Chapter 4

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The Development of Trees and Bushes Planted at the Municipal Waste Dump

1. Introduction

The work carried on at botanical gardens in the field of acclimatisation and the developmental rhythmicity of plants provides valuable information about the properties of observed tree, bush and perennial species. In consequence, botanical gardens are institutions that due to the broad range of plants in their possession – in some cases as many as a few thousand taxa – are in a unique position to assist in efforts at the biological management of transformed areas. This knowledge may be utilised in practice, when using plants for the purpose of biological reconstruction of areas devoid of flora – among others at aboveground municipal waste dumps.

In the process of spatial planning, aboveground dumps constitute a particular challenge, both as regards the rational direction of their management (agricultural, forest- or construction-oriented, or recreational) and the shaping of the appearance of these spatial bodies in a manner harmonised with their surroundings. The final stage of their rehabilitation should be biological reconstruction – primarily of the dump slopes and cap. This is done by sowing grass mixes and planting specific species of trees and shrubs, oftentimes selected intuitively. The objective of this procedure is to stabilise the surface of slopes and counteract erosion phenomena, and also visually connect the new geomorphologic forms with their surroundings. Compact turf retains rainwater, while the roots of trees and shrubs integrate surface soil layers with underlying formations.

2. Environmental conditions existing at aboveground waste dumps

The functioning of municipal agglomerations has always been connected with the generation of wastes, which cover three states of matter, i.e. the liquid, gaseous and solid phases. During the past dozen or so years, due to the scale of the phenomenon (in Poland, for example, some 100 million tons of wastes are being generated annually since 2000), the problem of rational management of solid municipal wastes is gaining ever greater attention. This is connected with the impact of waste dumps on neighbouring areas, being as they are a source of toxic reflux, the point from which odours emanate, a potential source of dangerous pathogenic microorganisms (of tuberculosis, tetanus, typhoid fever, etc.), an emitter of dusts, etc.

Municipal waste dump formations frequently attain a cubic capacity of hundreds of thousands of m^3, thereby incidentally creating new spatial bodies that disrupt the surrounding environment and change its appearance on a topographic scale. Until the nineteen nineties, the technology of storing solid municipal wastes consisted in their random gathering on heaps, which made difficult (and still makes difficult) their subsequent rehabilitation and environmental management. During and following utilisation, waste dumps in Poland are lined with mineral soil and subsequently covered with a layer of soil that facilitates the sowing of grass mixes, which makes it possible to commence the detailed process of biological rehabilitation.

This method of procedure, i.e. the lack of a synthetic layer that would function as a screen cutting off surface layers from the base, makes it possible for roots to grow through the layers of mineral soil, soil and clay. In the long term, this will allow them to reach the deeper-lying wastes and refluxes. Depending on the types of wastes, one may expect unfavourable changes in the chemical composition of plants, with the extremity being lethal concentrations in leaves and the dying out of entire plants altogether.

Due to the unfavourable changes taking place in the cap of the dump, literature states that grass mixes may be introduced only after some 10 to 15 years, i.e. following the stabilisation of physical and chemical processes, including consolidation, the thermal stabilisation of the formation, and after the most intense phase of methane emission. The importance of this process is illustrated by the emission, for example, by the dump in Suchy Las, Poznań, Poland of 600 m^3 of waste dump gases per hour (Fig. 1). Methane (CH_4) (40-55%) carbon dioxide (CO_2) (20-45%) are predominant in its composition, while the production of electricity from its combustion amounts to 1 MW per hour (!).

