Relation between hydraulic properties and plant coverage of the closed-landfill soils in Piacenza (Po Valley, Italy)

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Abstract

In this paper the results of a study of soil hydraulic properties and plant coverage of a landfill located in Piacenza (Po Valley, Italy) are presented, together with the attempt to put the hydraulic properties in relation with plant coverage. The measured soil water retention curve was first compared with the output of pedotransfer functions taken from the literature and then with the output of the same pedotransfer functions applied to a reference soil. The landfill plant coverage was also studied. The relation between soil hydraulic properties and plant coverage showed that the landfill soils have a low water content available for plants. The soils low water content ~~and this fact,~~ together with the lack of depth and compacted structure, justifies the presence of a nitrophilous, disturbed-soil vegetation type, dominated by ephemeral annual species (therophytes).

1. Introduction

The soil water is a fundamental resource for the components of the ecosystem. The knowledge of the hydraulic properties of soils is therefore ~~fundamental~~ important in many scientific disciplines, from agriculture to ecology, since the amount of water and the strength, it is held by soil, represents the prerogatives for the vegetation and all other organisms development ~~of the vegetation and all other organisms~~.

Direct measurements of soil hydraulic properties are rarely performed because they require lengthy and costly analysis; as an alternative, analysis of existing databases of measured soil hydraulic data may result in pedotransfer functions (PTFs) (Wösten et al., 2001). These functions often prove to be good predictors for missing soil hydraulic data. The PTFs are empirical relationships between soil hydraulic properties and some basic soil properties more easily available such as texture, bulk density, organic carbon content (Baker, 2008; Bouma and van Lanen, 1986; Pachepsky and Rawls, 2004; Vereecken et al., 2010; Wösten et al., 2001). To derive the PTFs, databases of soils from all over the world were used. Generally soil databases emphasize on soil taxonomy and have limited unsaturated soil hydraulic data. With this in mind, the international Unsaturated Soil Database (UNSODA) (Leij et al., 1996) and subsequently, the European database of soil hydraulic properties (HYPRES) (Nemes et al., 2001a; Wösten et al., 1999; Wösten and Lilly, 2004) were developed. Both these databases contain a wealth of information about soil hydraulic data, measurement method and other relevant soil data (Nemes et al., 2001a).

The processing of the PTFs can be performed using computer programs such as CalcPTF 3.0 (Guber and Pachepsky, 2010), ROSETTA (Schaap M.G., et al., 2001) (which is available as stand-alone program and also as a part of the simulation model HYDRUS 1D (Simunek, J., et al., 2008)), SOILPAR (Acutis, M. and Donatelli, M., 2002) and SPAW (Saxton and Willey, 2006).

The relationship between volumetric water content and matric potential is the soil water retention curve, which allows to derive available water for plants by comparing the water content at the different ~~rates of~~ suction (negative pressure) applied.

In recent decades the increase in human population and activities has resulted in an ongoing depletion of soil resources, to the point that the authorities have included in their priorities the recovery of degraded areas. ~~Among the degraded soil characters there is a~~ The lower ability to make water available for plants and microorganisms is own of a degraded soil, thus, in order to carry out soil restoration, it is important to know its hydraulic properties.

In this work a degraded cover soil of a landfill located in Piacenza was studied. ~~This cover soil is made by~~ The soil used to closed the landfill is a natural soil coming from different areas ~~sites~~ near Piacenza, and it can be classified as an Anthrosol (FAO World Reference Base for Soil Resources): a soil formed or profoundly modified through ~~throught~~ long-term human activity, such as from addition of organic waste or household waste, irrigation or cultivation. This soil showed very low fertility during more than 30 years: there is no chemical contamination justifying its condition, so the soil can be described as a degraded soil.

Recently the ~~nature of~~ landfill soils and the vegetation were studied, and so the site environmental quality - the relationship between soil chemical analysis and ecological indicators (Manfredi et al., 2012), the floristic-vegetational indexes (Giupponi et al., 2013b), the presence and development of Onopordum acantium subsp. Acanthium (Giupponi et a., 2013a) - is described

A lot of studies on landfills can be found in literature, such as studies about root contamination by gas (Gilman et al., 1982), about methane production (Themelis and Ulloa, 2007), microbiological studies (Boeckx et al., 1996), but nothing can be found about hydrological properties of cover soil in relation to the plant coverage.

The aim of this work is to put the hydraulic properties of landfill soil ~~cover~~ in relation with its vegetation, and to assess whether predictive systems ~~presently used~~ (PTFs) are suitable for predicting them.

2. Materials and methods

2.1 Study area

The closed landfill of municipal solid waste of Borgotrebbia is located in the territory of Piacenza (Po Valley, Italy, coordinates: 45° 03' 58" N, 09° 39' 06" E) at an altitude of 60 m. It is an area of 200000 m^2 and is located along the right bank of the Trebbia River near its confluence with the Po River. Climatic data show that the average annual temperature is 13,3° C while the average annual rainfall amounts to 778 mm, most of which is concentrated in the periods of March and September.

The landfill was opened from 1972 to 1985 and then was closed and covered with a layer about 50 cm depth ~~made up~~ of different degraded soils, ~~on average 50 cm thick~~, left to be colonized by spontaneous plant. ~~Since 2005 some modifications occurred after planting trees and shrubs, which involved only a small portion of the site thus having little success~~. The soils used to close the area are loamy soils with a predominantly multi-faceted structure, they have low porosity and, by their nature, they are compact. A further compactation was induced by compression ~~caused~~ by operations ~~generally~~ carried out ~~at the closure of~~ to close the landfill in order to avoid the leakage of gas and infiltration by rain~~water~~. Now the area is involved in a Life+ project (Life 10 ENV/IT/000400 New Life, http://www.lifeplusecosistemi.eu), which includes among the objectives the treatment of degraded soils through an innovative reconstitution method ~~aimed~~ to improve their quality ~~their improvement~~.

2.2 Soil

Physical-chemical analysis of the soil

Eleven sampling points were chosen as representative of the closed landfill area after a preliminary study. Initially they were sampled in the area 51 points, following a grid division NE-SW NW-SE; and the distribution of the observed different vegetation types - the plant communities differ in structure and floristic composition according to the different environmental factors such ~~above all~~ the type of soil. By statistical elaboration of the 51 chemical analysis 11 soils resulted to be the most representative of the area.

The 11 soil samples were taken at 25 cm depth and chemical and physical ~~routine~~ analyses were carried out based the Methods of Soil Chemical and Physical Analysis as described in the Official Gazette of the Italian Republic: texture and grain size (Italian position Method II.5 Suppl. Ord. G.U. n° 248/21.10.1999; international position ISO 11277), primary and secondary structure, organic carbon (Italian position Method VII.3, Suppl. Ord. G.U. n° 248/21.10.1999, Walkley-Black,), salinity (Italian position Method IV.1 Suppl. Ord. G.U. n° 248/21.10.1999, international position ISO 11265, aqueous extract 5:1), total limestone (Italian position Method V.1, Suppl. Ord. G.U. n° 248/21.10.1999, international position ISO 10693), water potential (Italian position Method VIII.3, Suppl. Ord. G.U. n° 173/02.09.1997, international position ISO/DIS 11274, sand box and Richards plates; measurements performed on undisturbed samples). The results of the physical-chemical analyses were used as input for the elaboration of 18 different PTFs (Tables 1 and 2). As the bulk and particle density of samples aren't measured, the literature values for loamy soils were used: bulk density 1.3 g/cm^3 and particle density 2.3 g/cm^3.

2.2.1 Water retention models

Most of the mathematical models that describe the soil hydrologic behavior are based on non-linear relationships between the volumetric water content in the soil, θ, the suction applied by the soil, h, and the hydraulic conductivity (Hillel, 1998); the functions θ(h) and K(h) describe the hydraulic properties of a soil through a parametric equation (Leij et al., 1997). Some predictive methods for estimating hydraulic conductivity are based on direct observations of water content in the soil measured at different values of suction (Romano and Palladino, 2002). To overcome all the cases in which it is not possible to measure it, a group of functions called pedotransfer functions (PTFs) have been developed. PTFs correlate the water retention and hydraulic conductivity with some easily measurable chemical and physical properties of the soil such as texture, density, porosity, and organic carbon content (Elsenbeer, 2001; Tietje and Hennings, 1996; Tapkenhinrichs and Tietje, 1993). Most PTFs are regression equations that are derived from data collected during specific campaigns and are reliable for describing the soil hydraulic properties (Romano and Palladino, 2002).

In this work the measured water retention curves were compared with those obtained using 17 PTFs proposed in the literature that are based on databases of soils distributed worldwide following two models: Brooks and Corey (1964) and van Genuchten (1980), (Rawls et al., 1998, 1992, 1982a; Saxton and Rawls, 2006; Saxton et al., 1986; Tanij, 1990).

