Glossary of terms and basic characteristics to be reported in scientific publications on growing media

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Abstract

In the research community of growing media and compost science, there is an increasing confusion related to inappropriate use of terms, and to a lack of description of minimal chemical, physical, biological characteristics of growing media for adequate data interpretation in scientific publications. A survey was conducted between the summer of 2019 and the autumn of 2020 among growing media scientists to help addressing these two issues. The first part dealt with a glossary of terms of importance that needed to be defined and clearly pointed to an agreement on most of proposed definitions. The survey showed clearly that a better definition of the following terms are needed: 1) hydroponics and soilless culture, 2) growing media components, especially peat itself, and 3) finally some basic characteristics of growing media. The second part surveyed the minimal characteristics to be given in papers, where respondents unanimously indicated that among chemical properties, pH and electrical conductivity should always be given. Meanwhile, most respondents expressed that nutrient concentration measured by medium saturated extract be given too. The following items were suggested to be "nice to have" for interpreting related data, although not "compulsory given": exchangeable anions, cation, and anion exchange capacity, as well as $CaCO_3$ as indicated by a majority of the respondents. In terms of biological properties, a majority indicated that respiration rate and phytotoxicity tests should be reported. Some respondents suggested that indices of organic matter stability as well as C/N ratio should also be reported and colony forming unit counts and biological analyses would be nice to have. In term of physical properties, a majority indicated that air-filled porosity, easily available water, bulk density, total porosity, and hydraulic conductivity should be minimally given. Meanwhile, a majority also indicated that shrinkage, water retention curve, hydrophobicity test, relative gas diffusivity as well as unsaturated hydraulic conductivity curve should ideally be provided for better interpretation.

Keywords: growing media characteristics, chemical properties, biological properties, physical properties, norms

INTRODUCTION

It is important for scientific papers published in the literature on growing media to provide basic information on growing medium physical, chemical and biological characteristics to allow proper evaluation and interpretation of the data presented, and to allow comparisons between experiments over time and meta-analysis. Some parameters were defined in the past for basic characteristics (de Boodt and Verdonck, 1972) and methods were published in many scientific papers, documents such as CEN standards and more recently in books (Gabriels, 1994; Caron et al., 2015; Raviv et al., 2019). However, additional parameters have been introduced with increasing use of different types of biomass to replace peat and also with the introduction of new parameters linked to transfer and modeling (Gislerod, 1982; da Silva et al., 1995; Caron et al., 2013; Fields et al., 2020). Moreover, it appears that with increasing research efforts widening the application of growing media, there was a need to agree on common terms so that research results remain understandable and comparable on a common basis. These two issues were discussed at the last ISHS symposium on growing media in Milano, Italy, in 2019 and participants agreed to form a working group to address

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them. A survey was sent to the growing media research community to identify a common basis for definitions, terms and concepts that should be reported in future papers and adopted by ISHS. Participants from both research institutions and private industry participated in this survey.

The results of the survey are divided in two sections. The first one proposes definition of terms often used in the growing media sector but with sometimes contradictory or inaccurate definitions. Please note that not all terms are reported here; only included were those proposed in the survey and suggested to be critical to be defined. They represent those terms for which, based on discussion, there was a need to provide a strict definition as much as possible to avoid confusion in scientific reports. For some terms, there was disagreement between participants. The proposed terms are therefore a compromise and reflect the emerging consensus among opinions expressed.

MAIN DEFINITIONS

Soil

A soil is the outer layer of the Earth's crust resulting from physical, chemical and biological weathering over millions of years. It consists mostly of inorganic particles including sand, silt and clay, and a lesser proportion of organic matter sorbed onto mineral surfaces to form micro and macro aggregates or in living and dead forms of microfauna and microflora. Mineral soils are characterized by textural classes based on their particle size distribution and their relative proportion. Mineral soils contain less than 30% organic matter on a dry mass basis while organic soils have a proportion ranging from 30 to 100%. Comments: The definition was modified to refer only and with more accuracy to mineral soils themselves.

Compost

Compost is biologically stable organic material that underwent a composting process (biological process with a thermophilic aerobic, and a mesophilic phase followed by a maturation phase aiming at stabilizing carbon and killing plant propagules, weed seeds and pathogens). Compost is the result of three processes: human management, aerobic decomposition and development of internal biological heat to transform organic feedstock into a new material with limited recognizable portions of the original feedstock.

