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REVIEW ARTICLE

Organic substrate for transplant production in organic nurseries. A review

Jose Antonio Pascual[1] · Francesco Ceglie[2] · Yuksel Tuzel[3] · Martin Koller[4] · Amnon Koren[5] · Roger Hitchings[6] · Fabio Tittarelli[7]

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Abstract
A transplant can be defined as a seedling or sprouted vegetative propagation material grown in a substrate or in the field, for transfer to the final cropping site. Nurseries use a range of growing media in the production of transplants, and the quality of a substrate may be defined in terms of its feasibility for the intended use and also according to the climatic condition of the production site. Peat is the worldwide standard substrate, but because of its origin and the increasing environmental and ecological concerns, new alternatives have been proposed for organic production. Here, we reviewed these new alternatives, assuming that the proposed growing media will need to respond in a proper way to specific plant requirements while also taking them into consideration to be environmental friendly, at the same time. Appropriate composting management combined with suitable feedstock material can produce substrates with adequate properties to develop transplants. Potential added-value benefits of particularized compost have been highlighted, and these include suppressiveness or capacity for plant pathogen control, biofertilization, and biostimulation. This added value is an important point in relation to the framework of organic agriculture because the use of chemical fertilizers and pesticides is limited. Different permitted fertilizers are proposed by incorporating them by dress fertilization before planting or by foliar fertilization or fertigation during the seedling production phase. In this context, specific beneficial microorganism inoculation demonstrates better and quicker nutrient solubilization. Its inclusion during seedling production not only facilitates plant growth during the germination and seedling stages but also could bring efficient microorganisms or beneficial microorganisms to the field with the transplants. This review will help to bridge the gap between the producers of compost and the seedling plant producers by providing updated literature.

Keywords Beneficial microorganisms · Compost · Fertilizer · Nursery · Seedling · Substrate

✉ Jose Antonio Pascual
jpascual@cebas.csic.es

[1] Department of Soil and Water Conservation and Organic Waste Management, Centro de Edafología y Biología Aplicada del Segura, CSIC, 30100 Murcia, Spain

[2] Department of Organic Agriculture, Mediterranean Agronomic Institute of Bari, Centre International de Hautes Etudes Agronomiques Méditerranéennes, Valenzano, 70010 Bari, Italy

[3] Department of Horticulture, Faculty of Agriculture, Ege University, 35100 Izmir, Turkey

[4] Research Institute of Organic Agriculture, 5070 Frick, Switzerland

[5] Hishtil Plant Nursery, 4995000 Nehalim, Israel

[6] RMH Consulting, Carmarthenshire, Wales, UK

[7] Consiglio per la Ricerca in Agricoltura e l'analisi dell'economia agraria–Research Centre for Agriculture and Environment (CREA-AA), Rome, Italy

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1 Introduction to the transplant production in the organic nursery

1.1 Background

The organizational separation of transplant production from crop production is a recent global trend, especially for vegetable and floriculture/ornamental crops requiring special techniques and facilities (Kubota et al. 2012). A transplant can be defined as a seedling or sprouted vegetative propagation material grown in a substrate or in the field, for transfer to the final cropping site (Fig. 1; Unal 2013). This new production system has taken place over the past two decades to increase resource use efficiency and reduce environmental impact (Restrepo et al. 2013). Cultivation from seedlings has many advantages including earlier harvest; more efficient use of land, time, energy, and seeds; and healthy and homogenous production. It can also lead to a reduction in or zero use of chemical herbicides along with a reduced need for mechanical and/or hand weeding. These represent great advantages for organic agriculture, and in order to benefit from these advantages, farmers have, whenever possible, modified their system of production, thus increasing their demands for seedlings of the more widely cultivated vegetable crops (Unal 2013).

The main inputs in greenhouse nurseries are seeds, labor, growing media, fertilizers, permitted pesticides, and the infrastructure itself (Restrepo et al. 2013). The labor to produce seedlings can reach 59% of the total costs, followed by the growing media that can reach 23% of the total cost; these are variable figures that depend on the crop, season, and climate of the place where the greenhouse is sited (Restrepo et al. 2013). Transplant production can vary according to whether they are grown in physical trays or in pressed blocks of growing medium with no physical walls (Fig. 1). Where trays are used, they can be made of different materials, mainly polystyrene or plastic. Trays also vary according to the size and number of individual cells and can range from 72 cell trays used for grafting melon and water melons to 384 cell trays for lettuces and onions. The number of transplant production stages can also vary from one-stage plantation, as usual in Mediterranean conditions, to two stages for some fruit vegetables such as tomatoes, peppers, and eggplants in Central and Northern Europe. Two stages mean an additional transplanting from a first small container to a second bigger one before transplanting to the soil. This is used

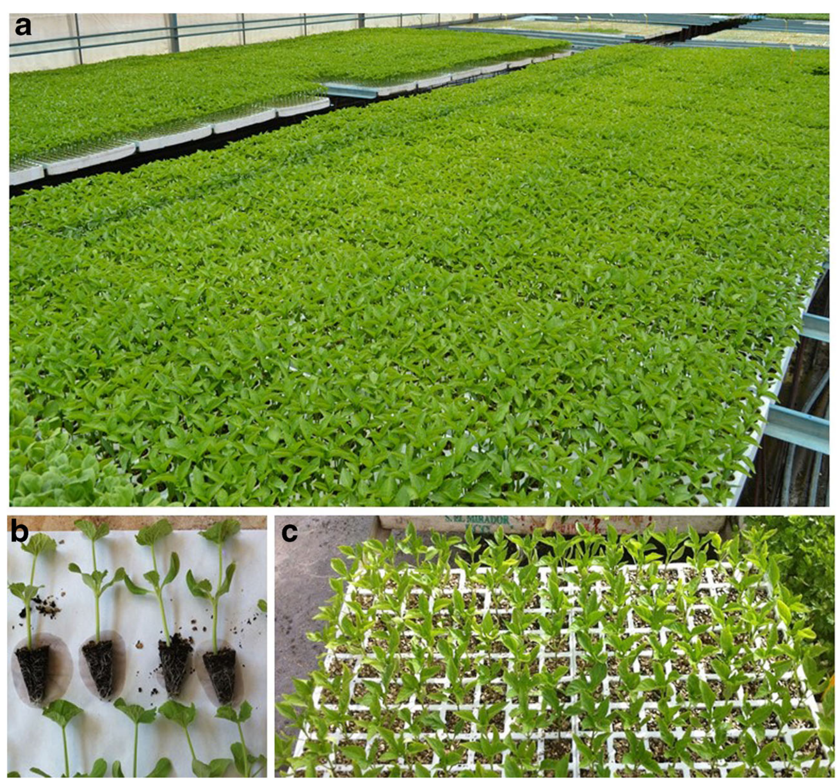

Fig. 1 **a** Overview of a greenhouse nursery with the disposal trays. **b** Example of a typical nursery tray for growing pepper transplants. **c** Shape of a transplant once it is out of the tray. Picture by J. Pascual and F Tittarelli

worldwide for greenhouse crops to delay the transplanting, to save heating costs, and to achieve an earlier harvest.

1.2 Main issues to overcome transplant production in the organic nursery

Organic transplants are produced in accordance with the rules and principles laid down in EU Regulations Nos. 834/2007 (EC 2007) and 889/2008 (Reg (EC) No 1107/2009. Therefore, seeds, fertilizers, and plant protection and disinfection are used only if they have been authorized for use in organic production under the regulations (FIBL and IFOAM 2011 (EGTOP report); Tuzel et al. 2014). Another main difference is the site itself, which must be totally separated from the conventional nursery area where both production systems are operated by the same producer. The site must be certified by the relevant organic authority or certifier.

As a general consideration, it is possible to state that the main purpose of growing media is to satisfy the needs for good seedling growth within the limited space of a container and to prepare the seedlings for successful transplantation into the field. The quality of growing media is one of the main factors influencing the success of horticultural nursery activity (Raviv and Lieth 2008), and it is directly linked to the quality of the materials utilized in growing media formulations (Reis and Coelho 2007). The choice of appropriate substrate is therefore an important factor in promoting the optimum growth of plants. Nursery producers know that the better the media, the better the transplants, and this assumption is confirmed by the scientific literature on the subject (Cantliffe 1993; Leskovar and Stoffella 1995; Gruda and Schnitzler 2004; Paul and Metzger 2005; Hasandokht and Nosrati 2010; Kubota et al. 2012). Growing media are responsible for the provision of suitable water, nutrients, and oxygen for seedling development and also to physically support the whole plant growth even after transplantation into soil (Raviv 2005). Nurseries use various growing media in the production of transplants, and the quality of a substrate may also be defined in terms of its feasibility for the intended use and according to the climatic condition of the production area (Hasandokht and Nosrati 2010; Schmilewski 2009). For this reason, a wide number of chemical, physical, biological, and economic characteristics of the constituents must be considered when developing media formulations (Schmilewski 2009).

2 Growing media characteristics for transplant production

Growing media must address the requirements of seeds and seedlings and must have the necessary physical, chemical, and biological characteristics required to germinate and grow plants in their early stages. Growing media should ideally contain ingredients that are from certified organic sources wherever possible. The use of all the materials listed in Annex I of the Reg. EC 889/2008 (including peat) as ingredients in growing media for organic production is allowed. However, there is a lack of general standard procedures at the European Union level (Kang et al. 2004), and some rules are only available at the national level [for example, RAL in Germany (Bundesgütegemeinschaft Kompost e.V., www-kompost.de)]. The main physical, chemical, and biological characteristics of growing media have been a matter of debate throughout the world over the last decades, especially in the framework of a comprehensive revision of regulation on organic agriculture. Peat cannot be used for open field amendment despite its organic origin, a prohibition that originated from the principle of ecology aiming to reduce the use of non-renewable resources and to protect environmental features such as landscapes and peatland habitats (EGTOP report). Because of this concern, the regulation has introduced a derogation to allow peat only for growing media preparation. However, the restriction to a "maximum 80 % by volume of growing media" is under discussion at the European level (EGTOP report).

