Hydrological characteristics of the soil of a degraded area: comparison between physical, chemical and floristic-vegetational analysis

Manfredi P.[1], Cassinari C.[2], Giupponi L.[3], Sichel G. M.[1] and Trevisan M.[2]

[1]m.c.m. Ecosistemi s.r.l., Gariga di Podenzano, Piacenza, Italy; [2]Istituto di Chimica Agraria e Ambientale, Università Cattolica del Sacro Cuore, Piacenza, Italy; [3]Istituto di Agronomia, Genetica e Coltivazioni erbacee, Università Cattolica del Sacro Cuore, Piacenza, Italy

Introduction

This work is part of a project co-funded by the European Union, "Environmental restoration of degraded and desertified soils by a new treatment technology for the recovery of the land" (Life 10 ENV IT 400 "New Life"), which consists in the testing of an innovative technology to restore degraded and desertified soils.
The project area (20 ha) is situated in the municipality of Piacenza (Italy), where over the 70s and 80s a landfill for municipal solid waste was created; subsequent restoration work involved covering it with a layer of soil. The treatment of the land will be tested through the use of equipment (patented by the company m.c.m. Ecosistemi) for the mechanical and chemical processing of different types of soil present in the area. The conceptual model of the system applied involves the disintegration and reconstitution of soil using a process that operates mainly on its structural elements, the physical incorporation of organic matrices, and chemical stabilization of organic carbon. The first phase of the New Life project involved the physical-chemical characterization of the soil coverage of the landfill, which revealed 12 different types. Concurrently, a floristic-vegetational study of the area was conducted, which revealed the presence of species found on nitrogen-rich disturbed soil, belonging to the phytosociological class *Stellarieta mediae*. This paper aims to analyze the hydrological characteristics of the 12 soil types in relation to vegetation cover, identifying details suitable for the evaluation of the process of land degradation on the basis of comparisons between theoretical and instrumental data taken from pedotransfer functions.

Materials and Methods

Physical-chemical analysis of the soil

Water potential (pF): Official Method Suppl. Ord. G.U. 173 02/09/1997 - ISO / DIS 11274 (Richard's tensiometric cassette and plate)
Organic carbon VII.3 Official Method (Walkley-Black)
Limestone total: Official Method V.1
Texture and grain size: Official Method II.5
Salinity: Official Method IV.1 (aqueous extract 5:1)

Pedotransfer functions

Pedotransfer functions were developed to derive water retention parameters using basic soil properties such as soil texture, bulk density, organic carbon content. These pedotransfer functions are based on two different models:

1) The van Genuchten water retention equation (1980)

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

2) The Brooks-Corey model (1964)

$$\frac{\theta-\theta_r}{\phi-\theta_r}=\begin{cases}\left(\dfrac{h_b}{h}\right)^{\lambda}, & h>h_b\\ 1, & h\le h_b\end{cases}$$

Key:
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).

HYPRES (Hydraulic Properties of European Soils) database (Wösten et al., 1999) draws together the basic soil information and soil hydraulic data from which pedotransfer functions (PTFs) are applicable. Two different sets of pedotransfer functions were derived to establish a suitable dataset: class and continuous pedotransfer functions. Class pedotransfer functions predict the average hydraulic characteristics for a soil texture/pedological class; continuous pedotransfer functions predict van Genuchten parameter dependency on the more easily measured basic soil properties (percent of clay and silt, organic matter content, bulk density).

The computer program calculator CalcPTF was developed to estimate the parameters of the van Genuchten and Brooks-Corey water retention equations. This calculator estimates the parameters of the two models using equations suggested by different authors (Saxton et al., 1986, Campbell and Shiosawa, 1992, Rawls and Brakensiek, 1985, Williams et al., 1992, Oosterveld and Chang, 1980, Mayr and Jarvice, 1999, Wösten et al., 1999, Varallyay et al., 1982, Vereecken et al., 1989, Tomasella and Hodnett, 1998, Rawls et al., 1982, Gupta and Larson, 1979, Rajkai and Varallyay, 1992, Rawls et al., 1983).