Soilless growing medium

A soilless growing medium is a material, other than natural mineral soil in the ground, in which plants are grown. It offers physical, chemical and biological support, and to store and exchange nutrients, water and gases. It is made of constituents (or ingredients) mixed in different proportions and additives (ingredients requiring government approval). Comments: Sometimes referred in regulations to as potting soil and substrate. Substrate is commonly use in microbiology referring to materials used to support the growth of microorganisms. A majority of respondents mentioned that "horticultural substrate" should be used instead to avoid any confusion and to reflect the related policies in place in different locations. For the wide majority of respondents, water/nutrient solution should definitely be excluded from soilless growing media and should be referred to specifically as hydroponics (see below), also to be consistent with some definitions in some countries' regulations.

Hydroponics (also refers to water or solution culture)

Hydroponics (also refers to water or solution culture): a specific soilless culture production system. In scientific papers, it should be used for cultivation on liquid media only. Comments: This definition reflects the widest consensus.

Soilless culture or production

Soilless culture refers to a plant cultivation system which does not use natural soil, or at least the majority of the growing medium constituents are not soil; it includes systems using 1) soilless growing media (e.g., peat-, bark-, wood-, or coir-based) in containers (e.g., in pots, troughs, or bags), 2) nutrient solution [deep water culture systems, nutrient film technique (NFT)], and 3) aeroponics, aquaponics.

Sphagnum

Sphagnum: any of an order (*Sphagnales*, containing a single genus *Sphagnum*) of typical mosses that grow only in wet areas where there remains but become compacted with other plant debris to form peat. *Sphagnum* is a genus of approximately 380 accepted species of mosses.

Peat moss

Peat moss is the accumulation of partially decayed vegetation or organic matter derived primarily from mosses. It is characterized by the origin of the predominant plant material, which can include those from the genus *Sphagnum* or *Hypnum* and other plant material that is found in peatlands, bogs, moors or muskegs. Comments: Botanical composition should be given along ideally with color and density (e.g., *Sphagnum* or *Hypnum* peat moss).

Peat

Peat is a brown non-viable deposit resembling soil, formed from the partial decomposition in the wet acidic conditions of the above or upper layers vegetation of bogs and ferns, and harvested mainly for fuel and horticultural purposes. Comments: Botanical composition is usually referred to as three types: moss peat (predominantly *Sphagnum* and sometimes *Hypnum*), sedge peat (sedge, grasses, herbs), and wood peat (formed from trees and shrubs). Types other than *Sphagnum* should be reported since this can have significant effect on the expected behavior: sedge and wood.

Coir

Coir is a natural fiber extracted from the outer husk of coconut. It is fibrous material found between the hard, internal shell and the outer coat of a coconut as it can hold large quantities of water. Comments: As with peat, additional information should be provided. The process of transformation can generate from the fiber milling of husk either fibers or fine particles (the terms such as “pith” and “coco peat” should definitely be avoided as they create confusions, and the consensus is unanimous on this point). The term fines or dust should be used to avoid confusion. The coconut husk can also be crushed to generate medium particles or cut to generate chunks. Details on transformation should be given as this can significantly impact on resulting properties. Additional properties, such as fiber size distribution, dry bulk density, physical, chemical and biological properties, should be reported as well.

CHARACTERISTICS

Physical

1. Easily available water.

Easily available water: water retention curve at a recommended suction range of -1 to -5 kPa. Comments: Should be communicated as EAW(x-y), with x and y as the upper and lower suction values of the range chosen, particularly if different from the -1 to -5 kPa.

2. Air-filled porosity.

Air-filled porosity: this represents the proportion of void occupied by air at a given suction in a growing medium saturated for 24 h and allowed to drain to equilibrium. Commonly reported at 10 cm of water or 1 kPa. Comments: As for easily available water, it should ideally be reported at different suctions. The proportion of trapped air should ideally be mentioned too. For greenhouse or nursery operation conditions, we should use air filled porosity at container capacity (see below).

3. Fiber, aggregate and particle (material) size distribution.

Fiber, aggregate and particle (material) size distribution: percentage of dry weight for different fiber, particle and particle sizes. Comments: Based on comments received, it is proposed to report minimally the following distribution, where X is the dry mass fraction of material.