Nursery growing media characteristics have been deeply debated and investigated in the scientific literature (Abad et al. 2001; Benito et al. 2006; Pagliarini et al. 2012). The ideal main characteristics which play key roles in the success of a substrate are reported in Table 1 (Caron et al. 2014). The physical properties of the growing media are the most important parameters related to plant performance in pots (Raviv et al. 1999; Abad et al. 2001; Pagliarini et al. 2012). Easily available water should range from 20 to 30%, and less available water should be the lowest possible to give the better substrate

Table 1 Ideal characteristics of growing media (Benito et al. 2006; Raviv and Lieth 2008; Abad et al. 2001)

Porous enough both to drain easily excess water and to allow sufficient oxygen and carbon dioxide exchange at the root level
Enough water holding capacity
pH around neutrality
Electrical conductivity feasible for root growth and seedling development
Cation exchange capacity level able to provide nutrients for healthy plant development by creating a reservoir of available nutrients
Appropriate level of nutrient ratio, mainly nitrogen, phosphorus, and potassium related to carbon
Hold transplants firmly in place
Keep constant volume when wet or dry and generally retain its properties
Free from weeds, nematodes, and diseases
Easy storage for long periods of time without changes in physical and chemical properties
Easy handling and blending
Light in weight to ease transport to the planting site
Low content of silt, clay, and ash

in terms of water holding capacity (Amha et al. 2010; Londra 2010). The distribution of air, water, and solid in a container medium depends on several factors including pore space, bulk density, particle size distribution, container shape and volume, and media settling (Lemaire 1995; Abad et al. 2001; Schmilewski 2009; Ayanfeoluwa et al. 2015). The accepted range of values of the physical parameters is recorded in Table 2 and can be taken as general criteria (Abad et al. 2001; Pagliarini et al. 2012).

Chemical properties of the formulated growing media also affect plant growth and nutritional response in different ways (Salifu et al. 2006). The most important characteristics of growing media that determine the suitability of the substrate are included in Table 3 (Raviv et al. 2002). The C/N ratio has been used as a growing media index to represent its stability as it has been established that a C/N ratio of 15 permits plants to uptake nitrogen without it leaching as nitrate and C/N ratios above 15 represent values at which nitrogen is immobilized (Dresboll and Magid 2006). Higher C/N represents a higher risk of immobilized nitrogen (unavailable to plants) while lower C/N is better for nursery plant production (Zucconi et al. 1981). There are other ratios such as mineralized NO_3/N (Fuchs and Biophyt 2000) where a ratio above 0.8 indicates good N availability and low phytotoxicity due to the reduction of ammonium through mineralization to nitrate. Table 4 shows the optimal chemical conditions for different plants and sodium salinity and sensitivity according to Verdonck et al. (1983).

The biological properties of growing media are also important, and until now, they have often been characterized as the absence of negative aspects such as plant pathogens, weed seeds, insects, and diseases which may adversely affect the vigor of transplants (Lemaire 1995). During recent years, the importance of low microbial activity in reducing competition for nutrients has also been pointed out. It is also important to emphasize that some positive aspects, such as the presence of beneficial microorganisms, have started to be considered (Pascual et al. 2000; Berg and Smalla 2009). Beneficial

Table 2 Physical parameters of the growing medium

Physical parameters	Definition	Preferable value
Texture and structure	It refers to the size and distribution of particles in soil or mix, and it is really related to water retention and air porosity. Structure refers to the combination of different size particles. For example, pore diameter can be reduced if smaller particles occupied the spaces left by larger particles	It is reported as good substrates when they were with medium to coarse texture, equivalent to a particle size distribution ranging between 0.25 and 2.5 mm (Benito et al. 2006)
Total porosity	It determines the available free space for water, air, and root growth. The degree of porosity is responsible for good gas exchange capacity for root system. In general, large pores aid aeration whereas small to fine pores aid water retention	Porosity should provide enough water and oxygen to plants. Porosity is considered to be good when in the range 50–80% by volume (Beardsell et al. 1979; Jaenicke 1999)
Particle size	It is the structure and organization of the particles	Representation of a wide range of all sizes from the No. 4 to No. 200 sieves (Lemaire 1995). The higher the coarseness, the lower the water holding capacity. Small particle size indicates high values of easy available water (Schmilewski 2009)
Water holding capacity	It is the amount of water held by the substrate without leaching to ground from the container. The water available for plants is named water retention, and it is approximately 60% of the total water holding capacity. It depends on the growing media, but the container used is also a factor	The ideal water holding capacity is 40–65% that corresponds with water retention of 25–30% (Abad et al. 2001)
Bulk density	It is the mass of material particles divided by the total volume they occupy. It is strictly linked to the degree of particle compaction	It should not exceed 0.4 g cm^{-3} for vegetable seedlings (Abad et al. 2001)
Shrinkage ratio	It refers to the volumetric decrease percentage due to a loss of water. It is an indicator of the stability of the substrate during the time of its usage. It is essential for long-term container growth. A high degree of shrinkage leads to root destruction	The optimal values are those that do not exceed 30–35% shrinkage (Gebhardt et al. 2010)
Hydrophobic inertia	It refers water repellency indicating the difficulty to be wet. The determination is developed by using capillary rise and droplet methods (Michel and Lazzeri 2010)	The optimal values for peat ranged from − 32 and − 100 kPa. Lower values of − 100 kPa would be considered as a hydrophobic substrate

Table 3 Physicochemical characteristics of growing media that determine the suitability of the substrate

Parameter	Definition	Preferable value
pH	It is defined as the acidity of the medium. The pH of substrate affects the mobility and availability of nutrients. If it is not within the desired range, nutrients can become either unavailable or toxic. Also in organically certified nurseries, substrate pH can be slightly modified by mineral additives (e.g., lime or sulfur) (Schmilewski 2009)	Desired pH range 5.5–6.5 (Jaenicke 1999), although each plant shows their optimum pH value
Cation exchange capacity (CEC)	It represents the ability of a material to adsorb positively charged ions. It is one of the most important factors affecting the fertility of a growth substrate. CEC indicates the fertilizer storage capacity of the substrate and indicates how frequently fertilizer needs to be applied	Higher than 140 mEq/100 g results in nutrient retention in the media. Less than 100 mEq/100 g can cause nutrient leaching. For example, perlite and sand have very low CEC values relative to peat and vermiculite components (Lemaire 1995)
Electrical conductivity (salinity)	*t* is the expression of the capacity of a solution to conduct an electric current. In horticulture, it is related to the total soluble salts of a saturated extract of either soil or organic material	The average value for an ideal substrate was 0.42 dS/m in a range from 0.33 to 0.51 dS/m (Abad et al. 2001). High EC causes poor shoot and root growth
Stability rate	It refers to the stability rate of the media (Dresboll and Magid 2006). It influences the decomposition rate of media. The higher the C/N ratio, the higher the risk of nitrogen being unavailable to plants and may reflect a tendency for the media to experience rapid decomposition and subsequent decrease in volume and aeration	C/N ratio around 15 permits nitrogen uptake by plants, but when it is lower than 15, part of it is leached, and when it is higher than 15, nitrogen starts to be immobilized (Hartz and Johnstone 2006)

microorganisms can interact with the plant by acting as biofertilizers, biostimulants, and/or biopesticides, permitting the reduction of inputs in a sustainable production system (Okon and Labanderagonzalez 1994; Pascual et al. 2002; Harman et al. 2004; Alabouvette et al. 2006; Bonanomi et al. 2007; Castro et al. 2007; Montesinos-Navarro et al. 2012).

Nursery media are either based on a sole growing medium constituent or on a mixture of various materials. Mixtures of various constituents with complementary physical and chemical properties are widely used to produce desirable substrate characteristics (Montesinos-Navarro et al. 2012) and to produce tailored growing media which respond to the specific requirements of the target plants. The organic constituents may be either from biological sources (peat, coconut coir, and composted organic wastes), or inorganic substrates may be derived from unmodified sources (sand, tuff, and pumice) and processed materials (expanded clay as perlite and vermiculite).

3 Peat as main traditional substrate for transplant production: environmental reasons underpinning the research for peat alternatives

In general, peat has been the most common constituent of growing medium (Bunt 1988). It is usually included in substrates because it increases the water holding capacity, has a good cation exchange capacity, does not contain phytotoxic substances, and has a low bulk density. This is an issue that must be addressed since almost 80% of growing media used in Europe is constituted of peat materials (Abad et al. 2001). The

Table 4 Physicochemical and chemical characteristics for growing plants with different sensitivity to salinity levels (Verdonck et al. 1983)

Parameter	Unit	Level of salt sensitivity to NaCl		
		Sensitive	Moderately sensitive	Salt-tolerant
pH (H_2O)		4.0–5.5	4.3–5.8	4.5–6.0
Electrical conductivity	dS m^{-1}	0.40–0.75	0.40–0.75	0.40–0.85
Nitrogen	mg l^{-1}	25–40	25–70	30–100
Phosphorus	mg l^{-1}	> 30	> 30	> 30
Potassium	mg l^{-1}	90–175	120–250	150–360
Calcium	mg l^{-1}	> 400	> 400	> 400
Magnesium	mg l^{-1}	125–200	150–300	150–300

H_2O extract (1:5 *v*/*v* extracts) for the first three parameters, and NH_4 acetate for the rest amount of white peat consumed annually has been estimated as approximately 30 million m^3, half of it is used for producing growing media for commercial horticulture, and 25% of this is used extensively in conventional nurseries (Altmann 2008). The use of peat and the expanding growing media industry in the European Union is estimated to be worth €13,000 million and generates approximately 11,000 jobs (EPAGMA 2012).

