From Forest Nursery Notes, Summer 2011

153. Preparation of artificial substrates for plant growth optimization in environmental restoration. Cella, R., Ciccu, R., and Digita, S. D. IN: 12th International Symposium on Environmental Issues and Waste Management in Energy and Mineral Production SWEMP 2010, Proceedings. Czech University of Life Sciences, Prague. 9 p. 2010.

NOTICE: THIS MATERIAL MAY
BE PROTECTED BY COPYRIGHT
LAW (TITLE 17, U.S. CODE)

Preparation Of Artificial Substrates For Plant Growth Optimization In Environmental Restoration

R. CELLA, R. CICCU and S. DESSÌ
DIGITA, University of Cagliari, Italy

Abstract: The paper deals with with the problem of identifying a the most suitable artificial substrate, obtained by mixing varying proportions of natural components, for root formation on *Artemisia arborescens* L. cuttings.
For this purpose different substrates have been prepared obtaining the growth curves as a function of time for different clones of the plant. For each of them water retention characteristics were observed using a special apparatus for measuring water flowrate released by a sample placed inside an air-tight cell versus time under a given pressure inside the vessel.
The results of experimental tests are illustrated and some conclusions drawn concerning the problem of plant growth in arid areas with the goal of keeping desertification under control.

Keywords: Substrate, Plant growth, Environmental Restoration,

Introduction

Mining together with agriculture, urban expansion, deforestation and other human activities, while fostering social and economic progress, also causes considerable damage to the environment, including the loss of fertile soils and the onset of progressive desertification.
Recently new technologies, collectively known as soil bioengineering, have been developed aimed at promoting plant growth through the creation of a new substrate capable of supporting soil forming processes.
A theoretical and experimental study has been undertaken at the University of Cagliari concerning in particular the ability of some pioneer plants to colonize poor soils to initiate the growth of plant species until a stable system is ultimately achieved.
Pignatti (1997, pg 463) defines *environmental recovery* as those actions that "*tend to promote the spontaneous recovery of the indigenous vegetation*" in areas where human activities have led to the destruction of the original plant cover and the removal of the underlying soil.
Generally speaking, the objective of environmental remediation schemes can be said to have been achieved when a site subjected to anthropogenic pressure for production purposes, and that has subsequently undergone remediation for restoring the autochthonous vegetation, blends in perfectly with the surrounding undisturbed lands that have maintained their natural characteristics.
Clearly, this goal presupposes that the mature climax stage of the plants (Pignatti, 1997), be achieved at the least possible cost and in the shortest possible time. With this objective in mind, modelling plant growth of the species to be employed can prove useful (Dennis et al., 1985; Garcia, 1983), each species belonging to one of the successional stages tending towards the climax stage.

The growth curves for these species can be determined as a function of the nutritional content of the different types of artificial substrate used, which are generally placed over the barren soil.
It may happen that the design constraints include the shortage of water for post planting irrigation, especially in arid zones. In these cases the physical/hydraulic characteristics of the substrate (Clarke, 1984), particularly water retention capacity, are equally as important as the nutritional properties.
In light of the above considerations, the present paper describes an exploratory investigation aimed at evaluating the potential use of three different substrates for environmental remediation purposes. The study consisted in measuring the growth of *Artemisia arborescens* L. (Grosso et al., 2007), as well as determining specific hydraulic parameters of the substrates using an experimental apparatus currently being tested.

1 – Experimental Design, Materials And Methods

Tests were conducted following a matrix design (Diagr.1) to enable comparison of the growth of two populations of *Artemisia arborescens* L. (Fam *Asteraceae*), each comprising genetically identical plants obtained via agamic propagation (cuttings), grown on three different types of artificial substrate.

Diagr.1	Substrate 1	Substrate 2	Substrate 3
Clone A (Escalaplano)	CA/S1	CA/S2	CA/S3
Clone M (Mandas)	CM/S1	CM/S2	CM/S3

A total of six growth experiments were conducted for different clone/substrate combinations. Water retention properties of the three substrates were then determined using the experimental set up described in § 1.3

1.1 – Clone selection and Artemisia arborescens L. populations

To eliminate any influence of genetic variability, two mother plants were selected from which the cuttings were taken for producing the clone populations A and M.

