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Applying spent coffee grounds directly to urban agriculture soils greatly reduces plant growth

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ABSTRACT

There are frequent anecdotal recommendations for the use of locally produced spent coffee grounds in urban agriculture and gardens, either through direct soil application or after composting with other urban organic wastes. This study investigates the scientific basis for direct application of spent coffee grounds (SCG) and the influence of different: (i) plant pH and nitrogen preferences, (ii) soil types, and (iii) application rates. We specifically consider impacts upon plant growth, soil hydrology and nitrogen transformation processes.

We grew five horticultural plants (broccoli, leek, radish, viola and sunflower) in sandy, sandy clay loam and loam soils, with and without SCG and fertilizer amendments. The same horticultural plants were grown in the field with 0, 2.5, 5, 10 and 25% SCG amendment rates. Plant biomass growth was related to soil pH, soil moisture, nitrogen concentration and net mineralization, as was weed growth after harvesting.

All horticultural plants grew poorly in response to SCG, regardless of soil type and fertiliser addition. Increasing SCG amendment significantly increased soil water holding capacity, but also decreased horticultural plant growth and subsequent weed growth. There was evidence of nitrate immobilization with SCG amendment. Growth suppression was not explained by soil pH change, or nitrogen availability, so is more likely due to phytotoxic effects.

Fresh SCG should not be used as a soil amendment in 'closed loop' urban food production systems without consideration of potential growth suppression. Further research is required to determine the optimal composting conditions for SCG and blends with other organic wastes.

1. Introduction

The global population is predicted to reach between 8 and 11 billion by 2050 and the proportion living in towns and cities is predicted to be 66% (UNDESA, 2014). For a highly urbanized global population, two key challenges are (1) the provision of necessary resources (food, water, power) to urban centers and (2) the processing of urban waste produced in urban centers. To meet these challenges, new, innovative and sustainable urban solutions are required (Hoornweg and Bhada-Tata, 2012; UNEP, 2010). Innovative 'closed-loop' waste solutions that make local use of waste as a resource, and thereby also minimize the volume of waste sent to landfill (Lehmann, 2011a).

Organic waste represents nearly half of all global waste produced (Hoornweg and Bhada-Tata, 2012). Organic food waste represents up to 18% of solid waste in Australia (OzHarvest, 2010), yet only a few countries, such as Sweden, have legislated against food waste entering landfill (Eriksson et al., 2005). One potential application for organic food waste produced in cities is soil amendment to increase plant productivity in urban horticulture or food production and/or to assist in soil remediation (Brown et al., 2011; Cogger, 2005; Lehmann, 2011b) as well as overall urban sustainability and environmental impact (Martínez-Blanco et al., 2009). Using organic food waste as a soil amendment is not a new concept as throughout history civilizations have used organic food waste as a soil amendment (Parr and Hornick, 1992). Soil organic amendments can improve plant growth by directly improving key soil physical, chemical and biological properties (Brady and Weil, 2014; Handreck and Black, 2002; Quilty and Cattle, 2011). Soil properties that have been shown to improve after organic waste amendment include nutrient availability, soil water and nutrient holding capacities, soil structure and water infiltration, soil pH, reduced nitrate leaching, soil biological activity and long-term carbon sequestration (Diacono and Montemurro, 2010; Haider et al., 2014; Quilty

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and Cattle, 2011). Supplying organic amendments deep in a soil profile can also improve plant biomass allocation and water use efficiency (Espinosa et al., 2011; Gill et al., 2012).

Soil organic amendments supplement existing soil organic matter (SOM) which constitutes (i) living microbial biomass, (ii) detritus, and (iii) humus. Increasing the proportion of humus in a soil can increase cation exchange capacity, so adding organic waste to soils with little clay or little SOM will theoretically have the greatest overall benefit.