The functions used to describe water retention properties are the following:

the van Genuchten (1980) water retention equation

$$\frac{\theta-\theta_r}{\theta_s-\theta_r} = \frac{1}{\left[1+(\alpha h)^{n}\right]^{m}} \qquad (1)$$

the Brooks and Corey (1964) equation

$$\frac{\theta-\theta_r}{\phi-\theta_r} = \left(\frac{h_b}{h}\right)^{\lambda},\ h > h_b; \qquad 1,\ h \le h_b \qquad (2)$$

where:

θ = volumetric soil water content ($cm^3\ cm^{-3}$);

θ_r = residual soil water content ($cm^3\ cm^{-3}$);

θ_s = saturated soil water content, ($cm^3\ cm^{-3}$);

ϕ = soil porosity, ($cm^3\ cm^{-3}$);

λ = pore size distribution index (dimensionless);

h = capillary pressure (cm);

h_b = air-entry pressure (cm);

α = parameter of the van Genuchten equation corresponding approximately to the inverse of the air-entry value, (cm^{-1});

m, n = empirical shape-defining parameters in the van Genuchten equation, (dimensionless).

The values of the parameters (θ, θ_r, θ_s, ϕ, λ, h_b, α, m, n) are predicted by PTFs, which are developed from measured data set (Wösten et al., 2001).

In this study the processing of the PTFs was performed using the program CalcPTF 3.0 (Guber and Pachepsky, 2010) - it contains a class of PTFs generated from database HYPRES - Table 3.

CalcPTF 3.0 is a computer program PTFs calculator developed to estimate parameters of the Brooks and Corey and the van Genuchten models. The inputs used in this program are: soil texture, organic carbon content, bulk density and particle density.

The database HYPRES (Hydraulic Properties of European Solis - Wösten et al., 1999) draws together some basic soil information and soil hydraulic data from which PTFs applicable to Europe can be derived (Nemes et al., 2001b). By the HYPRES database two different sets of PTFs were derived: class pedotransfer functions and continuous pedotransfer functions. Class PTFs predict the hydraulic characteristics for each of the five texture classes (coarse:

clay<18% and sand>65%, 18%<clay<35% and 15%<sand; medium: clay<18% and 15%<sand<65%; medium fine: clay<35% and sand<15%; fine: 35%<clay<60%; very fine: 60%<clay) and for two pedological classes within them (topsoils and subsoils) plus an additional class which encompassed the organic soil horizons. Continuous pedotransfer functions can predict hydraulic properties from individual measurements of soil texture, organic carbon content and bulk density.

The goodness of the PTFs and their ability to describe the hydraulic characteristics of the landfill coverage soils was calculated through the root mean square error (RMSE) test based on the difference between the values of volumetric content of water, at different suctions, measured and estimated, starting from the following equation:

$$\mathbf{RMSE} = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(\theta_i - \theta_i^{*})^2} \qquad (3)$$

where:

N = number of measurements;

θi and θi * = volumetric water content (θ %) measured and estimated.

The hydraulic data of the landfill cover soils obtained instrumentally and through PTFs were also compared with those of a reference soil. The reference soil chemical-physical properties are chosen to describe a not degraded natural soil with the same texture - silt loam, bulk and particle density - 1.3 g cm^{-3}, 2.3 g cm^{-3} of landfill soils, but with an average organic carbon content of 1% - typical of Piacenza natural soils - well structured and depth 1 m. The volumetric water content of the reference soil at different suctions was calculated through the arithmetic mean of the water contents from the 17 PTFs, so it is possible to achieve an estimate of available water content.

2.3 Flora and Vegetation

The vegetation data were collected by making up 52 phytosociological relevés using the method of the Zurich-Montpellier school (Braun-Blanquet, 1964). The sampling sites were selected to summarized the vegetation of the whole area. Each relevé involved an area of 16 m^2 (4 m x 4 m) and was georeferenced. For each sampling site the present plant species were listed and their cover estimated using the values of the Braun-Blanquet conventional scale (r = sporadic species; + = <1 %, 1 = 1-5 %, 2 = 5-25 %, 3 = 25-50 %, 4 = 50-75 %, 5 = 75-100 %). The relevés were periodically monitored from April to September 2012.

Pignatti (1982) was consulted for the identification of the species, while the specific nomenclature is according to Conti et al. (2005). In order to process the biological spectrum of the plant list, the data concerning the biological form according to Raunkiaer (1934) (Therophytes - T: annual herbs; Hemicryptophytes - H: perennial herbs; Geophytes - G: perennial herbs with underground storage organs; Chamaephytes - Ch: woody plants with buds at no more than 25 cm above the soil surface; Phanerophytes - P: trees and shrubs with buds over 25 cm above the soil surface) were taken from Romani and Alessandrini (2001).

Landolt's F index (soil moisture) (Landolt, 1977), updated by Landolt et al. (2010), provides a guide on the need of water by plant species during their growth period. The F values range from 1 to 5 (1 = very dry; 1,5 = dry; 2 = moderately dry; 2,5 = fresh, 3 = moderately moist; 3,5 = moist; 4 = very moist; 4,5 = wet, 5 = flooded or submerged) and were attributed to all the species recorded in order to obtain information on the degree of humidity of the landfill soil cover. To each species was also assigned its respective life strategy according to Grime (2001, 1979) (c = competitive strategists, r = ruderal strategists, s = stress-tolerant strategists), retrieving this information from Landolt et al. (2010), according to the adjustments proposed by the author. Starting from the climate, soil and vegetation data reference crop evapotranspiration (ETo), the total available moisture (TAM) and the readily available moisture (RAM) were calculated using the CropWat 8.0 software (© FAO 2009) according with Allen et al. (1998) and Doorenbos and Kassam (1979).

3. Results

3.1 Soil

By the measurement of volumetric water content it is possible to describe the water retention curve for all the samples. Table 2 shows the measured volumetric water contents ~~of all the samples~~ at the different suctions investigated and Fig. 1 shows their water retention curves. The water retention curves - with the exception of the sample 8 - have similar trend, for suction values less than 10 kPa they don't have very different values while in the end part - when the suction is high - show some differences. The curves slope increases from 10 to 33 kPa due to the different water extractor used - sand box for 10 kPa and Richards plate for 33 kPa.

As one of the study aims is to compare the landfill soil with a natural reference soil, in the first part of paper sample 5 is analyzed. Sample 5 is the only landfill soil showing the same amount of organic carbon than reference one.~~, because this sample has the same organic carbon content of reference soil.~~

Using sample 5 chemical-physical data as input of PTFs, the sample 5 predictive water retention curve is compared with the measured one. This comparison is shown in Fig. 2 ~~shows the sample 5 water retention curves developed from the PTFs compared with the measured one~~; in this Figure ~~Fig. 2~~ the curves by Wösten et al. (PTFs applicable to Europe soils) are highlighted. From ~~a~~ the comparison ~~of the 17 curves with the measured one~~ it clearly emerges that for suction values lower than 100 kPa all PTFs except one overestimate the measured data, whereas for suction values of 1500 kPa for 12 cases the measured value is higher than the predicted one.

To identify which of the authors, and thus of the models, are more accurate in describing the hydraulic behavior of the landfill soils, samples chemical-physical data are used as input of PTFs, so all water retention curves are developed and then RMSE test was used (Fig. 3, Table 4). ~~Through the calculation of RMSE (Fig. 3, Table 4) it was possible to identify which of the authors, and thus of the models, are more accurate in describing the hydraulic behavior of the landfill soils.~~ It emerges that the curve by Wösten al. (1999) - continuous pedotransfer function - is the closest to the measured data. ~~on the contrary the curve by Tomasella and Hodnett (1998) is the worst - it is no wonder because the curve by Tomasella and Hodnett is processed by a Brazil soils database~~. The results of this test and the comparisons indicate the need to conduct studies to develop new parameters values able to describe the behavior of degraded soils.

To compare natural soils with reference one, reference soil water retention curves were ~~also used to~~ developed using the PTFs. The reference soil water retention curve is described as the arithmetic mean of volumetric water content at different suction values obtained from processing PTFs. The sample 5 water retention curve is comparing with the reference one (Fig. 4). This comparison reveals that the reference soil PTFs data always overestimate the measured data for all suction values lower than 100 kPa, whereas for suction values higher of 300 kPa measured data are greater than reference soil.

To compare the measured hydraulic properties of the landfill soil with the reference soil, their volumetric water contents - at suctions 0.10 kPa, at field capacity, at wilting point and the available water for plants - are compared. The histogram in Fig. 5 shows the water content at a suction of 0.10 kPa; soils have values similar to each other (average θ % = 48.61 %, standard deviation 3.18 %), and also similar to the reference soil (θ % = 46.32 %).

The field capacity is described as the optimal relationship between water and air in the soil; this condition is verified when the micropore volume is entirely occupied by water while macropore volume is entirely occupied by air. In the literature the field capacity is representing by the water content at suction values in the range of 10 kPa and 33 kPa (10kPa for sandy soil and 33kPa for other soils). At field capacity (histogram Fig. 6) the sample soil average θ % is 26.05, standard deviation 4.68 %, this value lower than that of the reference soil (θ % = 30,16 %).

The histogram in Fig. 7 shows the soils at a suction of 1500 kPa (wilting point); the average of volumetric water content of soils sampled is θ % = 19.98 %, standard deviation 5.97 %; the trend in this case is very variable, with one soil that has a water content of θ % = 27.91 % and another θ % = 10.86 %. The reference soil instead has a value of θ % = 13.66 %; in 9 soils the water content is higher than that of the reference soil.

