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Recycling of P and K in circular horticulture through compost application in sustainable growing media for fertigated strawberry cultivation

Bart Vandecasteele[a,*], Jane Debode[a], Koen Willekens[a], Tom Van Delm[b]

[a] Flanders Research Institute for Agricultural, Fisheries and Food (ILVO), Plant Sciences Unit, Burg. Van Gansberghelaan 109, 9820, Merelbeke, Belgium
[b] Proefcentrum Hoogstraten, Voort 71, B-2328, Hoogstraten (Meerle), Belgium

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ABSTRACT

Peat replacement by compost in growing media can increase the sustainability of soilless cultivation. Compost, when mixed into growing media, is a source of fiber, i.e., a rooting medium, as well as an important source of nitrogen (N), phosphorus (P) and potassium (K). Physical properties as well as nutrient levels in growing media are known to affect plant growth and health. Therefore we monitored the evolution of nutrient release in compost-amended growing media for strawberry in greenhouse culture with drip fertigation for a double cropping system of cv. Elsanta, i.e., autumn culture with continued culture in spring. Compost amended and other alternative growing media for strawberry production were tested during four years of trials at full-scale level in a professional greenhouse growing system, in order to optimize the new cropping system with alternative substrates. Compost amended substrates contained 20–100% (v/v) compost, with different compost types tested. We assessed effects on yield and nutrients, i.e. nutrient availability in the substrate, uptake in the plants, and losses with the drainage water, as well as effect on diseases and pests (infection by powdery mildew *(Podosphaera aphanis)*, aphids *(Chaetosiphon fragefolii)*, and the anthracnose pathogen (*Colletotrichum acutatum*)). Adding compost to growing media has potential to increase the sustainability of soilless strawberry culture. Results show that growing strawberries on alternative substrates is feasible, but the substrate mixtures containing compost required adjusted fertigation due to nutrients supplied by the compost. This study revealed that strawberry plants made highly efficient use of the P and K in the compost when P and K input by fertigation was reduced, and that compost addition results in reduced export and potential losses of nutrients with the drain water and spent growing media. In general, the compost-amended substrates with lower N fertigation performed well as a growing medium during the autumn culture, but in the continued spring culture, these substrates needed an adapted fertigation regime for N, P and K. The N supply by the tested composts during the autumn culture allowed for significant reductions in N supplied by fertigation, i.e., 50% reduction when 100% (v/v) compost was used, and 10% reduction when 20% (v/v) compost was used. Degree of infection with powdery mildew and aphids was strongly positively correlated with the N status of the crop, pointing at the risks of high N supply for the crop. At the end of the autumn culture, no significant positive or negative effect of the compost treatments on the latent survival of *C. acutatum* on the strawberry leaves was found.

1. Introduction

1.1. Background

Peat is a crucial carbon sink in terrestrial ecosystems (Dunn and Freeman, 2011). Peat is formed as a result of vegetation, predominately sphagnum moss, partially decomposing in a water-saturated environment. The peat formation process takes place over hundreds of years and results in sphagnum moss accumulation in wetlands referred to as peatlands (Dunn and Freeman, 2011). Peat is the main component of the current growing media used in substrate cultivation (Barrett et al., 2016). Peat use is under pressure because of (1) the increasing demand and rising prices for peat, (2) possible problems with availability in the near future due to environmental constraints related to CO_2 emissions (Fascella, 2015) and (3) its consistent failure to support sustained biological control of diseases (Hoitink and Boehm, 1999). The negative environmental impact of horticultural peat moss production and use is linked to two major factors (Quantis, 2012): (a) long distance transport

Abbreviations: CAS, compost-amended substrates; DM, dry matter; OM, organic matter; dOM, dry organic matter; NA, not assessed; OUR, Oxygen uptake rate; EC, electrical conductivity; EN, European Standards developed by the European Committee for standardisation; CCD, charge-coupled device

* Corresponding author at: Burg. Van Gansberghelaan 109, 9820 Merelbeke, Belgium.
E-mail address: Bart.vandecasteele@ilvo.vlaanderen.be (B. Vandecasteele).

