Determination of substrate characteristics for soilless culture

Lemaire F.

in

Choukr-Allah R. (ed.).
Protected cultivation in the Mediterranean region

Paris : CIHEAM / IAV Hassan II
Cahiers Options Méditerranéennes; n. 31

1999
pages 347-356

DETERMINATION OF SUBSTRATE CHARACTERISTICS FOR SOILLESS CULTURE

F. LEMAIRE
Institut National de la Recherche Agronomique, Station d'Agronomie,
Centre d'Angers, France.

Abstact: To test the ability of a material to be used as substrate, it is important to know the main physical, chemical and biological properties required for plant growth. Different technics are used to measure the total porosity, the water and air volume contents, the available water, the cation exchange capacity, the pH water, the electrical conductivity, the actual and future nutrient potential, the biostability and the receptiveness to benificial or phytopathogen microorganisms.

INTRODUCTION

The use of growing medium instead of soil in soilless cultures has emerged rapidly. Indeed, encompassing the roots in a limited volume imposes non limiting physical, chemical and biological properties on substrates. It appears quickly that new technics or modifications of known soil methods must be proposed for determination of properties, for example Penningsfeld and Kurzmann (1966), Anstett (1976). Two situations can be distinguished : analysis to control the making and to verify the conformity of the substrate ; analysis to follow the properties evolution during the growing in order to correct them if necessary.

This paper gives the principle of the used technics but not the directions for use because many procedures are existing in different countries.

SAMPLING METHOD

A sample is made with a small substrate quantity in comparison with the importance of the amount to be sampled but sufficient to fulfil the needs for laboratory analysis.

1- Sampling before the culture beginning

Substrate is delivered in bulk or in bag. In the first case, samples are taken in six spots distributed in the pile with three depths. These elementary takings are brought together, to constitute a mean sample of three liters for physical analysis. To avoid a possible materials selection, the quarter method is used (Fauche and Bourdain, 1996) : four parts are taken in two opposite diameters.

2-Sampling during the growing

Ornamental growings in containers and pots with mixtures of peat, ground pine barks, woody fibers, sand, expanded clay, perlite, vermiculite

If the substrate is homogenous and in case of big containers (7 liters and more), a probe stick is used ; in the case of fibrous or coarse mixtures, the "slice" method is employed. Two opposite "slices" are cut on the total height of the container. The situation of the slices is important when drip irrigation because of the dripper position.

To avoid problems of substrate sampling, Lemaire et al. (1995) advocate the induced percolate technic which is less destructive but allows only the determination of substrate nutrient potential.

Vegetable and cut flowers growings in slabs and bags with mineral or organic fibers.

The substrate is not taken but the circulating solution is sucked up with syringe at different places in the growing.
Whatever the sampling is before and during the culture, the substrate takes are analysed with the same technics.

DETERMINATION OF HYDRIC CHARACTERISTICS

In order that a material can be used as substrate, it is necessary to determine its properties towards the water and the air, which are bound to the concept of total porosity.

Total porosity

The total porosity is the volume of the empty spaces in relation to the total volume taken by the material.
To measure this property, the measurement of the apparent volume and the true volumic weights have to be done. The expression of the porosity is the following :

$$\text{porosity} = \frac{\text{dry true volumic weight - dry apparent volumic weight}}{\text{dry true volumic weight.}}$$

1. The dry true volumic weight is calculated from the following formula :

$$\text{dry true volume weight} = \frac{100}{\frac{m.0}{1,55} + \frac{100 - m.0}{2,65}}$$

with m.o = total organic matter content % weight.
1,55 = true volumic weight of the organic matter.
2,65 = true volumic weight of the ashes.
The total organic matter content is obtained by loss of mass on ignition.

The air and water retention

1. The total porosity is filled by air and water. To know the relative contents of the two components, it is necessary to study the variation of the water content in relation to the matricial potential of the water expressed in kPa or in pF units (pF = log h cm).

The pF or waterrelese curve is very specific of the hydric properties of a substrate (Lemaire et al., 1990). The following suitable characteristics can be obtained : the water volume at pF1 in %, the air volume at pF1 in % ; the water volume at pF2 in % ; the available water defined by the water amount between pF1 and pF2. (Figure 1)

Most of the analysis technics (ISHS, CEN, AFNOR) use the concept of the pF curve to characterize hydrically a material.