In general terms the available water for plant is defined as the difference between soil water content at suction 33 kPa - soil water content at field capacity - and 1500 kPa - soil water content at wilting point - (histogram Fig. 8). For the investigated soils the average amount of available water has a value of θ % = 6.06 %, very hight standard deviation 4.70 %, with a minimum value of θ % = 0.55 % and a maximum of θ % = 12.14 %; the reference soil has a value of θ % = 16.50 %.

All the sampled soils have a much lower available water θ % than the reference soil, despite having an organic carbon content about twice compared to the reference soil. Generally, high values of organic carbon correspond to high levels of organic matter, which enhances permeability and water availability in the soil. It would be interesting to study why a soil, presenting characters of physical degradation -compactation - associated with a lack of organic carbon content, has, on the contrary, a high organic carbon content. In this key it would be interesting, also, to study the carbon decomposition in humic and fulvic acids in association with limestone content.

3.2 Flora and vegetation

The total number of plant species sampled amounts to 90 (see Appendix A), almost all of them are very common and abundant in the province of Piacenza (Bracchi and Romani, 2010; Romani and Alessandrini, 2001). Most of the species were found to be competitive-ruderal (43 %) and ruderal (13 %) (Grime, 2001) and belonging to the phytosociological class

Stellarietea mediae R. Tx. Lohm. et PRSG. in Tx. 1950 which includes nitrophilous annual vegetation (Mucina et al., 1993; Oberdorfer, 1993; Ubaldi, 2008).

Fig. 9 shows the flora list biological spectrum. The study area has a particularly high percentage of therophytes (44 %) when compared to the values of the biological range of the province of Piacenza (23 %; Romani and Alessandrini, 2001) and Emilia-Romagna (28 %; Pignatti et al., 2001). Typically, ephemeral annual species tend to concentrate in urban environments (Sukopp and Werner, 1983) and in Italy, regardless of human disturbance, their percentage increases gradually from North to South in response to the emergence of a distinctly arid climate (Pignatti, 1994, 1976).

Fig. 10 represents the monthly rainfall and evapotranspiration and it should be noted that the ETo is greater than the rainfall in the period from May to August, indicating a summer drought.

The histogram referring to the F index (Fig. 11) shows that most of the found species require soils with a moisture content ranging from moderately dry to moderately moist. The typically xerophyte species and those found in submerged soils are absent, while there are two (*Bolboschoenus maritimus* (L.) Palla and *Eleocharis palustris* (L.) Roem. & Schult) that need wet soil.

In Fig. 12 the graphs referring to the amount of water lost from a common agricultural soil of medium texture 1 m deep (a), and the soil cover of the landfill (b) are presented, considering for both the climatic conditions of Piacenza and as a cover a grassland vegetation of perennial grasses (cool season grass varieties including bluegrass, fescue and ryegrass; Allen et al., 1998). The soil of the landfill has less water available to vegetation compared to agricultural soil.

4. Discussion and conclusions

In this study the attempt to put the hydraulic properties of degraded soil in relation with plant coverage is presented.

The hydrological properties of a degraded soil are described through a comparison between the laboratory tests and the results of predictive systems by PTFs, showing that the PTFs are not able to describe them.

The study of the hydraulic properties of landfill cover soils has outlined that these soils have less available water content in comparison with a natural reference soil; this is a character of degradation.

On the base of PTFs some conclusion can be formulated: PTFs have the advantage of being relatively inexpensive and easy to derive and use, but for application at a specific point and for soils that are outside the range of soils used to derive them, prediction with PTFs might be inadequate. In this case direct measurement is the only option (Wösten et al., 2001) and it can be interesting to make studies to develop degraded soils new PTFs parameters and to put them in relation to the type of soil organic content. Generally, high values of soil organic carbon correspond to high levels of organic matter, which enhances permeability and water availability. In this key it would be interesting to study why a soil, presenting characters of physical degradation - compactation - associated with a lack of organic carbon content, has, on the contrary, a high organic carbon content. It would be interesting, also, to study the carbon decomposition in humic and fulvic acids in association with limestone content.

*~~The loamy soils with a predominantly multi-faceted structure, such as those investigated, have low porosity and, by their nature, are compact; in this case, the compaction was induced by compression of the ground during works that are generally carried out at the closure of a landfill in order to avoid the leakage of gas and infiltration by rainwater.~~

Analyzing vegetation it can be said that the landfill vegetation is mainly related to the soil characters. The low water content, together with the lack of depth and compacted structure, would justify the current presence of a vegetation cover which consists predominantly of therophytes instead of a more developed and stable perennial vegetation with shrubs and trees, as observed for other landfills several years after their coverage (El-Sheikh et al., 2012; Huber-Humer and Klug-Pümpel, 2004; Rebele and Lehmann, 2002). The high frequency of therophyte does not seem to be justified by summer drought and by the low level of human disturbance that affected the area in recent years, given that, under the same climatic conditions, the potential vegetation of the area should be represented by riparian forests of *Populetalia albae* Br.-Bl. 1935 (Puppi et al., 2010) which, although not very widespread, are present and contiguous to the landfill.

The presence of *Bolboschoenus maritimus* (L.) and *Eleocharis palustris* (L.) that need wet soil is explained by the fact that F refers to soil water availability during the time of year when the species carry out their vegetative cycle (Landolt et al., 2010). In this case the above-mentioned hydrophilic plants were detected only in the spring months when the monthly evapotranspiration is less than or equal to rainfall.

In comparison with agricultural soil in the same climatic conditions the landfill soil has less water available to vegetation and this contributes to causing water stress for plants over a longer period (March to September) and is more pronounced, as the amount of water absorbed by plants during the summer is close to their permanent wilting point (TAM line).
By the low water content in association with high organic carbon, the lack of depth, compacted structure of these soils and the current presence of a vegetation cover which consists predominantly of therophytes the aim of New Life project, studying a treatment for restoring degraded soils is very important; and it will be also interesting to study the hydraulic properties of degraded soil in comparison with the same one reconstituted.

Appendix A

n	Specie	Life form	F index	Plant strategy	Presence
1	*Abutilon theophrasti* Medik.	T	2.5	cr	3/52
2	*Agrimonia eupatoria* L.	T	2	cr	2/52
3	*Allium* spp.	-	-	-	1/52
4	*Alopecurus myosuroides* Huds.	T	3	r	10/52
5	*Alopecurus pratensis* L.	T	3.5	cs	5/52
6	*Alopecurus rendlei* Eig	T	3	crs	7/52
7	*Amaranthus retroflexus* L.	T	2,5	cr	18/52
8	*Ambrosia artemisiifolia* L.	T	2	cr	15/52
9	*Amorpha fruticosa* L.	H	3.5	crs	1/52
10	*Aristolochia clematitis* L.	G	3.5	cr	2/52
11	*Arrhenatherum elatius* (L.) P. Beauv. ex J. & C. Presl	H	3	cr	21/52
12	*Artemisia vulgaris* L.	G	2.5	crs	13/52
13	*Atriplex patula* L.	T	2.5	cr	10/52
14	*Avena fatua* L.	T	2.5	cr	14/52
15	*Ballota nigra* L.	T	2.5	cr	4/52
16	*Bolboschoenus maritimus* (L.) Palla	T	4.5	cs	1/52
17	*Bromus hordeaceus* L.	T	3	cr	14/52
18	*Bromus sterilis* L.	T	2	r	30/52

19	*Capsella bursa-pastoris* (L.) Medik.	T	2	r	6/52
20	*Cardamine hirsuta* L.	T	3	rs	3/52
21	*Cerastium* spp.	-	-	-	9/52
22	*Chenopodium album* L.	T	2	r	27/52
23	*Cichorium intybus* L.	T	2.5	crs	2/52
24	*Cirsium arvense* (L.) Scop.	T	3	cr	6/52
25	*Cirsium vulgare* (Savi) Ten.	T	3	cr	1/52
26	*Convolvulus arvensis* L.	T	2.5	cr	50/52
27	*Crepis setosa* Haller f.	H	1.5	r	5/52
28	*Crepis vesicaria* L.	T	2	cr	2/52
29	*Cynodon dactylon* (L.) Pers.	T	2	cs	44/52
30	*Dactylis glomerata* L.	H	3	crs	6/52
31	*Dipsacus fullonum* L.	T	3.5	cr	1/52
32	*Echinochloa crusgalli* (L.) P. Beauv.	G	3.5	cr	3/52
33	*Eleocharis palustris* (L.) Roem. & Schult.	H	4.5	crs	2/52
34	*Elymus repens* (L.) Gould	T	3	cs	52/52
35	*Erigeron annuus* (L.) Desf.	H	2.5	cr	2/52
36	*Euphorbia cyparissias* L.	H	2	crs	1/52
37	*Galium aparine* L.	G	3	cr	8/52
38	*Galium verum* L.	H	2.5	crs	2/52
39	*Geranium dissectum* L.	T	3	cr	17/52
40	*Geranium molle* L.	H	2.5	cr	9/52
41	*Hordeum murinum* L.	T	2	r	23/52
42	*Humulus japonicus* Siebold & Zucc.	T	3.5	cr	1/52
43	*Hypericum perforatum* L.	G	3	crs	2/52
44	*Lactuca serriola* L.	H	2	cr	9/52
45	*Lamium purpureum* L.	T	3	r	7/52
46	*Lapsana communis* L.	T	3.5	cr	2/52
47	*Lepidium draba* L.	G	2	cr	3/52
48	*Lolium perenne* L.	H	3	cr	4/52
49	*Lythrum salicaria* L.	T	4	cs	1/52
50	*Malva alcea* L.	T	2.5	cs	2/52

