Growing Media

Nazim Gruda
University of Bonn

Muien M Qaryouti
National Research and Development Center for Sustainable Agriculture (Estidamah),

This publication capitalizes on the experience of scientists from the North Africa and Near East countries, in collaboration with experts from around the world, specialized in the different aspects of greenhouse crop production. It provides a comprehensive description and assessment of the greenhouse production practices in use in Mediterranean climate areas that have helped diversify vegetable production and increase productivity. Guidance is provided on potential areas for improvement of greenhouse cultivation. More specifically the document aims at strengthening technical capacity in the use of Good Agriculture Practices (GAP) as a means to improve product quality and safety, and achieve sustainable production intensification of greenhouse vegetables in countries in Mediterranean climate areas. The publication is also meant to be used as a reference and tool for trainers and growers as well as other actors in the greenhouse vegetables value chain in this region.

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Good Agricultural Practices for Greenhouse Vegetable Crops - Principles for Mediterranean Climate Areas

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Good Agricultural Practices for greenhouse vegetable crops

Principles for Mediterranean climate areas

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11. Growing media

Nazim Gruda,[a] Muien M. Qaryouti [b] and Cherubino Leonardi [c]

[a] University of Bonn, Institute of Plant Sciences and Resource Conservation, Germany
[b] National Center for Agricultural Research and Extension, Amman, Jordan
[c] Department of Agrarian and Food Production Science, University of Catania, Italy

INTRODUCTION

In Mediterranean countries, most protected cultivation growers use soil – often associated with soil pests, salinity problems and excessive application of pesticides (nematocides, fungicides, insecticides and herbicides). Residues can be a danger to human health (for both consumers and producers) and often lead to environmental pollution. Several techniques have been introduced to the region to overcome such problems with minimum negative impact on the environment and human health: soil fumigation using solar energy, use of grafted seedlings and soilless culture.

This chapter examines growing media used in soilless culture; they represent one of the main solutions for soil problems, have positive effects on the environment and improve fertilizer and water-use efficiency. This is especially the case in Mediterranean countries where shortage of good quality water is a major constraint in protected cultivation. At present, a relatively small proportion (approximately 10%) of growing media – which are very important for a good start to plant cultivation – can be used for the production of seedlings and transplants.

The cultivation of plants in systems without soil *in situ* is defined in literature as "soilless culture" (Gruda, 2009). Many such systems are based on the use of solid rooting media for growing plants. They are usually called "growing media" or "substrates"; however, sometimes terms like "aggregate systems", "supporting media" or "potting soil" are used. With reference to plant cultivation and propagation, "growing media" or "substrates" are defined as all those solid materials, other than soil, which alone or in mixtures can guarantee better conditions than agricultural soil (for one or more aspects). Hence, media of different origin take on the role of soil and provide anchorage for the root system, supply water and nutrients for the plant, and guarantee adequate aeration in the root area (Gruda *et al.*, 2006).

Growing media are used in containers (organic substrates, perlite etc.). However, sometimes they are used in the form of prepared cubes (rockwool cubes for seedling and transplant production), bags and slabs (peat-based substrates and rockwool, respectively), mats (polyurethane foam) and troughs (rockwool); these last three are also used for vegetable production in soilless culture systems.

While development is very country related, from a historical point of view the development of growing media can be expressed in distinct steps (Gruda, 2012a):

- Until the 1950s, horticulturists used gardening soil – mixtures of own composted organic waste and mineral soil, used both for plants with bare roots and for plants with root balls.
- In the 1950s, peat culture substrates, mixed with clay or alone, were developed. These substrates became established in the 1960s and peat became the main component of growing media.
- In the mid- to late 1970s, rockwool substrate spread throughout Western Europe and became important for vegetable cultivation. Tomatoes, cucumbers and bell peppers were grown in rockwool slabs, wrapped in plastic film. Rockwool is still one of the most popular growing media in vegetable soilless culture.
- In the 1980s and 1990s, specific mixtures for specific plants were produced from peat – the ease of rockwool cubes and slabs was combined with good growing properties.

The development and refinement of growing media in horticulture in the 1980s and 1990s coincided with increased ecological awareness. In recent years, many innovative cultivation procedures using new growing media methods have been developed, including systems without a solid medium, as well as aggregate systems in which inorganic or organic substrates are used (Gruda, 2009). Different materials can be used as growing media offering numerous advantages:

Compared with water culture and aeroponics:

- reservoir for water and plant nutrients
- adequate oxygen exchange
- anchorage or support for plant
- lower rhizosphere temperature excursion

Compared with natural soil culture:

- standardization
- light weight
- virtual absence of pests
- cultivation without soil

There are also disadvantages compared with on-soil cultivation:

- volume limitation
- balanced fertilizer ratios requirement
- potential expense
- rapid development of deficiency symptoms

CHARACTERISTICS OF GROWING MEDIA

When choosing a growing medium, knowledge of its characteristics (physical, chemical and biological) is very important, because they affect plant response and production cost. Absence of pests and pathogens is essential; biostability and biological inertia are other parameters to be taken into consideration, particularly when long cycles are carried out or the growing medium is reused during successive growing cycles. There are different national and international standard methods used for the investigation of substrates. In order to simplify international information exchange, the ISHS (International Society for Horticultural Science) method is suggested as a standard.

Physical properties

The physical properties of substrates give important information concerning numerous parameters, for example: water/air ratio (required for proper regulation of irrigation); and volume weight or bulk density. On the basis of such parameters, it is possible to make further calculations of the substrate's mineral content (Gruda and Schnitzler, 1999a; Gruda and Schnitzler, 2004a). Furthermore, it is important to know water distribution and movement at root level.

The fact that growers cannot affect a target change of the physical characteristics of substrates or substrate mixtures within a culture means that it is essential to select the correct substrate before cultivation starts (Verdonck and Demeyer, 2004). Given that the volume of growing media in the containers is relatively small, the requirements regarding a substrate's physical properties and their standardization are very high.

Besides the standard ISHS method, the negative or positive pressure method (mostly used for the investigation of water content in mineral soils) can also be used for the investigation of a substrate's physical properties. Gruda and Schnitzler (1999a) found close relationships between the modified ISHS method and the two other methods at pF = 1.0, 1.7 and 2.0. Other methods are used as industrial standards in certain countries, for example, CEN (European Committee for Standardization) in the EU region.

Volume weight or bulk density (g/cc)

Dry mass per unit volume is related to discrete mineral particles and to amorphous compounds, the latter represented by organic matter. As some media are composed of more than one ingredient, the characteristics of each ingredient contribute to the total of volume weight of the medium (Raviv *et al.*, 2002). Moreover, the quantity of organic substrate in a container (in some degree inorganic as well) can be affected by substrate compression. Different volume weight can lead to different physical properties as well as to diverse nutrient levels in the substrate. Therefore it is recommended to determine the volume weight on the basis of real container/pot conditions (Gruda and Schnitzler, 1999a).