In the mid-nineteen nineties, employees of the Botanical Garden of the Adam Mickiewicz University planted approximately 60 species of trees and shrubs, both native and non-native, on the slopes and cap of the Municipal Waste Dump of the City of Poznań in Suchy Las. The species in question were the following:

1. *Acer campestre* L.
2. *Alnus glutinosa* (L.) Gaertn.
3. *Amorpha fruticosa* L.
4. *Aronia* × *prunifolia* (Marshall) Rehder
5. *Caragana arborescens* Lam.
6. *Caragana frutex* (L.) K. Koch "Latifolia"
7. *Catalpa* × sp.
8. *Carpinus betulus* L.
9. *Celastrus orbiculatus* Thunb.
10. *Cornus alba* L.
11. *Cotoneaster lucidus* Schltdl.
12. *Crataegus monogyna* Jacq.
13. *Deutzia* × sp.
14. *Elaeagnus angustifolia* L.
15. *Fagus sylvatica* L.
16. *Forsythia* × *intermedia* Zabel
17. *Fraxinus excelsior* L.
18. *Fraxinus pennsylvanica* Marshall
19. *Ginkgo biloba* L.
20. *Hippophae rhamnoides* L.
21. *Larix kaempferi* (Lamb.) Carriere
22. *Larix* ×*marschlinsii* Coaz
23. *Ligustrum vulgare* L. 'Atrovirens'
24. *Loniceria* ×*xylosteum* L.
25. *Lycium barbarum* L.
26. *Magnolia kobus* DC.
27. *Malus* ×*purpurea* (Barbier *et al.*) Rehder
28. *Malus* × sp.
29. *Orixa japonica* Thunb.
30. *Philadelphus coronarius* L.
31. *Pinus mugo* Turra
32. *Pinus sylvestris* L.
33. *Populus tomentosa* Carr.
34. *Prunus cerasifera* Ehrh.
35. *Prunus mahaleb* L.
36. *Prunus padus* L.
37. *Pyracantha coccinea* M. Roem.
38. *Pyrus* sp.
39. *Quercus robur* L.
40. *Rhamnus cathartica* L.
41. *Rhus typhina* L.
42. *Ribes nigrum* L.
43. *Ribes petraeum* Wulfen
44. *Robina pseudoacacia* L.
45. *Rosa canina* L.
46. *Salix* ×*sepulcralis* Simonk. 'Chrysocoma'
47. *Salix* ×*sepulcralis* Simonk. 'Erythroflexuosa'
48. *Salix dasyclados* Wimm.
49. *Sarothamnus scoparius* (L.) W.D.J. Koch
50. *Sorbaria sorbifolia* (L.) A. Braun
51. *Sorbus aucuparia* L.
52. *Spiraea billardii* Herincq
53. *Spiraea densiflora* Nutt.
54. *Spiraea* ×*vanhouttei* (Briot) Zabel
55. *Symphoricarpos albus* (L.) S.F. Blake
56. *Syringa vulgaris* L.
57. *Tamarix tetrandra* Pall ex M.Bieb.
58. *Tilia* ×sp.
59. *Ulmus laevis* Pall.
60. *Viburnum lantana* L.

The plants, aged from 2 to 3 years, were prepared in containers, thanks to which their root systems were not damaged during planting. As regards soil cultivated plants, following planting their aboveground elements were cut short – even by as much as 2/3. Attention was paid to planting in autumn, when a larger percentage of plants take root. This is of particular importance on the Polish Lowlands, where in spring there occur periods of soil drought that last as many as two-three months, while the deficiency of precipitation in the vegetative season in relation to potential evaporation amounts up to 160 mm per annum.

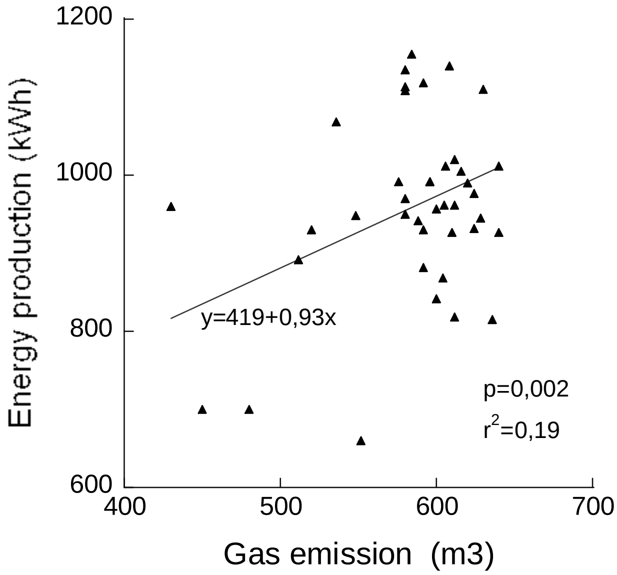

Fig. 1. The relationship between the production of electricity and the quantity of waste dump gas emitted from the Poznań Waste Dump in Suchy Las (2009-2011)

