Special Section: Organic Materials Used in Agriculture, Horticulture, Reconstructed Soils, and Filtering Applications

This editorial highlights contributions to the special issue, Organic Materials Used in Agriculture, Horticulture, Reconstructed Soils, and Filtering Applications.

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Organic Materials Used in Agriculture, Horticulture, Reconstructed Soils, and Filtering Applications

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Organic material has historically been used in growing media and has traditionally been harvested from peatlands. Deposits of organic material in peatlands may also be very productive when cultivated. This editorial brings attention to different sources of organic material, including peatlands, and their use as growing media and farmland. The editorial identifies new fields for which organic material may be used like green roof and filtering applications. Concepts developed in these fields are widespread in different journals and, as a result, soil scientists are somewhat unfamiliar with recent developments in the characterization of growing media and their different uses. This special issue illustrates concepts used in growing media science, and brings attention to these new fields of investigation to benefit soil scientists and horticulturists.

Organic materials are commonly used to manufacture growing media (root zone substrates) for greenhouse and nursery crop production, as well as for home gardening (Fig. 1). The dominant organic material has historically been peat, harvested from deposits of undecomposed plant materials formed in poorly drained areas described as peatlands. The Histosols forming on these peatlands can also be very productive when drained, cultivated for agricultural use, and carefully managed.

Using organic growing media has raised the productivity in containerized horticulture systems considerably relative to that in mineral soils, since the introduction of soilless media in the 1930s and 1950s (Bunt, 1988). This occurred, despite the limitations imposed by small rooting volumes, through advancements in the understanding of water, air, and nutrient storage and exchange; improvements in water and nutrient management; and better control of soilborne pathogens. The important development of soilless cultures began predominantly with peat-based substrates introduced in the 1930s (Puustjärvi, 1977). In the following decades, mineral components were rapidly introduced into artificial organic growing media either to improve drainage, air filled porosity, and buffering capacity (perlite, vermiculite, pumice, calcined clays) or to add more weight (sand). Starting in the 2000s and originating in Europe, the trend has returned toward organic substrates because of consumer demands for more "natural" media (Caron and Rochefort, 2013). At the same time, public and regulatory concerns regarding the protection of peatlands and the necessity to recycle industrial or urban organic wastes helped to introduce new organic components. These components are now sourced from composts and manures of various origins, as well as coconut coir, bark, wood fibers, and biochar. For commercial media, these components need to be obtained from quality stock that is readily available, lightweight, relatively free of weeds and pathogens, inexpensive, environmentally friendly, and consistent in its physicochemical properties.

The physicochemical properties of growing media facilitate crop and root zone management, aiming to: (i) supply roots with water, gas exchange, and nutrients; (ii) provide physical support; and (iii) allow optimal root development. Commercial growing media are further tailored to the demands of a diversity of plants and applications (e.g., outdoor nursery, indoor greenhouse, production of transplants or seedlings) in a wide variety of container sizes. In these, plants depend on a comparatively small root-zone volume, resulting in high root densities and lower resilience compared to field-grown crops. In addition, unlike soils, the properties of growing media with high organic contents are dynamic. Physical and chemical properties of growing media change as organic matter oxidizes, media consolidate, nutrients and fine particles leach, salts accumulate, and root growth and expansion reduce macropores to a much larger extent than in mineral soils over a short time course, as outlined by Caron et al. (2015). Still, much of the media selection and management is based on initial properties at the time of planting. For example, water management in growing media is based on plant available water and air-filled porosity derived from the water retention characteristic. However, pore size distribution, total porosity and particle size of growing media may change drastically during the plant-growth period and lead to deficiencies in water, air or nutrient supply, which result for instance in hypoxia or temporary wilting, and a higher risk of physiological disorders like tip burn for lettuce, blossom end rot for tomatoes, or flower abortion.

Fig. 1. Successful greenhouse and nursery production of plants is largely dependent on the properties of the growing media. A variety of organic and inorganic components are used in varying combinations to manufacture growing media. (Photo by Sylvain Charpentier showing repotting of plants in a commercial nursery production.)