Diagr.2	Location cuttings taken	Date cuttings taken	N° cuttings per test
Clone A	Escalaplano	11/07/09	33
Clone M	Mandas	30/07/09	35

Each cutting was grown inside a PVC truncated cone shaped container, with a diameter of over 9 cm and a volume of around 370 cm^3. 30 days after planting, the height of each cutting was recorded every week.

1.2 – Growth Substrates

The test substrates were obtained by mixing an organic with a mineral constituent in the proportions by volume shown in Diagram 3.
The first substrate is "Floragard", a pH-neutral sphagnum peat moss sold in 70 litre bags and having the typical organic content shown in Diagr. 4.

Diagr.3	SUBSTRATE 1	SUBSTRATE 2	SUBSTRATE 3
PEAT	50%	66.7%	83.3 %
SAND	50%	33.3%	16.7%
SAND:PEAT	1:1	1: 2	1:5

Diagr.4	Organic C (% S.S.)	Organic N (% S.S.)	Organic matter (% S.S.)	pH
	20.00%	0.2 %	40.00%	3.5 / 6.5

The mineral constituent consists of sand coming from Loc. S'Arenarxiu (Serdiana). Diagr. 5 shows the lithologic composition of the rock to be ground, while the grain size composition of the end product is shown in Fig. 1.

Diagr. 5	Granite	Porphyry	Quartz
	40%	59%	1%

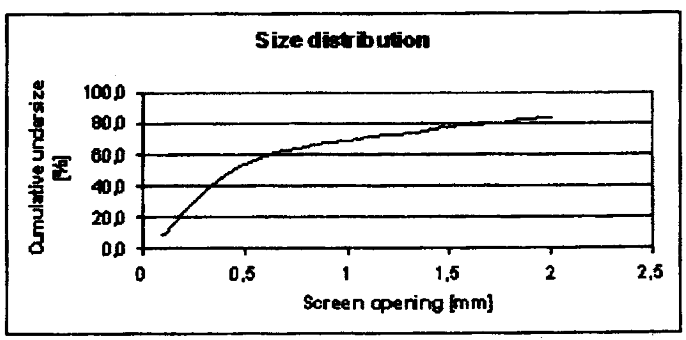

Fig. 1 Particle size distribution of the screend sand used for the substrates.

Prior to mixing, both the organic and mineral components were screened through a 2 mm square mesh sieve so as to retain the coarse material.

1.3 – Experimental set up for water retention determination

In order to gain an understanding of the mechanisms underlying water retention capacity of the three substrates, a prototype experimental apparatus has been developed (Fig 2) consisting of a 1 cm thick clear Plexiglass cylinder, 39 cm high with an internal diameter of 9.5 cm.

Two 15 cm diameter lids are bolted to the upper and lower faces of the cylinder. Two gate valves are inserted into the upper lid for regulating water and air intake, while the lower lid is fitted simply with a gate valve for regulating water flow at the outlet.
The apparatus is provided with gaskets and safety systems to enable internal pressures of up to 8 bar to be attained, as well as two filters, one in wire mesh, the other in cellulose, for retaining the particulate matter contained in the substrate.