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of peat and (b) release of CO_2 associated with peat extraction, use and disposal. Peat decomposition during use and disposal has a high climate change impact: 300 kg CO_2 equivalents per 1 m^3 peat (much higher than the 75 kg CO_2 equivalents per 1m^3 wood fiber) (Quantis, 2012).

One way to reduce this environmental impact is to replace peat in growing media. Coir fiber products are one option but their sustainability is also being questioned due to the need for transportation over long distances, processing the coir and the high ecosystem quality impacts (Quantis, 2012). Locally produced plant fibers, composts and biochars have been proposed as an interesting alternative for peat (Quantis, 2012; Fascella, 2015; Barrett et al., 2016; Boldrin et al., 2010; Kern et al., 2017). These materials may vary in their physical properties, effect on pH, nutrient content and interaction with N, all of which affect the quality of the growing media. Nutrients can be supplied to strawberry in soilless cultivation by fertigation, pre-harvest foliar application with chemical sprays (Singh et al., 2008), compost leachates (Singh et al., 2010), or nutrients released by the growing medium. Growing media and the applied fertilizers may differ in their nutrient efficiency (Warren et al., 1995). Jackson and Wright (2009) observed lower amounts of N leaching when a substrate with higher N immobilization was used, thus reducing the environmental pressure of horticulture under circumstances when leached water is not reused. Increasing the N or P use efficiency in soilless media (Warren et al., 1995; Owen et al., 2008) is gaining more attention as a way to increase the sustainability of this cropping system by reducing nutrient losses via leaching. Replacement of mineral fertilizers and/or peat in growing media may require adjustments to the nutrient supply for the crop and can also affect the nutrient use efficiency. Combinations of solid and liquid organic fertilizers in unfertilized peat-based growing media may replace the conventional system of inorganic fertilization (Pokhrel et al., 2015). Based on foliar concentrations, however, Pokhrel et al. (2015) conclude that nutrient deficiency in the second half of the culture for N, Ca, Fe, Mn, B and Zn in combination with a K/Ca and K/Mg supply imbalance caused lower yields for the organic fertilization strategies. The high pH in the root zone for the organic fertilization strategies might have caused lower availability of some of the nutrients (Pokhrel et al., 2015).

Barrett et al. (2016) state that soilless cultivation systems possess an enormous potential to utilize organic waste products from other industries and, at the same time, recycle valuable nutrients and potential environmental pollutants (e.g. N and P). Compost is a source of fiber (i.e., medium for rooting), beneficial organisms and nutrients, which makes it an interesting candidate for partial replacement of peat in growing media. Compost was previously reported to successfully replace peat up to 100% (Zaller, 2007), indicating its potential as structuring material for plant rooting, i.e. as a source of fiber in growing media. According to the environmental inventory modeling by Boldrin et al. (2010), the substitution of peat with compost in growing media has some potential environmental benefits. Compost has a lower impact on global warming because of the biogenic origin of the carbon contained (Boldrin et al., 2010). Compost being a source of nutrients (Barrett et al., 2016; Blok, 2016) also has potential for substituting commercial mineral fertilizers, which may result in reduced eutrophication due the slower nutrient release from compost and other organic fertilizers and thus a lower risk for nutrient leaching as compared to fertigation with mineral fertilizers. Reduced production of N and P fertilizers has an especially large positive impact on the environment (Boldrin et al., 2010).

