Reusing Greenhouse Growing Media

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Abstract

The disposal of used growing media represents one of the weak points for the application of hydroponic technology to greenhouse and nursery production. In many cases, especially mineral wools, exhausted substrates are disposed to landfill. However, landfill costs are increasing and landfill sites are becoming ever more unavailable. Thus, substrate reutilization must be strongly encouraged along with the reduction of substrate volume applied per plant. The paper reports a literature survey on the biological, technological and environmental implications of the reuse of exhausted substrates in soilless culture.

INTRODUCTION

In greenhouse and nursery crops, the disposal of artificial growing media (or substrate) at the end of cultivation is a potential threat to the environment due to a number of reasons. In fact, they may contain pesticides (Dekker et al., 1995; Drakes et al., 2001) and affect the landscape visual amenity, in particular when they are discarded illegally. Several types of substrates, such as mineral wools, are disposed to landfill at the end of one or more growing cycles; however, landfill costs are increasing and landfill sites are becoming ever more unavailable. Recently, Montero et al. (2009) used Life Cycle Assessment (LCA) tool to evaluate several greenhouse production systems in Europe; they concluded that substrate manufacturing has an important environmental burden. Thus, substrate reutilization must be strongly encouraged along with the reduction of substrate volume applied per plant.

Since sustainability has become a major concern in our society, minimizing the environmental impact of any kind of human activity is a major task to pursue. In accordance with the Directive 2008/98/EC of the European Parliament (The Council of the European Communities, 2008), "*waste prevention should be the first priority of waste management, and reuse and material recycling should be preferred to energy recovery from waste, where and insofar as they are the best ecological options*".

The concept of '3R' (Reduce, Reuse and Recycle) can be applied to the entire life cycle of growing media used in both hobby and professional horticulture. According to European Directive on waste (The Council of the European Communities, 2008), the term '*substrate reuse*' stands for the operation by which growing media that are not waste are used for the cultivation of the same or similar crops, while the term '*recycle*' means that waste substrates are reprocessed into materials either for the original or other applications. Reuse represents an important option for the environmental management of growing media and of the whole crop production cycle. Moreover, it may increase crop profitability, although substrate costs generally constitutes a small fraction of the total production costs of greenhouse and nursery crops (Montero et al., 2009).

The paper reports a short survey on the biological, technological and environmental implications of the reuse of exhausted substrates in soilless culture, including the treatments for their disinfection.

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USE OF GROWING MEDIA IN PROFESSIONAL HORTICULTURE

More than 100 and 200-250 m^3/ha are necessary for greenhouse cultivation, respectively, in rockwool and in perlite.

In the European Union, the total volume of growing media used yearly (including home gardening) is around 40 millions m^3 (15 millions tons); the consumption of mineral wool, perlite and peat in professional horticulture is about 0.90, 0.14 and 11.9 millions m^3, respectively (SV&A, 2005).

SUBSTRATE REUSE

The chance of reusing exhausted substrates, without any crop damage, depends on the physical-chemical properties of the material as well as on the crop's attitude, which is related to its tolerance to abiotic and/or biotic stresses due to such a reuse. Ideal media should have the following features (Fonteno, 1993; Lemaire, 1995):

- adequate mechanical properties to guarantee plant stability;
- low bulk density to facilitate the installation of growing systems;
- high porosity (not less than 75-80%);
- consistent distribution of air (oxygen) and water in order to sustain root activity;
- a pH between 5.0 and 6.5, or easily adjustable for instance, many types of peat are acid and therefore have to be neutralized with calcium carbonate;
- low soluble salts content;
- chemical inertia, that is the substrate should not interfere with the nutrient solution by releasing inorganic ions and phytotoxic compounds, or by immobilizing nutrients (e.g., phosphorus and nitrogen in some substrates);
- the ability to maintain the original characteristics during the cultivation, which may be quite long;
- the absence of pathogens and pests; however, the substrate must not be necessarily sterile.

The characteristics of the most widely used substrates are reported in Table 1.

Hydraulic properties are very important, in particular, the water and air content at container capacity, which is the amount of water and, for difference, air retained by the container after complete water saturation and free drainage. Total porosity, air-filled porosity, easy available water and bulk density can be accurately determined with complicated and time-consuming laboratory methods (Kipp et al., 2000; Raviv et al., 2002) or simpler methods that can be used at the farm gate (e.g., Montesano et al., 2004). Moreover, substrates must be standardized and uniform with each batch in order to permit the use of consistent fertilization and irrigation programs for each successive crop.