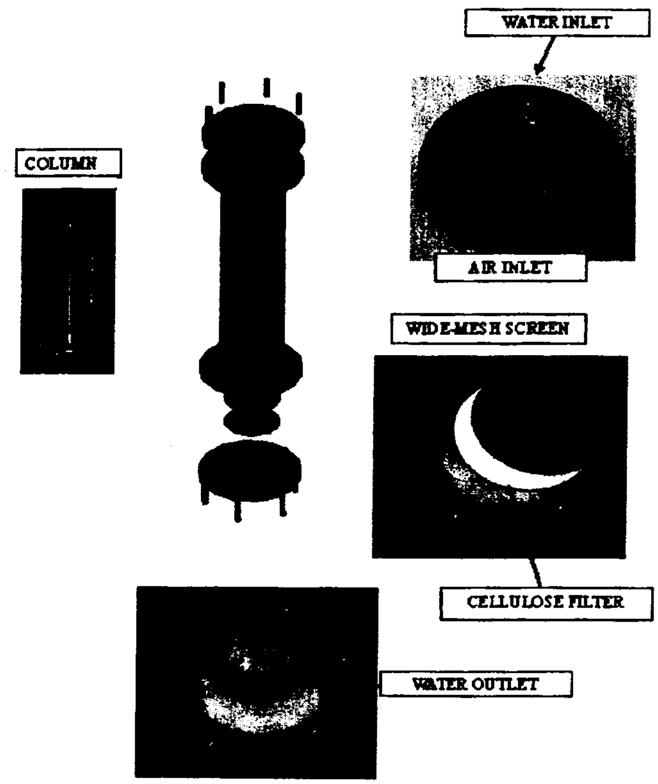

Fig 2. Exploded view of the experimental apparatus

The apparatus also comprises a compressor, an electronic balance and a series of accessories.
In order to obtain comparable substrate-water measurements, the samples were pressed using a 510.3 g circular compaction plate, varying both drop height to 10 cm or 20 cm, as well as the number of drops per sample. In this way two different energy levels Ep_A and Ep_B of 5 J and 30 J respectively were obtained.

$$Ep_A = m \cdot g \cdot h = 0.5103 \text{ kg} \cdot 9.81 \text{ m/s}^2 \cdot 0.1 \text{ m} = 0.5 \text{ J} \times 10 \text{ n} = 5 \text{ J}$$
$$Ep_B = m \cdot g \cdot h = 0.5103 \text{ kg} \cdot 9.81 \text{ m/s}^2 \cdot 0.2 \text{ m} = 1 \text{ J} \times 30 \text{ n} = 30 \text{ J}$$

The following steps were followed in the experimental procedure:
1) Weighting of 800 g of substrate sample;
2) Loading of the sample into the cylindrical vessel and subsequent compaction at either the energy level Ep_A or Ep_A as required by the test plan;

3) Measurement of the initial height (h_i) of the sample column inside the vessel;
4) Saturation with water of the soil, keeping open both water inlet and outlet valves for easier drainage of the excess water;
5) Upon reaching a steady flow, shut off of the water outlet and supply of additional water until forming a thin liquid layer at the top of the sample;
6) Opening of the water outlet (inlet closed), allowing water drainage by gravity for 10 minutes;
7) Increase of compressed air pressure inside the vessel to 0.5 bar and metering the volume of drained water every 30 s over 20 minutes after which flow rate became insignificant;
8) Repetition five times of the above step after increasing the pressure by 0.5 bar increments for each test up to 3 bar;
9) At the end of each series of tests the drained sample was again saturated with water keeping note of the final thickness of the column (h_f).

Step 5 allows the measurement of the *Saturation Volume* (SV), while step 6 gives the Retention Capacity (RC) (Clarke, 1984).
Concerning the results obtained at incresing air pressure (steps 7 and 8), the product between the nominal level of the pressure (P) and the corresponding volume of drained water (V) represents the work to be done for extracting it from the substrate (Salisbury et al, 1978) according to the relationship:

$$P \cdot V = (F/S) \cdot V = k \cdot (F/l^2) \cdot l^3 = F \cdot l$$

where S is the cross area of the column, F is the force acting on it, l is the linear dimension of the sample and k is a constant depending on the geometric features of the column.

2 – Experimental Results And Discussion

We compared the mean and standard deviation of the height attained by the two clone populations grown on different substrates and shown in Tables 1 and 2 for Clone A (Escalaplano) and Clone M (Mandas) respectively.
As Clone A was cultivated for 8 weeks but Clone M only for 6 weeks, the comparative analysis of growth data was restricted up to week six. For this purpose, the last row of Table 2 gives the coefficients of variation of the height Clone A at six weeks.