51	*Malva sylvestris* L.	T	2.5	crs	2/52
52	*Matricaria chamomilla* L.	H	3	r	2/52
53	*Medicago lupulina* L.	T	2	rs	3/52
54	*Medicago sativa* L.	H	2	cs	8/52
55	*Melilotus albus* Medik.	H	2.5	cr	3/52
56	*Mentha arvensis* L.	H	3.5	crs	2/52
57	*Myosotis arvensis* (L.) Hill	T	2	cr	2/52
58	*Onopordum acanthium* L.	T	2	cr	2/52
59	*Ornithogalum umbellatum* L.	H	3	crs	1/52
60	*Papaver rhoeas* L.	H	2	r	1/52
61	*Persicaria lapathifolia* (L.) Delarbre	H	2.5	cr	2/52
62	*Plantago lanceolata* L.	H	3.5	crs	8/52
63	*Poa pratensis* L.	T	3.3	crs	1/52
64	*Poa trivialis* L.	H	3.5	crs	14/52
65	*Polygonum aviculare* L.	T	3.5	r	23/52
66	*Portulaca oleracea* L.	H	2.5	r	1/52
67	*Potentilla reptans* L.	H	3	crs	3/52
68	*Ranunculus bulbosus* L.	H	2	crs	10/52
69	*Robinia pseudoacacia* L.	H	2.5	c	1/52
70	*Rumex crispus* L.	H	3.5	cr	44/52
71	*Rumex pulcher* L.	H	3	crs	5/52
72	*Salix alba* L.	T	4.5	c	1/52
73	*Salvia pratensis* L.	H	2	crs	2/52
74	*Solanum nigrum* L.	G	3	r	2/52
75	*Sonchus asper* (L.) Hill	H	3.5	cr	3/52
76	*Sonchus oleraceus* L.	H	3	cr	2/52
77	*Sorghum halepense* (L.) Pers.	H	2	c	2/52
78	*Stellaria media* (L.) Vill.	H	3	cr	14/52
79	*Tanacetum vulgare* L.	H	3.5	c	2/52
80	*Taraxacum officinale* Weber	G	3	crs	3/52
81	*Torilis arvensis* (Huds.) Link	H	2	cr	2/52
82	*Trifolium fragiferum* L.	H	3	crs	2/52

83	*Trifolium pratense* L.	G	3	crs	3/52
84	*Trifolium repens* L.	H	3	crs	4/52
85	*Valerianella* spp.	-	-	-	2/52
86	*Verbascum thapsus* L.	P	2.5	crs	4/52
87	*Verbena officinalis* L.	P	3	cr	8/52
88	*Veronica persica* Poir.	P	3	cr	15/52
89	*Vicia sativa* L.	T	3	cr	19/52
90	*Xanthium orientale* L. subsp. *italicum* (Moretti) Greuter	G	3	cr	4/52

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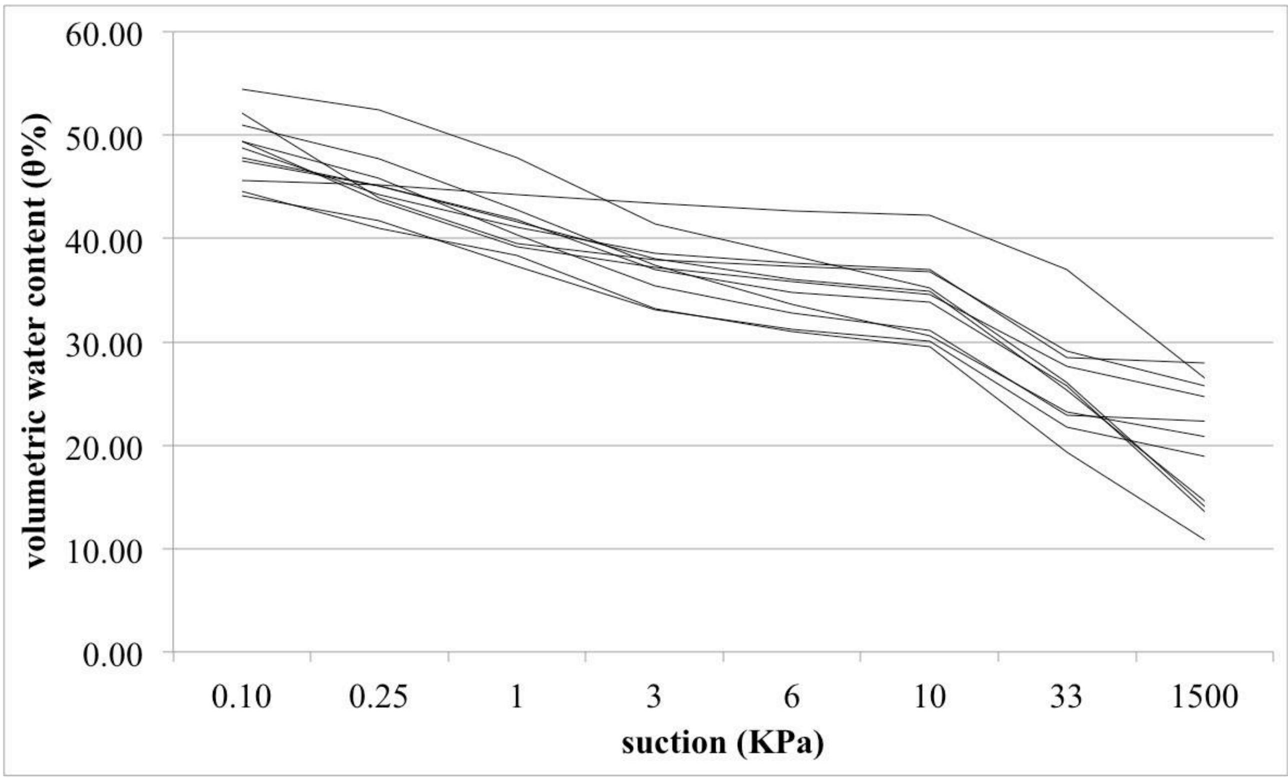


Figure 1. Water retention curves of sampled soils.

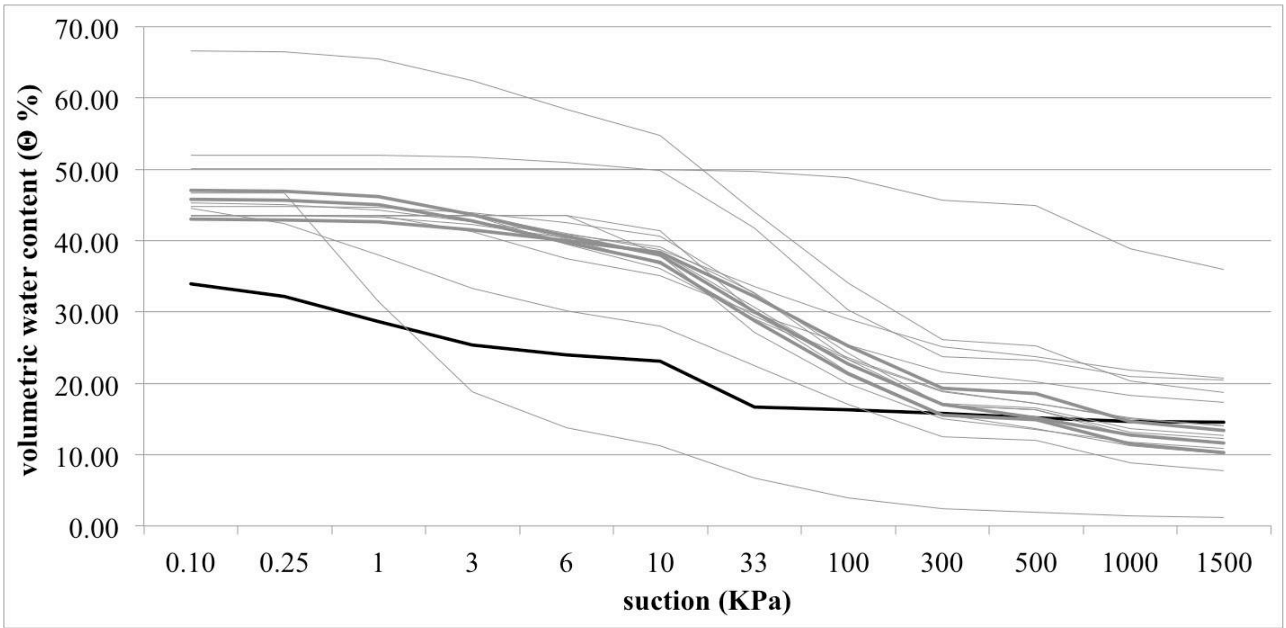


Figure 2. Sample 5: real (black) and PTFs water retention curves; the curves by Wösten et al. 1999 are highlighted.