The development of both trees and shrubs was systematically observed. Research into the seasonal rhythmicity of plants was conducted on the basis of a method of phenological observation elaborated at the Botanical Garden. This method consists in making weekly observations of the progress of successive developmental phases of plants, such as foliation, blooming, fructifying, the autumn discolouration of leaves, etc. At the same time, these observations took into consideration the vitality of the leaves and shoots of planted species. When comparing the dates of phenological occurrences at the waste dump and the references (which were the same species observed at the Botanical Garden), it was possible to determine the condition and health of trees and shrubs on the cap and slopes of the dump. It should be noted that plants situated on the waste dump were not watered. Such a broad spectrum of species was intended to enable the observation of the development of a more inclusive list of woody plants on the basis of the methodology of research into the seasonal rhythmicity of plants.

On the basis of the results of phenological observations conducted for this group, some twenty taxa that would be potentially useful for managing the degraded soil environment of waste dumps have been selected. However, the selected species require further research, including an attempt at determining intraspecies mechanisms enabling their proper development under such conditions. Even now the results of a few years of research into seasonal rhythmicity allow us to indicate species that would be useful for the biological management of such environments as early as the first few years following the end of operations/storage (provided that an efficient formation degassing system is in place). These results, obtained on the basis of phenological observations, may be used for the purposes of managing other facilities of a similar type.

The scientific objective of the project was to explain the adaptive mechanisms of selected tree and shrub species growing in the newly formed subsoil (Municipal Waste Dump of the City of Poznań in Suchy Las). Research performed hitherto points to three types of mechanisms responsible for the successful development of plants in such conditions. Detoxication mechanisms or ones helping to avoid substances that are harmful to plants may consist in the following:

- allocation of excess concentrations in leaves, with their multiple shedding during the vegetative season and the simultaneous creation of a new generation of leaves,
- embedding and accumulating absorbed excess concentrations of chemical substances in shoots. Under conditions of the constant inflow of substances of this type, the concentrations – initially tolerated – may subsequently attain lethal values for plants,
- the unimpeded development of certain species may point to a mechanism of selective absorption of ions from the subsoil.

A mechanism of this type may turn out to be particularly valuable on surfaces that are not completely isolated from the interior of the dump, e.g. at the summits thereof. This is so, because plants have no possibility of compensating for the defective chemical composition of the subsoil, e.g. by the development of a root system in an alternative part of the soil.

3. Importance of the project

The initial results of research into the seasonal rhythmicity of plants indicate that the successful effects of the introduction of selected species of woody plants make it possible to initiate soil-forming processes on the cap of a waste dump. The proper development of these plants helps create a biological screen of trees and shrubs after a period of some five years. Such a biological screen on the summits and slopes of a dump weakens the direct insolation of the surface, improves opportunities for soil retention, and creates conditions for the accumulation of humus, etc. Forest stands and shrubs functioning for approximately ten years enliven the soil substrate and initiate soil-forming processes. The change in the appearance of such dumps is very important in this context. During periods of drought, the surfaces of the formation are naked and devoid of plants, and can be modelled into gently-shaped hillocks thanks to the usage of varied greens. One may expect that results obtained during the implementation of the project will make it possible to determine the mechanisms responsible for the vitality of individual species under specific conditions of municipal waste dumps. Basing on initial observations, we will most probably encounter mechanisms facilitating the avoidance or toleration of stress by plants.

As regards the ability to avoid stress by plants, these may be the following mechanisms:

- excluding excessive concentrations of substances by means of transport barriers,
- binding parts of absorbed concentrations in the cells of shoots,
- reducing absorption by means of a mechanism enabling the selective uptake of ions from the solution, which entails the utilisation of a part of metabolic energy and the concomitant weaker growth of plants.