In recent years, there have been increasing environmental and ecological concerns about the use of peat as a growing medium because its harvest is jeopardizing endangered wetland ecosystems worldwide (Zaller 2007). In relation to peat extraction, several environmental organizations such as the International Mire Conservation Group (IMCG); the International Peatland Society (IPS), a growing media industry; the Society of Wetland Scientists (SWS); and the IUCN Commission on Ecosystem Management (CEM) have produced a Global Action Plan for Peatlands (GAPP). The vision statement of the GAPP recognizes the importance of peatlands to the maintenance of global diversity of ecosystems and species, the conservation of carbon vital to the world's climate system, and the wise use, conservation, and management of natural resources for the benefit of people and the natural environment. Peat utilization contradicts the basic principles of the organic agriculture method as defined in Regulation 834/2007 (EC 2007). For this reason, the EGTOP report proposed that "….to the listing of peat, the following restriction should be added: 'maximum 80 % by volume of growing media'."

Increasing demand and rising costs for peat as growing media in horticulture have led to a search for high-quality and low-cost substrates as an alternative. Industry dependence on this sector implies fluctuating prices, but there is a clear upward trend in average prices (13% increase during the 2006–2010 period (Restrepo et al. 2013)), depending on the scarcity of peat and its non-renewable nature, that could result in a loss of competitiveness for the nursery and greenhouse growing sector in relation to soilless substrates. The interest in finding low-cost, readily available substrates to replace peat moss has therefore become very important. The rate of peat consumption compared to other alternative materials has started to decrease but not for growing media in nurseries where it shows no sign of losing dominance (Altmann 2008).

4 Compost as a growing medium for transplant production

Different materials, which can potentially substitute for or combine with peat in growing media formulation, have been evaluated (Jayasinghe et al. 2010; Ceglie et al. 2011; Carmona et al. 2012). These include coir dust, pine bark, and wood fiber (Frost et al. 2002; Clemmensen 2004) along with sand, tuff, and pumice processed materials (expanded clay, perlite, and vermiculite). The origin and definition of each of these are listed in Table 5. These alternatives need to satisfy the relevant technical requirements and be readily available in sufficient quantities at reasonable cost. These materials have been used to produce tailored growing media which better respond to specific plant requirements, considering the requirements to be environmental friendly, and reduce production costs (Gruda and Schnitzler 2004).

Compost can be defined as a heterogeneous material obtained by partial degradation of mixtures of organic waste materials of different origins through an exothermic process carried out by aerobic microorganisms. Compost from various feedstocks is a renewable resource which can minimize the environmental impact of waste disposal through recycling in agriculture. Compost may have physical, chemical, and biological properties that can contribute to partial peat reduction in growing media formulations (Clemmensen 2004). On the other hand, its utilization is hampered by the lack of uniformity of compost characteristics over time, mainly because of different feedstock availability and poor control of the composting process. The main commercial goal of horticultural nursery activity, however, is the production of standardized and healthy seedlings which cannot be subjected to variable characteristics of the growing media used. Nevertheless, compost represents by far the most deeply investigated constituent of growing media (Pinamonti et al. 1997; Walker et al. 2006; Roberts et al. 2007; Tittarelli et al. 2009; Ceglie et al. 2015).

It is widely accepted that the term "compost" covers a huge range of materials and that not all compost would fit as suitable growing media constituents, given the need for homogenous properties. It is important for compost producers to understand that a nursery owner has different product requirements from those of a farmer (Pinamonti and Sicher 2001). Compost performance depends on the quality of the raw materials used in the formulation of the composting starting mixture (Ceglie et al. 2015) and on the quality of the composting process (Urrestarazu and Mazuela 2005).

Carmona et al. (2012) highlighted the most frequently cited problems of the use of compost in growing media for vegetable transplants. The results concerning the suitability of the tested composts varied significantly and were not always satisfactory. These failures were often linked to the materials used and the proportions in the mixtures. They were variously attributed to the presence of phytotoxins (Roe and Kostewicz 1992), high electrical conductivity (EC) (Herrera et al. 2008), immaturity in hardwood bark compost (Bearce and Postlethwait 1982), excess of NH_4^+ in spent mushroom compost (Lohr et al. 1984), heavy metal toxicity in urban solid wastes (Rosen et al. 1993), or poor physical properties caused by low aeration or scarce water holding capacity (Herrera et al. 2008; Carmona et al. 2012). Therefore, it is more a specific problem of compost production with adequate quality

Table 5 Different growing media components, origins, characteristics, and reasons to be considered as growing media

	Origin	Characteristics	Case of use
Inorganic component			
Perlite	It is an aluminum silicate of volcanic origin, and when it is crushed and heated rapidly to 1000 °C, it expands to form white, stable, sterile, and lightweight aggregates with a cell-like structure that creates tiny air tunnels, allowing water fluxes and gas exchange at the root level	It holds water in an amount 3 to 4 times its weight, and the water is mostly retained on the surface of the aggregates, meaning that mixtures with a high proportion of perlite are well drained and do not retain much water (Bunt 1988). Perlite granules have a density of 128 kg m^{-3} (Jaenicke 1999); very low bulk density, high porosity to water, high porosity to air, pH 6–8, and very low CEC	To increase water holding capacity and provide aeration
Vermiculite	It is a micaceous hydrated magnesium–aluminum–iron silicate, and it expands when heated above 1000 °C to form red–brown, sterile, and lightweight small pieces	It holds 5 times its own weight of water. Horticultural vermiculite density is in the range 78–125 kg m^{-3}. It can hold positively charged nutrients like potassium, magnesium, and calcium (Kuepper and Adam 2003), and it is graded to three sizes: coarse (2–3 mm), quite often used in growing substrates; medium (1–2 mm); and fine (0.75–1 mm); very low bulk density, very high porosity to water, high porosity to air, and pH 6–8	It is widely used as a bulking agent that reduces the compacting effect and keeps good aeration and drainage. It is worth noting that the structure of vermiculite is fragile, especially in the case of a mixture with heavy material, such as sand (Jaenicke 1999)
Sand	It comes from beaches, preferably from river beach because sand from seaside contains salts that must be leached before use	It varies in a wide range from 0.25 to 2 mm. The density is about 1600 kg m^{-3}. It is important to choose carbonate-free sands to avoid non-desirable effects related to nutrient immobilization (Bunt 1988); very high bulk density, moderate porosity to water, very low porosity to air, pH variable, and high CEC	It is used in propagation and to cover seeds after sowing in tray or press pots/blocks. It is used to increase the bulk density and to improve the drainage. Usually, it is included at a maximum of 10% of a substrate volume because its fine fraction clogs up the pores of the media
Gravel	As described for the sands, it may need a washing step to remove soil and sand particles	It is heavy with a bulk density that ranges from 1000 to 1700 kg m^{-3}	Fine gravel, up to 5 mm, has been used successfully in rooting cuttings
Pumice	It is the dust form of a volcanic rock that consists of highly vesicular, rough textured volcanic glass, which may or may not contain crystals. It is meshed at different sizes depending on the purpose	It increases the water retention capacity and decreases the bulk density of the mixture (Sahin et al. 2006)	It improves aeration and water holding capacity for a long period because of its stable structure and physical and chemical properties
Tuff	It is produced from ash and rock fragments ejected during volcanic eruptions. It consists of mostly silicon dioxide and aluminum oxide with small amounts of iron, calcium, magnesium, and sodium	It increases aeration and drainage in growing media	It possesses a buffering capacity and may absorb or release nutrients, especially phosphorus, that permit better plant growth during seedling (Raviv et al. 2002)
Organic component			
Wood fiber	It is derived from renewable resources (wood). It is fibrous in structure, porous, loose, and elastic (Schmilewski 2009). The use of conifer wood is preferred	Wood may be treated mechanically and/or thermally before being used (Schmilewski 2009). It has low bulk density, high air capacity, and low water capacity. pH is between 4.5 and 6.0	Due to its low shrinkage value, it can reduce the shrinkage of a peat mixture (Raviv et al. 2002). It is easy to re-wet after drying. Wood fibers can suppress pathogen like *Pythium* and can be used in peat blocks
Coir (coconut fiber)	It is the name given to the thick mesocarp or husk of the coconut fruit. When the husk is industrially processed, huge amounts of pith and short-length fibers are disposal as coir dust. Once coir dust is dried and compressed into bricks or bales, wrapped, and shipped, it is prepared for use as an organic substrate (Schmilewski 2009)	It can retain water up to 9 times of its weight, and it may last 2 to 4 times longer than peat. Dry bulk density is very low, with a pH range from 5.5 to 6.8. Usually, it contains higher levels of P, K, and Na	It is increasingly used as a substrate, because of its common characteristics with peat. Coir improves physical properties of the mixture and increases air space (Hanson 2003)
Bark	It is a by-product of paper mills and sawmills industry. This material cannot be used as it is because it has high lignin content that	The horticultural quality of the transplants produced on bark media depends on the botanical origin of the material, on the	It is recommended as a component in blends for potted herbaceous and woody ornamentals

Table 5 (continued)

