Microbial inoculants as a soil remediation tool for extensive green roofs

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ABSTRACT

Green roofs are increasingly used in the urban environment to insulate buildings, reduce stormwater runoff and remediate biodiversity lost in construction. Most common in the Northern Hemisphere are extensive green roofs, due to their low-cost and low-maintenance requirements. However, plant growth on these roofs is often limited and this could have implications for ecosystem service provision as well as reduce the economic feasibility of green roofs as an aesthetically successful product. In addition, the increasing popularity of green roofs as an eco-product means that a high number of these roofs, that do not reach their maximum potential in terms of plant growth, already exist, highlighting a need for a successful remediation tool post-build.

Previous studies suggest that the soil food web on green roofs, integral for nutrient cycling in soils, is also lacking and that this may be an effective aspect to target in order to improve plant establishment and success. Microbial inoculants have already been added to green roofs, but with little scientific research informing their application. In this field experiment we aimed to determine if the addition of these foundation species in green roof soil food webs, including mycorrhizas, Trichoderma spp. and soil bacteria, could improve the abundance and biodiversity of higher trophic species, such as microarthropods, and if this had resultant effects on plant growth on a mature green roof.

It was found that some microbial inoculants were more successful at remediating soil food webs than others, with Trichoderma in particular producing higher populations of some microarthropod groups. However, these changes in microarthropod community dynamics did not have a resultant positive effect on Sedum spp. growth. The authors hypothesize that mature green roofs have an established microbial community that may limit the success of commercial inoculants. This is the first study to demonstrate multi-trophic community changes as a result of the addition of soil microbial inoculants.

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1. Introduction

Green, or “living,” roofs (vegetated roofs) are of increasing interest to architects, city planners and civil engineers across the globe due to the multitude of benefits they can contribute to a buildings performance in areas such as energy efficiency and sustainable drainages (VanWoert et al., 2005; Jaffal et al., 2012). Extensive green roofs are common in the Northern Hemisphere, and in the UK usually comprise of a shallow substrate (no more than 10 cm) consisting of crushed brick, planted with hardy plants of the genus Sedum (Grant, 2006). Despite their continuing prevalence, many extensive green roofs fail to establish at a satisfactory rate or, in some cases, fail to establish completely and require costly remediation (McIntyre and Snodgrass, 2010). In addition to this economic problem, poor plant establishment could also result in green roofs that are not maximised in terms of their ecosystem services provision (Williams et al., 2014). For example, as carbon sequestration is related to plant biomass (Getter et al., 2009), the contribution to carbon savings afforded by a green roof with poor plant growth is likely to be negligible. Green roof vegetation is also expected to reduce indoor air temperatures via evapo-transpiration (Jim and Tsang, 2011) which, again, is likely to be affected by the size and health of plants on the roof. Hence the reported benefits of a green roof are inherently reliant on the success of vegetative growth.

Examining the soil biota present within the substrate of a green roof could hold the key to ensuring the success of vegetation establishment. To date, interactions between soil fauna and above-ground communities on green roofs have been largely ignored,

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despite above and below-ground communities at ground level having been shown to be inextricably linked (Wardle et al., 2004). Below-ground processes (or within substrate in the case of a green roof) are key for nutrient cycling, promoting plant productivity, permitting decomposition, buffering environmental changes and improving water retention (Neher, 1999).

Much of the nutrient cycling occurring in soils relies on three things: the decomposition of plants, exudate production by living plants and inputs of inorganic nitrogen (Neher, 1999). Decomposition is facilitated by microbes, including bacteria and fungi, microarthropods, such as mites and Collembo, and macroarthropods, such as earthworms, all of which reside in the soil (Neher, 1999). Previous research suggests that many of these key functional groups are missing or impoverished in a green roof environment (Rumble and Gange, 2013). In addition, those populations of microarthropods that are present on green roofs can experience dramatic seasonal population declines caused by drought (Rumble and Gange, 2013).

Getter and Rowe (2008) suggest that increasing the depth of green roof substrate benefits the growth of some Sedum spp. However, in the case of remediating green roofs that are already seen to be failing, adding substrate is far from ideal due to incurred cost, increased loading and the requirement to replant the roof. Thus, a remediation tool that is low-cost and low-maintenance needs to be investigated.

Green roofs are a harsh environment, typically experiencing high surface temperatures in summer and high winds throughout the year (Getter and Rowe, 2008). The microarthropod communities present reflect this, with the type of species found and their abundance similar to that of a desert, or glacial foreland (Wallwork, 1972; Kaufmann et al., 2002; Rumble and Gange, 2013). van der Heijden et al. (2008) suggest that bacteria and fungi are responsible for the majority of decomposition taking place in soils, but this varies between habitats. In desert soils, for example, the removal of fungi from soils can cause a decrease in soil decomposition of nearly 30%, whilst the exclusion of microarthropods can reduce decomposition by over 50% (Santos and Whitford, 1981). Thus, it can be inferred, that in an impoverished green roof soil community, decomposition may be limited and therefore enhancement of the soil community could have a positive effect on plant growth.