As regards the toleration of stress by plants, these may be the following mechanisms:

- tolerating disruption of ionic ratios in the organism,
- detoxification.

On the basis of results hitherto obtained from phenological observations conducted over a period of a few years, we may conclude that the mechanisms described hereinabove differ for different species of trees and shrubs covered by research. A difficulty in diagnosing the aforementioned mechanisms for the planted trees and shrubs may consist in the fact that only the most resistant species have remained on the slopes and cap, which thanks to their resistance have survived the unfavourable natural conditions. In contrast, the more sensitive species, for which changes in condition can be more easily observed, have disappeared within a few years of being planted.

The current state of knowledge in this field should be considered as unsatisfactory. In Poland as opposed to Western countries, following the end of operations the majority of dumps are not tightly isolated from the surface layer that covers the formation. For this reason, in the present instance we are dealing with the noxious impact of internally occurring physical and chemical processes on woody plants located on the cap and slopes. In literature it is stated that the biological rehabilitation of municipal waste dumps through the rational planting of trees and shrubs is possible 8 to 15 years after the completion of operations. Such a long interval increases the risk of occurrence of numerous undesirable processes in the external surface layer of the dump, namely:

- the possibility of occurrence of erosion dissections during storms, or even mass-movements,
- unfavourable physical processes occurring in the surface layer, devoid of trees and shrubs, due to unlimited insolation. This leads to its crusting over and the deterioration of conditions for gas exchange of the external layer of soil,
- petrification of the surface layer leads to a reduction of the humidity value of the subsoil by hindering the infiltration of rainwater. For biological rehabilitation, this is of particular importance in Wielkopolska Province, where potential evaporation (500 mm) during the vegetative period exceeds precipitation (350 mm).

4. Research methodology

The scientific method was based - using phenological observations - on research into the seasonal rhythmicity of nine species of trees and shrubs, connected with an analysis of the chemical composition of leaves and shoots conducted twice in the vegetative season, as well as biometric measurements (the dynamics of increase in the surface and mass of leaves, the thickness and increase in the length of shoots). In each instance, chemical analyses were performed twice for each location, on individual plants representative for a group, for the given plant species. The representativeness of individual plants refered to the average annual growth for a group and the temporal duration and intensity of phenological phases (duration of phases: foliation, discolouration of leaves, intensity of blooming, fructifying, etc.).

The following species have been selected for research:

- trees: field maple (*Acer campestre* L.), common hawthorn (*Crataegus monogyna* Jacq.), black alder (*Alnus glutinosa* L. Gaertn.), pedunculate oak (*Quercus robur* L.), common buckthorn (*Rhamnus catharticus* L.), fluttering elm (*Ulmus laevis* Pall.), common ash (*Fraxinus excelsior* L.),
- shrubs: dog rose (*Rosa canina* L.), wayfaring tree (*Viburnum lantana* L.).

When conducting research, measurements of biometric and biochemical parameters, such as: measurement of the length and thickness of one-year shoot growths, measurement of the content of water in leaves, measurements of the surface and mass of leaves (in order to calculate the specific leaf area (cm^2/g sm), analysis aimed at establishing the content of photosynthetic dyes and analysis of the content of nitrogen and carbon in plant material were performed.

The results of measurements performed made it possible to correlate the periods of occurrence and duration of phenological phases with the chemical composition and biometric measurements. Automatic measurements of the temperature of the subsoil, conducted in parallel at a depth of 0.5 m, allowed one to trace the impact of the heat generated during the process of digestion of wastes on the periods of occurrence of phenological phenomena (in comparison with controlled conditions at the Botanical Garden of the Adam Mickiewicz University).