Although it depends on origin and grain size, the average volume weight of peat materials is 0.09–0.20 g cm^{-3} (RAL, 1999). However, the requirements in relation to volume weight and substrates for containerized horticultural plants, e.g. for transplant production, depend on the production system and technology adopted. Volume weight affects the choice of substrates in various ways. For example, to prevent container instability in windy conditions, high volume weight media are required, while for frequently irrigated high intensity greenhouse crops, media of low volume weight are required (Raviv *et al.*, 2002; Wallach, 2008). Low volume weight is also important when transporting growing media.

Particle size

The array of particles can be divided into groups according to size, and the medium solid phase as a whole can be characterized in terms of the relative proportions of its particle size groups. The size and shape of particle size distribution are useful for estimating the hydraulic properties of the media, such as water retention and hydraulic conductivity (Wallach, 2008).

Gruda and Schnitzler (2006) observed a close relationship between the amount of solid particles < 1 mm and the water-holding capacity of substrates. For example, for a fine wood fibre substrate used as a component for production of press pots for vegetable seedlings, the maximum water capacity with 100 percent of particles < 1 mm was about 95 percent, while a complete absence of these particle sizes resulted in maximum water capacity of 70 percent. Therefore, it is possible to control the maximum water capacity by the quantity of fine particles.

Porosity

A growing medium, like soil, consists of three phases: solid, aqueous and gaseous. The pores are filled with air or water according to pore dimension and water content in the substrate. Although the porosity or total pore space (TPS) does not account for pore size distribution or water and air content in the pores, it is often used when characterizing substrates. The TPS of substrates is higher than in soils, where it is approximately 50 percent of the volume. De Boodt and Verdonck (1972) and Fonteno *et al.* (1981) point out that an ideal substrate should have a TPS of over 85 percent. In general, depending on shape, arrangement and particle size, organic substrate TPS is about 85–95 percent (Michiels *et al.*, 1993), while other growing media contain 60–90 percent (Raviv *at al.*, 2002). Analyses generally result in negative correlation of porosity and volume weight of growing media. However, the volume weight cannot accurately determine TPS if components with closed pores, such as perlite, pumice or expanded clay, are used (Bunt, 1976; Wallach, 2008). Plate 1 shows the closed porosity of an expanded clay granule after breakage.

Plate 1
Expanded clay closed porosity

Water and air ratio and pore size distribution

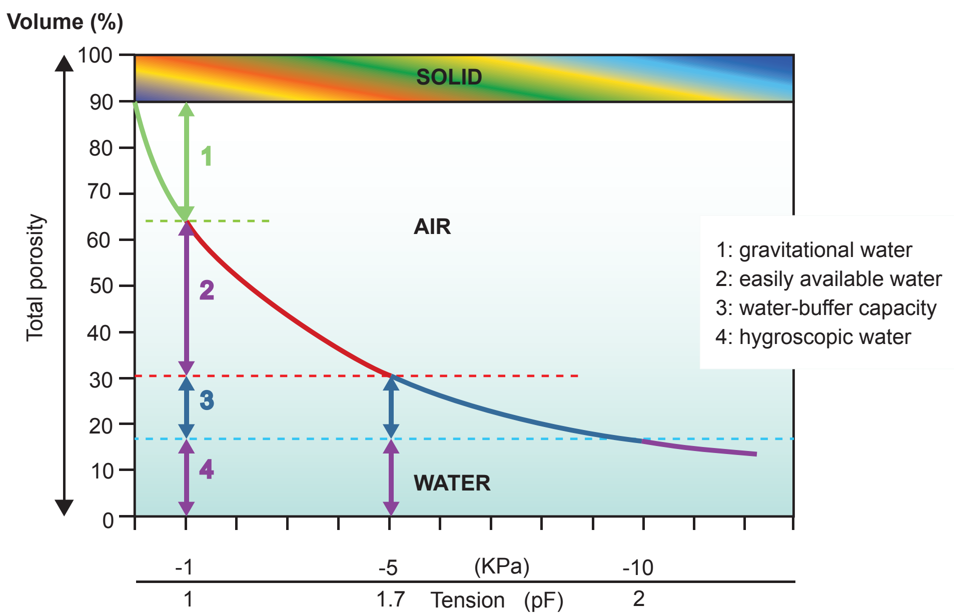
Water and air volume are the most important physical parameters for substrates (Bunt, 1976). Water must be available in the substrate at the lowest possible energy status while maintaining sufficient air supply in the root zone. The two parameters are antagonistic: if the pores are filled with water, air is missing and vice versa (De Boodt *et al.*, 1974). The volume of water that saturates a given volume of substrate is defined as its effective pore space (EPS) or air volume. The difference between TPS and EPS constitutes the volume of closed pores that are not accessible by water (Raviv *et al.*, 2002).

Container capacity (also known as "water-holding capacity") is the amount of water remaining in the container after water stops draining following saturation. The water content for growing media is usually defined at water suction of 1 kPa or at pF = 1.0. Water-holding capacity is one of the most important aspects to consider in irrigation frequency and volume management. However, within the same growing media, a given volume can hold a different amount of water when gravitational water stops draining. While "container capacity" and "water-holding capacity" are sometimes used as synonyms, container capacity is the total volume of water in the container, and water-holding capacity is the water content at pF = 1.0 (Gruda, 2005). Higher containers signify a higher water column (Fonteno *et al.*, 1981; Karlovich and Fonteno, 1986; Martinez *et al.*, 1991; Milks *et al.*, 1989; Gruda and Schnitzler, 2004a). Therefore, relatively less water is held by capillarity and adhesive forces and more water is drained by gravity (Gruda and Schnitzler, 2006). The upper layers of the substrate hold a lower amount of water, while potential water availability is much higher at the container bottom (Figure 1).

Gravitational force is higher in the upper part of the substrate; consequently, the water-holding capacity is lower in taller containers. Taller cells or containers have a larger percentage of TPS space, even if the same growing media or substrate mix is used.

FIGURE 1

Relation between growing media water content and its tension



Perelli and Pimpini, 2004

Therefore, when considering a different water-holding capacity in relation to container shape and height, it is generally better to speak of container capacity rather than field capacity. To this end, the container zoning concept (accounting for moisture characteristics and container geometry) is introduced to quantify the water-holding capacity.