Previous research suggests that green roof Sedum spp. can establish relationships with mycorrhizal fungi (Rumble and Gange, 2013), but that bacteria and free-living fungi are not present at sustainable levels in mature green roofs (Rumble, 2013). In other anthropogenic microbiol poor environments, such as amenity turf, the addition of microbial inoculants has been shown to have some beneficial effects on plant growth. For example, Butler and Hunter (2008) found that the addition of microbial inoculants to golf putting greens increased plant tolerance to stress. However, they questioned the ability of mycorrhizas to colonise roots in this environment. In general, it is recommended that testing be carried out on each new environment before industrial scale application of inoculants takes place, due to the potentially unpredictable results interacting soil microbes may proffer (Corkidi et al., 2004).

Little such testing has been carried out on green roofs, but the few studies that exist have also reported unpredictable findings. Molineux (2010) found that the addition of mycorrhizas and compost tea (liquid obtained via aerobic digestion of composites) to green roofs planted with Plantago lanceolata improved plant growth for the first year alone and some competitive effects between inoculants were noted. She also found that fungal and bacterial biomass on green roofs could be enhanced with the addition of microbial inoculants (Molineux et al., 2014). The need for studies such as this is pressing, as commercial inoculants, including mycorrhizas and other microbes, are already used in the green roof industry, for example on the California Academy of Sciences green roof (McIntyre and Snodgrass, 2010). This is despite the relative lack of empirical evidence to determine if they improve plant growth on green roofs, or have an effect on other green roof organisms.

Determining the effects of inocula addition on non-target living roof organisms, such as microarthropods, also provides clues as to how species interactions occur in green roof substrates, a factor that is completely unknown. The success of microbial inoculant addition in enhancing plant growth is reliant upon the microarthropods present, as these organisms contribute to the regulation of nutrient release from soil microbes (Bünemann et al., 2006). The relationships between and within and below-ground organisms are difficult to determine, due to the cryptic nature of soil, so soil food web experiments have typically been conducted by adding or removing soil food web components in order to observe resultant changes in flora and fauna. For example, Chen and Wise (1999), in exploring whether soil food webs are bottom-up or top-down controlled, added nutrients to the soil in the form of mushrooms, potatoes and instant Drosophila medium (Formula 4-24, Carolina Biological Supply, Burlington, North Carolina). They then studied soil arthropod communities to determine if increases in populations would result from the addition of these different nutrient sources, finding this to be true for most groups of soil fauna. Other studies testing the same nutrient addition principle have reported similar results (Kajak, 1981; Davidson and Potter, 1995). Commercial inocula could have similar effects to fertilizers, by mobilising nutrients currently unavailable to plants, enabling higher uptake (Schubert and Lubraco, 2000) and, theoretically, by providing food for higher trophic groups. To our knowledge, analysis of higher trophic groups within the soil after the addition of microbial inocula has never been conducted to test this theory.

Commercial inocula typically consist of three major groups of soil organism: mycorrhizal fungi, bacteria (particularly Bacillus spp.) and Trichoderma, again as a mix of species within the genus (Trabelsi and Mhamdi, 2013). In addition, commercial inoculants typically contain mixes of species, in order to increase the probability that a species specific relationship can develop (Koomen et al., 1987; Gadhave et al., 2016). There is evidence to suggest that in some cases, however, an antagonistic relationship may develop between inocula species (Molineux, 2010), negating their desired effect. Here we describe a study in which three commercial inocula mixes, encompassing mycorrhizas, bacteria and Trichoderma were added to a mature green roof to determine if commercial inocula applied singly, or in combinations, affects the soil microarthropod community, and if this has resultant (or independent) effects on plant growth. We hypothesised that the addition of microbial inoculants to a green roof will alter the abundance and community structure of microarthropods and that this would have a resultant effect on plant growth. However, whether this effect would be positive, or negative, is not predictable based on past research.

This is not only the first study to examine such interactions on a green roof but, to the authors knowledge, is the first study to examine if the addition of soil microbes has an effect on soil microarthropod communities in a field situation. It also has direct applicability to the green roof industry, where commercial inoculants are already applied but have not been thoroughly tested.

2. Materials and methods

2.1. Study sites

Permanent plots were established in a randomised block design on a green roof situated in the grounds of Royal Holloway, University of London in July 2011. This roof was the focus of a previous study examining microarthropod communities present in 2010–11 (Roof B: Rumble and Gange, 2013). The green roof is situated on the
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