The SPAW (Soil-Plant-Air-Water) computer model simulates the daily hydrology of agricultural fields. A set of generalized equations describes soil tension and conductivity relationships versus moisture content as a function of sand and clay texture and organic matter content (Rawls et al., 1982; 1992; 1998; Saxton et al., 1986). Tanij, 1990 added adjustments to the solutions to include the effects of bulk density, gravel and salinity.

In order to evaluate the quality of the pedotransfers fitting, the significance test was done using the root mean square error (RMSE) based on measured and estimated water content value.

Analysis of vegetation

The data on vegetation were collected by means of 52 phytosociological relevés (4 x 4 m) according to the method of the Zurich-Montpellier school (Braun-Blanquet, 1964). Each plant species was attributed its respective biological form in accordance with Raunkiaer (1934) in order to process the biological spectrum of the flora list. The ecological index F (soil moisture) defined by Landolt et al. (2010) was used to obtain information on the amount of water in the soil needed by plants during their growing season.

Analysis of climatic and soil water balance

Using climate data from the weather station of S. Lazzaro Alberoni (Piacenza), a Walter and Lieth (1960) climate diagram was drawn up.
The diagram of the soil water balance was obtained using the software CROPWAT 8.0 (Richard et al., 1998)

Results - Soil

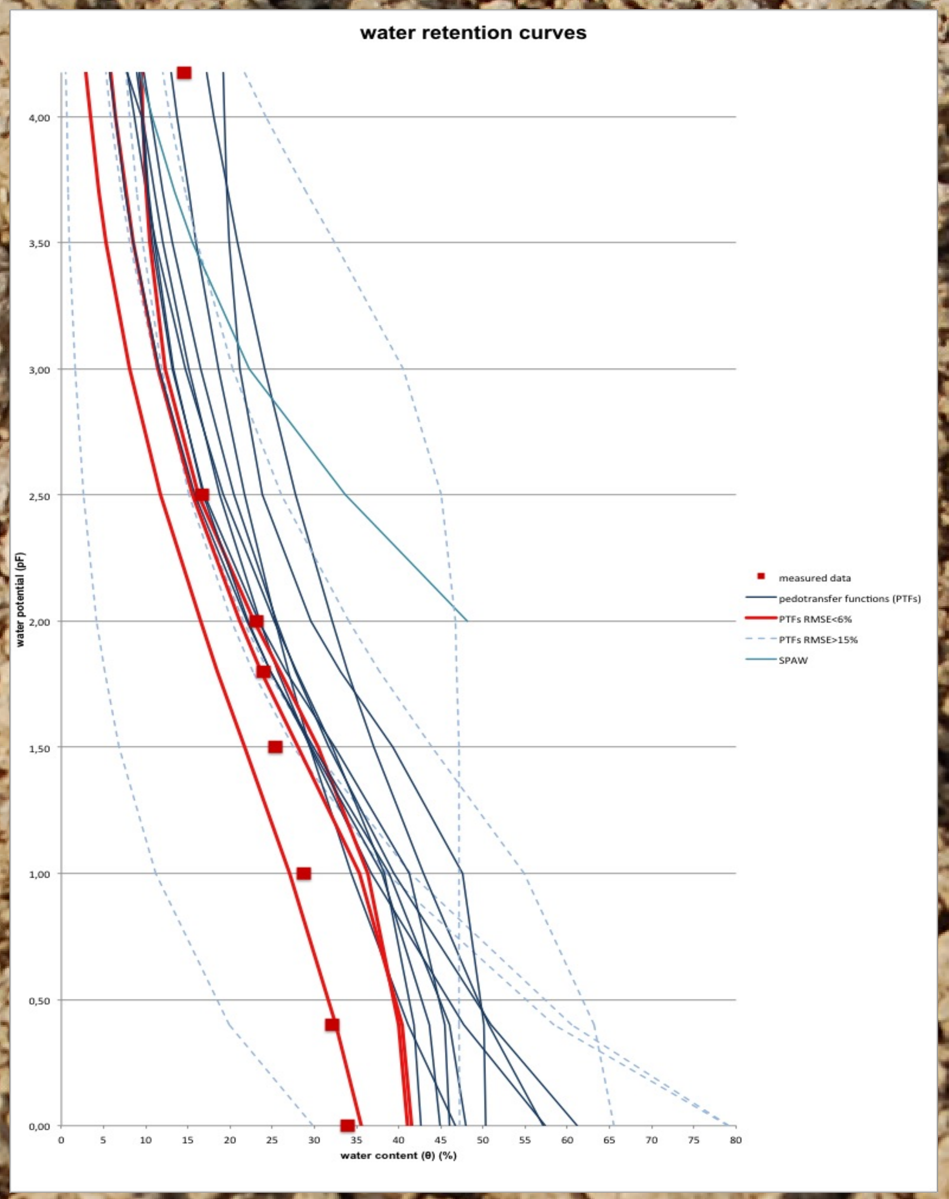

Fig 1. Comparison of water retention curves.

Soil sample	O.C. (%)	$CaCO_3$ (g/Kg)	Salinity (ds/m)	Sand (%)	Clay (%)	Silt (%)	Depth (cm)
6	1,94	130,2	0,197	21,9	12,3	65,8	55
13	4,13	147,7	0,212	17,5	12,9	69,6	30
16	4,14	190,4	0,152	27,9	12,3	59,8	60
18	2,17	121,9	0,338	17,5	19,7	62,8	47
21	1,67	38,5	0,232	11,5	14,7	73,8	30
25	1,04	134,8	0,167	12,2	12,4	75,4	62
33	1,35	57,4	0,196	10,3	14,7	75	32
38	1,92	229,8	0,130	33,3	12,5	54,2	45
39	4,10	266,7	0,288	16,7	16,8	66,5	47
45	2,35	138,1	0,252	25	12,3	62,7	47
47	2,68	59,9	0,136	18	9,8	72,2	50
51	3,63	128,9	0,248	17,8	12,3	69,9	40

Table 1. Physico-chemical characteristics of soils.

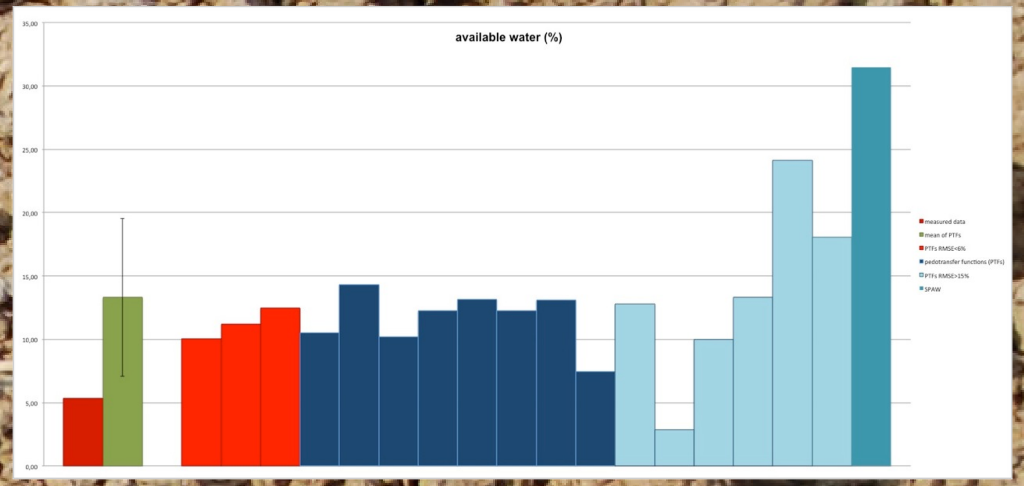

Fig 2. Water available in the soil.

Table 1 shows some of the physico-chemical characteristics of the 12 soils sampled. These values were used as input for the models developed.