One criterion for substrate classification is the quantity of free water that can be delivered to the plant roots at different water potential levels. However, not all the water in the growing media is available to the plant. According to Figure 1, the following types of water can be found in the substrate:

- Gravitational water (number 1 in Figure 1) – not held in the substrate and moves in response to gravity (the amount of free water in the pF range 1.0–2.0 [-1–-10 kPa] is an important parameter for substrate cultures).
- Easily available water (EAW) (number 2) – directly available to plants (the amount of free water when pF increases from 1.0 to 1.7 [-1–-5 kPa], it fills pores of 60–300 µm).
- Water-buffering capacity (WBC) (number 3) – serves as a reserve, when the plants transpire intensively (De Boodt and Verdonck, 1972) (the amount of free water when pF increases from 1.7 to 2.0 [-5–-10 kPa], it fills pores of 30–60 µm).

- Less readily available water – the amount of free water calculated when water tension increases from pF = 2.0 to 4.2.
- Unavailable water – water held by media at tensions of pF > 4.2 and the plant cannot remove it.

Large pores generally favour rapid drainage and adequate aeration for plants, while water is mainly held in small pores. Therefore, adequate pore size and distribution are critical for a good medium. However, other factors also have an impact. In wood fibre substrates, the pore size distribution of a growing medium is not only influenced by substrate type, but also by particle size, substrate compression (and consequently real volume weight), container size and height, volume loss during a growth cycle, and plant growth and root development (Gruda and Schnitzler, 2004a).

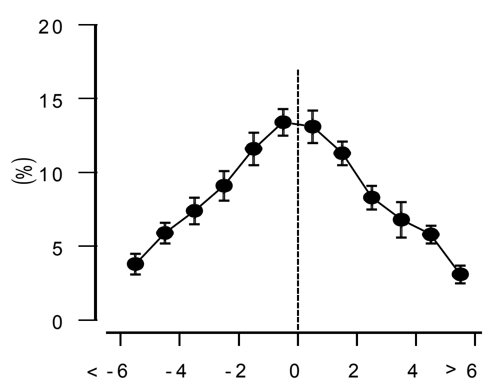
Hydraulic conductivity (cc/min)

The saturated hydraulic conductivity (K_{sat}) of a substrate is an indicator of drainage behaviour, also referred to as permeability, permeability factor, flowing rate and filter rate. Drainage behaviour is mainly defined by the percentage of macropores. Higher K_{sat} implies a higher percentage of macropores, while destruction of these pores leads to decreased K_{sat} (Gruda and Schnitzler, 2004a). According to Raviv *et al*. (2002) particles of smaller-sized individual grains have a larger specific surface area, increasing the drag on water molecules that flow through the medium. Therefore water flows off fastest in coarse growing media, followed by substrates and mixtures with smaller-sized particles.

What is more, in growing media with higher hydraulic conductivity, the water/nutrient solution passes more through the central part of the substrate near to the irrigation dripper and progressively less through the part of the substrate located closer to the container walls (Figure 2). This uneven distribution of nutrient solution in the substrate, apart from affecting the uptake of nutrients and water, can determine variations in electrical conductivity and pH in different parts of the rhizosphere.

Furthermore, as micropores increase, so does pore continuity. This can be documented through the pore tortuosity. Pore tortuosity represents a fitting factor and is linked to the fact that some of the pores are clogged up and that the real pathway for waterflow is longer than

FIGURE 2
Nutrient solution distribution in perlite (% referred to the total) in relation to the distance from dripper projection



Leonardi *et al*., 2001

the apparent one (Caron and Nkongolo, 2004). For peat substrate, the pore tortuosity was found to be closely correlated with the plant growth of *Prunus* × *cistena* sp. (Allaire *et al.*, 1996). Changes in tortuosity can also result from sample disturbances.

Thermal characteristics are mainly related to thermal conductivity and thermal diffusivity. It is important to know the possible effects of these characteristics on growing media and consequently on root temperature; they should be considered in relation to the water-holding capacity of the substrate, which in turn affects the apparent specific heat (cal C^{-1} cm^{-3}).

Chemical properties

For the evaluation of the chemical properties of a growing medium, the most important criteria are pH value, cation exchange capacity (CEC), salt concentration and nutrient content (macro- and microelements).

pH value

pH plays an important role in plant substrates, determining the availability of various nutrients. Although plant pH requirements differ, for most plants optimal nutrient availability occurs when the pH value of a nutrient solution is between 5.5 and 6.5. Higher values, even pH > 6.0, nearly always reduce the solubility of phosphates, iron and most micronutrients. Moreover, high pH values (> 7.5) in the irrigation water are undesirable, given the probable precipitation of Ca and Mg carbonates, as well as orthophosphates, which can clog the drippers.

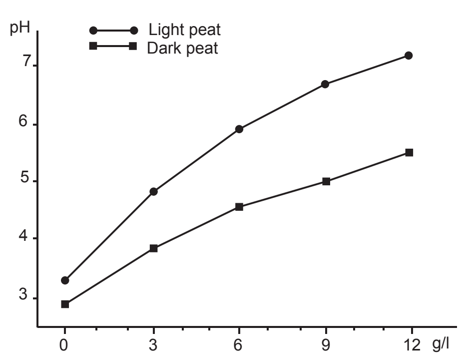
The pH value of the nutrient solution can also be important for the interaction between orthophosphate ions and solid constituents. Thus, low P availability may restrict crop productivity even shortly after P application (Raviv *et al.*, 2002). Significant variations in pH can occur for some substrates, depending on their provenance (Table 1). Therefore, correction may be advisable, taking into account the different reactions of the considered substrates (Figure 3).

TABLE 1
pH value of different substrates

Substrate	pH value
Expanded clay	4.5–9.0
Peat	3.0–7.3
Perlite	6.5–7.5
Pumice	6.7–9.3
Sand	6.4–7.9
Vermiculite	6.0–7.2
Volcanic tuff	7.0–8.0

Gianquinto and Pimpini, 2001

FIGURE 3
pH variations of peat one week after adding different amounts of calcium carbonate to the substrate



Fisher, 1985

In general, lower pH value and lower nutrient and salt content are better for substrate preparation and production. Initial materials with such characteristics (e.g. peat moss) permit substrate manufacture where:

- the pH value can be increased easily by lime addition;
- it is possible to regulate and balance the relatively high pH value of other component materials; and
- the demands or requirements of different cultures can be accurately taken into account, produced and controlled (Gruda, 2005).

Furthermore, it should be considered that pH values for some organic growing media (e.g. pine tree substrates) change during the storage process (Jackson *et al.*, 2009). It is therefore recommended to analyse the substrates immediately before plant cultivation and if necessary to adjust the pH value for optimal plant growth.

