation project took place in the period from 2008 to 2009. Forestry reclamation was carried out in 2009. The aim of this project was to establish the growth of particular plant species, quantify plant species survival and changes in species properties over time. A phased approach was utilized to evaluate the technical and economic feasibility of the reclamation project; based on the results of these evaluations, in 2011 approximately 90 % of plant species survived during the first phase of landfill reclamation. The composition of wood species selected for the plantation can be evaluated as appropriate. The success is determined by the selection of wood species and the care that was taken of the seedlings after the plantation (frequent watering in the first months after plantation and also regular pruning, as a part of the mowing process; less prosperous seedling trees were hoed). This paper presents the researchers' landfill reclamation project experience, including an estimation of reclamation rates achieved during the project, project costs and estimated composition of the reclaimed materials. It is expected that a similar composition of wood species will be used for reclamation of the second phase of the landfill body. Only with regard to species *Juniperus communis* it is advisable to replace it with another species, due to lower rooting success (42 % in 2010 and 37.3 % in 2011).

Key words: landfill reclamation, municipal waste, municipal solid wastes, reclamation, revegetation

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1. Introduction

Safe waste disposal is one of the major environmental issues facing society today, and landfills provide the most economical and simple means of disposing waste globally (Lamb et al., 2012). In many developed countries municipal solid wastes (MSW) are dumped in engineered sanitary landfills. Sanitary landfill has been widely accepted as a cost-efficient method for MSW disposal. At the same time, landfill leachate, a highly contaminated and complex wastewater is created during a landfill long-term stabilization process. This could threaten human health and the environment, as are surface water and groundwater (Chemalal et al., 2013).

Although there has been a significant increase in the reduction, reuse and recycling of solid waste, disposal to landfill will inevitably remain the most widely used waste management method. Methods of waste disposal vary with countries which may be attributed to various reasons such as amount and type of waste produced, type of waste collection, available of land area, environmental regulations practiced (Bolan et al., 2013). On the other hand, in many developing countries, the solid wastes are dumped in an uncontrolled manner, posing a threat due to some elements commonly found in wastes that come in forms known to be toxic to both humans and the environment (Kostopoulou et al., 2010; Nagendran et al., 2006; Seco et al., 2003; Sluser et al., 2017) Leachate that is generated by landfills is likely to contain a high concentration of organic matter and inorganic ions, including heavy metals because of their extensive use in different applications and their

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wide distribution (Al-Yaqout and Homoda, 2003; Kostopoulou et al., 2010; Seco et al., 2003). Thus, landfills constitute extremely variable and heterogeneous environments, as well as, degraded landscapes in urban areas. The high rate of urban expansion in modern cities makes residents directly exposed to waste annoyances, rendering landfill reclamation a public demand and an urgent need, especially in dry and semidry areas, like the Mediterranean zone, where the risk of erosion and desertification is high (Kim and Lee, 2005a; Kostopoulou et al., 2010; Rakimbei et al., 2007).

In recent times many local governments have been introducing engineered landfills with gas recovery systems, thereby landfills potentially providing a major source of CH_4 as a fuel source. Increasingly revegetation (i.e., phytocap) is practiced in traditionally managed landfills sites to mitigate the environmental impacts resulting from leachate generation and greenhouse gas (GHG) emission (Lamb et al., 2012). Revegetation also provides a major source of biomass for energy production (Bolan et al., 2013; Kostopoulou et al., 2010; Venkatraman and Ashwath, 2009). However as with other kinds of landscape rehabilitation, efforts to revegetate former landfills have met with varying success, although in most cases the efforts themselves have been quite modest (Robinson et al., 1992).

Natural or planted vegetation on a landfill has an important role in erosion control and removal of contaminants, besides imparting aesthetic value (Erdogan et al., 2011, Kostopoulou et al., 2010; Nagendran et al., 2006). The common practice is to reclaim completed sites by converting them to parks, golf courses, botanical gardens, recreation areas, or farmland, all of which require establishment of vegetation. However, difficulties in achieving this have been experienced in many countries, e.g. Finland, Hong Kong, the Unites States, and Great Britan (Chan et al., 1991).