	Origin	Characteristics	Case of use
	leads to low mineralization rate and high nitrogen immobilization. Therefore, a composting stage is suggested before its use in horticulture substrate preparation (Verdonck et al. 1983). The availability of bark-based substrates is limited on the market due to the increasing demands for other sectors, such as landscape mulch and fuel	particle size distribution, and on the type and duration of the composting process (Jaenicke 1999; Lemaire 1995). Composted pine bark lightens growing media mixtures, the bulk density is very low, and it decreases water holding capacity, with a pH range from 5.0 to 6.5	
Rice hull	Rice hulls or husk are the coatings of seeds, or grains, of rice. They are the outermost layer of the paddy grain that is separated from the rice grains during the milling process	Cheap organic by-product with a high capacity to increase porosity in growing media mixes It has been proven to be as effective as perlite for the production of a range of crops. This free-draining substrate has low to moderate water holding capacity, a slow rate of decomposition, and a low level of nutrients	It is always mixed with peat, for seedling germination, at a recommended ratio of 10% because of its negative effect on root development. Cultivars of tomato and pepper for transplanting were positively raised at low dose, but for other species as chicory, it was possible to include a higher percentage
Compost	They are characterized as stabilized organic materials that have passed through a thermophilic phase. The composting process can be applied to different types of fresh organic materials from sewage sludge, agriculture residues, by-products from agro-industry, municipal waste, etc. The process needs enough aeration to assure aerobiosis, moisture between 40 and 50% to permit a microbiological activity, and certain C/N ratio	Compost improves physical and chemical properties of the growing media and increases the availability of macro- and micronutrients and growth regulators for transplant growth (Abdallah et al. 2000; Ozores-Hampton et al. 2001)	Composts commonly added to growing media can increase plant-available nutrients; affect physical properties, pH, and nutrient relationships in the growing medium; promote or suppress diseases; and subsequently affect seedling growth (Manas et al. 2009; Perez-Murcia et al. 2006)

standards for growing media formulation than a general problem of incompatibility of compost as growing media.

4.1 Advantages to the use of compost in growing media: physical and chemical properties

Composts vary significantly depending on the composition and origin of the wastes used, e.g., agricultural waste (Lopez-Mondejar et al. 2010; Pane et al. 2013), agro-industrial waste (Ntougias et al. 2008), or animal manures and slurries (Ros et al. 2008; Bernal et al. 2009). Different residual biomasses, such as coconut coir (*Cocos nucifera* L.), husk fiber, rice (*Oryza sativa* L.) hulls (Evans and Gachukia 2007), switchgrass (*Panicum virgatum* L.; Altland and Krause 2009), spent mushroom compost (*Agaricus bisporus* and *Pleurotus ostreatus*; Medina et al. 2009), beached *Posidonia* residues (*Posidonia oceanica* L.), extracted sweet corn tassel (*Zea mays* L.; Vaughn et al. 2011), and giant reed wastes (*Arundo donax* L.; Andreu-Rodriguez et al. 2013), have been studied as partial or total substrate constituents. Numerous studies have also reported the use of compost, as a peat substitute in potting media. These include municipal solid waste compost (Raviv et al. 2002; Herrera et al. 2008), animal manure compost, green waste compost (Tittarelli et al. 2009), and agro-industrial compost (Jayasinghe et al. 2010; Ceglie et al. 2011; Kritsotakis and Kabourakis 2011; Carmona et al. 2012).

The limitations in compost-type utilization can be solved by identifying suitable input materials, standardizing the composting process to obtain homogeneous compost material, and testing it for specific plant growth (Bernal-Vicente et al. 2008). For this purpose, it is necessary to establish the minimum number of parameters for the determination of compost quality and to define standard composting processes for specific raw materials to obtain the expected compost quality. These parameters have been related to physical, chemical, and microbiological properties, and the most cited have been the ones related to salinity and maturity (Roe and Kostewicz 1992; Bernal-Vicente et al. 2008; Herrera et al. 2008; Carmona et al. 2012). Brinton (2000) presented a range of parameters based on different German, Austrian, and US bodies with recommended end-use values from specific tests for composts used as potting formulations (Table 6).

Compost improves the physical and chemical properties of the growing media and increases the availability of macronutrients, micronutrients, as well as plant growth regulators (Abdallah et al. 2000; Ozores-Hampton et al. 2001). Klock and Fitzpatrick (1997) pointed out that composts may be used alone as growing media where the following criteria are met:

Table 6 End-use test values recommended for compost: category potting mixes (assuming 40–50% of mix (*v*/*v*) is compost) (Brinton 2000)

Test parameter	German	Austrian	WERL (USA)
Salt	< 2.5 g l^{-1}	< 2 g l^{-1}	< 2 mmhos cm^{-1}
Available N	< 300 mg l^{-1}	< 800 mg l^{-1}	100–300 mg l^{-1}
Phosphate	< 1200 mg l^{-1}	< 800 mg l^{-1}	800–2500 mg l^{-1}
Potassium	< 2000	< 1500 mg l^{-1}	500–2000 mg l^{-1}
Maturity	Dewar V	Pass plant test	Solvita 7–8
Organic matter %	> 15	> 20	> 30
pH	Need to be declared	5.5–7.0	6–7
Foreign matter	Max 0.5% > 2 mm	Max 0.5% > 2 mm	< 1% > 2 mm

porosity in the range 50–80%, water holding capacity between 25 and 60%, bulk density from 0.30 to 0.75 g cm^{-3}, initial pH 5.5–6.5, initial soluble salt concentration from 0.33 to 0.51 dS m^{-1}, and a C/N ratio in the range 15–20. Composted materials that are highly compacted reduce the porosity of the growing media, but this negative physical parameter can be ameliorated by adding perlite or pumice to the substrate mixture (Fitzpatrick 2001). The main constraints in the use of compost in growing media formulation are the high electrical conductivity, the slightly alkaline pH (Verdonck et al. 1983), and the low water holding capacity (Abad et al. 2001). Soluble salt levels in compost depend on feedstock and processing. It has been proved that composts with lower salt levels supported growth better than those with higher levels (Garcia-Gomez et al. 2002). Both water holding capacity and the ratio of water to air in the root medium after drainage are important to produce quality transplants. Compost used as a constituent of growing media must be stable, with relatively low salinity, low concentration of phytotoxic ions and molecules, and free of phytopathogenic organisms (Raviv et al. 2002). Composts commonly added to growing media can increase plant-available nutrients; affect physical properties, pH, and nutrient relationships in the growing medium; promote or suppress diseases; and subsequently affect seedling growth (Manas et al. 2009). Therefore, a new and different approach for optimizing growing media has been proposed for obtaining the best results regarding plant growth and productivity (Ceglie et al. 2015). It has been based on the identification of a compost with the appropriate characteristics for the purpose that it has to be intrinsically related to the selection of the raw materials, their relative proportions, and the composting procedures used in the production of a feasible on-farm compost (Table 7).

In Europe, compost is used primarily to feed soil with organic matter, and only 15% of the compost produced is used as a base material for the formulation of commercial substrates for cultivation in containers (Rynk and Richard 2001; Raviv 2009). The combination of peat and compost in growing media is synergistic. Peat often enhances aeration and water retention while compost or other additives improve the fertilizing capacity of a substrate (Jayasinghe 2012). In addition, specific by-products and composts tend to have porosity and aeration properties comparable to those of bark or peat and, as such, are ideal substitutes in propagating media (Chong 2005). The greatest plant growth responses and largest yields have usually occurred when composts constituted only a relatively low proportion (25–50%) of the volume of the nursery container medium mixture (Pinamonti et al., 1997; Atiyeh et al. 2001; Garcia-Gomez et al. 2002; Papafotiou et al. 2004; Perez-Murcia et al. 2006).

Increasing demand and rising costs for peat as a growing medium in horticulture have led to a search for high-quality and low-cost substrates as alternatives (Chong 2005; Ostos et al. 2008; Moral et al. 2009). So far, compost is developing as a common media ingredient among organic growers (Kuepper and Adam 2003). Moreover, compost use in growing media increases the awareness about waste recycling.

4.2 Suppressiveness of compost for controlling plant pests and diseases: added value in the role of using compost as growing media

Seedlings growing in nurseries are susceptible to pathogen and pest attack which can reduce their growth and prevent transplantation into the field (Spies et al. 2011; Lopez-Mondejar et al. 2012). Nurseries are particularly exposed to the risk of disease emergence because of the temperature and humidity conditions of plant raising. The organic nursery needs to use more preventive techniques than conventional, because once diseases appear, it is more difficult to eliminate them due to the restriction on the use of pesticides.

Some research has been conducted to evaluate the effect of peats and composts made from a variety of input materials on the prevention or control of root and soil-borne diseases (Darby et al. 2006; Escuadra and Amemiya 2008). In general, peats tended to facilitate pathogen infection while the presence of compost in growing media successfully decreased the mortality rates (Fig. 2; Pascual et al. 2002; Ros et al. 2005; Blaya et al. 2015). These suppressive composts provide an environment in which plant disease development is reduced, even when the pathogen is favored by the presence of a susceptible host (Hadar and Papadopoulou 2012).