Earlier research into the development of trees growing on anthropogenic soils in the centre of Poznań (in the broadest meaning of the term) indicated insignificant correlations between the chemical composition of the substrate and plant material (Łukasiewicz 2002). The randomness and considerable diversity of the subsoil over a small area excludes a reliable interpretation of its impact on the development of plants. For this reason, in the case of artificial subsoils – such as man-made embankments – it would appear more appropriate to analyse the chemical composition of leaves. This would considerably reduce the costs of analyses, allowing attention to centre on the initial research topic.

5. Seasonal rhythmicity of plants

Nine phenological phases, separately for vegetative development and for generative development have been distinguished. They cover the most important stages of the annual life cycle of plants. These are the following phases, presented in proper order:

Vegetative phases:
- phase of leaf buds,
- phase of foliation,
- phase of autumn leaf discolouration,
- phase of dying and falling of leaves.

Generative phases:
- phase of flower buds,
- phase of blooming,
- phase of unripe fruits,
- phase of ripe fruits,
- phase of scattering of seeds.

Observations have been conducted every 7 days during the vegetative period in the years 2007-2009. In the initial and final period of a given phase, observations have been conducted every 4-5 days. The precision of observation dates thus obtained totals ± 1 day, which for an average phase duration of several dozen days was a sufficient value. The beginning and end dates of phenological phenomena were entered as successive days of the observation year. For the purposes of duration calculations, a 30-day division of each month has been adopted. The above assumption (each month comprises thirty days) was also used for the graphical presentation of the seasonal rhythmicity of plants in the form of diagrams.

When drawing phenological diagrams at the transformed stations within the area of municipal and industrial agglomerations, it became necessary to make their modifications. This was caused by the deterioration of the set of living conditions of plants growing in municipal conditions and thermal anomalies during the winter period, with the latter being observed in particular in the last decade. Thus, diagrams cannot be drawn in their current form without making changes. When the changes have been introduced, it became possible to correctly read the durations of individual phases and introduce them in a numerical format to further calculations and comparisons. In order to determine the intensity of fructifying, a five-point scale with 25% intervals was introduced. The species of trees and shrubs planted on the Poznań Waste Dump were referenced against the station at the Botanical Garden of the Adam Mickiewicz University in Poznań.

6. Environmental conditions at municipal waste dumps

When planning the new appearance of slopes of tip, it is necessary to gain an understanding of how they can be shaped using plants. The unfavourable impact of artificially created hills makes it considerably difficult (or altogether impossible) to ensure their proper development. This is caused primarily by the following:

- The excessively thin – in practice – layer of imported soil, 10-20 cm, frequently with insufficient nutritional content.
- A formed deeper subsoil ranging from 20 to 40 cm (which is justified for operational reasons), made up of heavy clay or silt, which has unfavourable physical properties. Under these conditions in summer, during a period of drought, water is unavailable for plants even at a soil humidity of approx. 35%, while in the autumn-winter period precipitation collects in pockets around the plants, causing them to rot.
- The toxicity of deposited precipitation and the caustic properties of refluxes.
- The generation within the dumping ground of waste dump gases, including first and foremost methane, which displace the air present in the soil. The lack of oxygen in the root layer is the direct cause of the dying out of plants.
- Insufficient precipitation on the Polish Lowlands during the vegetative season. For example, in Wielkopolska Province during the period of June – October, the average sum of precipitation totals 360 mm, while potential evaporation amounts to 500 mm; what is more, periods of drought lasting 2-3 months are not infrequent.
- The maximum insolation of waste dumps. The lack of shade results in the maximum insolation of both plants and subsoil. This is the cause of increased transpiration and excessive evaporation of water from the soil. On slopes with a southern exposure, this is additionally increased by the angle at which sunbeams fall, which reaches 90 degrees, leading to the overheating of plant leaves.
- Aboveground dumps are an obstacle to the horizontal, free movement of air. In consequence, the wind speed above the cap of the formation is 2 to 4 times greater (!) than at its foot.
- The lack of fully grown trees and shrubs results in young, newly introduced plants being eaten by animals, which are the main "food base" therefor.
- The cutting down of plants during the mowing of grass on dump surfaces "for aesthetic reasons".