- X > 20 mm: coarse fragments because of potential negative effect on water and gas transfers when mixed with fines;
- 20 mm > X>2 mm: as large fragments;
- 2 mm > X>1 mm: medium material;
- 1 mm > X>0.25: fine material;
- X < 0.25 mm: very fine material.

4. Bulk density.

Bulk density: refers to material density measured at standardized pressure and moisture content, with sample pre-preparation, expressed in dry mass per unit volume. Comments: Proposed method: EN-13040 and EN-13041. In many experiments the bulk density or the dry bulk density are reported in the methods. However, the bulk densities used in the containers of the experiment are not reported even though they can differ quite a lot from the reported values. This means the cultivation results are influenced by unreported circumstances. It seems both need to be reported; the standard dry bulk density (DBD) to be able to compare the material itself with other literature and the DBD as used in cultivation to exclude artifacts of the handling, potting and all others processing affecting properties.

5. Bulk volume.

Bulk volume: the volume, including the solids and the pores, of an arbitrary growing medium mass. Comments: The method for the field moist bulk density EN 13040 seems acceptable.

6. Wettability.

Wettability: the tendency of growing media mass to hydrate, usually expressed in time units or in rate of water content changes. It is proposed to introduce the definition of static wettability, where material wettability tests are performed in the laboratory under equilibrium conditions, to increase reliability of comparisons between materials (important for both trade and science). The definition of dynamic wettability is also proposed to describe growing media behavior in practical circumstances to increase understanding of the cultivation effects. Comments: For wettability, two main factors of influence are: a) time and b) the moisture level at which the measurement starts. The time and initial volumetric water content of the material should be reported.

7. Capillarity.

Capillarity: movement of water, mostly upward when referred to as capillary rise, under capillary forces (also known as capillary action). Comments: Used most of the time for upward movement but in reality, it can take place in any direction. Capillarity controls water movement in small pores through attraction of water for solid surfaces along small radius open pores or for neighboring water molecules (cohesion). Because the term and process are too vague for characterization purposes, reference to unsaturated hydraulic conductivity curve (see below) may be better and can carry much more useful characteristics for understanding and modeling water processes in growing media.

8. Container capacity.

Container capacity: equilibrium water content obtained on samples after irrigation and drainage for a given time (usually 15-60 min), without depth drainage limitations. Comments: A key point here is that under nursery and greenhouse conditions, growing media rarely reach full saturation and therefore container and field capacity is irrigation system dependent. The term should be used only when it is measured under greenhouse or nursery operation conditions, given the fact that the value is affected by both container size and shape. Methods of measurement should be reported as well as time of drainage. Air content should be reported as it is more relevant to evaluate the risk of overwatering.

9. Shrinkage.

Shrinkage: in porous media mechanics, growing media shrinkage is defined as the specific volume change of soil relative to its water content and is mainly due to the swelling of the material with some material reorganization (structural shrinkage). Comments: Other process simultaneously take place in use: material displacement, compaction by potting machine, organic matter decomposition and growing media settling following multiple irrigation and pronounced desiccation due to plant growth. This is part of the physical stability. Shrinkage should therefore describe the loss of volume because of the desiccation and early drainage only, process dominant under laboratory conditions. An important characteristic as it reflects the stability of the components. Results should be reported as a function of the original dry bulk density of the material.

10. Physical stability.

Physical stability: the ability of a product to maintain its physical dimensions and properties when exposed to conditions normally encountered in its service environment. The loss of the parameter within a given time duration. Comments: This parameter includes shrinkage and also many other processes like decomposition mentioned above. Here, three months is proposed as it is when the major changes in properties are seen and it is the needed time to get a good rooting establishment, after which the root system will start playing a very significant role in the evolution of the properties (Kerloch and Michel, 2015). The two parameters that are minimally proposed is the growing media volume loss and the change in air-filled porosity after the potting step and three months of use, a time that can be somewhat shorter for some specific crops. Alternatively, oxygen uptake rate may provide more relevant information according to some participants.