For both clones, the best results were obtained with Substrate 2, **8.82** cm and **7.81** cm for Clone A and Clone M respectively, while each clone responded differently to substrates 1 and 3.
Comparison of the coefficients of variation at six weeks (Table 2) shows that variations for Clone A are essentially small, while Clone M exhibits greater variability.

Table 1 – Mean, standard deviation and coefficients of variation of height of clone A populations (Escalaplano)						
	Substrate					
	1		2		3	
Week	μ	σ	μ	σ	μ	σ
1	1.63	1.62	2.05	1.79	2.66	1.62
2	3.12	2.17	3.7	2.34	4.46	2.63
3	4.57	2.52	5.02	3.01	6.2	3.05
4	5.51	3.06	6.41	3.67	7.31	3.56
5	6.35	3.31	8.15	4.25	8.08	4.05
6	6.66	3.67	8.82	4.6	8.46	4.19
7	7.4	3.99	9.81	4.82	9.1	4.6
8	7.48	4.18	10.26	5.01	9.36	4.68
Cv_{A8}	0.56		0.49		0.50	

Table 2 – Mean, standard deviation and coefficients of variation of height of clone M populations (Mandas)						
	Substrate					
Week	1		2		3	
	μ	σ	μ	σ	μ	σ
1	3.51	2.18	3.3	2.49	2.01	1.74
2	4.49	2.59	4.56	3.36	2.68	1.79
3	5.77	3.13	6	4.19	3.66	1.89
4	6.05	3.13	6.93	4.68	3.86	1.89
5	6.24	3.2	7.39	5.26	3.99	1.8
6	6.56	3.24	7.81	5.35	4.13	1.74
Cv_{M6}	0.49		0.69		0.42	
Cv_{A6}	0.55		0.52		0.50	

Regarding the substrate-water measurements taken using the apparatus described in §1.3., Tables 3, 4 and 5 show the experimental values obtained for compacted substrates with $Ep_A = 5$ J.
The first substrate releases only a small amount of water as it is able to absorb less, but exhibits good drainage properties. Substrate 3 holds a larger amount of water in its macro- and micropores and less force is required to extract it. The second substrate on the other hand already releases the greatest amount of water at low pressures.
On the basis of these findings, we opted for plant growth substrate 2, as constant water release is required for optimal growth.

Table 3 - Substrate 1 ($Ep_A = 5$ J)					
	Pressure [bar]				
Column height	0.5	1	1.5	2	2.5
- Initial h_i [cm]	11	11	11	11	11
- Final h_f [cm]	10.5	10.5	10.5	10.5	10.3
Water saturation [ml]	477.6	464	457.3	458.6	465.4
% Water	18	17	16	14	14
% Volume reduction	4.5	4.5	4.5	4.5	6.4

Table 4 - Substrate 2 ($Ep_A = 5$ J)					
	Pressure [bar]				
Column height	0.5	1	1.5	2	2.5
- Initial h_i [cm]	14.3	14	14	14	14
- Final h_f [cm]	13.6	13.5	13.3	13.2	13.3
Water saturation [ml]	451.5	401.7	403.9	409.2	402
% Water	43	29	21	16	9
% Volume reduction	4.9	3.6	5	5.7	5

Table 5 - Substrate 3 ($Ep_A = 5$ J)					
	Pressure [bar]				
Column height	0.5	1	1.5	2	2.5
- Initial h_i [cm]	20	20	20	19.5	19
- Final h_f [cm]	19.5	19.5	19	18.5	18.4
Water saturation [ml]	681.8	713.1	703.5	707.1	661.7
% Water	31	26	25	23	26
% Volume reduction	2.5	2.5	5	5.1	3.2

To evaluate the influence of degree of compaction, Substrate 2 which performed best in the growth tests, was compacted with $Ep_B = 30$ J. We observed that the reduction of macropores, in which free water is stored, resulted in a smaller quantity of water being needed for saturation.
The same effect was observed when increasing pressure from 0.5 bar to 1 bar and to a lesser extent to 1.5 bar.