Similar challenges exist for field-grown crops on Histosols (Fig. 2). Organic growing media show many similarities to Histosols as both are composed of material of very similar botanical origin (*Sphagnum sp.,* decomposed wood fragments, sedges, etc.) with similar physical and chemical properties. The management of large-scale agricultural production on Histosols, however, challenges concepts and paradigms of classical soil science; many physical properties differ dramatically from mineral soils, as is the case for growing media. In particular, the concept of available water differs from mineral soils because drying results in irreversible shrinkage leading to decreased porosity and changes in pore size distribution (Giskin and Levin, 1978) and water transfers are affected by poor interconnection between fibers (Örlander and Due, 1986). In addition, the soil structure is strongly affected by the position of the water table, where it affects the overburden pressure and subsequent compaction of the top horizons in Histosols (Caron et al., 2015). Also, evolution of the soil profile is linked to decomposition of the organic and debris fibers dominating the Histosols horizons. Due to the common composition of both growing media and Histosols, classical concepts used in soil science need to be adapted to these kind of porous media, as discussed in Hallema et al. (2015a,b) and Caron et al. (2015).

The interest in growing media is also rapidly expanding to new areas of inquiry such as berry production (e.g., strawberry, blackberry, raspberry, cranberry), "urban greening" with green roofs and walls, and urban agriculture on reconstructed soils (Fig. 3). Growing media also play a major role in space exploration for plant-based biological life support in space greenhouses (Monje et al., 2003), where the reduced gravity environment creates unique challenges for maintaining optimal root zone functions (e.g., Heinse et al., 2009; Jones et al., 2012). In addition, the ability of organic substrates to harbor microorganisms is increasingly being used in emerging applications like the suppression of plant pathogens (e.g., Noble and Coventry, 2005 and reference therein) or the filtering of waste water (Kennedy and van Geel, 2000).

Given that the applications and users of growing media are so varied and that the science is conducted in so many fields (horticulture, soil science, agronomy, silviculture, material science, and engineering), research papers on growing media have historically been published in a variety of journals. Concepts developed in these fields are therefore not widely shared among these disciplines, and soil scientists in particular are somewhat unfamiliar with recent developments in the characterization of growing media. This special issue on growing media will help facilitate the sharing of concepts and paradigms used in growing media science, and

Fig. 2. Organic media properties are also of importance for large scale production on Histosols. (Photo by Jean Caron showing mesclun production in Québec.)

Fig. 3. New applications for growing media are rapidly emerging, such as for green roofs, urban and space agriculture, and waste filters. (Photo by Sylvain Charpentier showing a green roof on a gymnasium in Angers, France.)

bring increased attention to the field. The 12 peer-reviewed papers in this special section cover a broad range of pressing issues. We highlight these contributions in four general categories: source materials of growing media, properties of media used in greenhouse and nursery, agricultural use of Histosols, and emerging new uses for growing media.

Sources of Organic Materials

An important issue for the growing media industry is worldwide, economic, and environmental pressures to replace some constituents used in growing media mixes. In Carlile et al. (2015), principal organic constituents of media and their properties are reviewed with particular attention to finding alternatives to peat, given concerns about environmental sustainability. The authors found that recent advances in the processing and quality control of coconut coir—a rapidly renewable product—make it a good alternative to peat. However, coir is sourced far away from its main users in Europe and North America. More local source materials such as composted wood fibers, bark, or agricultural, industrial, and municipal waste are reviewed by the authors, who point to current obstacles ranging from limited supplies and possible contaminant sources to competition with bioenergy production. These obstacles must be addressed by future research.

Another promising organic alternative to peat and aggregate media is biochar, which is manufactured from different organic materials combusted in the absence of oxygen. In this issue, Nemati et al. (2015) evaluated and tested biochar and found that biochar may be a good replacement for aggregate media. The authors describe physical and chemical properties of growing media mixed with biochar of varying particle sizes. Fine-textured biochar additions promoted water retention, while additions of coarse-textured biochar promoted drainage and aeration similarly to aggregates like perlite. In addition, biochar offers further benefits such as increased cation exchange capacity, which reduces nutrient leaching, and pH buffering of peat-based growing media mixes, which tend to be acidic, whereas biochar is alkaline. The authors point out, however, that despite the many benefits for growing media, biochar is unlikely to be widely adopted unless the product can be standardized for an industry that relies on homogenous and consistent properties.

In Caron et al. (2015), the authors bring attention to sphagnum farming (i.e., peatmoss cultivation), which provides a more renewable substitute to fossil peat where the living mosses in peatlands are harvested instead of their decomposed fractions. In this quest for new alternative components and designs of new substrates, it is important to note that characterization and prediction of physical and chemical properties of organic media use the same concepts and variables as soil science. However, the typical values and ranges of variation for key properties are significantly different and require a specific approach and appropriate measurement methods.