The water retention curves (fig. 1) shown are compared with point values measured in the laboratory (the data refer to a single soil). From the curves it is clear that the soil of the landfill presents a low water holding capacity compared to undisturbed soil that has similar texture, bulk density and organic carbon characteristics.

The histogram of fig. 2 shows the values of the percentage of water available; in this case too we note that the figure derived from laboratory measurements is much lower than the average values calculated from soil functions.
From the calculation of the RMSE, the Vereecken et al. (1989) (van Genuchten's model) appears to be the curve that is closest to the real values (RMSE < 6% in 9 out of 12 samples). Mayr and Jarvice (1999) (Brooks - Corey) has proved the worst (RMSE > 15% in 10 out of 12 samples).

Vegetation and water balance

The percentage of therophytes in the biological spectrum of fig. 3 is significantly higher (44%) than the spectrum for Piacenza (23%) and Emilia-Romagna (23%). In Italy the frequency of therophytes increases gradually from north to south in response to the emergence of a distinctly arid climate (Pignatti, 1976).

Fig 4 shows that most of the species identified need soils with a moisture content ranging from moderately dry to moderately moist during their growing season.

The climate diagram for Piacenza (fig.5) highlights a period of water deficit (hatched area) during the month of July. The brevity of this period does not seem to justify the high percentage of therophytes recorded.

The water balance of landfill soil covered by perennial herbaceous vegetation (fig. 6) indicates the presence of a long edaphic dry spell (May to September) which would justify the abundance of annual species (Therophytes) ending their life cycle before the onset of the adverse season (summer).

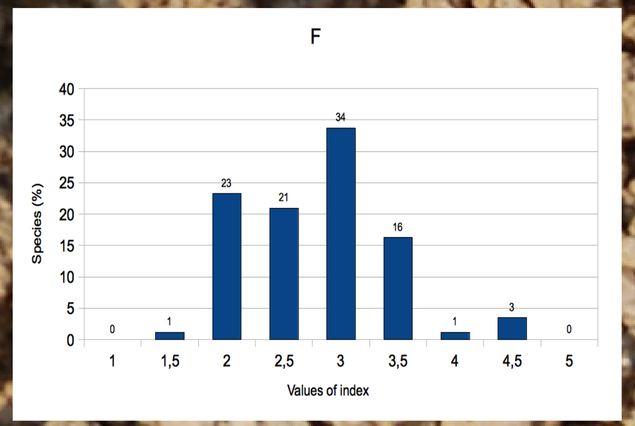

Fig 4. F index (soil moisture).

Key:
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.