Cation exchange capacity (CEC)

CEC gives information about the sorption force and buffering ability of a substrate for nutrients. Substrates with high CEC can store more nutrients and plants are fertilized more intensively. In addition, such substrates buffer the fertilizer or mineral materials better when hard water is used (Gruda, 2005). CEC is considered an important substrate characteristic when nutrient solution is not continuously offered and solid fertilizers are used. The growing media composition is important; continuous fertigation of on-substrate-grown crops enables the use of different substrates with different CEC. For example, the CEC of growing media can be very low (CEC ~1.5–3.5 meq/100 g, e.g. perlite) or high (CEC ~100–180 meq/100 g, e.g. sphagnum peat). However, even inert substrate accumulates organic compounds (e.g. plant roots or decomposed materials during the growth process) which can build up surface charge.

From a practical point of view, considering the small volumes of growing media used for vegetable production, high CEC growing media also lead to limited nutrient-buffering capacity; however, frequent fertigation can mitigate the negative effects.

Salt concentration

Growing media can sometimes have a relatively high salt concentration, for example, when the organic or mineral materials used as a substrate are collected from an area with significant salt sources (e.g. close to the sea). In these cases, excess salt leaching is required prior to substrate use.

Excess salt concentration can also be observed in organic substrates when high rate organic matter decomposition occurs. In most situations, the rate of release of mineral salts is about the same as the rate of uptake by the plants. Therefore, there is no excessive build-up (Handreck and Black, 2005). However, when materials that decompose easily are adopted, problems can be observed. In vegetable production the risk is not so frequent because the seedling production period is too short to determine such an effect, and in soilless cultivation it is not advisable to adopt unstable organic substrates, because decomposition would correspond to outstanding variation of substrate physical characteristics.

Biological properties

A good growing media must be free from pests and pathogens, biologically stable and not toxic.

Phytotoxicity

The use of forestry products (bark, sawdust, woodchips) as well as compost container substrates can involve problems of phytotoxicity. Phytotoxicity depends on the chemical composition of the substrate, which in turn can cause salinity, nutritional disorders and enzymatic or hormonal metabolic alterations (Ortega *et al.*, 1996). High potassium and manganese content (Maher and Thomson, 1991) and the presence of phenolic compounds (Ortega *et al.*, 1996), terpenes, organic acids and fatty acids (Morel and Guillemain, 2004) can be the cause of such problems (Gruda *et al.*, 2009).

Gruda and Schnitzler (2004b) report no plant growth inhibition when bark content in fresh pine or spruce wood fibre substrate is approximately 5 percent. On the contrary, a higher amount of fresh bark negatively affects plant growth. Using hardwood sawdust as a growing medium, it was found that the wood contained phytotoxins, which in return affected plant growth (Maas and Adamson, 1982). Indeed, these compounds have a protection effect and defend woods against insects or infections; therefore, they are toxic to other organisms, such as greenhouse plants cultivated in substrates originating from those materials (Gruda *et al.*, 2009).

Methods such as composting, ageing, leaching, washing, mixing and fertilization have been used to reduce or eliminate phytotoxicity properties (Ortega *et al.*, 1996; Gruda *et al.*, 2000). Gruda *et al.* (2009) reported that extracts from pine tree substrates produced by grinding loblolly pine tree (*Pinus taeda* L.) reduced the germination rate and radicle growth of tomato and lettuce; however, after washing, an improvement was recorded for radicle length of both species. Pre-treatments (e.g. substrate washing) can be recommended for use in the manufacturing process for pine tree substrates or by growers before planting.

Several authors have reported that the growth of fungi on woody tissues in solid-state fermentations on pine chip fermentations decreased toxicity (Dorado *et al.*, 2000; Linares *et al.*, 2003).

N-immobilization
The transfer of inorganic N-compounds into micro-organism bodies through nitrogen consumption and their reservation is known as N-immobilization. Net N-immobilization occurs in organic materials because of the wide range of C/N ratio, for example: in waste paper 135 : 1, in straw 50–100 : 1, in crusts 75–117 : 1, and in wood fibre substrates 100–272 : 1 (Gruda *et al.*, 2000).

Optimal plant growth is ensured only if sufficient nitrogen is available for both micro-organisms and plants (Handreck, 1992); different solutions have been developed for reducing N-immobilization. Composting makes it possible to use waste bark or wood as a substrate; while this process stabilizes the organic substances, it takes a long time and can lead to loss of raw material (Handreck, 1992; Prasad, 1997b).

Other methods involve adding supplemental substances to substrates to eliminate the "weaknesses" of natural wooden materials: for example, hydrolysis of woodchips under pressure in the presence of acids (Lemaire *et al.*, 1989). Using this method, the lignin-cellulose ratio in wood changes from 1 : 2–3 to 1 : 1–2. The supply of nitrogen and other mineral additives prior to manufacturing fibre substrates under high pressure and heat in the presence of water vapour, in order to improve substrate properties, is called "impregnation" (Penningsfeld, 1992).

GROWING MEDIA CLASSIFICATION AND CHOICE

Numerous plant substrates are used in various types of soilless culture systems. Moreover, new materials have been introduced worldwide. The international trend for substrate development tends towards the use of natural resources and renewable raw materials (Gruda, 2005).

Given their diversity, the classification of growing media helps growers make the right choice. Growing media are generally classified into organic and inorganic materials. Inorganic substrates can come from natural sources as well as processed materials; organic growing media can be synthetic (e.g. polyurethane) or natural organic matter (e.g. peat, wood-based substrates). Growing media can also be classified as fibrous (e.g. coir) and granular (e.g. perlite). Bearing in mind that important properties of growing media include their chemical characteristics, they can also be classified as active (e.g. peat) or inert (e.g. rockwool and sand). Herein is described the classification into organic and inorganic materials.

The choice of a substrate for soilless cultivation has technical and financial implications. There is no univocal scheme for the choice of growing media. In several areas where on-substrate cultivation is exploited, growers try to adopt local factory-manufactured products, or locally available cheap substrates, even when there is insufficient information about their physical and chemical characteristics and, consequently, their management.

Choosing a substrate

Desirable properties:

- Low volume weight
- Good reserve of easily available water and good aeration
- Good rehydration properties after drying
- Stable structure
- Good buffering capacity for an optimal pH
- Appropriate pH properties for the crop
- Uniform from batch to batch
- Free of phytotoxic compounds
- Low micro-organism activity
- Pest- and pathogen-free

Aspects to be considered:

- Availability of information on chemical and physical characteristics
- Type of soilless system adopted
- Shape and volume of the container
- Reusability
- Costs

The choice of a given growing medium without standardization does not guarantee correct nutrient solution management, given the more or less notable differences in substrate typology, provenance and batch. For a correct choice of growing media, some desirable properties should be considered, but it is rare to find growing media with all these properties, and in some cases pH correction, disinfection or substrate mixing is advisable to achieve the desired properties. Growing media mixtures are generally used in vegetable soilless greenhouses and in the seedling and transplant industry; they consist of growing media constituents and additives. Growing media constituents include a range of raw materials; general combinations include peat and other organic or inorganic materials and are formulated on a percentage volume basis. Growing media additives include fertilizers, liming materials, biocontrol or wetting agents, and are formulated on a weight basis. It is recommended to use finished products, not to experiment with self-produced mixtures.