Table 7 Effect of growing media on different crops

Growing medium components	Response	Reference
Peat Coir Vermiculite Perlite	100% peat, (75% peat + 25% vermiculite), or (50% peat + 50% vermiculite) had greater tomato root dry weight, stem diameter, leaf area, shoot dry weight, and stem length; more than 50% coir which exhibited reduced plant growth	Arenas et al. (2002)
Old peat 65% + white peat 30% + perlite 5% Old peat 65% + municipal solid waste compost 30% + perlite 5% White peat 65% + old peat 30% + perlite 5% White peat 65% + municipal solid waste compost 30% + perlite 5% Municipal solid waste compost 65% + white peat 30% + perlite 5%	Quality indices of tomato seedlings in white peat 65% + municipal solid waste compost 30% were similar to those grown conventional mixtures of old and white peat sphagnum (control)	Herrera et al. (2008)
Replacing commercial growing media with the different rates (0, 10, and 50%) of coffee pulp compost (CP)	At CP (10%), tomato serial biomass, seedling height, and the number of nodes/plant were higher than pro-mix media	Berecha et al. (2011)
Four rates (20, 45, 70, and 90%; *v/v*) on a volume basis of olive pomace waste (OPW) and green waste compost (GWC)	Treatments GWC 20%, 45%, and OWC 20% showed the best performances in tomato seedlings compared with peat	Ceglie et al. (2011)
Local peat (LP) + perlite (PER) + composted farmyard manure (CFYM; 1:1:1, *v/v*) LP + clinoptilolite (CLI) + CFYM (1:1:1, *v/v*) LP + PER + vermicompost (VC; 1:1:1, *v/v*) LP + CLI + VC (1:1:1, *v/v*) VC peat as control	LP + VC + CLI and LP + VC + PER were found as promising alternatives for tomato seedlings	Tuzel et al. (2015)
Compost of rose oil processing wastes, separated dairy manure, poultry manure, and straw mixed with local peat at the rates of 25, 50, 75, and 100% (*v/v*) Composting method: aerated static pile or turned windrow composting methods	Germination period was the longest in 100% compost use, and shoot biomass decreased with increasing compost rates in tomato seedling production	Oztekin et al. (2016)
Compost of 2-phase and 3-phase olive mill wastes and olive oil waste water sludge plus separated dairy manure, poultry manure, and straw Different rates of local peat at the rates of 25, 50, 75, and 100% (*v/v*) were assayed for tomato transplant production	Germination period was extended with the increase of compost rates. The highest tomato shoot dry matter was in the mixture with 25% of the enriched compost obtained from 3-phase olive mill wastes	Tuzel et al. (2016)
Garden wastes and cow manure compost at 0, 10, 20, 40, 60, and 100% (*v/v*) compared with peat (100%)	Quality of tomato and cucumber transplants of 100% compost was similar to the ones grown in peat (100%)	Ghanbari Jahromi and Aboutalebi (2009)
Urban solid wastes, sewage treatment plant, and vegetable wastes + white peat 47.7:47.5 (melon); 65:30 (WP/C) (tomato)	Increasing doses of compost substitution decreased germination speed of melon and tomato	Diaz-Perez and Camacho-Ferre (2010)

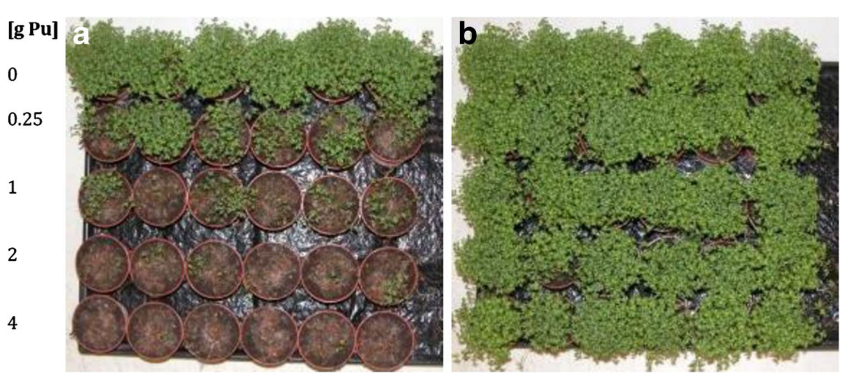

Fig. 2 Six-day-old cress grown in the presence of an increasing concentration of *Pythium ultimum* on a substrate containing 70% peat and 30% coco fibers and fertilized with 0.3 g N l^{-1} substrate horn flour (**a**) or a substrate containing 70% peat and 30% compost fertilized with 0.3 g N l^{-1} substrate crab shells to which 10 g l^{-1} *Gliocladium catenulatum* suspension was added (**b**). Picture by Veronika Hofer

Not all composts are suppressive, however, as this feature is dependent on the activities of antagonistic microorganisms, the plant host, the pathogen species involved, and the characteristics of the compost (Fuchs 2002; Bonanomi et al. 2006). Moreover, the ability of composts to suppress phytopathogenic agents varies and they can be inconsistent against different pathogens. Termorshuizen et al. (2006) assayed the effect of 18 composts against seven pathosystems (126 cases corresponding to 100%). They found disease suppression in 54% of the cases, no significant suppression in 43%, and disease enhancement in 3%. Particle size, nitrogen content, cellulose and lignin content, electrical conductivity, pH, inhibitors released by composts, and compost microbiota may also affect the incidence of soil-borne plant pathogens (Hoitink and Boehm 1999). These factors also include the nutritional status of the transplant and the pathogenic process of the specific pathogen (Aviles et al. 2011). For instance, a majority of Phytophthora root rot diseases are inhibited by pH below 5 (Blaker and MacDonald 1983). The low pH reduced sporangium formation, zoospore release, and motility. Besides, pH above 8 leads to the reduction of *Fusarium* wilts since pH is associated with the availability of macro- and micronutrients, important for growth, sporulation, and virulence of *Fusarium oxysporum* (Bernal-Vicente et al. 2008). Inclusion of lignin-rich or chitin residue feedstock in the compost enhances its suppressive capacity, because it contains compounds similar to those present in the pathogenic microorganism cell walls. Compost maturity is also another important factor to attend depending on the pathogen to be controlled (Bonanomi et al. 2010). For example, young compost is more effective in suppressing *Pythium*, while mature compost is recommended against *Rhizoctonia* (Harman et al. 2004; Bernal-Vicente et al. 2008, 2012). However, extremely stable composts do not support microbiological activity, so the potential for biological suppression potential is lost (Widmer et al. 1998). Next to the production processes, storage of compost also affects the activity of a compost (van Rijn et al. 2007).

The suppressive effect in composts has been classified as either general or specific. General suppression is induced by a large metabolically active microbial community, while specific suppression is attributed to specific microbial agents that proliferate in the presence of compost and affect pathogen growth or infection through a particular biological control mechanism (i.e., competition, antibiosis, parasitism, induced plant resistance, or a combination of these mechanisms; Hadar and Papadopoulou 2012). It is important to maintain the biotic factors that are related to suppressiveness in compost as much as possible in the final stage of the composting process, by avoiding overheating or steaming compost (Borrero et al. 2006; Fuchs et al. 2008). It is also important to store compost at optimal aeration and moisture content.

A more recent approach to compost suppressiveness has been the enrichment of compost with specific strains of biocontrol agents (Hadar and Papadopoulou 2012). Good results have been achieved with the introduction of species of genera *Acremonium*, *Chaetomium*, *Gliocadium*, *Trichoderma*, and *Zygorrhynun* spp. (Hadar and Papadopoulou 2012). It is also important to take into account the inoculation time (after the heat peak of the composting process) and obtain a critical concentration of the biocontrol agent (Bernal-Vicente et al. 2012). The use of certain *Trichoderma* spp. has been proposed because of the ability of these fungi to rapidly colonize the rhizosphere, control pathogenic and competitive microbiota, and improve plant health and root growth (Lopez-Mondejar et al. 2010; Bernal-Vicente et al. 2012).

Many factors must to be used to define a growing medium; in general, all these aspects are important but they are not practical for end-users to decide what to measure and which are the minimal characteristics of a growing medium to respond to its expectation. Mixture design surface has been presented as a promising technique, performing a simultaneous optimization of several response parameters of the transplants (Ceglie et al. 2015). This technique elaborates a mathematical model to predict the transplant performances in respect to the growing media components (Fig. 3). A successful scaling to semi-industrial level will give producers the possibility to realize growing media tailored at specific crop performances and based on the best mixture of components under economic and environmental points of view.

5 Fertilization strategies in organic greenhouse conditions

Seedling production requires very specific fertilization strategies due to the short cultivation period and the demand of specific nutrients (Möller and Schultheiß 2013). Roots are able to explore a relatively small volume of growing medium; therefore, efficient methods of nutrient supply are very important. In the case of conventional nurseries, the fertilization programs are managed through the addition of mineral fertilizers to provide most of nutrients required for plant growth (Möller and Schultheiß 2013). In organic nurseries, nutrients must be totally or partly released from organic amendments and it can be necessary to incorporate a significant proportion of nutrients in base and top dressing nutrition programs (Fig. 4). It must be taken into account that fertilizers must be in the Annex I list of permitted inputs for organic production (EC 889/08). Compost mineralization rates cannot supply nutrients to the whole plant demand period, but it is assumed that 40% of compost as an ingredient of the growing media is sufficient to supply plant nutrient demand in the early stages, at least for 2–3 weeks, except for nitrogen (Biernbaum et al. 2006). It is therefore necessary to add fertilizers as base dressings in the substrate

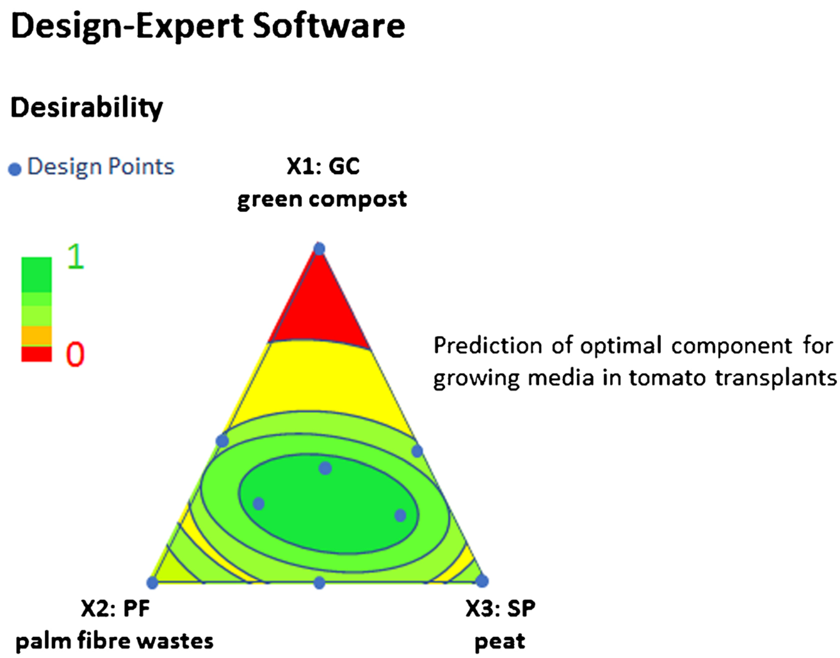

Fig. 3 Desirability prediction level of three components for a growing medium of tomato transplants. The scale green–yellow–red in the triangle surface represents the range from the best to the worst transplant production. Each triangle vertex represents one of the three different components (Ceglie et al. 2015)

before planting and/or by fertigation or foliar fertilization to supply the required nutrients during the seedling or transplant growth cycle (Möller and Schultheiß 2013).