Determining a suitable revegetation strategy for restoring waste landfills is a very complex and difficult problem (Al-Yaqout and Homoda, 2003). For revegetation purposes it is most efficient and economical to use naturally occurring vegetation and, at the same time, to select species that have high ability to survive, a factor that will shape the landscape of waste landfills after reclamation (Kim and Lee, 2005a; Kim and Lee, 2005b; Kostopoulou et al., 2010). In addition, the successful establishment of vegetation on landfills is an integral part of the planned end use (Trotter and Cooke, 2005).

The conditions usually prevailing at landfill sites, namely good drainage, high temperatures, infertile and compact top cover soil, existence of gases and toxic components, such as heavy metals, have negative consequences on plants, such as exposure to water stress, increase of oxygen demand and bad growth and development conditions (Kim and Lee, 2005a; Kim and Lee, 2005b; Kostopoulou et al., 2010; Nagendran et al., 2006; Yang et al., 2003), often leading to a poor and damaged vegetation cover (Leone et al., 1977).

Successful ecological reclamation depends on the establishment, growth, and reproduction of plants within the target community (Gillespie and Allen, 2004; Lori et al., 2009; Somodi et al., 2008). The degrees to which plant species successfully accomplish these life-history stages depend on the treatment's ability to both ameliorate the stresses imposed by site conditions and limit competition with unplanted species (Lori et al., 2009; Moloney, 1990). This is particularly important during the initial stages of development when plant communities undergo the most challenges to their establishment and survival (Lori et al., 2009; Montalovo et al., 2002; Moreno-de las Heras et al., 2008). The resiliency of populations through these and other stressful periods, such as seasonal drought, will improve the chances of reclamation success (Biederman et al., 2009).

The primary objective of landfill design and management is to contain waste materials and limit off-site transport to air (as dust) and water as contaminants (Lamb et al., 2012).

Landfill covers are used to reduce water percolation, thereby mitigating groundwater contamination risk of leachate generation. Traditionally, landfill covers have been designed to minimize water entry through the use of low permeability layers (e.g. compacted clay caps and geosynthetic liners) (Albright et al., 2006; Bolan et al., 2013). However, often this is not achieved due to formation of cracks as landfills age due to drying and wetting cycles associated with seasonal changes in rainfall and temperature (Albright et al., 2003; Bolan et al., 2013). Therefore, constructed caps are vegetated to prevent exposure and degradation of the barrier, and to promote water storage in the soil and evapotranspiration from the vegetation (Bolan et al., 2013). Caps are often vegetated by laying down topsoil as rooting substrate and sowing grass seeds (i.e. phytocapping). Even though the primary management goal is to develop vegetation cover to increase evapotranspiration and prevent cap exposure, high yielding plant species may be established, given adequate rooting substrate being maintained. Increasingly, phytocaps are being considered for use at a range of waste disposal sites in many countries (Bolan et al., 2013).

Revegetation technology also provides a plant cover on the surface of contaminated sites with the aim of reducing the mobility of contaminants within the vadose zone through accumulation by roots or immobilization within the rhizosphere, thereby reducing offsite contamination (i.e. phytostabilization) (Bolan et al., 2011; Bolan et al., 2013). The process includes transpiration and root growth that immobilizes contaminants by reducing leaching, controlling erosion, creating an aerobic environment in the root-zone, and adding organic matter to the substrate that binds the contaminant. This alternative technology also enhances the aesthetic qualities of landfills that are mostly adjacent to urban communities, and introduces economic benefits such as biomass generation for energy, timber and fodder (Bolan et al., 2013; Venkerman and Ashwath, 2009).

Details of only a few landfill reclamation projects are published in peer-reviewed journals, conference proceedings and magazine articles. Since most landfill reclamation projects are not research-oriented, they are seldom reported in targeted literature. Therefore, in addition to literature review, the author's closely collaborated with landfill owner.

The primary aim of this study was to establish the growth of particular plant species and to evaluate the measures that have been taken in this direction and to propose future steps of the Štěpánovice landfill reclamation. The objectives of this study were (i) quantify plant species survival, (ii) quantify changes in species properties over time, (iii) finance.