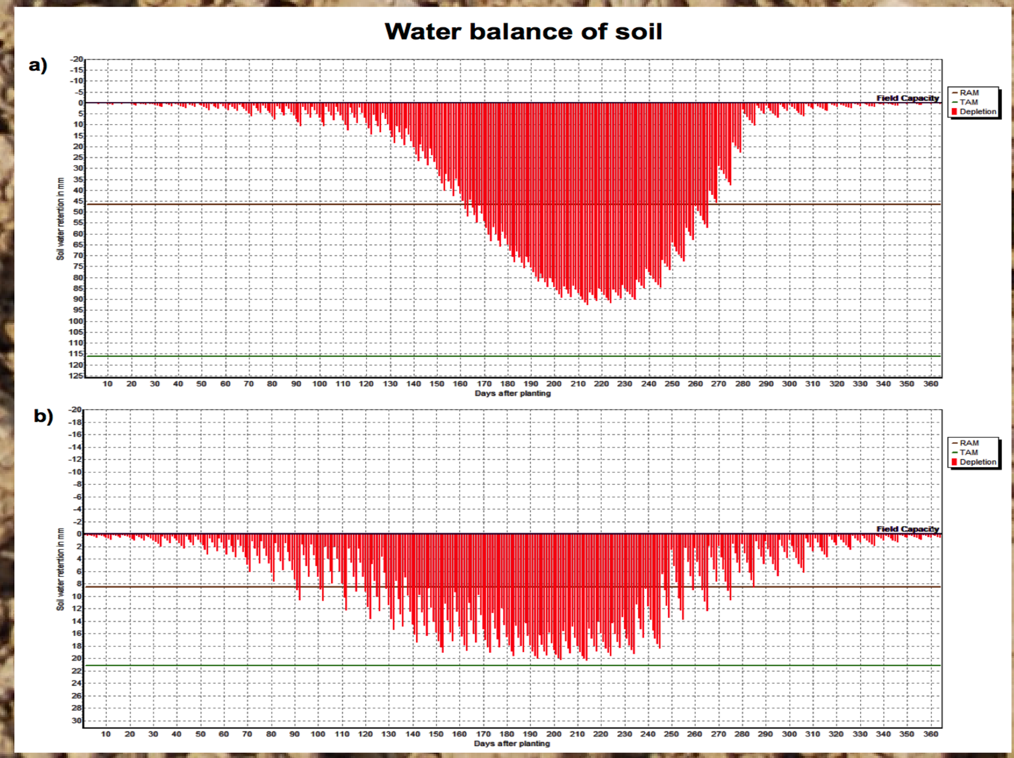

Fig. 6. Water balance of a soil under normal conditions (a) and soil of the landfill covered by perennial herbaceous vegetation (grass).

Key:
RAM = readily available moisture for the grass;
TAM = total available moisture for the grass.

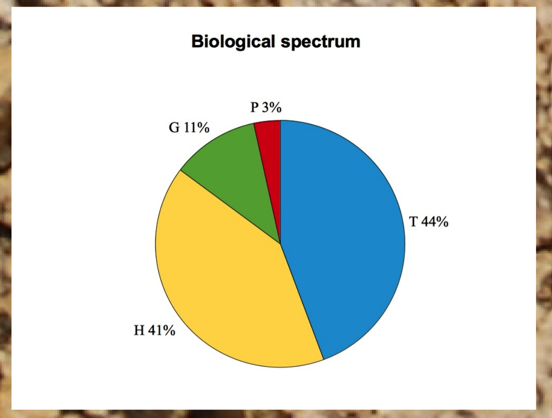

Fig 3. Biological spectrum of flora list.

Key:
T = Therophytes, annual herbs,
H = Hemicryptophytes, perennial herbs;
G = Geophytes, perennial herbs with underground storage organs,
P = Phanerophytes, trees and shrubs with buds over 25 cm above the soil surface.

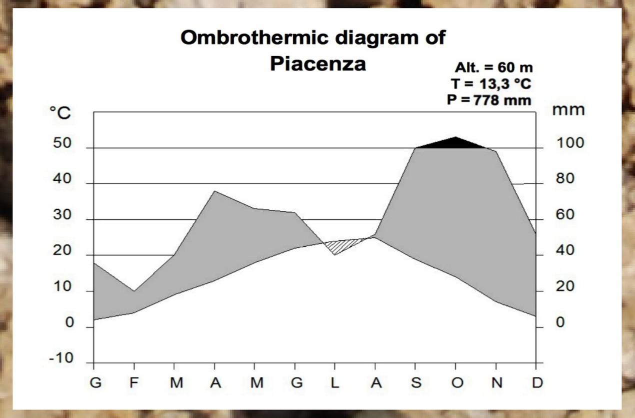

Fig 5. Climate diagram for Piacenza.

Key:
x-axis = months,
primary y-axis = temperature,
secondary y-axis = rainfall.

Conclusions

Most of the soils sampled display a water retention curve which highlights the low water holding capacity of these soils. The study carried out by the official method detected field capacity at low water content and points of wilting at high humidity/water content.
The climate diagram showed a slight dry spell, which when added to the low level of human disturbance affecting the area in recent years, does not justify the high presence of ephemeral plant species (Therophytes). Further clarification was obtained by calculating the water balance of the landfill soil, the graph of which reveals that the period of hydric stress is much longer (from April to September). The abundance of Therophytes is therefore due to a marked summer drought whose causes are mainly edaphic, i.e. related to the characteristics of the soil.

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