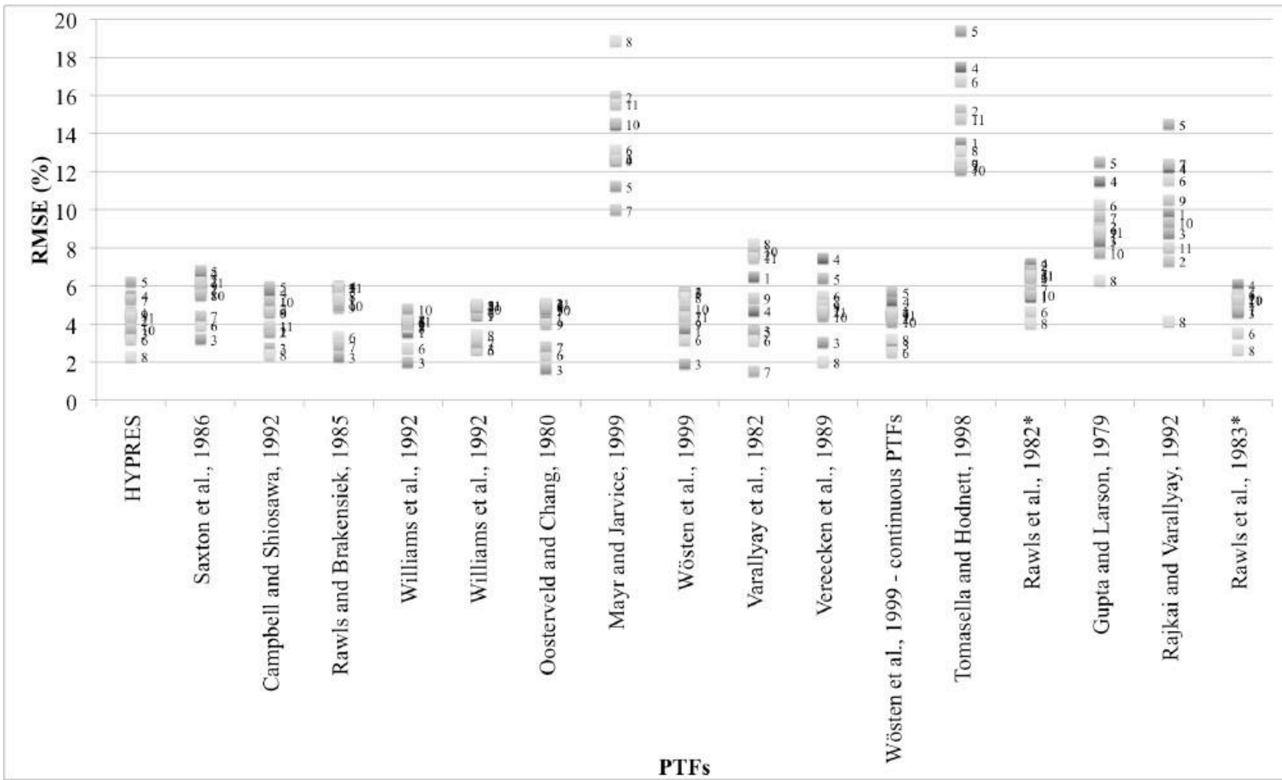


Figure 3. Matrix representing the result of RMSE test, each pixel for a combination of soil's PTF and RMSE.

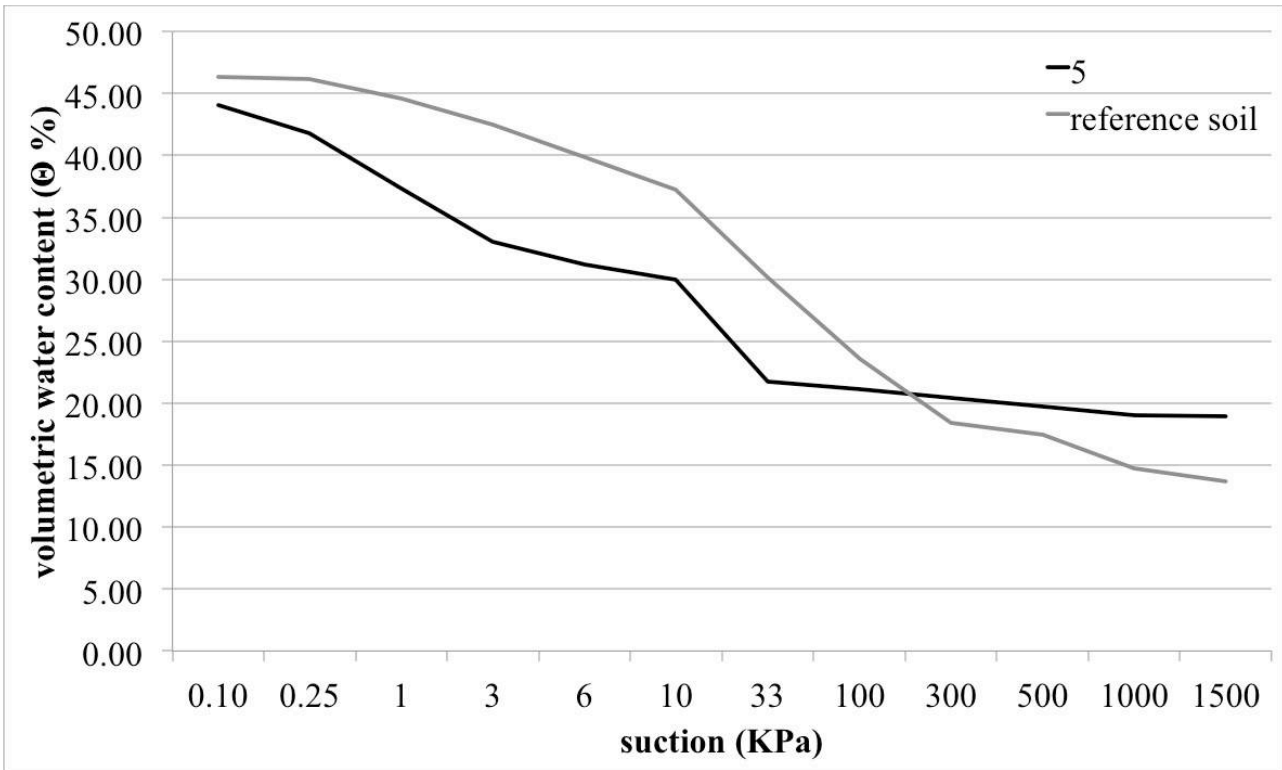


Figure 4. Comparison between sample 5 water retention curve and reference curve - described as the arithmetic mean of PTFs values.

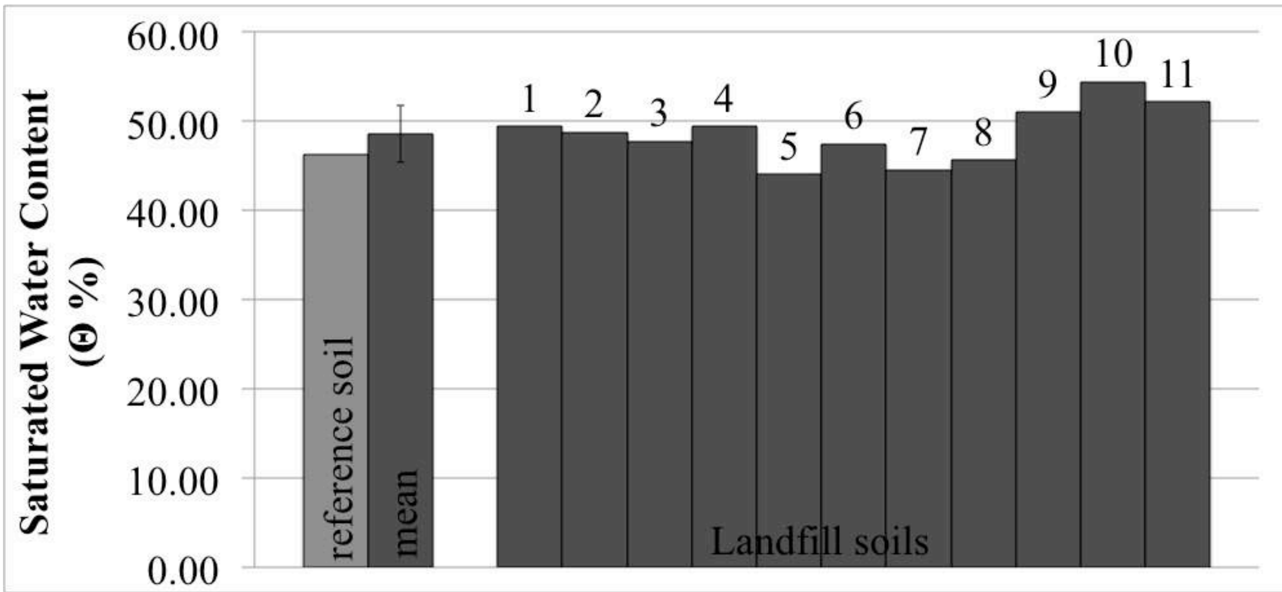


Figure 5. Volumetric water content (θ %) at suction 0,10 kPa: comparison between reference soil and landfill soils.

