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Review

Achieving environmentally sustainable growing media for soilless plant cultivation systems – A review

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ABSTRACT

Soilless cultivation is recognized globally for its ability to support efficient and intensive plant production. While production systems vary, most utilize a porous substrate or growing medium for plant provision of water and nutrients. Until relatively recently, the main drivers for the selection of the component materials in growing media were largely based on performance and economic considerations. However, increasing concern over the environmental impacts of some commonly used materials, has led researchers to identify and assess more environmentally sound alternatives. There has been an understandable focus on renewable materials from agricultural, industrial and municipal waste streams; while many of these show promise at an experimental level, few have been taken up on a significant scale. To ensure continued growth and sustainable development of soilless cultivation, it is vital that effective and environmentally sustainable materials for growing media are identified. Here we describe the factors influencing material selection, and review the most commonly used organic materials in relation to these. We summarise some of the renewable, primary and waste stream materials that have been investigated to date, highlighting the benefits and challenges associated with their uptake. In response to the need for researchers to better identify promising new materials, we present an evidence-based argument for a more consistent approach to characterising growing media and for a clearer understanding of the practical and economic realities of modern soilless cultivation systems.

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1. Introduction

Soilless plant culture is any method of growing plants without the use of soil as a rooting medium (Savvas et al., 2013). This relatively simple definition encompasses a diverse range of plant growth systems which generally involves containerization of plant roots within a porous rooting medium known as a 'substrate' or 'growing medium'. Compared with soil-based cultivation, soilless production can be more cost-effective (Grafiadellis et al., 2000), producing higher yields and prompter harvests from smaller areas of land (Raviv and Lieth, 2008; Nejad and Ismaili, 2014). Soilless systems also have generally higher water and nutrient use efficiencies (van Os, 1999; Savvas, 2002). As a result, they have become increasingly important globally over the last 50 years (Schmilewski, 2009).

Containerised plant production presents two fundamental challenges for healthy root growth. First, unlike a normal soil profile, a container environment provides a very shallow layer of growing medium which becomes quickly saturated during irrigation. Secondly, small container volume provides limited capacity for water storage between irrigation events (Bunt, 1988). Essentially, an effective growing medium must have a physical structure that is capable of sustaining a favourable balance between air and water storage both during and between irrigation events in order to prevent root asphyxia and drought stress (Fonteno, 1993; Caron and Nkongolo, 1999). The inability of soil to provide this balance at such small volumes is a key driver in the development of soilless growing media. Indeed, these media have been a pivotal innovation, allowing growers to carefully control water, air and nutrient supply to the plant roots whilst excluding soil borne pathogens (Raviv et al., 2002). The definition of an 'effective growing medium' is context specific however, there are some general considerations that apply to all soilless growing media. As well as an appropriate physical structure, a growing medium must provide a suitable biological and chemical environment in which plant roots can effectively access nutrients. It also needs to meet the practical and economic requirements of the grower; in short it must be affordable, easy to obtain and manageable.

Historically, drivers for the selection of soilless growing media have been based predominantly on performance and economic cost. However, societies, are becoming more environmentally aware (van Os, 1999), and sustainable practices are increasing globally (Greendex, 2014). In turn, there is an intensifying pressure on legislators, retailers and ultimately growers to reduce the environmental impact of plant production (Carlile, 1999, 2004a; Alexander et al., 2008; Schmilewski, 2014). This change in societal attitude is well exemplified by the drive to reduce the reliance of the northern hemisphere on peat-based growing media (Schmilewski, 2008a, 2008b; Wallace et al., 2010). In terms of performance and economic considerations, peat is in many ways an ideal constituent of soilless growing media (Bragg, 1990; Schmilewski, 1996, 2008a). It is low in plant nutrients but able to adsorb and release them when added as fertilizer (Bragg, 1991, 1998; Robertson, 1993; Maher et al., 2008). Widespread reserves of peat exist in the northern hemisphere, making it a readily available and relatively cheap resource (Robertson, 1993; Maher et al., 2008). Consequently, it has become the material of choice throughout plant production systems from propagation to saleable 'finished plant' material (Bragg, 1991). However, the extraction of peat has well documented negative impacts on the environment (Alexander et al., 2008); arguably the most important of these is the release of stable, sequestered carbon into the active carbon cycle, thereby exacerbating climate change (Cleary et al., 2005; Dunn and Freeman, 2011). During the last 20 years, peat extraction has come under increasing scrutiny throughout Europe and particularly in the UK (Carlile and Coules, 2013; Siegle, 2014; Alexander et al., 2008; Alexander and Bragg, 2014). This has generated an abundance of studies examining a diverse range of alternative materials (Raviv et al., 2002; Bragg and Brough, 2014). In the selection of new materials, environmental considerations have become as important as performance and economic cost. In this context there has been a justifiable emphasis on organic materials derived from agricultural, industrial and municipal waste streams (Chong, 2005; Raviv, 2013). The disposal of such materials already presents an environmental problem, and their re-use as growing media might provide a convenient solution. Yet despite this work, few of these materials have been widely adopted by the horticultural industry. There appear to be three main reasons for this; first, the alternative materials studied, have been selected predominately with environmental drivers in mind with significantly less consideration given to performance and economic cost. Secondly, the characterisation of these materials is carried out using a wide variety of approaches; this produces results that are difficult to compare and interpret among different materials. Finally, few researchers consider the commercial realities of growing media manufacture such as whether the volume of material available is sufficient to meet demand, or whether there are any legislative constraints which might impede uptake.

As the importance of soilless plant culture is likely to rise in the years to come, it is essential that researchers work with growing media manufacturers towards identifying new materials that are environmentally sustainable, commercially viable and able to perform as well as those they are replacing. This review seeks to critically evaluate the drivers that influence material selection for soilless growing media and explain why relatively few organic materials are in current common use. It then provides an overview of the diverse range of novel growing media materials that have been investigated, and highlights the challenges associated with their uptake. It concludes with an assessment of how a more consistent approach to material characterisation, and an improved understanding of the practical and economic realities of modern soilless cultivation systems, should enable researchers to identify promising new growing media materials.