Furthermore, the above properties assume importance according to the growing system adopted. Continuously fertigated crops do not necessarily require growing media with a high cation exchange capacity, compared with potted plants and containerized crops. For closed systems (comparison with open systems), a low water-holding capacity does not represent a problem, as it is possible to adopt frequent irrigation without loss of leached nutrient solution which is recycled. Moreover, for subirrigated crops, the suitability of the substrate in allowing capillary rise is very important for an appropriate distribution of nutrient solution in the growing media. In addition, other aspects related to the availability of water and electric power should also be taken into consideration; for example a blackout of a few hours (frequent in country areas) may prove particularly dangerous when a substrate with a low holding capacity is used.

Inorganic growing media

Besides rockwool, various inorganic substrates, such as perlite, tuff (a volcanic porous rock), expanded clay granules and vermiculite, as well as synthetic materials, have been used as growing media (Gruda *et al.*, 2006).

While in older installations, mainly gravel and sand were applied to improve aeration, nowadays lighter materials (e.g. rockwool, originally produced for thermal and acoustic insulation in the construction industry) are widely used (Raviv *et al.*, 2002; Gruda *et al.*, 2006).

Rockwool

Polythene-wrapped rockwool, thanks to its light weight and ease of handling, has become the dominant soilless culture system in Europe and is used throughout the world for both flowers and vegetables, e.g. tomatoes (Plate 2) (Gruda *et al.*, 2006). In addition, cubes or blocks of different sizes are used for seedling and transplant propagation and granulated rockwool is used as a component of potting mixtures. Rockwool is manufactured by melting basaltic rock with limestone and coke at high temperatures and spinning the melt into fibres. Afterwards the fibres are bound together by heating them with additives. Rockwool has a low volume weight of approximately 0.07–0.1 g cm^{-3} and a TPS of 92–97 percent. The main chemical characteristic of rockwool is that it is totally inert, except for some minor effects on pH. The initial pH of the material is rather high (7.0–8.0) and a pH adjustment is therefore required (Smith, 1987). Generally, the setup of a rockwool growing system is simple: rockwool slabs are placed in the rows, holes for plants are cut in the plastic surrounding the slabs, and the slabs are filled with


GRUDA, 2010

Plate 2
Greenhouse tomato plants, cultivated in rockwool slabs

solution. After soaking for about 24 hours, the transplants are placed on the slabs with drainage slits cut at the bottom. A complete nutrient solution is supplied to the rockwool cubes through the irrigation system. The key factor in managing the system is the management of the pH and EC (electrical conductivity) in the slab. Therefore samples of the nutrient solution from the slabs should be analysed periodically; at least once a month the nutrient solution should be analysed and, if necessary, the nutrient solution and frequency and time of irrigation adjusted.

Perlite

The use of perlite provides improved aeration and drainage and optimum moisture retention and nutrient availability. Perlite is not a trade name but the term used for naturally occurring siliceous volcanic mineral sieved and heated to 1000 °C. At these temperatures perlite expands to 4–20 times its original volume, due to the presence of 2–6 percent combined water in the perlite rock, producing a lightweight material with high porosity. Perlite can be used alone or mixed with other substrates for greenhouse plant production. It is a well-established substrate in Europe. The Mediterranean region has seen a rapid expansion of perlite soilless culture systems (growbags), pioneered by Spain, where they are used extensively, mainly for vegetable productions in the Almería and Murcia regions (Grillas *et al.*, 2001). There is a similar growth pattern (albeit on a smaller scale) observed in other parts of the Mediterranean, for example in Greece and North African countries. The high porosity helps to control the water-holding capacity and aeration of the substrate (Grillas *et al.*, 2001).

Vermiculite

Similarly to perlite, vermiculite is produced by heating the ground and sieved material to 700–1 000 °C. Vermiculite is sterile, light in weight and has a high TPS. Its volume weight is 0.1 g cm^{-3}. Vermiculite is used as a sowing medium, covering germinating seeds, and as a component of potting soil mixtures. Media containing vermiculite should be mixed dry; when mixed wet, the desirable physical properties deteriorate because particles tend to collapse flat (Handreck and Black, 2005). While perlite is mainly used to improve the drainage properties in a mix, vermiculite is used to increase the water-holding capacity of a growing medium. It can hold 3–4 times its weight of water. Furthermore, vermiculite can hold positive-charged nutrients such as K, Mg and Ca.

Zeolite

Zeolites are silicate mineral with extremely high exchange capacities. The many different zeolites found around the world vary considerably in hardness and in the proportions of cations they contain (Handreck and Black, 2005). Zeolites possess a relatively high volume weight (1.9–2.3 g cm^{-3}) and are therefore used in substrate mixtures; however, they are also used as single growing media. In a study with tomatoes, Savvas *et al.* (2004) reported highest yields when plants were grown in zeolite, followed by treatment involving zeolite in a substrate mixture.

GRUDA ET AL., 2006

Plate 3
Materials used as growing media
From left to right and top to bottom: rockwool, polyurethane foam, expanded shale, volcanic material, open porous clay granulate, expanded clay, perlite, black peat, coarse wood fibre, fine wood fibre, vermiculite, and light peat

The good performance of the plants grown in zeolite was due to the considerable cation exchange capacity, enabling a more efficient buffering of excess ammonium and Mg concentrations in the root environment. Moreover, zeolite was capable of absorbing part of the excess Mg, resulting in more balanced macronutrient cation ratios in the root environment. On the other hand, during the initial wetting of the substrates with nutrient solution, most of the K was absorbed on the surface of the zeolite; as a result, the K concentration was sharply reduced in the solutions drained from substrates with constituents comprising zeolite. Using zeolite in sand mixtures offers potential in countries where sand is abundant (Al-Ajmi *et al.*, 2009). Zeolite has also been reported to protect plants against toxicity (e.g. from ammonium – Handreck and Black, 2005) or from heavy metals (Kapetanios and Loizidou, 1992).