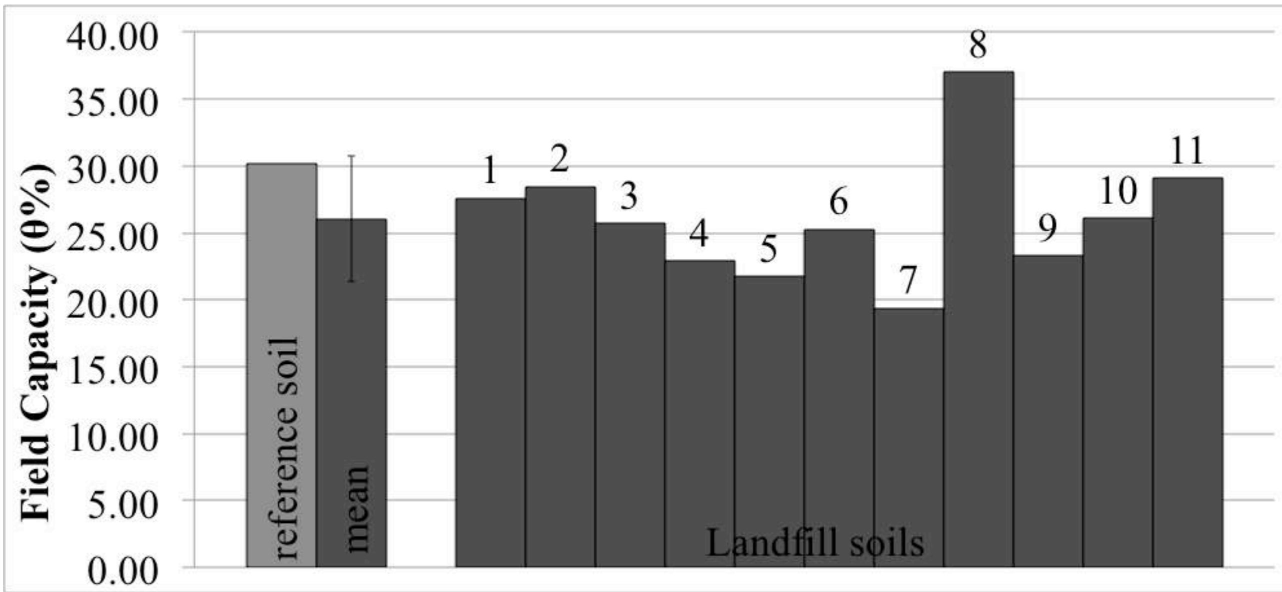


Figure 6. Volumetric water content (θ %) at field capacity: comparison between reference soil and landfill soils.

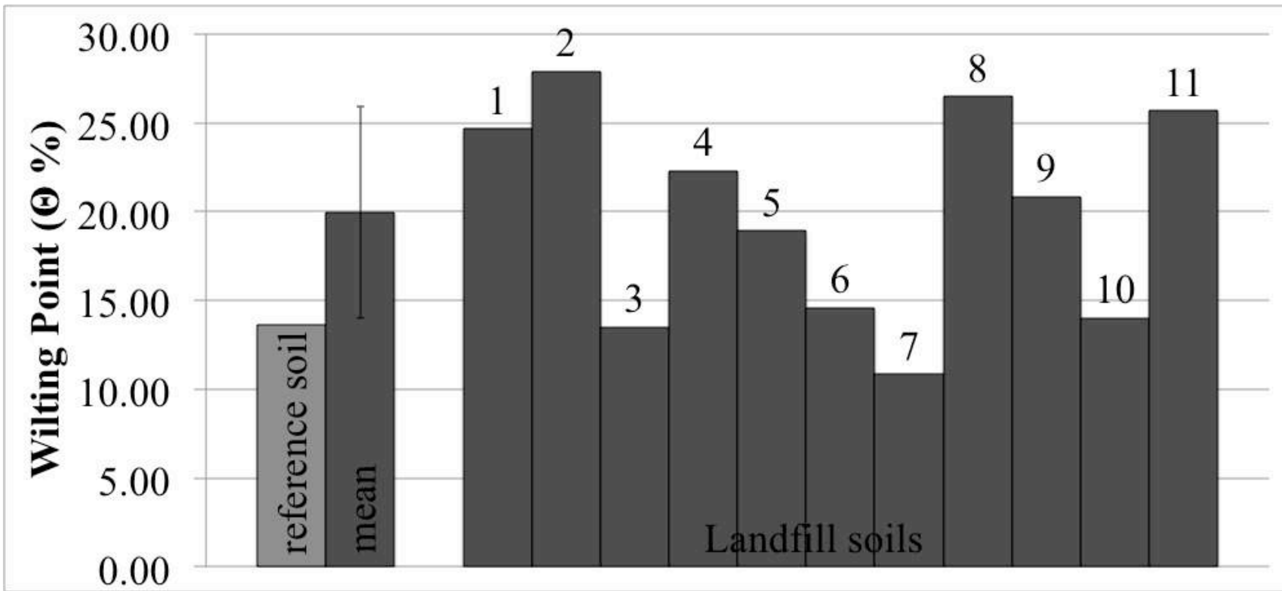


Figure 7. Volumetric water content (θ %) at a suction of 1500 kPa: comparison between reference soil and landfill soils.

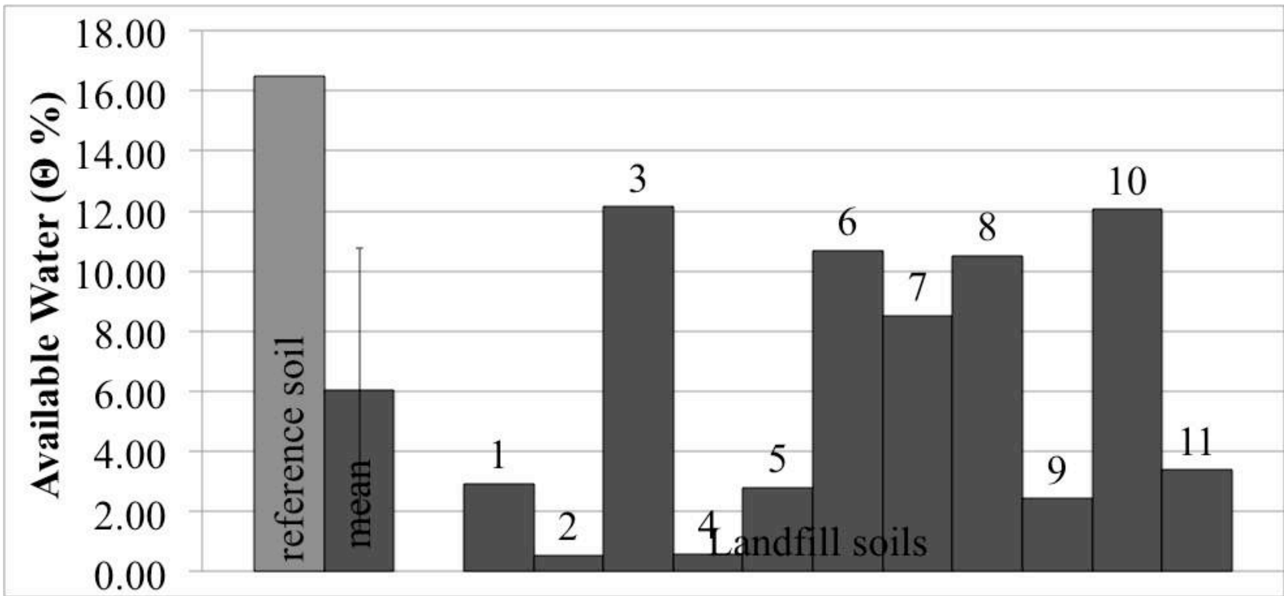


Figure 8. Available water to plants (θ %): comparison between reference soil and landfill soils.