The abovementioned factors illustrate the difficulties connected with the introduction of plants in habitats of this type. Generally, it has been found that the first plants may be introduced only 8 to 15 years after they are decommissioned. Experience, however, has shown that efficiently functioning degassing systems make it possible to introduce plants no later than two years after the formation of slopes.

7. Fate of plants growing on waste dump

In the reactions of trees and shrubs to unfavourable environmental conditions, mainly soil conditions at waste dumps, we may distinguish four developmental „strategies” of plants. These were the following reactions:

- The dying out of plants within a year of their introduction. This group includes the following: European larch *Larix decidua*, silver birch *Betula pendula*, maidenhair tree *Ginkgo biloba*, common sea-buckthorn *Hippophae rhamnoides*, and others.
- The untrammelled development of plants in the first few years following their introduction decreases radically in successive years due to the accumulation of toxic ingredients absorbed from the subsoil through their shoots. This was evidenced by spectacular development during the first two – three years. Following this period, however, progressive necrosis and gangrene of the shoots were observed – without any visible attack of pathogens in the form of mycosis or pests. Plants from this group included shrubby willow species (e.g. *S. viminalis*, *S. dasyclados*), which are used when setting up so-called biological refineries.
- Plants with an internal mechanism for the allocation (movement) of toxic concentrations or chemical compounds to the leaves. Once lethal concentrations are attained, the leaves gradually die and are shed. The shoots, in turn, remain alive with a small number of leaves. The process of the development of necroses and shedding of leaves was observed from the beginning of June, in parallel with the weakened vegetation occurring at this time. Species from this group included the black alder *Alnus glutinosa*, common buckthorn *Rhamnus cathartica*, fluttering elm *Ulmus laevis*, and others.
- Species that do not react negatively to nutritional ingredients absorbed from the subsoil. These plants did not display the loss of metabolic energy (described in literature) required to overcome the electrochemical barriers existing in the soil solution. This should result in smaller annual growth and overall weaker plant development. In the present instance, the development of trees and shrubs was surprisingly efficient, the growth of shoots considerable, and leaf sizes at a standard level for individual species. Following the initial growth period, tress started to bloom and bear fruit, creating seeds that were able to sprout. This group of plants included the Russian silverberry *Elaeagnus angustifolia*, four-stamen tamarisk *Tamarix tetrandra*, wolfberry *Lycium halimifolium*, field maple *Acer campestre*, and others.

8. Conclusions

Following ten years of observations of approximately thirty species and varieties of plants on the area of the Municipal Waste Dump of the City of Poznań in Suchy Las, we may indicate the species that hitherto have been characterised by favourable development. These are the following groups of plants:

- Trees characterised by favourable development:
  - Pedunculate oak – *Quercus robur*
  - Common hawthorn – *Crataegus monogyna*
  - European pear – *Pyrus communis*
  - European wild apple – *Malus sylvestris*
  - Green ash – *Fraxinus pensylvanica*
  - Field maple – *Acer campestre*
  - Black alder – *Alnus glutinosa*
  - Russian silverberry – *Elaeagnus angustifolia*
  - Cherry plum – *Prunus cerasifera*
  - European black pine – *Pinus nigra*
  - Common buckthorn – *Rhamnus cathartica*
  - Fluttering elm – *Ulmus laevis*
  - St Lucie cherry – *Prunus mahaleb*
- Shrubs characterised by favourable development:
  - Desert false indigo – *Amorpha fruticosa*
  - 'Atrovirens' European privet – *Ligustrum vulgare ‘Atrovirens'*
  - Dwarf honeysuckles – *Lonicera xylosteum*
  - Wolfberry – *Lycium halimifolium*
  - Bird cherry – *Prunus padus*
  - Dog rose – *Rosa canina*
  - Four-stamen tamarisk – *Tamarix tetrandra*

For these taxa there were no significant statistical differences regarding the duration of the foliation phase and, as regards new plants, of the blooming and fructifying phases. Expected differences may become apparent after the completion of the research cycle and the obtainment of the results of analyses of the chemical composition of leaves and biometric parameters, including – for example – the SLA (specific leaf area).

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