2. Experimental

2.1. The landfill presentation - site description

The landfill under investigation is located 1 km north of Štěpánovice commune and 1 km south of Dehtín commune, Czech Republic. GPS coordinates of the test point - 49°26'15.934"N, 13°16'55.352"E. In this area, the mean annual precipitation is 582 mm and the mean annual temperature is 8.0°C (maximum 32.3°C and minimum -4.5°C during the reporting period). The landfill has been operating since summer 1996. It is situated in the north part of widely opened valley directed towards W-E. The bottom part of this area (S-W) is restricted with a nameless stream being the right tributary of Úhlava River. The upper part of the area (N-E) is covered with woodland vegetation predominated by *Pinus sylvestris*. The south slope is mainly used for agricultural crop production: rapeseed (*Brassica napus*), wheat (*Triticum spp.*) and permanent grassland. The landfill is located at the North Slope from the valley axis. In the past, the landfill area was used as a meadow for grazing (Kotovicová et al., 2011). The landfill has a total authorized volume of about 569,000 m^3; at the moment, it is being used to dispose mixed municipal waste. The landfill (Figs.1-2) is formed by three sub-landfills: landfill A (closed in 2003, area 8,750 m^2); landfill B (working from 2003, area 26,000 m^2); landfill C (that will work after closing part B) (Fig. 1, Fig. 2). The total volume of both (A, B) parts of the landfill is 289,000 m^3. Planned service life of the facility is up to year 2018 (Kotovicová et al., 2011; Vaverková et al., 2013). Particular details of waste composition, waste quantity stored in the landfill and landfill gas management are not presented in this article. Detailed information and data were described in the articles "Emission assessment at the Štěpánovice municipal landfill focusing on CO_2 emissions" and "Can vegetation indicate a municipal solid waste landfill's impact on the environment?"

2.2. Aforestation

Technical recultivation (laying and compacting layers of soil above the landfill lining) of Štěpánovice MSW landfill was carried out in 2008.

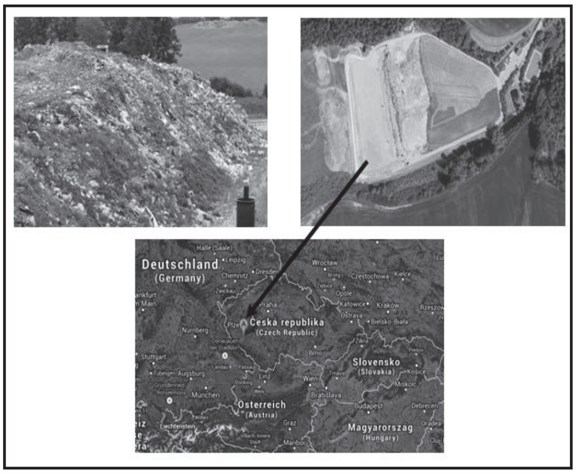

Fig. 1. General site location
(Left top – Adamcová, 2014, Right top – www.seznam.cz, upper states – www.maps.goolge.com)

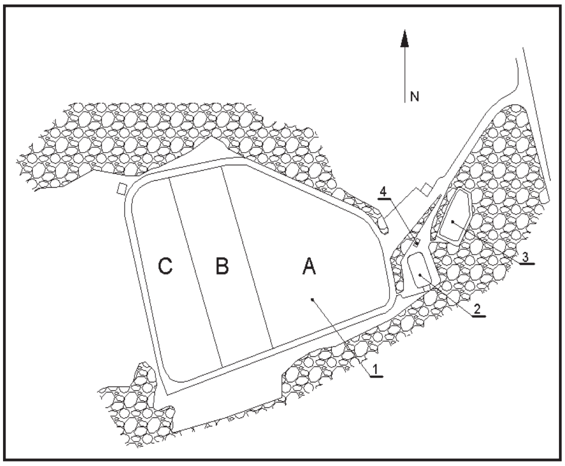

Fig. 2. Map of three sub-landfills (Kotovicová et al., 2011; Vaverková et al., 2013): 1 – landfill, 2 – leachate pond, 3 - rainwater reservoir, 4 - entrance gate

Following the completion of technical recultivation, biological recultivation (grass covering, plating of bushes and trees) was carried out in 2009. The selection of biological reclamation was based on the assessment of the current state of the area. The reclaimed part of the affected area is quite steep (slope inclinations: 1:2.75) and on its S, E and W side continues the original grassing.