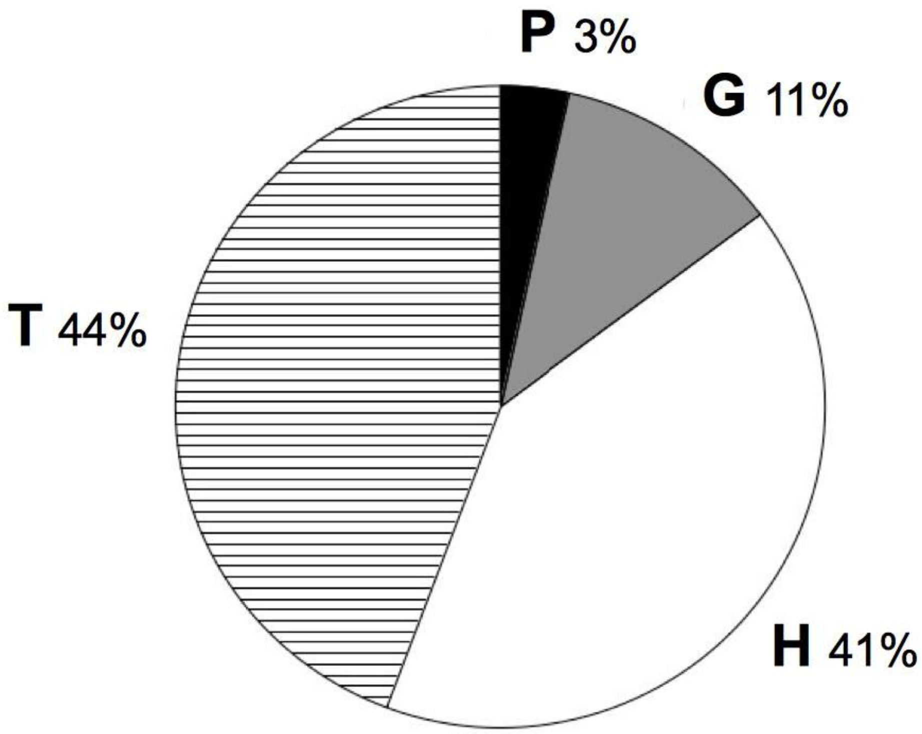


Figure 9. Biological spectrum of flora list (T= Therophytes; H= Hemicryptophytes; G= Geophytes; P= Phanerophytes).

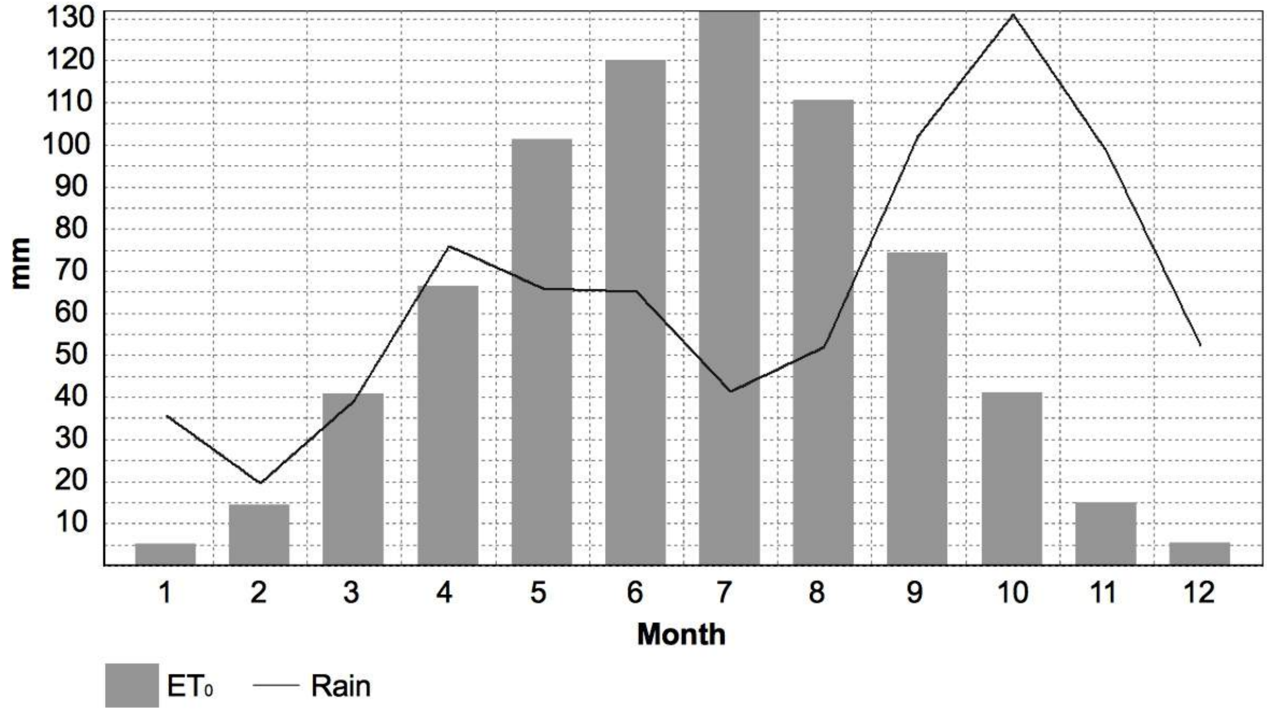
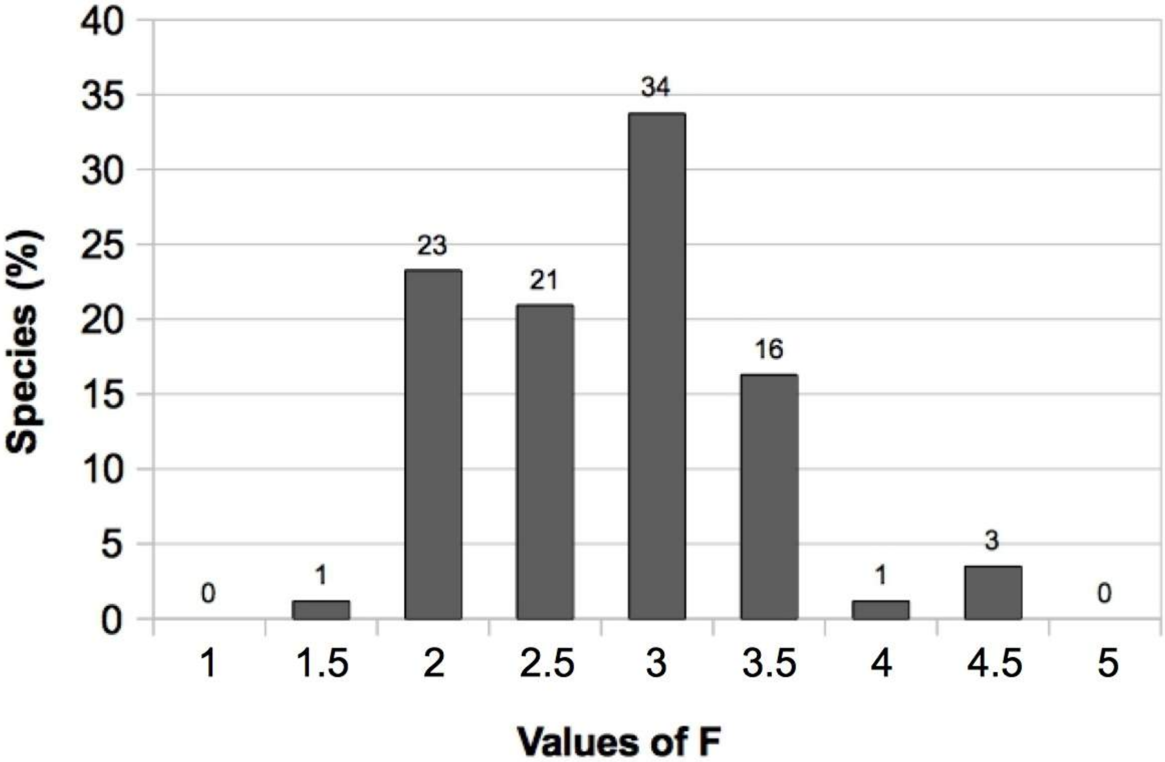


Figure 10. Monthly rainfall and evapotranspiration (ETo). Climate data source: San Lazzaro Alberoni weather station (Piacenza 1961-2005).

Figure 11. F index (soil moisture). Percentages are weighted by the frequency of the species in the monitoring sites (see column “Presence” in the Appendix). Legend: 1 = very dry, 1,5 = dry, 2 = moderately dry; 2,5 = fresh, 3 = moderately moist; 3,5 = moist, 4 = very moist, 4,5 = wet, 5 = flooded or submerged.