Pumice

Pumice is a natural product, a light silicate mineral of volcanic origin. It is used as substrate for fruit vegetables (tomato, cucumber, pepper) and for cut flowers. There is increased interest in growing plants in pumice, because it requires relatively low investments and is easily applicable in existing growing systems. Pumice can be used for many years, so it produces relatively little substrate waste. In addition, pumice is friendly to the environment, because no harmful production processes are involved (Boertje, 1995). Pumice is common in areas rich in volcanic activity, such as the Portuguese Azores, the Greek islands, Iceland, Japan, New Zealand, Russia, Sicily, Turkey and the United States (Raviv *et al.*, 2002). High transport costs limit its use in areas that do not have local deposits. Pumice has a low volume weight of 0.4–0.8 g cm^{-3} and a TPS of 70–85 percent (Boertje, 1995). Pumice has a neutral pH; it contributes little to plant nutrition, but does not decrease the availability of fertilizer nutrients (Handreck and Black, 2005).

Sand

Many grades of sand are available and can be used as a growing medium or as a component of various substrate mixtures in order to improve the drainage properties. Pure sand is widely used in deserts and coastal plains, because it is a cheap, local, natural source. The volume weight of sand is 1.48–1.80 g cm^{-3} and the TPS is relatively low at 0.30–0.45 (Raviv *et al.*, 2002). In Almería, beach sand is used as mulch on a stratified, artificial soil profile: manure is placed in strips, about 1 m wide and 2 cm deep, between the sand and the 20 cm of loam or clay soil placed on top of the original, rocky, sandy loam soil (Castilla *et al.*, 1986). According to the author, the use of sandy mulch soil in greenhouse crop production reduces loss through evaporation and allows the use of more saline water without reducing the harvest.

Tuff

Tuff is the common name for volcanic material used as a growing medium for greenhouse crops in several countries around the world. It has a TPS of 60–80% and a high surface area. The volume weight of tuff is 0.8–1.5 g cm^{-3}. Rapid cooling of magma during eruption prevents the formation of primary minerals and, therefore, pyroclastic materials contain mainly vesicular, volcanic glass. The physical and chemical properties of tuff are determined mainly by its mineralogical composition and weathering stages, as well as the grinding and sieving processes (Raviv *et al.*, 2002). Tuffs possess a buffering capacity and may absorb or release nutrients, especially P, during the growth period (Raviv *et al.*, 2002).

Expanded clay granules

Expanded clay is a granular product with a cellular structure. It is produced by heating dry, heavy clay to 1100 °C: water is released, causing the clay to expand. The raw material must have a low content of soluble salts to avoid having to add substances, such as lime, during the process. Expanded clays are light with a low volume weight of 0.28–0.63 g cm^{-3}; chemically, they are neutral, with a pH of about 7.0 (Raviv *et al.*, 2002). While expanded clays are used primarily for indoor plants in offices, they are also used for different greenhouse hydroponic cultures (Cervelli and Farina, 1994; Schnitzler *et al.*, 1994; Dobricevic *et al.*, 2008).

Organic growing media

The organic materials most available and applicable are peat, composts, bark and wood residues. However, availability alone is not sufficient: a substrate should be a standardized and growth-promoting product (Gruda, 2005). The organic substrates most used are described below.

Peat

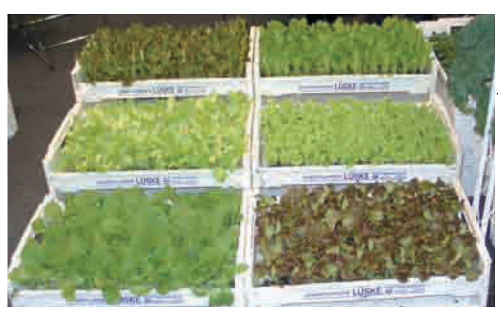
Peat is the most widely used growing media and substrate component in horticulture, currently accounting for 77–80 percent of the growing media used annually in Europe's horticultural industry (Gruda, 2012a). Seedlings and transplants are grown predominantly in organic substrates based on peat (Plate 4); it is also used in horticulture as a raw material for substrates in which container plants are grown (Gruda, 2005). Peat has long been used as a component of standardized growing media; however, research in the 1960s showed that it could be used as a growing medium in its own right both for container plants and for vegetable and cut flower production (Puustjarvi, 1973). Peat substrates offer numerous advantages and their nutrient content and pH are easy to control because both are initially low.

Peat is formed as a result of the partial decomposition of sphagnum, other mosses and sedges. Under cool waterlogged conditions, sugar and celluloses decompose, leaving behind the lignified cell walls and humus. Different types of peat vary in their degree of decomposition (Handreck and Black, 2005). Plant species, climate and water quality all affect the distinct characteristics of peat (Raviv *et al.*, 2002).

Advantages of peat as a growing medium

- Relative consistency
- Low nutrient content
- Low pH
- Light weight
- High volume of pores
- Good air capacity
- High water-holding capacity
- High CEC
- General freedom from pollutants, pathogens and seeds of weeds
- Stable structure
- Ease of storage
- Possibilities for reuse or recycling

Gruda, 2005; Gruda *et al.*, 2006



GRUDA, 2006

Plate 4
Peat-based growing media, used in press pot industry for production of lettuce seedlings

TABLE 2
Characteristics of different peats

Characteristics	Light peat	Dark peat	Black peat
Organic matter (% d.m.)	94–99	94–99	55–75
Ash (% d.m.)	1–6	1–6	23–30
Total porosity (% vol.)	84–97	88–93	55–83
Water-holding capacity (% vol.)	52–82	74–88	65–75
Volume weight (g/cc)	0.06–0.12	0.14–0.20	0.32–0.40
Cation exchange capacity (meq/100 g)	100–150	120–170	80–150
Total nitrogen (% d.m.)	0.5–2.5	0.5–2.5	1.5–3.5
C/N ratio	30–80	20–75	10–35
pH in water	3.0–4.0	3.0–5.0	5.5–7.3
Degree of decomposition[a]	H1–H3	H4–H6	H7–H10

[a] According to Von Post (1937).
Gianquinto and Pimpini, 2001

Von Post (1937) suggested a classification of peat types, based on their degree of decomposition: light peat, dark peat and black peat (Table 2). The higher the degree of composition, the higher the pH value of the peat. For example, sphagnum peat has a very low degree of composition and an acidic pH of 3–4: it may be directly applied to acid-loving plants; alternatively, the pH may be adjusted using dolomite lime. Peat is a very porous substrate with an excellent water-holding capacity; it is therefore used together with other growing media to increase the water mixture properties and reduce the weight of the mix for long distance transportation. Potential constraints are the instability, slumping and shrinkage of peat that can occur in container culture (Plate 5). Nevertheless, finding a replacement for peat as a horticultural substrate is an increasingly pressing issue.