Neither agricultural nor orchard reclamation were appropriate for the landfill. For the agricultural type of reclamation there is a condition of suitable level terrain with easy access for technologies for cultivating the agricultural area. Orchard reclamation was not appropriate with regard to the operation of second phase and (later) third phase of the landfill.

As a remedy for the intervention of the construction of the landfill site to nature, afforestation was proposed, aiming to integrate the landfilll more convinently into the zoning plan. It is planned that the afforestation will result into a forest, which will be a part of the territorial system of ecological stability.

Adjusting the first phase of the landfill body led in the second phase to covering and soundproofing the operation of the landfill on the E side. Reclamation of the landfill in the first phase was implemented on the area of 9,000 m^2 (2,200 m^2 of flat land, 6,800 m^2 of slopes). Afforestation was carried out gradually. When selecting trees, the conditions (temperature, rainfall, terrain, altitude, etc.) of particular site were taken into account.

3. Results and discussion

3.1. The course of reclamation - Establishment of grassland

Upon the completion of the technical reclamation (in 2009) an herb layer was established on the reclaimed area. For the purpose of grassland establishment, grass mixture with high anti-erosion effect was used. The proportional representation of grass types is shown in Fig. 3. The quantity of utilized seed in kg/100 m^2, the seed price and the quantity of utilized seed is shown in Table 1.

The selected grasses meet the characteristics specified in the Czech National Standard ČSN 80 8335. For economic reasons manual sowing was given priority to hydroseeding. The area was seeded by grass mixture, followed by lawn care, cutting two to three times per year. In autumn months' compost was applied in the amount of about 30 m^3/ha^1. The compost was applied with compost spreader. Compost consists mainly of humus, the invaluable resource. It retains water in soil, captures harmful substances and balances the acidity. Humus as well as other soil organic substances reduce the risk of erosion and also stimulate growth and enhance plant health. The total cost of establishing the grassland area of 9,000 m^2 amounted to 6,581.12 EUR, grass mixtures price reached 647.87 EUR and 0.73 EUR per m^2 was the remuneration for reclamation company for the implementation, i.e. 6,568.14 EUR in total.

3. 2. Planting of wood species for reclamation

The establishment of the herb layer was followed by plantation of woody plants for reclamation. The selection of (woody) plants was performed in accordance with the suitability of plant species for reclamation purposes and also with regard to species composition nearby the landfill. The requirement of tree root system, which must not impair the isolating impervious layer for at least 30 years (estimated time of evolution of landfill gas), was taken into account. The root system must withstand any extreme soil conditions and must be shallow.