11. Relative gas diffusivity.

Relative gas diffusivity: the soil-gas diffusivity for a given gas in a growing medium (Ds) is commonly expressed relative to the diffusivity of this same gas in free air (Do) as the As for organic matter, authors should report multiple values: a value expressed per g of dry weight organic matter, a value per unit of rooting media volume; and the DBD and OM of the medium as used (i.e., in the pot, not in the lab method) gas relative diffusivity (Ds/Do). Comments: During storage, gas exchange takes place predominantly in the air-filled pore space, and gas exchange processes are then related to gas diffusivity, a property dependent on pore shape, size and connectivity. The parameter should be reported as relative gas diffusivity (Ds/Do) to be independent of the gas used for characterization. Also, as air-filled porosity and unsaturated hydraulic conductivity, it is strongly dependent on container geometry and sizes, and therefore should be reported at a standard water potential equilibrated after full saturation as otherwise the value will be highly variable. The value of -1 kPa may be used as a standard and as a minimal characterization. Many studies have reported that there are good relationships between relative gas diffusivity and plant performances, better than air filled porosity (Allaire et al., 1996; Caron et al., 2010).

Chemical

1. Electrical conductivity (EC).

Electrical conductivity (EC): conductivity (or specific conductance) of an electrolyte solution is a measure of its ability to conduct electricity. Hence it is a measure for the concentration of ions. Comments: The SI unit of conductivity is Siemens per meter (S/m), however, in the context of growing media, the levels are usually expressed in dS/m. Furthermore, it is important to mention the unit with its reference temperature, since in Europe the reference is at 20°C, and in the USA the reference is 25°C. It is noted that EC value does not distinguish between nutrient ions and non-nutrient ions. The method used and the dilution factor should be reported as well.

2. Salinity.

Salinity relates to the degree of saltiness or the relative proportion of saltiness solutions, which can be either the water used for irrigation or the solution in the rootzone. It refers to the salt content of the growing medium, more precisely to the concentration of undesired ions in solution, though the salt content in the growing media refers to salts also, since the ions in solution are in equilibrium with the precipitated salts. Salinity can be caused by non-nutrient ions such as Na^{+}, Cl^{-}, HCO_3^{-}, and also by excessive nutrient ions such as Ca^{2+}, Mg^{2+}, SO_4^{2-} and even K^{+}.

3. pH.

The pH of a solution in equilibrium with the growing medium. Comments: Methods of extraction and dilution factor should always be mentioned for interpretation and comparison.

4. Organic matter content.

Organic matter content: amount of organic components expressed as a percentage of weight over the weight of the dry sample. Comments: Many participants agreed that the value should also be reported per unit of rooting media volume with the DBD of the medium as used (i.e., in the pot, not in the lab method).

Biological

Suggestions and comments received were numerous and a consensus emerged about the lack of sufficient scientific basis about critical biological parameters to propose a criterion.

1. Biostability.

Biostability refers specifically to the biological stability of the growing medium, which differs from the physical stability mentioned above. Comments: CEN (Comité européen de normalization) has issued two methods for characterizing the stability. The oxygen uptake rate method and the self-heating test (Raviv et al., 2019).

2. Suppressiveness.

Suppressiveness: no definition is proposed as the concept seems too vague to express such in standardized values.

OTHER TERMS TO BE ADDED

pH

Some participants raised the missing definition of pH. Now included above.

Units

Several participants also raised the question of units. It is clear that those amendments should not be expressed as percentage without mentioning units associated (volume per volume or mass per mass, or mass per volume). Also, information about the water content at which the mass is determined would be relevant. For example, fertilizers, lime and additive applications could be expressed as gram per liter of growing media and amendments as gram of dry matter or fresh matter per liter of growing media, but with further reference to their water content at which measurements were performed.

BASIC (COMPULSORY OR MINIMAL) OR NICE TO HAVE (IDEALLY PROVIDED) GROWING MEDIA CHARACTERISTICS TO BE REPORTED IN PAPERS

Table 1 summarizes the number of participants who proposed properties that should be compulsory given in papers (referred to as Minimal characteristics and norms), nice to have but not compulsory to be reported in a paper (referred to as ideally provided), or of limited interest in papers (referred to as unnecessary). Single answers provided by a whole group (one department or one commercial company for example) were counted as one opinion.

Table 1. Numbers of participants classifying the importance of different parameters. There were 23 participants in total.