5.1 Base dressing fertilization

Organic fertilizers are mainly based on animal manures and by-products such as mature manure, dried blood, hoof and horn, dehydrated and pelletized blends of animal and/or plant wastes, and by-products of fish, livestock, food, and other processing industries (Table 8). Nicola and Basoccu (1994) concluded that N was the major factor affecting seedlings. In organic systems, nitrogen management is based on nitrogen sources that must be mineralized by soil microorganisms before becoming available for plant uptake. For example, blood meal addition increases fresh and dry weights of plants grown in compost because microbial activity is improved rather than because of the addition of nutrients (Leonard and Rangarajan 2007).

In general, organic fertilizers have slow-release characteristics due to organically bound nitrogen. The rate of net nitrogen mineralization from solid organic fertilizers varies from slow to fast and depends mainly on the C/N ratio and the temperature (Hartz and Johnstone 2006). This means that different nitrogen management strategies will be required depending on the climate conditions and that the type and size of organic substrate should be adjusted according to growing temperatures to achieve better seedling hardening, establishment, and yield. Moderate climate regions traditionally use bigger growing media volumes (e.g., pressed peat blocks) than warm regions to buffer the reduction of microbial nitrogen mineralization due to low temperatures. Composting is another factor that reduces mineral N content by increasing the organic matter stability, whereas anaerobic fermentation results in reduced available content of available N (Gutser et

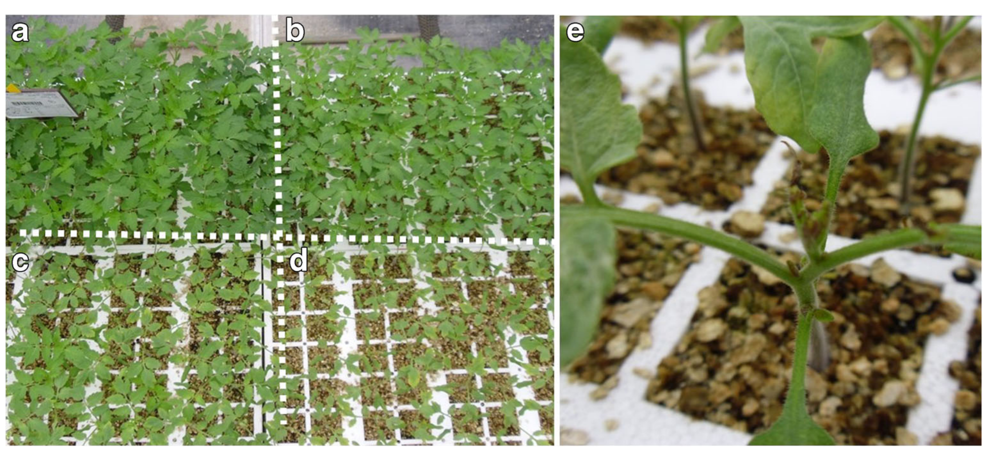

Fig. 4 Tomato rootstock grown in organic media (Klasmann-Deilmann). **a** Irrigated by water and chemical fertilizer (7:3:7). **b** Only irrigated by water. **c** Incorporated "Guano" organic. **d** Fertilization with 50 ppm N: "Nugro" organic. **e** The use of 50 ppm N by Nugro fertilizer caused atrophy and deformation of the shoot tips. Picture by A. Koren

Table 8 Mineral nutrient value of some organic and mineral fertilizers permitted by the EU regulation in organic agriculture (McLaurin and Reeves 2006)

Material	N	P_2O_5	K_2O	Relative availability
Organic origin				
Alfalfa meal	3.0	1.0	2.0	Medium-slow
Blood meal	12.0	1.5	0.6	Medium-rapid
Bone meal (steamed)	0.7–2.6	11.0–34.0	0.0	Slow-medium
Brewers grain (wet)	0.9	0.5	0.1	Slow
Cocoa shell meal	2.5	1.0	2.5	Slow
Ground coffee (dry)	2.0	0.4	0.7	Slow
Cotton gin trash	0.7	0.2	1.2	Slow
Cotton seed meal (dry)	6.0	2.5	1.7	Slow-medium
Eggshells	1.2	0.4	0.1	Slow
Feather	11.0–15.0	0.0	0.0	Slow
Fish meal	10.0	4.0	0.0	Slow
Fish emulsion	5.0	2.0	2.0	Medium-rapid
Fish scrap (dry)	3.5–12.0	1.0–12.0	0.8–1.6	Slow
Garbage tankage (dry)	2.7	3.0	1.0	Very slow
Grape pomace	3.0	0.0	0.0	Slow
Greensand	0.0	1.0–2.0	5.0	Slow
Guano (bat)	5.7	8.6	2.0	Medium
Guano (Peru)	12.5	11.2	2.4	Medium
Algae extracts	0.9	0.5	1.0–4.0	Slow
Vinasses (processed molasse)	4.5	0.3	5.5	Medium-rapid
Manure (cattle, horse, sheep, swine)	0.3–0.6	0.2–0.3	0.3–0.8	Medium
Poultry (75% water)	1.5	1.0	0.5	Medium-rapid
Mineral origin				
Colloidal phosphate	0.0	18–24	0.0	Slow
Rock phosphate	0	20–32	0	Slow
Granite dust	0.0	0.0	3–5	Very slow
Potassium sulfate	0	0	21	Rapid

al. 2005). Koller et al. (2004) studied different organic nitrogen sources (Table 8), concluding that the animal-based fertilizers were more suitable for base dressing, in terms of higher production and less phytotoxic symptoms, than some plant-based fertilizers.

Chitin-containing fertilizers (e.g., crab shell or by-products of *Penicillium* fermentation) are known for their phytosanitary side effects on fungal disease, e.g., corky root rot (*Pyrenochaeta lycopersici*; Michel and Lazzeri 2010), because they can boost the populations of microorganisms that can break down chitin, which are well-defined suppressive microorganisms (Haas and Defago 2005; Gagnon and Berrouard 1994).

A negative aspect of organic fertilizers results from the attraction of sciarid flies (e.g., *Bradysia* sp.). Ammonia and other by-products released during the mineralization process of fertilizers appear to be major attractants for female sciarid flies. The larvae of sciarid flies normally feed on algae and fungi in growing media, but they can also feed on plant roots and cause severe damage to seedlings (Koller et al. 2004). Sciarid flies in growing media could be controlled by *Steinernema feltiae* and *Bacillus thuringiensis* subsp. *israelensis* to a sufficient extent degree (Koller et al. 2004).

It is worth noting that in organic agriculture, the opportunities for the use of mineral fertilizers are restricted to rock phosphates and potassium sulfates for phosphorus and potassium enrichment of the substrates (Table 8). Generally, the use of natural rock materials releases some macro- and micronutrients which are converted to the soluble form available for plants leading to higher fresh and dry weights of seedlings (Park 2011).

Badran et al. (2007) studied the effectiveness of rock phosphate and potassium sulfate incorporated in compost for organic tomato transplant production. It was demonstrated that sulfate did not produce any effect on plant, but rock phosphate improved the composting process itself by accelerating organic matter decomposition as evidenced by transplant growth increase (Caravaca et al. 2005; Richardson et al. 2009). Furthermore, the phosphorus availability during composting can be further increased if some microorganisms are inoculated such as *Aspergillus niger*, *Pantoea agglomerans*, and *Pseudomonas putida*. These microorganisms favor plant phosphorus uptake due to acid production in the rhizosphere or by higher root exudate production as a consequence of compost biostimulation of the plant (Hayat et al. 2010; Park 2011).

In this context, the efficacy of some fertilizers has been improved by the simultaneous addition of specific microorganisms that promote faster and more efficient nutrient solubilization. As an example, the addition of arbuscular mycorrhiza or *Aspergillus niger* together with natural rock phosphate resulted in better plant growth due to their reduction of rhizosphere pH and the higher amount of available phosphorus used by plants (Caravaca et al. 2005; Medina et al. 2009). In other examples, the addition of biofertilizer microorganisms such as *Azospirillum*, *Rhizobium*, or *Bacillus* improved organic matter mineralization in the substrate, leading to the uptake of released nutrients by plants (Bashan and Holguin 2004; Vassilev et al. 2006; Hayat et al. 2010). These microorganisms will be discussed in greater detail in Section 6.