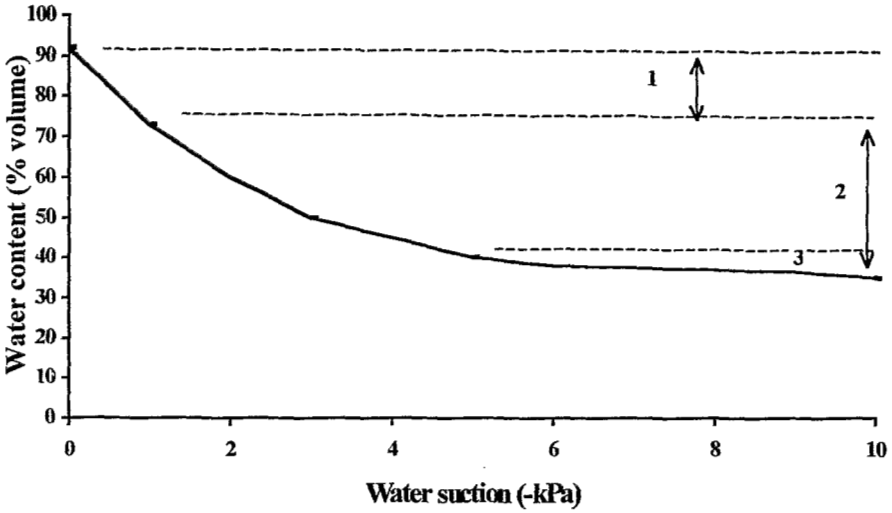

Figure1. Variations of the substrate water content with the suction potential
P = porosity; 1 = air content at - 1 kPa suction; 2 = water availability;
3 = buffer power of hydric potential between - 5 kPa and - 10 kPa suction

2. Principle of the technic.

The water saturated sample is put in a known volume ring, submitted to an increasing drying out by suction, weighed and oven dried at temperature 105°C.

The apparatus is formed by a suction table made by a box filled with sand of determined particle sizes (0,085 à 0,2 mm) ; this sandbox has a drainage tube linked up with a suction regulator (figure 2). This one allows to produce a given depression measured in water height : for example, 10 cm (pF1) and 100 cm (pF2).

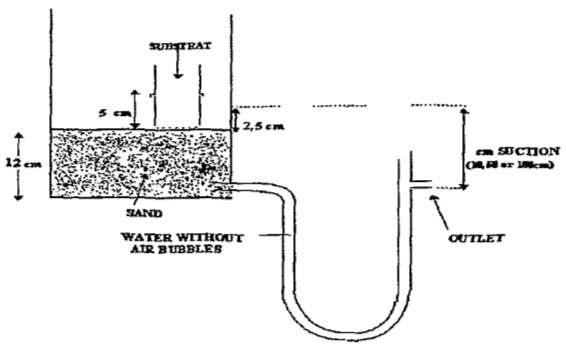

Figure 2. Suction regulator

3. Used procedures

Different procedures used in the three following technics : AFNOR, CEN and ISHS are shown in the table 1. The ring volume, the time of sample wetting before suction, the time of suction, the drying and the organic matter content determination are not the same. Table 2 shows consequences for the different hydric parameters values of two substrates. In relation with the kind of substrate, the three methods give same or different results : for example water volume at pF1 values are different for sphagnum peat but similar for pine barks ; apparent volumic weight values are similar for sphagnum peat but different for pine bark 5. Few variations are existing for the total porosity of the two substrates. Those differences are due to the ring volume, the wetting time and the duration of the suction.

Table 1. Procedures used by AFNOR, CEN, ISHS methods for hydric properties determinations (Mongondry, 1996)

	AFNOR	CEN	ISHS
Volume determination	double ring	double ring	double ring
Ring volume	384,88 ml	± 415,0 ml	192,42 ml
Wetting of the sample	three times 24 hours	24 hours in 2 liters pots 48 hours with a 50 cm suction ; fill the rings and wetting during 24 h	48 hours
Suction duration	sandbox 72 hours	sandbox 48 hours	sandbox 48 hours for every pF value
pF value	pF 1	pF 1	pF 1, pF 1.5, pF 1.7, pF 2
Drying	till constant weight	till constant weight	till constant weight
Organic matter content	6 hours at 550°C	16 hours at 550°C	6 hours at 550°C