Properties of Growing Media Used in Greenhouses and Nurseries

In Caron et al. (2015), the adaptation of mineral soil concepts for horticultural growing media are discussed (Fig. 4). The authors point out that the main concepts that require adaptation are those linked to the use of different container configurations, the fragile nature of substrate and its sensitivity to disturbance, and the need to rethink the concept of aeration and water availability in organic growing media. They recommended methods to measure physical properties that minimize the disturbance to growing media and Histosols. They also state that measurements should be repeated to capture the evolution of such properties during use. The prediction

Fig. 4. Papers in this special issue review properties of organic components and discuss alternatives to peat substrates, while also addressing key differences from mineral soil, which require specific measurement methodologies. (Photo by Jean Caron showing solute transport experiments in peat.)

of air-filled porosity and available water should embrace the van Genuchten–Durner (Durner, 1994) approach to incorporate wetting angle changes during the rewetting process when characterizing water sorption curves. They also recommended that gas diffusivity should be used to develop an aeration index to link growing media properties to plant performances, thus guiding substrate manufacturing. Finally, Caron et al. (2015) propose norms to guide the manufacturing process of growing media.

Major advances have been made in the technology used to monitor water content and water potential in soils. Such technologies are increasingly being used to improve water management and minimize waste of irrigation water and nutrients. With these advances comes an increased need to accurately quantify the hydraulic properties of these media and how they evolve with time. In containerized soilless crop production, the volume of roots can become as important as the volume of the solid phase in the substrate, and it is easy to understand that during plant growth, fluid transfers properties are deeply modified. Kerloch and Michel (2015) studied the combined effects of root development and irrigation management on the hydraulic properties of sphagnum peat, coir, wood fiber, and bark. The authors found that aeration increased with time as a result of decreased pore tortuosity with increasing effective gas diffusion in all media. Simultaneously, however, the total porosity tended to decrease with time. In addition, the authors observed degradation in wettability (i.e., increase in contact angle) with successions of wetting and drying cycles of the media, which partially offset the increases in water retention due to consolidation and reduction in macroporosity.

The wettability of organic growing media and how it affects water retention is reviewed in detail in Michel (2015). The author highlights relationships and consequences of changes in wettability on physical properties of growing media. With regard to measurements, the author stresses that the commonly used water-drop penetration test and contact angle measurement are insufficient to describe the dynamics of wettability observed with changes in water content, thus affecting hysteresis phenomena in drying and wetting cycles. Results presented by Michel (2015) suggest that wettability is also a function of the growing medium pore-size distribution, which is consequential for the effects of water management on the root development in growing media.

Another aspect of water management under intense cultivation using growing media arises from the frequent irrigation with highly concentrated nutrient solutions, resulting in a high risk of excessive salt buildup in the media. Leaching must be performed at regular intervals to avoid salt accumulation. With regard to this issue, Caron et al. (2015) focused particularly on the presence of an immobile fraction that is likely to decrease the efficiency of leaching. The immobile fraction may lead to important salinity buildup as a result of sorption during intensive cultivation with frequent fertilization.

Agricultural Use of Histosols

The sensitivity of organic soils to disturbance and the specific organization of its fibrous nature have key implications for water transfers in Histosols. To enable agricultural use, these fragile soils are drained, which accelerates decomposition of organic matter and subsidence. Vehicular traffic further leads to the rapid formation of a compacted layer. With degradation of cultivated peatlands arise challenges to ensuring proper drainage and availability of water to actively growing plants. A study of limiting water flow in organic soils, which causes tip burn (i.e., calcium deficiency in the leaf) in lettuce, is presented in Périard et al. (2015). The authors used numerical modeling in Hydrus 2D (Šimůnek et al., 2012) to identify thresholds in soil matric potential at which insufficient root-water fluxes lead to tip burn. The field-scale implications for proper irrigation on Histosols are discussed in Lafond et al. (2015), who recommended zonal management of water in organic soils. The authors analyzed the spatial distribution of soil water availability used for precision irrigation management in Histosols to improve water use efficiency, as the water transfer properties of such soils are rapidly limiting. Hallema et al. (2015b) addressed the negative effects of accelerated oxidation of drained Histosols, combined with tillage and compaction due to tractor wheeling, which lead to changes in the soil physical and hydraulic properties. The authors evaluated soil water retention data for a series of cultivated Histosols and found that soils with higher organic matter content were more susceptible to the formation of a compacted layer as a result of agricultural practices, thus explaining drainage issues not commonly expected in undisturbed Histosols. In Hallema et al. (2015a), the authors studied the spatial distribution of this compacted layer and suggested that compaction is linearly related to the time since reclamation, but that observed changes in saturated hydraulic conductivity probably occurred within the first year after reclamation.