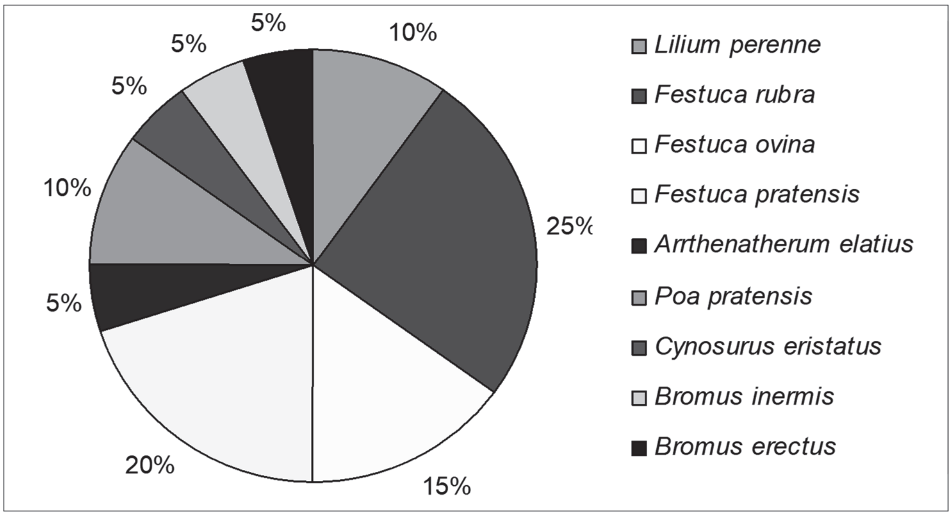

Fig. 3. Proportional representation of grass types

Table 1. Quantity and price of utilized seed

Plant species	*[%]*	*The quantities of seed [kg/100m^2]*	*The price of seed [EU/kg^1]*	*The second seed [kg]*	*Total [EUR]*
Lilium perenne	10	0.23	2.19	20	43.79
Festuca rubra	25	0.53	3.10	46	142.67
Festuca ovina	15	0.23-0.30	3.10	26	80.64
Festuca pratensis	20	0.24-0.40	3.10	35	108.56
Arrthenatherum elatius	5	0.18	2.74	15	41.05
Poa pratensis	10	0.15	5.47	13	71.15
Cynosurus eristatus	5	0.15	3.47	13	45.06
Bromus inermis	5	0.15-0.20	3.28	17	55.83
Bromus erectus	5	0.15-0.20	3.28	18	59.11
Total	-	-	-	203	647.87

It is expected that the proposed modification of the habitus of landfill body by ameliorating and basic woody plants will result to overall aesthetic and functional improvement of the area. Considering their natural incorporation, shrubs and woody plants were thoroughly selected in 2009; their species and seeding frequency is presented in the graph (Fig. 4). In total 2,250 wood species were planted in 2009.

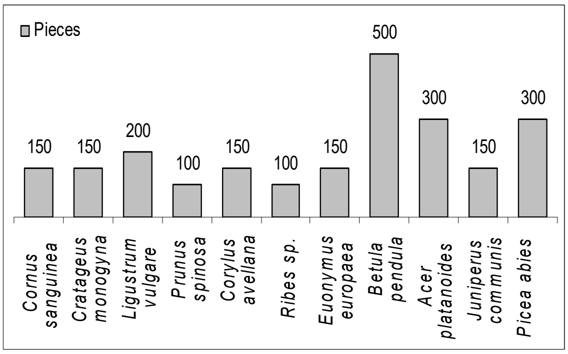

Fig. 4. Wood species and their quantity in 2009

Planting of containerized seedlings with aboveground height of approximately 0.5 m was carried out on the contours and in separate bordered areas, where it creates the hedgerow. Access roads for potential future enhancement of the landfill, such as control points, or a burner for combustion of landfill gas, were taken into consideration when planting. This manner of plantation secured landfill slopes that are exposed to abiotic influences with anticipated possibility of erosion furrows.

In the upper half of the landfill and at the edge of the landfill shrubs with amelioration purpose were planted. Shrubs (groves) create a suitable shrub edge that meets the requirements of the ecotone transition band. Shrub formations allow the creation of suitable biotope for the settlement of many animal species that are endangered in cultural agricultural landscape. In particular, it concerns protected species of small songbirds, such as warblers and shrikes.

3.3. Plant material and conditions of plantation

Within the implementation of aforestation of the first phase of Štěpánovice landfill, packaged planting material was used. It did not include cultivars that would unnecessarily increase the investment costs, but the basic types. Trees had continous terminal bud and quality root system (in line with the Czech National Standard ČSN 48 2115 - Forest tree species planting stock).

The planting was carried out by a specialized company, which proceeded according to the Czech National Standard ČSN 46 4902 - Cultivars of ornamental wood species - common and basic provisions and in compliance with the Czech National Standard ČSN DIN 18 916 - Orchard and landscaping - Development and maintenance plant care.

3.4. Care for the established planting

In the first years after the plantation of the wood species, there was a considerable lush growth of grasses and ruderal vegetation. A simple measure to successful growth of woody plants and quality herb layer was timely mowing (three times per year). For their successful development it was important to secure strict protection of planted seedlings and provide inspections of performed works. During the period of three years following the planting (2009-2012), seedlings were monitored as well as the expansion of weed species; timely remedies were provided, such as replacement seedling, repellent painting, fence reparation, providing support for trees (stabilizing poles), irrigation, regular mowing of the entire herb layer. In addition, organic and mineral fertilizers support as well as suitable agrotechnology are of significant importance.