Characteristic	Unnecessary	Minimally given	Ideally provided
Physical properties			
Air-filled porosity (1 kPa)		**11**	4
Easily available water (-1 to -10 kPa)		**10**	6
Bulk density		**8**	6
Total porosity		**11**	5
Hydraulic conductivity	3	**7**	5
Shrinkage		6	**8**
Water retention curve		5	**10**
Hydrophobicity	3	5	**7**
Penetrometer test	**9**	2	4
Relative gas diffusivity	3	3	**9**
Unsaturated hydraulic conductivity curve	2	3	**9**
Chemical properties			
pH		**14**	1
Electrical conductivity		**14**	
Total analysis	2	**6**	5
Medium saturated extract (direct available elements in the rhizosphere)		**7**	6
Potentially available elements (exchangeable ions)	2	2	**9**
Cation and anion exchange capacity	3	5	**6**
$CaCO_3$	2	4	**7**
Biological analysis			
Phytotoxicity test		**7**	**7**
Respiration rate		**9**	7

Numbers in bold indicate the highest number of positive answers for the different classes assigned to a parameter.

Among chemical properties, participants mentioned that pH and EC should always be given, and a majority of respondents expressed that nutrient concentration measured by medium saturated extract should be given too. Still for chemical properties, exchangeable anions, cation, and anion exchange capacity as well as $CaCO_3$ should be ideally provided for a majority of respondents. For biological properties, most respondents indicated that respiration rate and phytotoxicity tests should be reported. Additional parameters were suggested by some respondents. Indicators (e.g., respiration rate) of organic matter stability as well as C/N ratio should also be reported. Along the same lines, colony forming unit counts and biological analyses (e.g., microbial biomass and/or diversity) would be nice to have too. One group also mention that the ISMO (index of stability of organic matter) should be ideally provided on top of those listed above.

In term of physical properties, there was a clear move toward additional information about dynamic indices. Indeed, while a majority indicated that air-filled porosity, easily available water, bulk density, total porosity, and hydraulic conductivity should be minimally given, a majority of respondents also indicated that shrinkage, water retention curve, hydrophobicity test, relative gas diffusivity as well as unsaturated hydraulic conductivity curve should ideally be provided for better interpretation of growing medium performances.

The survey also asked what the proposed method for those parameters were.

Unfortunately, suggestions were limited to one or two opinions, too low a number to reflect a consensus. In the same time, the majority of respondents indicated that assessment of properties should be performed both under laboratory and operation conditions, which can have a huge impact on methods chosen. In that case, we left that question open and refer readers to specific chapters on methods provided elsewhere for providing characterization in the lab or greenhouse and nursery operation conditions (Raviv et al., 2019; Caron et al., 2008, 2015; CEN methods).

This survey also revealed opinion trends in parameters which will impact on the method chosen. Indeed, many methods characterize static properties while there is a growing interest on dynamic parameters (water and gas exchange), as exemplified by Caron et al. (2015), Caron and Michel (2021) and Fields et al. (2020). Also, as pointed out by many, the basis for expressing analytical results is of importance, with many methods expressing results in percentage of weight while the percentage of volume might be critical particularly when comparing growing media with different dry bulk density (Raviv et al., 2019). Finally, a third point of critical interests is the evolution of growing media during cultivation where properties may change rapidly due to the action of roots, microbial activity, and numerous other processes (Allaire-Leung et al., 1999; Cannavo and Michel, 2013; Kerloch and Michel, 2015). Methods should be chosen to be able to diagnose such evolution during growing media use (Allaire et al., 1996; Caron et al., 2010).

FURTHER WORK ON TERMINOLOGY AND METHODS

The proposed definition will be submitted for approval, modification if necessary and adoption by the ISHS working group on growing media to provide further reference for scientific papers in ISHS publications. This should be seen as an evolving work since context of applications, the development of new production systems and of new growing media will bring additional needs for modifying and proposing new definitions. As indicated by many participants in the survey such additional work should be conducted to develop consensus about methodologies for characterization, on the expression of the characterization results, the development of dynamic measurements and the characterization performed under operation conditions.

CONCLUSIONS

The survey revealed that most of the concepts introduced from the work of de Boodt and Verdonck (1972) are widely adopted and should be included in scientific papers. A clear majority also expressed the wish that indicators for the dynamics of water and gas movement processes related to operation conditions or related to the transfer process itself would be nice to have in the coming future. New criteria and definition should be proposed for biological activity and organic matter status and evolution.

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