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Deinking sludge in the substrate reduces the fertility and enhances the plant species richness of extensive green roofs

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ABSTRACT

Green roofs provide ecological benefits to urban areas and the use of biodiverse communities enables the vegetation to recover from stress caused by dry conditions. Recycled waste materials are often used as substrates and extensive research on their physical and chemical properties has been carried out. In this study, we evaluated different amounts of deinking sludge pellets as an alternative substrate component in establishing drought-tolerant herbaceous communities on green roofs. Three substrates were prepared aimed at providing decreasing fertility: a commercial substrate composed of tephra and compost (control); an experimental substrate composed of tephra, pellets, and compost, and another one consisting of tephra and pellets. A mixture of 30 species, including native herbaceous species and sedum, of Mediterranean phytocenosis, was transplanted on all the substrates. A physical and chemical characterization of the substrates was carried out. The plant ecological functionality, life forms and richness, and the abundance of flower-visiting insects were studied. The substrate composition affected the plant community cover and richness. The amount of pellets in the two experimental substrates reduced the availability of resources (nitrogen and moisture content) promoting diversity, in terms of the number of species, as well as the hardiness of the vegetation. Our results are of great interest for obtaining a biodiverse mosaic habitat in green infrastructures, by measuring out the quantity of infertile materials in the substrates.

1. Introduction

Green roofs are ecologically beneficial to the urban environment as they enhance plant and animal diversity. Rooftops are extreme environments in terms of temperature, moisture, light intensity and wind speed, and thus the selection of growing substrates and suitable vegetation are key to their functionality as well as reducing the management costs (Oberndorfer et al., 2007; Ampin et al., 2010). Roof growing substrates should be stable, permanent and lightweight, and provide nutrients and physical support for the plants (FLL, 2008; www.livingroof.org). Today many companies produce substrates and technologies aimed at developing these green infrastructures.

However, the substrates developed for the continental and northern regions of Europe do not perform well in the south, because of the different climatic conditions, with long droughts in summer followed by heavy rains (Burés, 2013). This has opened a wide door for the studies of roof growing media in the Mediterranean, where the beneficial effects of green infrastructures are urgently needed due to the increasing summer heat. While for intensive green roofs, substrate fertility is necessary, as the kind of vegetation and the level of maintenance are similar to real gardens, for extensive green roofs, the right balance of inert and active materials is essential (FLL, 2008). A higher resource availability in the substrates can easily shift the vegetation to a mass of weeds, despite the shallow layer (Cook-Patton and Bauerle, 2012). On the other hand, in a nutrient-deficient habitat, plant development is limited, which facilitates the coexistence of different species, creates gaps for regeneration, limits the biomass of weeds, and requires no maintenance. However not all species are able to adapt to such an environment, especially ruderals which are nitrogen demanding (Grime, 2001).

Many studies (Molineux et al., 2009; Ondoño et al., 2015; Ntoulas et al., 2015; Noya et al., 2017) have focused on turning waste into a useful material for growing plants on roofs, such as brick rubble, rice husks, poultry manure, sawdust, compost, paper sludge, however the

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nature and the suitability of these materials is still debatable. Important aspects are related to the costs, including the local availability, and possible recycling industrial by-products for recycling.

Compost, is a cheap and easily available material. It is produced by municipalities and comes from green or mixed green and household waste. Compost improves the water retention, structural quality, nutrient content and microbial activity of the growing media, creating better conditions to establish vegetation. However, compost also has some drawbacks: it is hydrophobic when completely dry, it tends to reduce its volume, absorb solar irradiation and greatly increase the organic matter. As a consequence, the amount added as an amendment in a substrate needs to be carefully evaluated, in order to reduce species competition (Nagase and Dunnett, 2008).

Deinking paper sludge is produced in great quantities by the recycled paper industry and can be used in limited amounts as a substrate for the restoration of mines and other degraded sites, as it is mainly composed of calcium carbonate. Deinking and primary paper sludge can be used effectively as a soil amendment, provided that plants receive adequate supplemental nutrients (Norrie and Gosselin, 1996). This suggests that deinking sludge may meet the requirements of extensive green roofs in terms of weight and water retention, and at the same time reduce habitat fertility and plant biomass, thus enhancing the establishment opportunities for plants with different life forms. However, its use as pellets added to the growing media for green roofs has not been reported.

How to vegetate extensive green roofs is still a matter of on-going research. For example, is it more appropriate to use a few species or biodiverse vegetation? Is it better to select horticultural plants or identify local ecological models? The development of new ecosystems enables the integration of human society and the nature surrounding it with benefit of both. In terms of ecological engineering the species introduced by human action can survive and self-organise, relying more to natural dynamics than artificial inputs (Mitsch and Jørgensen, 2003).