5.2 Top dress fertilization strategies

Popescu et al. (2004) showed that growing media cannot be successful in organic transplant production without any top dress application during the plant growth. It is hard to generalize from these results, however, because of the high variability of the composition and nature of the organic amendments, the cell size of the trays, and the specific experimental conditions. In temperate regions, it is possible to use base fertilizers only, specifically by using trays with large cell sizes or in peat blocks with no trays. In high-temperature areas such as the Mediterranean areas, mineralization is sometimes too fast and this limits the sole use of base fertilizers in the growing media. Organic nurseries, in the Mediterranean, use other fertilization techniques, such as foliar or root application, to supply the growing media substrates. Nielsen and Thorup-Kristensen (2004) demonstrated that the choice of growing media and fertilization strategy is one of the greatest challenges for organic seedling production because of the restricted number of growing media. Efficient methods of nutrient supply are therefore recommended, and these include the use of foliar application of fertilizers in liquid form delivered from hydrolyzed feather, meat, bone, and blood meal for crop fertilization (Gaskell and Smith 2007). Fertigation is also considered to be an optimal system for the supply of required nutrients as it is based on the application of diluted liquid fertilizers directly at the root level. It has the advantages of increasing nutrient uptake and reducing water and nutrient leaching loss. Fertigation opens up a range of opportunities because its flexible fertilization patterns enable growers to manage specific nutritional requirements not only for different crops on the same kind of substrates but also during the growth of the same crop during its different stages of development. Fertilizers suitable for fertigation must be mixed in water, and they should not react with any substances in the irrigation water to form insoluble precipitates (McLaurin and Reeves 2006; Gaskell and Smith 2007). Most of fertigation products are usually composed of dehydrated and pelletized blends of animal and/or plant wastes and by-products of fish, livestock, food, and other processing industries (Table 8). The ebb–flood system is an alternative to fertigation in seedling production. It is a form of hydroponics where the seedling in the growing medium is periodically flooded with the required fertilizers.

Top dressing with liquid fertilizers is used to improve nitrogen fertilization (Gaskell and Smith 2007). Unlike dry fertilizers, which are not easily applied through irrigation systems, liquid fertilizers are more suitable for fertigation in drip systems which are popular in arid and hot climate zones.

As mentioned in Section 5.1, climate conditions are important in the determination of nitrogen uptake efficiency (Hartz and Johnstone 2006). For example, the commercial production of vegetable transplants in the Mediterranean Basin faces several problems connected to the use of fertilizers. In summer, the nurseries are exposed to high temperatures, above 35 °C during the day and about 15 °C at night. Seedling production with detached and shallow media increases the exposure of the substrate and the roots to the high ambient temperatures. Symptoms like budless tomato transplants, root burn, and physiological deformation in transplants are common, and the cause is not always clear (Wetztein and Vavrina 2002). These symptoms may be due to ammonium toxicity or other gas emissions, but the problem is not yet solved so further research will be needed to identify the causes (Wetztein and Vavrina 2002).

6 Beneficial microorganisms: plant growth-promoting rhizobacteria and biological control agents

Plant growth and productivity is heavily influenced by the interactions between plant roots and the surrounding microbial populations. The plant rhizosphere harbors microorganisms that may have positive, negative, or no visible effect on plant growth. The main positive effects are related to (i) suppression of disease (biocontrol), (ii) enhancement of nutrient availability (biofertilization), and (iii) production of plant hormones (phytostimulation) (Martinez-Viveros et al. 2010; Bhattacharyya and Jha 2012). Beneficial microorganism inoculation is one of the aims of agricultural biotechnology, with a key goal of reducing reliance on chemical fertilizers and pesticides in conventional agriculture, and to permit functional organic agriculture where synthetic inputs are not permitted (Minorsky 2008; Adesemoye et al. 2009).

There are many factors which should be taken into consideration to obtain benefits from bio-inoculation (Berg and Smalla 2009), including the selection of the appropriate microorganisms based on the target host plant, indigenous microbial communities, environmental conditions, inoculant density, suitability of carriers, compatibility with integrated crop management, and soil type. The inclusion of beneficial microorganisms during seedling production would permit two main benefits: (i) facilitating plant growth during the germination and seedling stages and (ii) introducing with the transplant to the soil beneficial microorganisms (Zehnder et al. 2001).

6.1 Microbial inoculation for disease and pest control

Microorganisms that suppress plant pathogens are referred as biological control agents (BCAs) (Harman et al. 2004). The BCAs used in agriculture today can be classified into two types. One group includes those microorganisms that can control a large spectrum of taxonomically diverse pathogen hosts, including species of *Bacillus*, *Pseudomonas*, *Streptomyces*, *Trichoderma*, *Clonostachys*, and some yeasts. The other group can counteract only one of a few targeted pathogens and includes biocontrol species of *Agrobacterium*, *Ampelomyces*, *Coniothyrium*, non-pathogenic *Fusarium*, atoxigenic *Aspergillus*, etc. (Ruocco et al. 2015). Currently, there are a limited number of biological control products available on the market with the situation varying from country to country. In countries, such as the USA, Australia, and New Zealand, the use of BCAs to control aerial and soil-borne plant pathogens is a widespread control method. However, in the European Union, few microorganisms are currently approved under Regulation EC 117/2009, which was implemented on 14 June 2011 (Table 9). The new regulation contains the text of reference which regulates the use of plant protection products (PPPs), including chemicals as well as microbial biological control agents (http://ec.europa.eu/food/plant/pesticides/eu-pesticides-database/public/?event=product.selection&language=EN).

The success of BCAs is due to several properties that can be summarized in various strategies. The oomycetes *Phytophthora* ssp. and *Pythium* spp. are described as highly sensitive to microbial nutrient competition. They depend on exogenous carbon sources for germination to infect host plants (Hoitink and Boehm 1999). Competition for nutrients and space is one of the modes of action of many BCAs such as *Trichoderma* spp. (Alabouvette et al. 2006).

Competition for micronutrients such as iron is also frequently found, being one of the modes of action of fluorescent *Pseudomonas* which produces siderophores limiting growth and germination of chlamydospores of pathogenic *Fusarium oxysporum* (Heydari and Pessarakli 2010). It is known that *Trichoderma harzianum* secretes iron-chelating siderophores that limit the availability of iron for the germ tube growth of *F. oxysporum* (Verma et al. 2007).

Representatives of a range of species of bacteria (*Pseudomonas*, *Burkholderia*, *Bacillus*, *Serratia*, *Streptomyces*) and fungi (*Trichoderma*, *Penicillium*, *Gliocadium*, *Sporidesmium*, non-pathogenic *Fusarium* spp.) have been identified as antagonistic to one or more soil-borne plant pathogens (Aviles et al. 2011). Positive correlations have been found between these microbial species and the ability of composts to suppress soil-borne pathogens (Bonanomi et al. 2010). The effectiveness of the application of microorganisms such as *T. harzianum* under seedling nursery conditions was related directly to the growing media formulation, because the formulation had a clear influence on the survival of this antagonistic fungus. A commercial bentonite–vermiculite formulation based on *T. harzianum* strain CECT 20714 could be effective in greenhouse nurseries (Bernal-Vicente et al. 2008) with a double objective as follows: (i) to enhance plant growth and (ii) to reduce the incidence of *Fusarium* wilt in melon plants.

6.2 Biofertilization and biostimulation effect

Some microbial species promote plant growth through nitrogen fixation, phosphate solubilization, production of phytohormones like auxin and cytokinin, and production of volatile growth stimulants such as ethylene and 2,3-butanediol (Ryu et al. 2003; Vessey 2003; Castro et al. 2009). The production of phytohormones is now considered to be one of the most important mechanisms by which many beneficial microorganisms promote plant growth (Spaepen et al. 2007). Phytohormones are molecules acting as chemical messengers, and they play a fundamental role as growth and development regulators in plants. Numerous fungal and bacterial species can affect plant phytohormone metabolism (Tsavkelova et al. 2006). Indol-3-acetic acid (IAA)-mediated ethylene production can be increased through plant growth-promoting rhizobacteria (PGPR)-inoculated tomato plants (Ribaudo et al. 2006). At present, auxin-synthesizing rhizobacteria are the most studied phytohormone producers (Tsavkelova et al. 2006; Spaepen et al. 2007). *Azospirillum* is one of the best studied IAA producers (Dobbelaere et al. 1999). Other IAA-producing bacteria belonging to the genera *Aeromonas* (Halda-Alija 2003), *Azotobacter* (Ahmad et al. 2008), *Bacillus* (Swain and Ray 2007), *Burkholderia* (Halda-Alija 2003), *Enterobacter* (Shoebitz et al. 2009), *Pseudomonas* (Niranjana et al. 2009), and *Rhizobium* (Ghosh et al. 2008) have been isolated from different soil rhizospheres.