New Fields

The use of growing media is rapidly expanding to new fields. For example, plants have been grown successfully in reduced gravity on the MIR and International Space Stations. Use of growing media is likely to be part of any future long-term missions as they provide food and fiber, recycle waste, reduce carbon dioxide, and produce oxygen for astronauts. One of the main challenges to crop production is the management of water and air in growing media. In this issue, Heinse et al. (2015) showed that water distributions in millimeter-sized calcined clay media can be fundamentally different in the absence of hydrostatic forces, leading to reductions in the diffusive gas exchange in these media compared to Earth environments. The authors discuss how their results explain previously observed signs of hypoxia in space-grown plants, and they suggest that future space-greenhouse designs should consider novel approaches for water and gas exchange in root zones.

Growing media mixed as base products for substrates used in horticulture are also good materials for green roof installations. They are lightweight, with a low dry bulk density, and possess a large and coarse porosity. However, organic materials in green roofs are expected to not only retain water and support plant growth, but they must also delay stormflow through water retention and interception. In addition, they must also help mitigate energy and heat transfer to the buildings on which they are installed, acting as insulating materials when dry and conducting materials when wet. In this way, they can facilitate cooling of buildings with latent heat losses through evapotranspiration. In this issue, Charpentier (2015) conducted one-dimensional simulations to predict peat substrate behavior under different rainfall scenarios. Results showed that water storage properties and rainfall distribution were more important for controlling heat exchange than substrate thickness. This research highlights that hydraulic properties of organic materials are more important than thermal properties for the design of green roofs that function equally well in summer and winter.

The on-site sanitation of domestic wastewater is a challenge to improving the quality of natural waters. Many systems use the ability of organic substrates to fix the microorganisms that replace mineral filters with improved efficiency for purification. The organic component is also very efficient at fixing heavy metals found in wastewaters. However, the development of a bacterial layer at the top surface (i.e., biomat) may lead to a critical loss of efficiency of biofilters. Mostafa and van Geel (2015) showed that the pore structure of peat allowed a better distribution of microorganisms within the filter material, efficiently preventing bioclogging relative to a sand filter. It also showed that the preparation of the peat (loose vs. compact) had an important impact on the efficiency of the biofilters, and hence, on its duration.

Opportunities and Challenges

Papers in this special section represent a selection of contributions to the field of growing media science and point to the continued improvement and innovation in a diversity of applications. Their publication here exemplifies the constructive contributions to growing media science that span traditional disciplinary boundaries. Development of new knowledge has led to a better understanding of limitations that may occur with the introduction of novel organic sources to growing media mixes. The current trend away from nonrenewable resources, like peat, to materials based on waste- or by-products, promises a more sustainable use of resources. We suggest this trend will likely continue through intensive research, despite concerns over pathogens, contaminations, availability, and consistency. Important efforts are and will be invested in sphagnum farming to develop a more responsible approach toward use of peat for growing media production.

Given the high performance already observed with some of these substrates, we are optimistic that even more significant increases in crop performance are possible in the future. The need for improved productivity with finite or even shrinking agricultural lands will result in an increased need for growing media adapted for a wider variety of container configurations and growing environments, most likely located within urban areas, roofs, building walls, highway rights of way, and similar opportunities on nontraditional farmland. Papers published in this special issue illustrate how classical mineral soil concepts derived from an agricultural background must continue to evolve given these new opportunities.

In summary, while the findings published in this special section showcase progress and potential for the sustainable use and application in precision agriculture toward future food security, many key gaps persist, warranting further development. Future research should focus on transient physical and chemical properties of media and exchange processes in limited rooting volume, and should explore creative venues for further advancing growing media applications to expand growing surfaces to feed an increasing worldwide population under a high productivity constraint.

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