A number of modifications may occur during cultivation such as: alterations of porosity (compaction) and water holding capacity, changes in pH, salinity (EC) and cation exchange capacity, proliferation of fungi, bacteria, nematodes and other parasites, accumulation of toxic compounds released from the roots and from the decomposition of organic matter (Raviv et al., 1998; Lemaire and Marfà, 1998; Hanna, 2005). Modifications of physical properties influence many different processes such as: organic matter decomposition; root activity; compaction and particle aggregation; swelling and shrinkage due to wetting-drying cycles; transportation of fine particles to the container bottom with irrigation water. Higher salinity and pH are often detected at the end of cultivation as a result of fertigation and/or application of alkaline water, which is available to the growers in many regions, especially in the Mediterranean area.

Rockwool slabs can be manufactured with low or high fiber density to be used for single or multiple crops, respectively. However, Bussels and McKennie (2004) reported that single-crop slabs comprised 95% of those imported in New Zealand in 2003 because they are quite homogeneous from slab to slab and are preferred by the growers in consideration of easy control of EC and moisture content.

Several authors investigated crop response to the cultivation in reused substrates compared to virgin substrates. Some of them found a reduction of crop yield and/or produce quality in reused media (e.g., Abd-Elmoniem and El-Behairy, 2004), while many others found no or minimal differences between virgin and reused substrates (Rea et al., 2008; Celikel and Caglar, 1999; Giuffrida et al., 2007; Acuna et al., 2005; Fernandes et al., 2007; Urrestarazu et al., 2008). Hanna (2005) reported that cleaning and disinfecting with hot water (96°C) perlite before reuse gave greater marketable yield and heavier tomato fruit compared to virgin perlite. The observed yield benefit of perlite recycling was ascribed to the collective effect of salt leaching, medium disinfection and the presence of optimum level of nutrients, because generally it takes time to restore optimum nutrient level in new perlite.

MICROBIOLOGICAL IMPLICATIONS OF SUBSTRATE REUSE

In principle, any unused substrate is safe from the phytopathological point of view but it may easily be contaminated by pests and pathogens and/or by root exudates (allelopathy). Although soilless culture is considered one of the most effective mean to reduce the risk of root-borne diseases in greenhouse crops, the recirculation of nutrient solution and/or the cultivation in used substrate increase dramatically the risks associated to root-borne pathogens and pests such as nematodes (Postma et al., 2008; Steward-Wade, 2011). Rockwool, coconut-peat and perlite, which are largely used in soilless culture, are suitable for nematode infestation (Hallmann et al., 2005). Both chemical and non-chemical strategies to control root diseases are available, but pragmatic evaluations of their advantages and drawbacks have to be considered carefully (Van Steekelenburg, 1992), particularly when substrates are reused for a new growing cycle. Several methods may be adopted in order to reduce the pathological risks associated to the reuse of growing media, including agronomical/technical (component selection), biological, physical, chemical and other non chemical methods.

Biological Control

Occurrence of suppressiveness to plant disease agents in soils has been deeply investigated while disease suppression in soilless culture systems, naturally or artificially induced, is a new research area.

The use of selected substrates and/or substrate components may help in reducing the aggressiveness of root and basal diseases (Borrero et al., 2009; Fernandes et al., 2007; Yu and Komada, 1999). *Fusarium* wilt diseases cause severe losses in a wide variety of crop plants including tomato; although wilt resistant cultivars have been available for decades and provide some degree of control, the occurrence and development of new pathogenic races is a continuing problem. Effective soil fungicide treatments for this disease are also unavailable. Difficulties in controlling *Fusarium* wilt have stimulated the search for biocontrol systems. The natural suppressiveness of certain soils and composts to *Fusarium* wilt is the result of complex interactions between the abiotic characteristics of the media and the microbial populations (Hoitink et al., 1993). In contrast to highly stabilized peat, composts serve as a food base for indigenous microbes, introduced biocontrol agents and sustain suppression based on the activities of microbial communities (Hoitink and Boehm, 1999). Several levels of suppression to different *formae speciales* of *Fusarium* wilt in comparison to peat-based growth media are achieved by different plant growth media amended with composts (grape marc, cork, spent mushrooms) (Borrero et al., 2009).

Van der Gaag and Wever (2005) compared the susceptibility of cucumber to *Pythium* root and crown rot in rockwool, coir dust, pumice and perlite under near-commercial conditions. Rockwool was the most conducive for *Pythium* diseases probably due to reduced microbial activity and high water content capacity. High microbial activities have often been associated with substrate suppressiveness against *Pythium* diseases (Craft and Nelson, 1996). Pumice and perlite also do not allow the development of microbial populations; however, under operative conditions they hold less water than rockwool and, thus, are less favorable for *Pythium* spp.