3.5. Total cost of aforestation

The list of works carried out within the biological (forestry) reclamation of phase I of the landfill including financing costs is stated in Table 2. The total cost amounted to 23,636.38 EUR without VAT.

Table 2. Total cost of aforestation of the first phase of the landfill

Item	*Costs [EUR]*
Total costs of grassland establishment	7,216.02
Planting of wood species for reclamation	16,420.36
Biological reclamation in total (without VAT)	23,636.38

3.6. Evaluation of realized biological reclamation

Fig. 5 shows the landfill body (first phase) before the realization of technical reclamation and subsequently planned forest reclamation. Fig. 6 shows the landfill body following the aforestation (herb layer and planted wood species) in 2009. The frequency and species representation of grasses and woody plants is stated in Table 1, Figs. 4 -6.

Fig. 5. Landfill body prior to afforestation (Vaverková, 2007)

Fig. 6. The conditon of realized aforestation in 2009 (Vaverková, 2009)

In 2009 a total of 2,250 wood species were planted. Fig. 7 describes the success rate (rooting) of particular tree species utilized for forestry reclamation after a period of one year (situation in 2010). In 2010 the reclaimed area contained 2,066 woody plants, thus the overall success rate was 91.8 %.

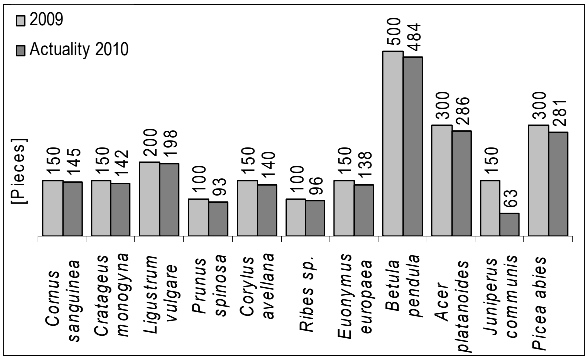

Fig. 7. Rooting succes rate of particular wood species in 2010

Table 3 illustrates proportional succes rate of particular wood plant species in 2010 compared to year 2009. The highest proportional sucess in 2010 showed the following wood plants: 1. *Ligustrum vulgare* (99 %), 2. *Betula pendula* (96.8 %) and 3. *Cornus sanguinea* (96.6 %).

Table 3. Proportional success rate of particular wood plants in 2010

	Success 2010 [%]
Cornus sanguinea	96.6
Cratageus monogyna	94.6
Ligustrum vulgare	99
Prunus spinosa	93
Corylus avellana	93.3
Ribes sp.	96
Euonymus europaea	92
Betula pendula	96.8
Acer platanoides	95.3
Juniperus communis	42
Picea abies	93

Fig. 8 illustrates the situation (year 2010) in the reclaimed area of the landfill body after one year from the plantation of each wood species. Fig. 9 illustrates the success rate (rooting) of each wood species utilized for forestry reclamation after the lapse of two years from the plantation (situation in 2011). In 2011 the reclaimed area comprised a total of 2,044 wood plants (about 106 plants less than in 2009), thus the overall success rate reached 90.8 %. Table 4 illustrates the proportional success rate of each wood species in 2011 compared to year of plantation 2009. The highest proportional success in 2011 showed the following wood plants: 1. *Ligustrum vulgare* (99 %), 2. *Betula pendula* (96.4 %) and 3. *Cornus sanguinea* (95.3 %).

Fig. 10 illustrates the situation (year 2011) in the reclaimed area of the landfill body after the lapse of two years from the plantation of particular woody plants.