Table 2. Hydric characteristics of pine bark and sphagnum peat determined by three methods : AFNOR, ISHS, CEN (Mongondry, 1996)

	AFNOR Method		CEN Method		ISHS Method	
	Sphagnum peat	Pine bark	Sphagnum peat	Pine bark	Sphagnum peat	Pine bark
Apparent volumic weight g/cm^3	0.072	0.209	0.070	0.172	0.071	0.181
True volumic weight g/cm3	1.96	1.70	1.52	1.59	1.96	1.69
Porosity % vol	96.2	87.6	95.3	89.0	95.2	88.8
Water volume % at pF 1	62.9	35.0	50.2	34.4	69.2	36.6
Water volume % at pF 2	ND	ND	ND	ND	32.5	30.7
Available water %	ND	ND	ND	ND	36.7	5.9
Air volume at pF 1	33.3	52.6	45.1	54.6	26.0	52.2

DETERMINATION OF CHEMICAL CHARACTERISTICS

The determination of total elements contents in a substrate does not give any valuable agronomic informations except for the total C and N contents.

The pH

The presence of H^+ in a liquid medium determines the acido-basic reaction. The pH of a substrate is the pH of the solution around the substrate because the H^+ protons in the solution are balanced with those fixed by the CEC. To determine the pH, water is added to the substrate with a view to

obtain a water / substrate volumic ratio 1,5 (100 ml substrate and 150 ml water). After 15 minutes or one hour according to the technics, the pH water is determined with a pH meter. Most of substrates have a pH water between 3,5 and 9. (Table 3).

Table 3. Cation exchange capacity (CEC) and pH $_{H2O}$ of substrates

Type of materials	CEC eq/m^3	pH(H_2O)
Natural organic materials		
French brown peat	200 à 400	5.0
Compost hardwood bark	184	7.5
Waste compost	158	6.5
White peat	115	4.5
Fresh ground pine bark	95	5.1
Woody fibre	10	4.5
Natural mineral materials		
Coarse vermiculite	27	7.5
Coarse perlite	6	6.9
Fine vermiculite	< 2	8.7
Rockwool	0	7.5
Sand	0	6 à 8

The Cation Exchange Capacity (CEC)

It indicates the substrate ability to keep the major and the minor mineral elements required for the plant nutrition and supplied by fertilization.

This property is given by the mineral (clay) and organic (humus) colloïds which have generally negative charged surfaces. The CEC is expressed as milliequivalent / liter substrate.

The presence of organic materials in the substrates needs the use of a special technic in view to not alter the organic matter. The principle is the following : CEC saturation with H^+ protons by HCl ; substitution of H^+ ions by Ba^{++} ions (baryum acetate) ; determination of H^+ ions concentration with a basic liquor.

Table 3 shows the measured CEC with this method for different substrates. Two groups can be defined : with CEC, sphagnum and brown peats; without CEC, perlite, woody and mineral fibers, sand. The two groups are used in mixtures for container and pot crops but the second group is only devoted to vegetable and cut flowers growings.

The nutrient potential

This property depends on the nutrient quantity present in the substrate, the CEC value and the kind of grown plants with high or low mineral requirements. A limit is given to the nutrient potential by the salinity of the solution around the roots. The salinity is expressed by the concentration of water soluble salts (g/l substrate) or by the measure of the electrical conductivity EC (mS/cm) of the solution. Penningsfeld and Kurzmann (1966) have divided horticultural plants into three classes according to their salinity resistance : classe I, high sensibility ; classe II, medium sensibility ; classe III, salinity resistant. Gabriels (1972) has listed a great number of plants in each class. The electrical conductivity is determined in the water extract obtained for the pH measurement with the aid of a conductivimeter. The interpretation of the EC data takes into account the plant nature and the substrate dry volumic weight as shown in table 4.