GRUDA, 2012

Plate 5
Shrinkage of peat substrate in container

Peat-substitute growing media or alternatives to peat

The increased environmental awareness of consumers, the constant dismantling of ecologically important peat bog areas, and the pervasive waste problem all force the horticulture industry to re-examine its practices (Gruda, 2005; Gruda, 2012b). Numerous plant substrates have been introduced worldwide as peat substitutes or as peat-alternative growing media. Herein, only the most important substrates are presented, together with local materials used or suggested for use as growing media, such as composts of agro-industrial, animal and aquatic plant waste (Bragg, 1998), rice hulls (Evans and Gachukia, 2004 and 2008; Robbins and Evans, 2010) and peanut hulls (Bilderback *et al.*, 1982). Recently, biochar, a form of charcoal manufactured from organic matter by heating in an anoxic situation (pyrolysis), has been used in agriculture and introduced into horticulture as a growing medium. Different materials, including coir, sawdust and woodchips, as well as cheap locally available sources, such as straw and organic waste can be used for its production.

Converting organic waste into biochar by heating organic material produces a standardized medium, with high stability, less volume weight, and good aeration and water-holding characteristics. Biochar can absorb phytotoxic compounds, is not easily available for micro-organisms, and has the advantage of being carbon neutral (Nichols and Savidov, 2010). Different experiments with different vegetables have been conducted, but to the authors' knowledge, biochar has not been commercially used in soilless Mediterranean greenhouses to date. Alternatives to peat used as growing media in the horticultural industry are described below.

Coir (coconut fibre)

Coir is used mainly in the greenhouse industry. The raw material, which looks like sphagnum peat but coarser, is derived from the husk of the coconut fruit commercially grown in, for example, Sri Lanka, India, the Philippines and Latin America.

Coir has good aeration and water-holding characteristics. Coir dust has a TPS (total pore space) of 86–94% and an AFP (air-filled pore space) of 9–14%, while coir fibre has a TPS of 98% and an AFP of around 70% (Raviv *et al.*, 2002). According to Prasad (1997a), coir dust is characterized by a relatively high EAW (easily available water) of around 35%. However, the water-buffering capacity is lower in coir than in peat, and the level of air space varies considerably depending on the origin of the material.

Leaching of nitrogen is marginally higher in coir than in peat when comparing materials of similar particle size. On the other hand, CO_2 evolution and stability indicate that coir is less stable than Irish peat (Prasad, 1997a) and the total water-holding capacity in coir waste is lower than in peat (Noguera *et al.*, 2000). Sometimes higher total soluble salts, sodium and chloride levels are found in coir: Noguera *et al.* (2000) investigated 13 coconut coir wastes commercially produced in six countries in Africa, America and Asia and found salinity varied between 0.4 and 6.0 dS m^{-1}. To be of good practical quality as a soilless culture substrate, coir has to be washed during production.

The typical pH range for coir is 5.5–6.8; it contains significant amounts of phosphorus (6–60 ppm) and potassium (170–600 ppm) (Robbins and Evans, 2010). A major advantage of coir is its relatively high elasticity and that it can be compressed in so-called coir briquets (Salvador *et al.*, 2005) which facilitate transportation from the country of origin. Since coir contains more lignin and less cellulose than peat, it is more resistant to microbial breakdown and may shrink less; it is also easier to re-wet after drying than peat moss (Robbins and Evans, 2010).

Bark

Bark is a by-product of the wood and paper industry. It is usually stripped from trees, milled and screened into various sizes. As bark can be produced in different particle sizes, it is possible to make different mixes with different physical properties. Furthermore, according to Prasad and Chualáin (2004), the air- and water-holding capacity of bark can be adjusted by varying the percentage of fine material (< 1–2 mm). Bark is described as fresh, aged or composted (Robbins and Evans, 2010). Aged or composted bark is used for plant cultivation (Plate 6). Composting is recommended to eliminate phytotoxins. N may be added during composting to overcome N immobilization (Solbraa, 1979).

Bark is a lightweight material with a volume weight of 0.1–0.3 g cm^{-3} (Raviv *et al.* 2002). Pine-bark-based substrates provide very good aeration and a moderate amount of available water; however, they have little water-buffering capacity and frequent irrigation is required. Owen *et al.* (2008) suggested, therefore, amending bark substrate with industrial mineral aggregate following studies showing reduced water application needs and increased plant stomatal conductance and carbon assimilation when plants are grown in such substrates compared with in pine bark alone. Some fresh bark types contain toxins, including high levels of monoterpenes and phenols, which may prove harmful to plants. Tree species, age, harvest time, soil type and geographical region are factors affecting phytotoxicity (Raviv *et al.*, 2002). High manganese content, especially at low pH could also be a source of potential phytotoxicity (Maher and Thomson, 1991). As mentioned earlier, composting or ageing are good measures against phytotoxicity.

A positive property of bark is its relatively low cost. Shaw *et al.* (2007) performed a sensitivity analysis using five years of market data on 'Galia' muskmelons to show potential losses and profits using bags or pots filled with

GRUDA, 2004

Plate 6
Aged pine bark used as a container substrate for bell pepper cultivation

either perlite or pine bark. An economic analysis determined that pine bark was nearly one-eighth the cost of perlite and could be reused for several consecutive crops, resulting in reduced production costs and greater profits. However, bark could become a limited resource due to the changing timber industry and the fact that it is an effective energy source (Owen *et al.*, 2008).

Sawdust

The volume weight of sawdust is slightly less than sphagnum peat moss; it has similar water retention to pine bark but greater air space after drainage (Bilderback, 1982). As with hardwood bark, plant growth is restricted in uncomposted sawdust. However, the carbon to nitrogen ratio is much higher in sawdust than in bark and N must be added: an estimated 2–3 percent N by weight is required to compost sawdust. On the other hand, hardwood sawdust decays more rapidly than softwood sawdust and requires about 1 percent more N by weight to achieve decomposition (Worrall, 1985). Moreover, old sawdust has a lower N requirement than fresh sawdust. Handreck and Black (2005) reported rapid decomposition of whitewood sawdust in pots, with volume loss of up to 50 percent in one year, causing slumping and sometimes an enormous loss of air porosity. The microbes causing this decomposition have a high soluble nitrogen requirement, necessitating heavy applications of nitrogen fertilizer (Handreck and Black, 2005). Starck *et al.* (1991) found the lowest content of total and soluble nitrogen in leaves of carnation plants grown in sawdust in comparison to peat or mixtures of peat and sawdust. Higher doses of nitrogen increased the inflorescence diameter of plants grown in sawdust and in a mixture of 25 percent peat and 75 percent sawdust. In addition, using hardwood sawdust as a growing medium, it was found that wood contained phytotoxins negatively affecting plant growth (Maas and Adamson, 1982).