The *Sedum* species (e.g. *S. album* and *S acre*) are widely used by companies producing green infrastructures for this purpose. Sedums have won the "survival-on-roofs contest" worldwide due to their succulence, CAM (crassulacean acid metabolism) and propagation facility. However, these species create a uniform and thick vegetation, which also prevents the spontaneous establishment of adventitious species (Emilsson, 2008). Meadow species borrowed from the local vegetation, together with spontaneous colonization, successfully contribute to green roof planning (Catalano et al., 2016). Diverse roof vegetation also supports abundant and diverse fauna and improves long term performance (Cook-Patton and Bauerle, 2012), in terms of ecological functionality and life forms, and enhances the survival of some species (MacIvor et al., 2013) together with the multifunctionality of ecosystem services (Lundholm, 2015; Monteiro et al., 2017).

The particular strategies of Mediterranean herbaceous flora that enable them to survive long periods of desiccating conditions considerably enhance green roof performance (Monterusso et al. 2005; Benvenuti and Bacci, 2010; Benelli et al., 2014; Ondoño et al., 2015). These characteristics include succulence, annual cycle and underground storage organs. Forbs, perennials and annuals, have a structural complexity, which is successful in ecological complementarity (Cook-Patton and Bauerle, 2012), they die back in summer and both are effective in the regenerative phase of the vegetation, after stress or disturbance (Grime, 2001). Perennials spread through vegetative propagation, and annuals spread thanks to the persistence of the seed bank, which is why they are both considered successful on green roofs (Van Mechelen et al., 2014).

A winning strategy in the greening of extensive roofs may be to find local ecological models such as the natural vegetation of dry and stressful habitats, and try to establish them on the right substrate (Francis and Lorimer, 2011; Lundholm, 2015). However, roof conditions are so particular that the species should also be tested first in real situations (i.e. on the roof rather than simulations at ground level) to confirm their suitability (Rayner et al., 2016).

The establishment of biodiverse vegetation on rooftops attracts fauna by setting up trophic webs (Colla et al., 2009; Tonietto et al., 2011). This highlights the potential role of green roofs as a habitat for insects, which are threatened by many environmental factors worldwide (Rollin et al., 2016). Green roofs therefore enhance the biodiversity in anthropized areas by contributing to the urban-rural ecological network. From an ecological reconciliation perspective, they can also be effective in involving urban dwellers in social activities (Francis and Lorimer, 2011; Ignatieva et al., 2011). A mosaic of different green roof substrates, in terms of physical (texture) and chemical (organic matter) composition and thickness, facilitates the presence of microhabitats and fauna, through the development of plant structural complexity and phenological complementarity (Brenneisen, 2006; Bates et al., 2013; Madre et al., 2013).

Our aim was to assess the effectiveness of deinking sludge in reducing substrate fertility and consequently in improving the coexistence of stress tolerant native herbaceous species with sedum in extensive green roofs. The objectives were (i) to obtain a greater plant functional diversity, and (ii) to attract flower-visiting insects.

2. Materials and methods

2.1. Experimental design

The trial was set up in October 2014. We report the results of two growing seasons in 2015 and 2016. The roof where the experiment was carried out was on a building of the National Research Council in Pisa (Italy), approximately 10 m above ground level, at lat 43°71′ N, long 10°42′ E. The climate is Mediterranean and between July and September 2015–2016 the maximum and minimum temperatures were respectively: 29.7°; 19.6° and 29.2°; 18.8° (http://www.sir.toscana.it). Temperature and relative air humidity of the experimental site were recorded every thirty minutes by a weather station installed near the experimental boxes. Rainfall data were recorded every 24 h using a 70 mm rain gauge. The data were collected from January 2015 until September 2016 (Table 1).

Three materials were chosen for the substrates: deinking sludge from the production of recycled paper supplied by Lucart, Lucca – Italy, pelletized to obtain a compact easy-to-handle material (P hereafter) (Fig. 1); compost derived from municipal selected organic waste, composed of domestic (50–70%) green (30–50%) and agricultural (0–5%) waste, supplied by Siena Ambiente spa (C hereafter); Vulcaflor, a commercial substrate supplied by EuroPomice, composed of tephra 0–12 mm (pumice 30% + lapillus 60%) and organic matter (peat + compost 10%), which is widely used on extensive green roofs (V hereafter). Table 1 reports the main physical and chemical properties of the original materials used for the substrates, as provided by the companies themselves. The heavy metal content in the deinking sludge and the compost were within the Italian legal limits for this kind of waste. The compost absorbed water in a much higher percentage than

Table 1
Climate data, monitored during the trial. Values in bold indicate the lowest and the highest values for each parameter. Air RH = Air Relative Humidity.

Year	Months	Daily temperature (°C)			Rainfall (mm)	Air RH (%)
		Min	Max	Mean	Sum	Mean
2015	January–March	1.3	19.9	10.6	237	71.6
	April–June	9.7	35.7	20.8	97	67.4
	July–September	16.7	40.5	26.5	142	65.3
	October–December	3.7	23.2	13.7	230	84.6
2016	January–March	1.3	20.6	10.8	310	80.3
	April–June	10.7	33.9	18.3	227	70.1
	July–September	18.2	39.3	28.3	208	60.4