Table 4. Substrate analysis by water extraction. Standards for results interpretation (Lemaire et al., 1990)

a. Salinity rates in g/l substrate

Plant	Deficiency	Mean values	Toxicity
1. High sensitive plants to salinity	< à 0,5 g/l	1 à 1,5 g/l	> à 2 g/l
2. Mean sensitive plants to salinity	< à 1 g/l	1,5 à 3 g/l	> à 4 g/l
3. Resistant plants to salinity	< à 1,5 g/l	3 à 5 g/l	> à 6 g/l

b. Mineral contents in water extract

Plant	N NO_3	NO_3^-	N NH_4^+	P_2O_5	K_2O	CaO	MgO	Cl^-
1	150 à 220	660 à 1000	Not Superior to the quarter of NO_3^- content	60 à 90	180 à 270	70 à 110	30 à 50	< à 150 according to the species
2	220 à 450	1000 à 2000		90 à 180	270 à 540	110 à 220	50 à 100	
3	450 à 750	2000 à 3300		180 à 300	540 à 900	220 à 370	100 à 150	

To know the availability of the cations and anions in the growing medium, extractions with different reagents : water, CaCl2, have been proposed. Schmilewski and Günther (1988) have recorded them in the different european countries. Gabriels and Verdonck (1991) have proposed a reference method from the works of a ISHS working group for standardization of analytical methods.

More recently, Alt and Peters (1993) have proposed a method which uses CaCl2 + DTPA reagent allowing to determine cations and anions with one extraction. Lemaire et al. (1995) have compared results obtained by the water and the CaCl2 + DTPA methods. The nitric and ammoniacal nitrogen, potassium and sodium contents have similar values with the two methods ; with the CaCl2 + DTPA method, the P content depends on the supplied P form : mineral or organic.

The use of reagent such as ammonium acetate and citric acid allows to determine the total nutrient potential : exchangeable potassium, calcium and magnesium contents and assimilable phosphorus as in the soil.

DETERMINATION OF BIOLOGICAL CHARACTERISTICS

1. Receptiveness to microorganisms (phytopathogens, mycorrhiza and bacteria) : technics are existing but are not commonly used by routine analysis.

2. Biostability of organic materials.

a- The plant and animal organic matter is bound with the decay process under the influence of microorganisms. Two simultaneous ways exist in the decay process : quick mineralization ; humification and slow mineralization. The original matter disappears partly and a new material, the stabilized organic matter appears. It is accompanied by a more or less loss of organic matter

according to the kind of raw material : for example, 75 % in three months for a wheat straw (Lemaire, 1993).

2-Definition of the biostability

The biostability is the property of an organic material to loss small amount of organic matter and to keep its primordial physical and chemical properties during several months.

3-Used technics

a- the total C and N contents give the C/N ratio. Higher the C/N ratio, slower the decaying, better the biostability is. Table 5 from Allison (1973) shows the C/N ratio for barks and woods of different species.

Table 5. Bark C/N ratio and percentage of C released as CO2 after 60 days soil incubation (from Allison, 1973)

Species	C released as CO2		
	C/N ratio	Without N	With N
Redcedar	223	17.7	18.2
Cypress	145	5.9	4.5
Western larch	309	5.6	4.8
Red fir	189	9.0	7.5
White fir	383	10.4	7.9
Douglas fir	1285	10.6	7.8
White pine	509	5.0	3.8
Shortleaf pine	400	4.4	4.1
Loblolly pine	620	3.6	3.5
White oak	322	27.4	26.4
Red oak	162	22.9	32.2
Hickory	116	11.7	9.6
Yellow poplar	135	37.5	42
Chestnut	173	23.1	27.6
Black walnut	254	13.7	11.4

b- respirometric technics : Cappaert et al. (1976), Nicolardot et al. (1986) measure the oxygene consumption and carbon dioxyde production by an organic sample in a special apparatus. Nicolardot et al. (1986) give two step values of oxygen consumption : under 7 mg O_2 per g dry matter, the product is stabilized ; over 15 mg O_2, the material is surely not composted.

c- biochemical technic of C analysis to calculate the index of biological stability (ISB) (Lineres and Djakovitch, 1993). Contents of soluble, hemicellulose, cellulose and lignine C are determined in an organic sample.

d- biostability index (Lemaire, 1996) calculated from curves of organic matter evolution with the time in the conditions of the culture (temperature, moisture, container) without plants. Biostability index is amount of remaining organic matter expressed in percentage of the initial amount of organic matter. A comparison between the technics is shown in table 6. The C/N ratio does not correlate well with the two others.

Those determinations are still in an experimental phasis but, will be necessary in the future because many organic materials coming from industrial, agricultural and human activities arrive in the market.