Table 6 – Substrate 2 ($Ep_B = 30$ J)						
	Pressure [bar]					
Column height	0.5	1	1.5	2	2.5	3
- Initial h_i [cm]	13.6	13.3	13.3	13.3	13.3	13.3
- Final h_f [cm]	13.1	12.9	12.9	12.9	12.9	12.8
Water saturation [ml]	411.9	399.8	408.9	412	446.7	458.1
% Water	35.5	23.8	14.1	21.7	18.0	14.4
% Volume reduction	3.7	3	3	3	3	3.7

Table 7 shows the parameters that provide a comparison of the data given in the previous tables, from which it emerges that the relative increase in weight of the peat-like material content gives rise to:

1) a decrease in specific weight γ;
2) an increase in end weight.

Table 7					
Substrate	Start weight [g]	End weight [g]	Total water [ml]	Initial moisture [%]	γ [kN/m^3]
S1 ($Ep_A = 5$ J)	800	1039.4	768	12.97	3.14
S2 ($Ep_A = 5$ J)	800	1137.5	862.7	10.35	2.42
S3 ($Ep_A = 5$ J)	800	1265.3	1404.6	14.71	1.73
S2 ($Ep_B = 30$J)	800	1123.6	927.3	14.71	

3 - Conclusions

As mentioned in the introduction, the goal of the exploratory investigation was to devise a methodological approach to environmental rehabilitation measures aimed at optimizing not only growth curves, but also water use, that in some cases may be subjected to severe constraints .
In this context, the choice of substrate needs to be tailored to the specific circumstances, evaluating the values of the biometric and hydraulic parameters. With regard to the latter, the experimental apparatus described in §1.3 proved useful though clearly there is room for improvement. These improvements should concern automation of parameter measurements by means of suitable hardware interfaces and software, as well as the identification additional parameters.

Acknowledgements

The authors wish to acknowledge Nuova Cem.Ar. Granulati Srl Strada St. 387. km. 23.500 09040 Serdiana (CA), Italy for having supplied and characterized the mineral component of the substrates.

References

Clarke, R.T., Mathematical models in Hydrology. *FAO Irrigation and Drainage Paper,* 1984 (FAO: Rome).

Dennis, B., Brown, B. E., Stage, A. R., Burkhart, H. E., Clark, S., Problems of modeling growth and yield of renewable resources. *American Statistics*, 1985, **39**, pp. 374-383.

Garcia, O., A stochastic differential equation model for the height growth of forest stands, *Biometrics*, 1983, **39**, pp. 1059-1072.

Grosso, M., Cella, R, Baratti, R., Development of a probabilistic model for the plant growth in the nursery phase. In *CIGR Section VI International Symposium on FOOD AND AGRICULTURAL PRODUCTS: PROCESSING AND INNOVATIONS*, 2007 (Naples, Italy), pp. 24-26.

Pignatti, S.(Ed.), *Ecologia Vegetale*, 1997 (UTET, Torino).

Salisbury, F.B., Ross, C.W., *Plant Physiology*, 1978 (Wadsworth Publishing Company: Belmont (CA), USA,).

CZECH
UNIVERSITY
OF LIFE SCIENCES PRAGUE

Severočeské doly a.s.
Chomutov
člen Skupiny ČEZ

12th International Symposium on Environmental Issues and Waste Management in Energy and Mineral Production SWEMP 2010

May 24-26, 2010

Czech University of Life Sciences Prague, Czech Republic

Proceedings

Editors:
P. Sklenička, R. Singhal, I. Kašparová

This publication was supported by research plan of the Ministry of Education, Youth and Sport of the Czech Republic NPVII 2BO 8006 – "New approaches to research of effective procedures for recultivation and rehabilitation of devastated regions", and is an outcome of long-term, fruitful co-operation with Severočeské doly a.s. company.