The extent of organic matter decomposition influences the composition of bacterial *taxa* as well as the populations of biocontrol agents and their activities (competition, antibiosis, parasitism and systemic induced resistance; Hoitink and Boehm, 1999). Artificial introduction of selected microrganisms has been demonstrated to really increase substrate suppressiveness against root rot diseases (Grosch et al., 2001; Fravel and Larkin 2002; Hanafi et al., 2007; Horinouchi et al., 2007; Howell, 2003; Borrero et al., 2009). The artificial introduction of selected microrganisms may also be combined with other disease control tools including the application of fungicides (Song et al., 2004), nutrients (e.g. calcium; von Broembsen and Deacon, 1997) or specific irrigation methods (e.g. subirrigation coupled with the addition of surfactant to the recirculating nutrient solution, instead of drip irrigation; Stanghellini et al., 2000).

Several studies demonstrated that suppressiveness to soil-borne disease of soilless growing media can be induced by introducing microbial antagonists preliminarily isolated from suppressive soils and/or used soilless media. Biological control agents should be added as early as possible in order to achieve a stable microbial community with a maximum of beneficial organisms before the development of pathogen populations.

The microflora in used rockwool was found to play a key role in suppressing several root rot diseases (including *Pythium*) in cucumber (Postma et al., 2005), *Fusarium* crown and root rot of tomato (Clematis *et al*., 2009; Minuto et al., 2007) and *Fusarium* wilt of tomato (Srinivasan et al., 2009;). The strategy would be expected to be easily integrated with other non chemical control methods, such as slow sand filtration, a technique effective to limit the spread of several zoosporic and non zoosporic soil-borne diseases throughout closed systems without affecting the non-pathogenic microflora resident in the soilless system. Clematis et al. (2009) demonstrated the natural occurrence of suppression of *Fusarium* crown and root rot of tomato in perlite reused after tomato cultivation. Suppressiveness was maintained after disinfection (autoclaving), thus suggesting that it was mediated not only by the resident microflora.

Disinfection Methods

The use of physical (steam and solarisation) or chemical control (fungicide, fumigation) methods for substrate recycling can represent a viable and straightforward solution (Hallmann et al., 2005).

Solarization can reduce soil-borne inoculum of crop pests and also increase the concentration of soluble mineral nutrients (Stapleton, 2000). In a tomato crop, Moncada et al. (2008) compared both new and used coconut coir dust; the second substrate had been used in two successive cultivations and was solarized before use. No effects were found in terms of crop yield and fruit quality, previously used for 2 harvesting cycles.

SUBSTRATE RECYCLING

When reuse as growing media is not feasible and the option of disposal in landfill is not available (Bussel and McKennie, 2004), the exhausted media must be recycled. Exhausted substrates can be used as soil amendment (e.g. to improve poor physical properties of clay soil) or mixed with other substrates. Rockwool slabs can be incorporated (as chopped small particles) into peat- or compost-based media to increase porosity and water holding capacity of the mixture (Kim and Jeong, 2003) and reduce the use of non-renewable material as peat. The possibility of utilizing used rockwool slabs (after removal of plastic sleeves) as mulch around avocado trees was explored in New Zealand (Bussel and McKennie, 2004). The mulch successfully suppressed weed growth for two years without affecting the growth of avocado trees.

In the last decade, various methods have been developed for rockwool recycling. In The Netherlands, nearly all (90%) used rockwool slabs is currently collected and processed at large-scale facilities (located in the Netherlands and in Belgium), where they are turned into bricks for houses or re-manufactured into horticultural or insulation rockwool (Van Den Bosch, 2004).

In the Euphoros project (www.euphoros.wur.nl), the feasibility of recycling exhausted perlite from greenhouse cultivation into construction blocks with respect to the prevailing norms for building industry was investigated by Perlite Italiana (Corsico, Milano, Italy; www.perlite.it). Several combinations of used and new materials with different binders were tested with promising results.

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Tables

Table 1. Optimal range for the values of some physical-chemical parameters in a number of growing media widely used for greenhouse and nursery cultivation.

Substrate	Bulk density (g/L)	Total porosity (%v/v)	Air-filled porosity (%v/v)	Easily available water (%v/v)	CEC (meq/100 g)	pH
Light peat	60-100	90-95	30-35	35-45	100-200	2.5-4
Dark peat	100-150	85-90	30-40	30-40	100-300	5-7
Vermiculite	90-150	90-95	35-40	7-10	80-150	7-7.5
Sand	1400-1700	35-40	5-10	25-30	45-105	6-8
Perlite	80-120	85-90	50-60	10-15	1.5-4	7-7.5
Rockwool	80-90	94-97	10-15	80-85	0-2	7-7.5
Exp. clay	600-900	85-90	40-50	10-15	70-120	5-7
Pumice	650-950	65-75	40-50	10-15	0-2	6.5-7.5
Ideal		60-85	30-55	20-30	>10-15	5.0-6.5