Table 6. Comparison of the biostability appreciation by the proposed technic (biostability index), the C/N ratio, the biological stability index (ISB) for the studied materials

Kind of organic product	Biostability index	C/N	ISB
Yard composts	89 to 96	10 to 13	78
Fine bark compost	97.4	92	60 to 100
Ligno-cellulosic fibers	95 to 97	400	--
Raw coir	100	220	--
Sphagnum peats	85 to 94	20 to 40	80 to 100
Flax wastes	59.6	110	--
Wheat straw	38	80	10 to 30

CONCLUSIONS

The characteristics of a substrate are numerous to appreciate its quality, formed by its advantages and its disadvantages. From this knowledge, a grower could choose the fertilizing and the irrigation technics as the table 7 shows.

Table 7. Classification of growing systems (from Anstett, 1976)

Type	Irrigation	Substrate properties		Fertilization	
		Physical	Chemical	Before the culture	During the culture
1	Continuous	Inactiv	Inactiv		Complete nutrient Solution
2					
3				Neutralization + minor elements	
4	Periodical	Activ	Activ	Neutralization + complete fertilizer	NKP Solution
5				Neutralization + P + minor elements	NK Solution
6				Neutralization + slow-release fertilizers	NKP Solution
7					Surface application of slow-release fertilizer

References

Allison F.E., 1973. Soil organic matter and its role in crop production. Elsevier Ed. Amsterdam, 637 pages.

Alt D. and Peters I., 1993. Analysis of macro and trace elements in horticultural substrates by means of the CaCl2 + DTPA method. Acta Hortic., 342, 287-292.

Anstett A., 1976. Propriétés physiques et chimiques des substrats utilisés pour les cultures en conteneurs. Les cultures en conteneurs. Journées d'étude de l'Horticulture et des Pépinières. XIII, 5-12.

Cappaert I., Verdonck O. and Boodt de M., 1976. A respiratory apparatus for the behaviour of organic materials. Proc. intern. Symp. on soil organic matter studies. 6-16 sept. 1976. Brunswick, IAEA-SM, 211/62, 131-167.

Fauché P. and Bourdain M.A., 1996. Gestion à partir du substrat : a) le prélèvement d'échantillon, b) l'analyse du substrat. CR La Fertilisation en pépinière. Journée du 22 février 1996 Angers. IFHP Ed. Paris 51-62.

Gabriels R., 1972. Tolérance aux sels de cultures agricoles et horticoles. Revue de l'Agriculture, 25 (1), 53-72.

Gabriels R. and Verdonck O., 1991. Physical and chemical characterization of plant substrates : towards an european standardization. Acta Hortic. 294, 249-259.

Lemaire F., 1993. Emploi des matières organiques comme substrat dans les cultures hors sol. PHM Revue Horticole, 336, 10-17.

Lemaire F., Guérin V. and Charpentier S., 1995. A management of fertilization for container crops by means of induced percolate analysis. Acta Hortic. 401, 451-459.

Lemaire F., Sigogne M. and Stiévenard S., 1995. Evaluation du potentiel chimique des supports de culture. PHM Revue Horticole, 361,49-54.

Lemaire F., Dartigues R., Rivière L.M. and Charpentier S., 1990. Cultures en conteneurs et en pots. Principes agronomiques et applications. INRA/PHM Edit., 184 pages.

Lineres M. and Djakovitch J.L., 1993. Caractérisation de la stabilité bioligique des apports organiques par l'analyse biochimique. Matières organiques et Agricultures. Decroux J. et Ignazi J.C. Ed., Blois, 159-168.

Mongondry C., 1996. Méthodes d'analyse des supports de culture horticoles. Etude critiques des projets de norme. Mémoire fin d'études MST Université d'Angers, 39 pages.

Nicolardot B., Chaussod R., Morel J.C., Guckert A., Benistan D., Catroux G., and Germon J.C., 1986. Application simple de la maturité des composts urbains en relation avec leurs effets sur la production végétale. Agronomie 6, 819-827.

Penningsfeld F. and Kurzmann P., 1966. Cultures sans sol ou hydroponiques et sur tourbe. La Maison rustique Ed., 219 pages.

Schmilewski G. and Günther J., 1988. An international comparative study on the physical and chemical analysis of horticultural substrates. Acta Hortic. 221, 425-442.