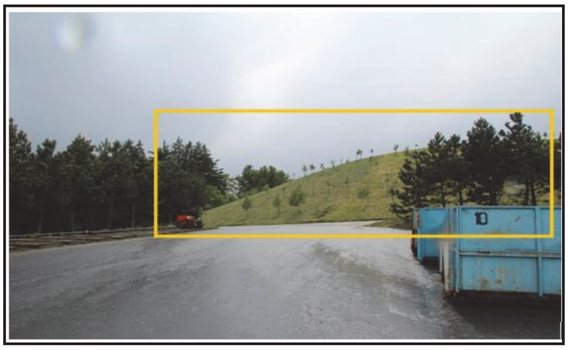

Fig. 8. Condition of aforestation in 2010 (Vaverková, 2010)

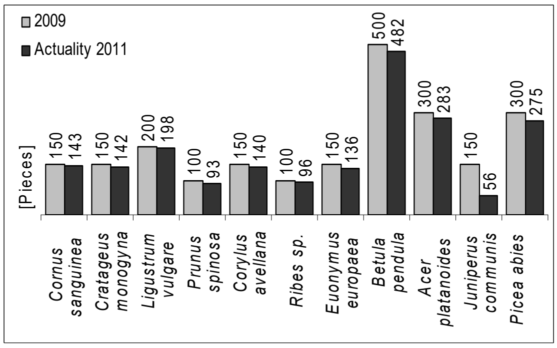

Fig. 9. Rooting succes rate of particular wood species 2011

Table 4. Proportional success rate of particular wood species in 2011

	Success 2011 [%]
Cornus sanguinea	95.3
Cratageus monogyna	94.6
Ligustrum vulgare	99
Prunus spinosa	93
Corylus avellana	93.3
Ribes sp.	96
Euonymus europaea	90.6
Betula pendula	96.4
Acer platanoides	94.3
Juniperus communis	37.3
Picea abies	91.6

In 2012 the control of frequency and success of the rooting of wood species was not carried out. The situation in 2013 is documented via photographs displayed below (Fig.11).

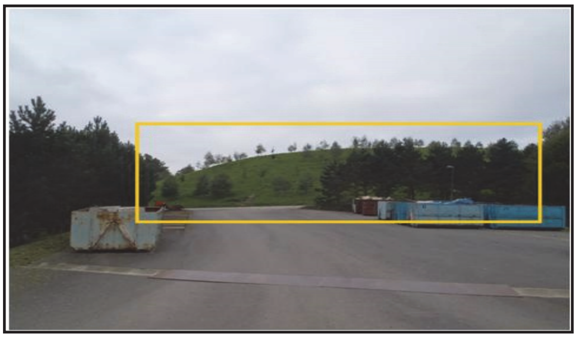

Fig. 10. The condition of aforestation in 2011 (Vaverková, 2011)

(a)

(b)

Fig. 11. The condition of aforestation in 2013 (Vaverková, 2013): (a) view W, (b) view E

In spring 2013 the reclaimed area was newly planted by 250 seedlings of *Picea abies* to complement the required number of wood species planned in the forestry reclamation. Newly planted wood species were marked due to protection within periodic care of the reclaimed area of the landfill body.

While landfilling provides a simple pathway for waste disposal, it causes environmental impacts including leachate generation and GHG emissions. Landfills with gas recovery systems can be used to capture CH_4 as a fuel source. Similarly, advanced revegetation technique (e.g., phytocapping) to manage landfill leachate generation provides a major source of biomass for energy production (Bolan et al, 2013) Landfill gas (LFG) capture is likely to contribute to a number of environmental and social benefits including improved groundwater and air quality, reduced risks of CH_4 gas concentrations and exposure of residential areas to odor. Phytocapping technique can be used to revegetate landfills with endemic plants species for the creation of a natural ecosystem (Bolan et al., 2013).

The design and installation of successful vegetative caps require an understanding of soil physics, nutrient chemistry, organic chemical toxicity, plant physiology, and hydrology that come together to achieve the regulated performance goals. Tree covers provide numerous auxiliary benefits, including aesthetic appeal, GHG sequestration, creation of wildlife habitat, and a crop that offers potential future revenue (Licht et al., 2001).

4. Conclusions

Forestry reclamation was carried out in 2009. The composition of wood species can be evaluated as successful. The overall plant species survival rate in 2011 was 90.8 %. The plant species survival is determined by the selection of wood species and the care that was taken of the seedlings after the plantation.

Similar composition of species will be used for reclamation of the second phase of the landfill body. Only with regard to species *Juniperus communis* it is advisable to replace it for another species, due to lower rooting success (42 % in 2010, 37.3 % in 2011).

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