As a component of the growing medium, compost provides nutrients, is a rooting medium and affects the physical properties of the substrate, and may increase the disease resistance of the crop (Benito et al., 2006; Aidahmani et al., 2005). Because greenhouse strawberry culture is intensive in terms of infrastructure, plant density, expected crop yield, nutrient and pesticide use, applying compost without adjusting the nutrient supply may result in nutrient leaching and a higher risk for plant diseases since an unbalanced nutrient supply can cause higher susceptibility to diseases and pests in the crop (Huber and Haneklaus, 2007; Précigout et al., 2017). An excessive N and/or K supply resulted in higher susceptibility for plant pathogens in case of anthracnose (*Colletotrichum gloeosporioides*) (Nam et al., 2006) and powdery mildew (*Podosphaera aphanis*) (Xu et al., 2013) on strawberry but not for *Botrytis cinerea* on tomato plants (Lecompte et al., 2010). Moreover, a recent study suggest that increased N fertilization may also affect the latent period of the infection process of fungal pathogens (Précigout et al., 2017). Imbalances in nutrient ratios may also lead to negative effects such as tipburn; a higher risk of tipburn incidence was reported by Palencia et al. (2010) in case of K:Mg ratios over 3.4 and K:Ca ratios over 1.8. Results of Sharma and Singh (2008) indicate that excess of N and K and deficiency of Ca and B are related to the production of malformed fruits and buttons or nubbins in strawberry. The fertilizer supply should therefore be adjusted for compost-amended substrates (CAS), based on the nutrient supply provided by the compost. Tagliavini et al. (2005) concludes that a precise control of nutrient supply is feasible with (1) flexible nutrient supply techniques such as fertigation and (2) ongoing monitoring of nutrient availability in the soil and/or in the plant.

Strawberries require high levels of nutrients for optimal production (Tagliavini et al., 2005). High N, P and K concentrations are found especially in the fruits. Total plant uptake was reported to be larger for K > N > Ca > Mg > P (Tagliavini et al., 2005). Remobilization of N reserves (stored before dormancy) during regrowth in spring was found to be important in soilless cultivation with regular fertigation: 40% of the stored N was translocated to new growth after winter (Tagliavini et al., 2005). In some trials, CAS were also fertilized with the same dose of controlled release fertilizers as the control treatments (e.g., Hicklenton et al., 2001; Owen et al., 2008), hindering the proper assessment of the fertilizer value of the compost. In other trials fertilized peat was replaced by compost or vermicompost (Zaller, 2007) but it is difficult to provide equal amounts of fertilizers in these experiments where peat was replaced gradually. In trials without additional fertilizer application it was observed previously that N release by composts may be too low for optimal crop production: applying three types of municipal solid waste compost at twice the recommended N rate in open field strawberry culture did not provide sufficient N to plants resulting in lower yields than expected (Hargreaves et al., 2009). Balci et al. (2016) also reported that N was the limiting element for strawberry growth for field application of different organic wastes at 5 tons/acre.

1.2. Research objectives

In this paper we assess the effects of compost addition to growing media in terms of chemical (mainly in terms of nutrient supply and leaching) and physical (i.e., as a fibrous matrix for rooting) substrate properties. The focus is on P and K supply by compost with additional N supply, as N releasing capacity of compost is known to be too low for optimal N supply for strawberry (Hargreaves et al., 2009; Balci et al., 2016). We want to quantify the contribution of P and K from compost to the plant uptake and to loss to the environment when N was supplied by fertigation or as organic N. We hypothesize here that compost amendments, being a fibrous rooting medium and a slow-release source of nutrients, are able to guarantee a balanced supply of all essential nutrients except N, both in terms of a continuous release during the growing season as in terms of the ratio between nutrients, resulting in strawberry production comparable to peat-based growing media with drip fertigation, being the conventional cultivation system.

An additional strength of compost is its potential suppressiveness against pests and diseases (Table 1), although this is highly dependent upon the plant-pathogen system studied and the compost used (França and van der Wurff, 2016; Termorshuizen et al., 2006). In this paper, we assessed the effect of CAS vs. no-CAS against two important strawberry foliar fungal pathogens (powdery mildew and anthracnose) and one