Woodchips and wood fibre substrates

Woodchips are readily available materials from the wood and paper industry. Pure untreated spruce and pine woodchippings with little bark from the woodworking industry can be shredded under frictional pressure and a wood fibre substrate (WFS) produced. The TPS of wood fibre substrates is similar to that of peat substrates and is over 90 percent, while the volume weight is generally 0.083–1.50, depending on the particle size and substrate compaction. The diminution of particle size leads to an increase in the volume weight (Gruda and Schnitzler, 2004a). Wood fibre substrates are characterized by low water retention with less easily available water and water-buffering capacity compared with peat-based substrates, good air content and high saturated hydraulic conductivity (Gruda and Schnitzler, 2004a; Gruda, 2005). Therefore, frequent irrigation is very important when wood fibres are used as growing media; optimal plant growth requires high moisture levels. Gruda and Schnitzler (2000) recommend irrigation set points at -30 hPa for optimal morphological leaf and root development of tomato transplants in an ebb/flood system; the irrigation frequency must be higher than in a peat-based substrate.

As with sawdust, the carbon to nitrogen ratio of woodchips and wood fibres is extremely high, requiring adequate amounts of nitrogen and composting to avoid negative effects on plant growth. In strongly fibrous and relatively loose wood substrates, micro-organism activity is sturdily promoted. The micro-organisms need mineral nitrogen for the synthesis of their own protein components. The immobilized N is no longer available for plants. N-immobilization in wood substrates can cause substantial nourishment problems for cultivated plants and thus become one of the most important factors leading to possible yield losses (Gruda and Schnitzler, 1997 and 1999b; Gruda *et al.*, 2000).

However, nowadays specially produced N-impregnated wood fibres can be used to reduce subsequent N-deficiency during the growing period. Gruda *et al.* (2000) studied the mechanism of N-immobilization for white peat and for WFSs with and without additional impregnation. Three levels of nitrogen fertilizer were tested. N-immobilization was calculated on the basis of N-balance including N-uptake by plants and residual mineral N in the substrates. Strong net N-immobilization was revealed in non-impregnated wood fibre substrates. In white peat and WFS *Toresa spezial*, N-immobilization was low with little variation in the values. N-immobilization for pots with and without plants was approximately 100 mg per litre for all three N-levels. The authors, therefore, recommended the use of N-impregnated wood fibre substrates with additional N-fertilization. However, general recommendations about additional fertilizer are difficult, given the strongly varying mineral nutrient content of different substrate loads.

Worldwide competition in the wood products industry also influences the prices of wood-based substrate; in recent years, the energy crisis has made the situation even more critical as wood is used as renewable fuel material. While the use of wood as an energy source is not a new phenomenon, the impact of its use as a biomass energy source has increased significantly in recent years.

Compost

The term compost is used to describe all organic matter that has undergone long, thermophilic, aerobic decomposition. Composts can vary according to the raw material used and the exact nature of the process (Raviv *et al.*, 2002). A wide range of organic waste can be composted for use as growing media: municipal solid waste, sewage sludge, poultry litter, chicken manure and other animal excreta, poppy straw, cotton gin trash, and waste from the food and processing industry. The latter includes apple pomace (Chong, 1992), corn cobs (Kianirad *et al*., 2009), cotton gin waste (Krewer *et al*., 2002), grape marc (Reis *et al.*, 2003), grape stalks (Tattini *et al.*, 1992), olive marc (Pages *et al.*, 1985), olive-mill waste (Papafotiou *et al.*, 2004 and 2005), sugarcane fibre or bagasse (Cintra *et al*., 2004) and vegetable residues (Vallini *et al.*, 1992).

Prasad and Maher (2001) recommend using composted materials such as green waste and biowaste as a component of a growing medium (up to 50 percent) but not on their own. Constraints to the use of composted green waste are: high EC, high concentration of potassium, nitrogen and ammonium, and high shrinkage (Handreck and Black, 2005). Plant pathogens and weed contamination could also be potential problems if the temperatures and time exposure are insufficient and the composting process is not properly conducted (Gruda *et al.*, 2006). However, through a good composting process, compost generally possesses a suppressive effect against pathogens. Using compost provides alternatives in sustainable horticulture.

The physical and biochemical properties of compost used as growing media vary greatly, depending on the materials used, the method adopted and the stage of maturity. The most beneficial effect of compost inclusion in a growth medium is its nutritional contribution. Non-mature compost can immobilize a significant amount of N, but once stabilized, compost acts, to a large extent, as a slow-release fertilizer (Raviv *et al.*, 2002).

GROWING MEDIA REUSE

In soilless crops, the substrate is not renewed each year, but reused for successive growth cycles. Each time a soilless growing system is replanted, roots are left in the substrate and organic matter may be partially decomposed, increasing water-holding capacity and in some cases CEC.

Possible consequences of reuse are: variation in structure and composition, variation in the air-filled porosity and water-holding capacity ratio, and contamination by soil-borne diseases.

The international trend for substrate development tends towards the use of natural resources and renewable raw materials. When growing media companies, even peat producers, in the medium and long term actively participate in the search for peat alternatives and invest in new innovative technology, they will be investing in their future (Gruda, 2012a).

A high value in the future will be given to substrate development, assurance of quality of the final product, and the suitability for plant cultivation by simultaneously respecting environmental aspects and sustainability (Gruda, 2005).

TABLE 3
Volume weight, air at pF = 1 (% apparent volume), and easily available water (% apparent volume) for some new and reused substrates

	Reuse	Volume weight (g/cm^3)	Air (%)	EAW (%)
Coir	No	0.07	35.0	27.4
	Yes	0.09	24.4	30.3
Peat	No	0.13	44.8	24.1
	Yes	0.15	35.2	26.0
Sand	No	1.15	30.7	19.2
	Yes	1.16	13.4	34.4

Giuffrida *et al.*, 2001

GAP recommendations

- The wide range of substrates available means it is difficult to make a correct choice. For appropriate management of nutrient solution and fertigation, information concerning their chemical and physical characteristics is required; even within the same substrate, significant variations can occur:
  - Determine the substrate's physical and chemical characteristics and, if necessary, make adjustments to meet plant requirements.
- Shape and volume of the container affect water-holding capacity:
  - Consider the container when choosing a substrate.
- Choice of substrate depends on the grower's capability to handle growing media with characteristics that can greatly differ from those of agricultural soil:
  - Acquire the necessary information and know-how.
- Adapt the irrigation strategy to the physical properties of the substrate.
- The agro-economic suitability of a given substrate is not the sole consideration. The direct (i.e. substrate disposal) and indirect (i.e. leaching requirement) environmental impact must be taken into account in order to improve the efficiency *lato sensu* of the adopted soilless growing systems. Growing media companies and vegetable producers are no longer evaluated only according to their financial success:
  - Consider sustainability and environmental protection.
  - Adopt green technologies.

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