Species (%)
40
35
30
25
20
15
10
5
0
0
1
23
21
34
16
1
3
0
1
1.5
2
2.5
3
3.5
4
4.5
5
Values of F

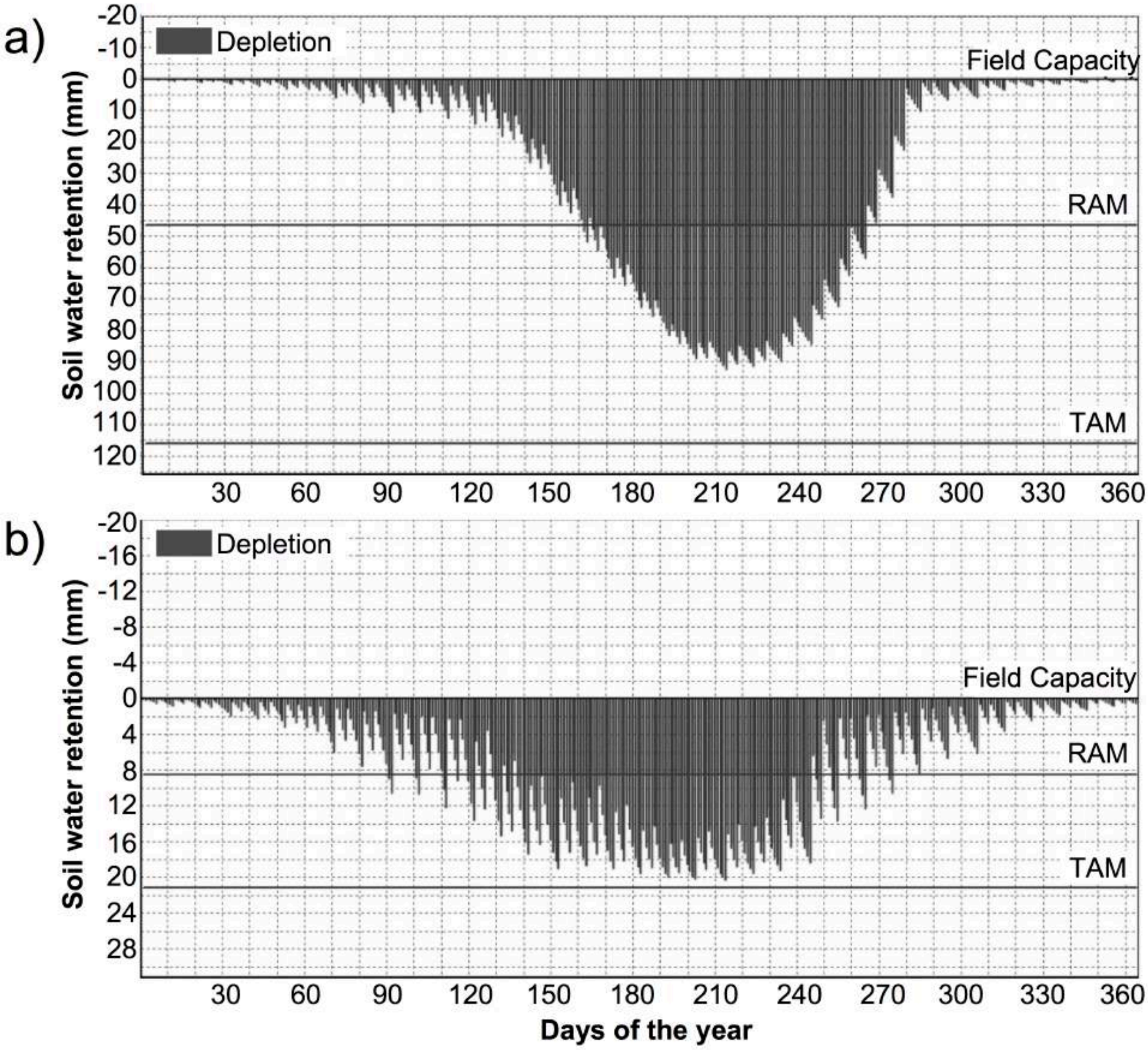


Figure 12. Water lost from agricultural soil (a) and from the landfill cover soil (b) by Crop Wat 8.0 software. Legend: RAM = readily available moisture; TAM = total available moisture.

Table 1. Results of chemical and physical analyses performed on soils. legend: A.B. = Angular Blocky; Sa.B. = Subangular Blocky. G. = Granular, P. = Platy, S.G. = single grain.

Sample	Organic Carbon content	$CaCO_3$	Electrical Conductivity	Sand	Silt	Clay	Soil Thickness	Structure of soil
	%	g/Kg	ds/m	%	%	%	cm	
1	1.94	130.2	0.197	21.9	12.3	65.8	55	A.B. – Sa.B.
2	4.13	147.7	0.212	17.5	12.9	69.6	30	G. –Sa.B.
3	4.14	190.4	0.152	27.9	12.3	59.8	60	G. –Sa.B.
4	1.67	38.5	0.232	11.5	14.7	73.8	30	Sa.B. – G.
5	1.04	134.8	0.167	12.2	12.4	75.4	62	P.
6	1.35	57.4	0.196	10.3	14.7	75	32	Sa.B. – G.
7	1.92	229.8	0.130	33.3	12.5	54.2	45	S.G. – Sa.B.
8	4.10	266.7	0.288	16.7	16.8	66.5	47	A.B. – G.
9	2.35	138.1	0.252	25	12.3	62.7	47	A.B. – Sa.B.
10	2.68	59.9	0.136	18	9.8	72.2	50	Sa.B. – A.B.
11	3.63	128.9	0.248	17.8	12.3	69.9	40	Sa.B. – G.

Table 2. Volumetric water content (θ %) from instrumental analysis at different suction values.

Sample	Suction (-kPa)							
	0.10	0.25	1	3	6	10	33	1500
1	49.45	43.58	39.21	37.23	35.88	34.54	27.60	24.66
2	48.75	44.27	41.05	38.62	37.61	36.98	28.46	27.91
3	47.77	45.12	41.83	37.00	34.80	33.83	25.71	13.57
4	49.42	45.87	40.40	35.46	32.77	31.13	22.91	22.32
5	44.09	41.77	37.31	33.07	31.20	30.01	21.73	18.92
6	47.46	45.06	41.60	38.08	36.02	34.85	25.29	14.59
7	44.55	40.98	38.32	33.25	30.97	29.48	19.37	10.86
8	45.63	45.15	44.21	43.46	42.71	42.30	37.02	26.50
9	51.01	47.71	42.76	37.37	33.58	30.55	23.27	20.84
10	54.43	52.41	47.81	41.39	38.38	35.18	26.08	14.02
11	52.16	43.94	39.52	37.90	37.27	36.78	29.09	25.69

Table 3. Authors, localization of database and model used for the different PTFs. Legend: VG = van Genuchten, BC = Brooks Corey.

PTF	Region	Model
HYPRES	Europe	VG
Saxton et al., 1986	USA, nationwide	BC
Campbell and Shiosawa, 1992	No particular	BC
Rawls and Brakensiek, 1985	USA, nationwide	BC
Williams et al., 1992	Australia	BC
Williams et al., 1992	Australia	BC
Oosterveld and Chang, 1980	Canada, Alberta	BC
Mayr and Jarvice, 1999	UK	BC
Wösten et al., 1999	Europe	VG
Varallyay et al., 1982	Hungary	VG
Vereecken et al., 1989	Belgium	VG
Wösten et al., 1999	Europe	VG
Tomasella and Hodnett, 1998	Brazil	VG
Rawls et al. 1982b (corrected for OM according to Nemes et al., 2009)	USA, nationwide	VG
Gupta and Larson, 1979	Central USA	VG
Rajkai and Varallyay, 1992	Hungary	VG
Rawls et al. 1983 (corrected for OM according to Nemes et al., 2009)	USA, nationwide	VG

Table 4. Results of the calculation of RMSE; * = corrected for OM according to Nemes et al., 2009.

PTF	RMSE % (for samples)										
	1	2	3	4	5	6	7	8	9	10	11
HYPRES	4.6	4.2	3.6	5.5	6.2	3.2	5.3	2.3	4.5	3.7	4.4
Saxton et al., 1986	5.9	6.3	3.2	6.7	6.8	4.0	4.5	5.6	6.0	5.6	6.2
Campbell and Shiosawa, 1992	3.7	3.6	2.8	5.7	6.0	4.6	4.8	2.4	4.7	5.2	3.9
Rawls and Brakensiek, 1985	5.4	5.9	2.3	6.0	5.9	3.4	2.9	5.5	4.9	5.0	5.9
Williams et al., 1992	3.6	4.0	2.0	4.2	4.2	2.8	4.2	3.8	4.0	4.8	4.2
Williams et al., 1992	4.5	5.0	2.7	5.0	5.0	2.7	3.0	3.5	4.5	4.8	5.0
Oosterveld and Chang, 1980	4.4	5.1	1.7	5.0	4.8	2.4	2.8	4.9	4.0	4.8	5.1
Mayr and Jarvice, 1999	14.5	16.0	12.7	12.6	11.2	13.2	10.0	18.9	12.6	14.5	15.6
Wo¨sten et al., 1999	3.7	5.7	1.9	5.7	5.6	3.2	4.5	5.4	4.0	4.8	4.4
Varallyay et al., 1982	6.5	7.7	3.7	4.7	3.6	3.2	1.5	8.2	5.4	7.9	7.5
Vereecken et al., 1989	4.8	4.7	3.1	7.5	6.4	5.5	5.2	2.0	5.0	4.4	4.7
Wo¨sten et al., 1999	4.7	4.3	3.0	5.2	5.7	2.6	4.6	3.2	4.5	4.2	4.5
Tomasella and Hodnett, 1998	13.6	15.2	12.2	17.5	19.4	16.8	12.4	13.1	12.4	12.1	14.8
Rawls et al., 1982*	5.5	7.1	6.5	7.2	6.8	4.7	5.9	4.1	6.4	5.5	6.6

Gupta and Larson, 1979	8.3	9.2	8.4	11.5	12.5	10.3	9.6	6.3	8.9	7.8	8.9
Rajkai and Varallyay, 1992	9.8	7.3	8.8	12.2	14.5	11.6	12.4	4.2	10.5	9.4	8.0
Rawls et al., 1983*	4.7	5.4	4.6	6.1	5.6	3.6	4.8	2.7	5.5	5.3	5.3