A classic example of biofertilization is nitrogen fixation by microorganisms such as *Azoarcus* sp., *Beijerinckia* sp., *Klebsiella pneumoniae*, *Pantoea agglomerans*, and

Table 9 Microbial control agents with status of approved under Reg. (EC) No. 1107/2009 (repealing Directive 91/414/EEC)

Microbial control agent	Strain	Use
Adoxophyes orana GV	BV-0001	Insecticide
Ampelomyces quisqualis	AQ-10	Fungicide
Aureobasidium pullulans	DSM 14940, DSM 14941	Bactericide Fungicide
Bacillus firmus	I-1582	Nematicide
Bacillus pumilus	QST 2808	Fungicide
Bacillus subtilis	QST 713	Bactericide Fungicide
Bacillus thuringiensis subsp. *aizawau*	ABTS-1857, GC-91	NS
Bacillus thuringiensis subsp. *israeliensis* (serotype H-14)	AMS-52	NS
Bacillus thuringiensis subsp. *kurstaki*	ABTS 351; PB 54; SA 11; SA 12; EG 2348	NS
Bacillus thuringiensis subsp. *tenebrionis*	NB 176 (TM 141)	NS
Beauveria bassiana	ATCC 74040; GHA	Insecticide
Candida oleophila	0	Fungicide
Cydia pomonella granulovirus CpGV	NS	Insecticide
Gliocadium catenulatum	J1446	Fungicide
Helicoverpa armigera nucleopolyhedrovirus	Hear NPV	Insecticide
Lecanicillium muscarium (formerly *Verticillium lecanii*)	Ve6	Insecticide
Metarhizium anisopliae var. *anisopliae*	BIPESCO SIF52	Insecticide
Paecilomyces fumosoroseus Apopka	97	Insecticide
Paecilomyces fumosoroseus	Fe9901	Insecticide
Paecilomyces lilacinus	251	Nematicide
Phlebiopsis gigantean	Several strains	Fungicide
Pseudomonas chlororaphis	MA342	Fungicide
Pseudomonas sp.	DSMZ 13134	NS
Pythium oligandrum	M1	Fungicide
Spodoptera exigua nuclear polyhedrosis virus	NS	Insecticide
Spodoptera littoralis nucleopolyhedrovirus	NS	Insecticide
Streptomyces K61 (formerly *Streptomyces griseoviridis*)	NS	Fungicide
Streptomyces lydicus WYEC 108	NS	Bactericide Fungicide
Trichoderma asperellum (formerly *T. harzianum*)	ICCO12; T25; TV1	Fungicide
Trichoderma asperellum	T3T	Fungicide
Trichoderma atroviride (formerly *T. harzianum*)	IMI 206040; T11	Fungicide
Trichoderma atroviride	I-1237	Fungicide
Trichoderma gamsii (formerly *Trichoderma viride*)	ICC080	Fungicide
Trichoderma harzianum	T-22; ITEM 908	NS
Trichoderma polysporum	IMI 206039	Fungicide
Verticillium allbo-atrum (formerly *Verticillium dahliae*)	WC5850	Fungicide
Zucchini yellow mosaic virus	Weak strain	Fungicide

NS not specified

Rhizobium sp. which are reported to fix atmospheric N_2 (Riggs et al. 2001; Vessey 2003). Phosphate-solubilizing microorganisms are another example of biofertilization that have been recorded, converting the insoluble form of phosphorus to the soluble and available form through acidification, secretion of organic acids or protons (Richardson et al. 2009), and chelation and exchange reactions (Hameeda et al. 2008). Saprophytic bacteria and fungi are reported to solubilize phosphate in soil due to chelation-mediated mechanisms (Whitelaw 2000). The most significant phosphate-solubilizing microorganism reported is from genera such as *Microbacterium*, *Pseudomonas*, *Rhizobium*, *Beijerinckia*, *Burkholderia*, *Enterobacter*, and *Serratia* (Mehnaz and Lazarovits 2006). There are also reports on the efficacy of combinations of *Bacillus* and *Microbacterium* inoculants to improve the uptake of some minerals such as Ca, K, Fe, Cu, Mn, and Zn by crop plants (Karlidag et al. 2007), through the stimulation of proton pump ATPase, forcing the decrease in rhizosphere pH (Mantelin and Touraine 2004).

Close examination of the individual effects of beneficial microorganisms leads to the conclusion that many of the best strains are multifunctional. Thus, many beneficial microorganisms simultaneously solubilize phosphate, produce auxins that stimulate root growth, and produce antibiotics and siderophores that may function in the suppression of plant pathogens. In most cases, individual strains vary considerably in performance and there is no clear relationship between taxonomy and microbial functions that can be used to monitor the population size and activity of these bacteria based on quantification of specific taxonomic groups in the soil. The best example of such inconsistency is found in the body of work on *Azospirillum*, which was initially based on this bacterium's ability to fix nitrogen, but which was later shown to affect plant growth by the production of phytohormones (Spaepen et al. 2007). Similarly, many phosphate-solubilizing bacteria have been screened and selected based on their ability to solubilize hydroxyapatite on agar media, but they have later been found to affect root growth by the production of plant growth hormones.

Arbuscular mycorrhizal fungi (AMF), grouped into the phylum Glomeromycota, can form mutualistic symbiotic relationships with most land plants and can colonize a wider soil volume (Richardson et al. 2009). The AMF receive carbon from their host while favoring plant growth through their ability to exploit resources and deliver nutrients, especially phosphorus, and water back to the plant (Smith and Read 2008). AMF may inhibit pathogen proliferation through the formation of a bacterial community that limits the pathogen invasion (Li et al. 2006; St-Arnaud and Vujanovic 2007). The successful use of AMF in sustainable agriculture requires the selection of the appropriate host/fungus combination and the infectivity and efficacy being two of the criteria for the selection (Tarbell and Koske 2007).

6.3 Interaction among beneficial microorganisms

In the rhizosphere, interactions between microorganisms are crucial to ensure their successful establishment in plants, and from these interactions, beneficial effects on plants can be observed. The combination of AMF and the strain of *Trichoderma* harzianum (T78) produces better plant establishment in melon plants under nursery conditions (Martinez-Medina et al. 2013). The presence of *T. harzianum* significantly increased root colonization by *Glomus intraradices*, *Glomus constrictum*, and *Glomus claroideum*, reaching values significantly higher than the most effective AMF *Glomus mosseae* (Fracchia et al. 2000). *Trichoderma koningii* combined with *Pseudomonas chlororaphis* or *Pseudomonas fluorescens* Q2–87 gave higher suppression of the severe plant disease wheat take-all than *T. koningii* alone (Duffy et al. 1996). Another case is the combination effect of *Trichoderma virens* GI-3 combined with *Burkholderia cepacia* which provided greater protection to pepper seeds than either antagonist inoculated separately in the presence of four soil-borne pathogens. Datnoff et al. (1995) reported a higher suppressive effect against *Fusarium* crown and root rot of tomato with the combination of *T. harzianum* and *G. intraradices* than with each biological agent applied alone. Combinations of the AMF and *T. harzianum* could control *Fusarium* wilt more effectively than each AMF applied alone. It is worth noting, however, that the effects of the interaction between AMF and *T. harzianum* may be very different depending on the AMF, the saprophytic strain, and the host plant (Fracchia et al. 2000), and in general, it can be attributed more to the type of strain than the species or genus (Martinez-Medina et al. 2014). Martinez-Medina et al. (2013) studied the effect of the pre-inoculation by AMF and the specific *T. harzianum* T78, demonstrating that plants co-inoculated with the AMF and *T. harzianum* at the nursery had similar growth and fruit production in nutrient-poor soil compared to mineral-fertilized soil without pre-inoculation.

The application of beneficial microorganisms to transplants can be done in different ways. The first example involves liquid applications from a previous fermentation. These microorganisms can either be based on a mineral medium or on an organic oil-based solution. The main advantages are related to the simplified system of production and application for the farmers. As they are applied directly, liquid inoculants allow direct contact of seed with the microorganisms and consequently increase the survival of microbial strain on plant roots. However, they may fail to provide a protective environment for the microbial strain, leading to a decrease of the inoculated microbe population, possibly due to poor adaptation to the medium and/or the lack of physical protection. Different clays such as bentonite, perlite, and vermiculite have been used as carriers of some strains such as *T. harzianum* T78. The use of clays is based on the incorporation of hypha and spores between the physical parts of clays, which provides physical conditions adequate for the development of this antagonistic fungus. Both bentonite and vermiculite have a laminar structure, large surface area, and high capacity for adsorption and absorption and so can provide the moisture, nutrients, and also the oxygen needed for fungus growth (Bernal-Vicente et al. 2008). Bio-encapsulation is another way to assure better survival both during storage and following inoculation into the environment. Bioencapsulation uses natural polymers such as alginate produced by brown algae such as *Macrocystis pyrifera*, *Laminaria digitata*, *Laminaria hyperborean*, and *Ecklonia cava* and bacteria such as *Azotobacter vinelandii* and *Pseudomonas* strains.

One of the pitfalls in the use of microorganisms, and therefore a limitation of their commercial distribution, is the lack of consistency in the results obtained because different authors showed contrasting results. Improving the understanding of modes of action may produce promising results in the control of plant pathogens. This could identify critical threshold population sizes that are likely to be required to induce the expression of some traits, particularly those involved in biocontrol. The cumulative effects of microorganisms that influence root growth rates, root system architecture, root hair formation, and longevity will indirectly affect the ability to acquire water and nutrients and the tolerance of root loss from disease. More in-depth research, on which mechanisms are most important and how to manage soil microflora to obtain expression of these traits, is the future great challenge for consistent microbiota use in agricultural systems.

7 Main conclusions and future challenges of growing media

Peat use could be reduced considerably in growing media if replaced by a proportion of compost or other proposed materials supplemented with coir and mineral. This substitution would permit the production of higher transplant biomass and plant growth as good as peat, in particular, due to the improvement of physical, chemical, and microbiological properties. These materials, such as added-value compost or tailored compost, would bring added values that peat cannot provide, such as the feeding of seedlings with macro- and micronutrients or the carrying of beneficial microorganisms needed to mineralize compounds into plant-available nutrients and to suppress plant pathogens.

There is an information gap between the producers of growing media, in particular compost producers, and the requirements of nurseries, which should be overcome by the provision of trusted common information for both markets. There is a lack of practical research, and more attention must be paid to the involvement of the whole chain from input and growing media producers to the seedling and vegetable growers. It needs to be demonstrated that mixtures of added-value growing media could be upscaled from laboratory size to amounts of several cubic meters or tons without losing their useful properties, taking into account several weeks of storage which is unavoidable in commercial handling. These steps are necessary to translate the achievements of the research on growing media into farm practice. It is important to carry out a more in-depth analysis of the effects of specific composts used by nurseries to assure the best seedling growth conditions.

More involvement of compost producers and end-users in educational and planning efforts could improve the quality of growing media by introducing added-value characteristics, reducing the use of peat that would permit a more sustainable regime as claimed by stakeholders of organic agriculture.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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