As organic matter decomposes in the soil, nitrogen (N) is made available through microbial mineralization processes. Ammonification transforms organic N to ammonium (NH_4^+), which can be followed by nitrification which transforms NH_4^+ to nitrate (NO_3^-). These forms of inorganic N can accumulate in the soil and/or be readily taken up by plants. However, other microbes can also take up the available NH_4^+ or NO_3^- to support their own metabolic needs, a process known as microbial immobilization, such that little inorganic N is left available for the plants (Brady and Weil, 2014; Handreck and Black, 2002). Amending soil with organic waste that has a high C/N ratio (poor quality) is likely to lead to immobilization of N as providing a new carbon (C) dominated substrate means that the availability of N is likely to now limit soil microbial mineralization processes, so all available inorganic N will be taken up (immobilized) by the microbial biomass. Adding a poor quality organic waste to a soil with high SOM will have less of an impact than adding the same organic waste to a soil already deficient in SOM.

Organic wastes can produce phytotoxic organic substances as they decompose aerobically, and the level and progression of phytotoxicity has often evaluated using seed germination bioassays (Soares et al., 2013). Some organic wastes used in soil amendment can also lead to additions of heavy metals, phenolic compounds, ethylene, excess accumulation of salts or organic acids—all leading to potentially negative soil biological and phytotoxic responses (Helfrich et al., 1998; Soares et al., 2013).

Coffee is the number two world commodity after crude oil (Mussatto et al., 2011b) and as such there are considerable organic waste streams associated with the coffee industry. Over 90% of coffee production occurs in developing countries, whereas the majority of coffee consumption and spent coffee ground (SCG) waste occur in developed countries and are focused in their cities (Ponte, 2002). Worldwide, SCG production is estimated at six million tonnes per year (Mussatto et al., 2011b). Urban SCG waste is often separated at the point of drink preparation, and can easily be kept separate from other food and organic wastes. As such, the physical, chemical and biological characteristics of SCG can be more confidently predicted and maintained. This is critical when considering making use of an organic waste as an economic and commercial resource.

Many gardening and horticultural ‘grey literature’ sources encourage the use of SCG as a direct soil amendment (Schalau, 2010) even though the scientific evidence for plant growth benefits, without prior composting of SCG, are scant. SCG generally has an N concentration of between 1.0 and 2.5% and a C/N ratio of between 20 and 25, which is greater than most horticultural soils and considerably greater than that of soil microbial communities (Mussatto et al., 2011a; Pujol et al., 2013). The phenols of SCG may be toxic to soil microorganisms and plants, but at the same time these toxins provide a natural pesticide and herbicide (Cruz et al., 2012). Composted coffee grounds have been shown to positively increase the growth of certain horticultural plants in specific soils (Morikawa and Saigusa, 2008), but the evidence for non-composted SCG is less clear. Soil amendment with SCG can simultaneously increase plant biomass whilst decreasing plant foliar N content, although the impacts vary among plant species (Cruz et al., 2012; Yamane et al., 2014). SCG may reduce soil pH as it is often acidic (Mussatto et al., 2011a). Horticultural plants with different N and pH preferences are likely to respond differently to SCG soil amendments, and how these plant responses are mediated by soil type, is a key research question.

This study aims to understand the impacts of using SCG as a direct soil amendment without prior composting in an urban horticultural context. Four specific research questions were posed within this study:

1) How does direct SCG amendment affect the growth of common horticultural plants with varied nutrient and pH preferences when grown in different soil types?
2) Do different rates of SCG amendment lead to different horticultural plant and weed growth responses?
3) How do soil N dynamics change in response to direct SCG amendment?
4) How does direct SCG amendment affect the hydrology and acidity of different soil types?

2. Materials and methods

SCG waste was collected from six Melbourne cafés to investigate the variation in chemical properties according to bean type, roasting and processing technique. The pH and EC was measured using a 1:5 vol. extract (Handreck and Black, 2002). Total C and N was measured using a dry combustion total CNH analyser (LECO^{TM}). From one café, SCG was collected repeatedly, air-dried and stored for subsequent glasshouse and field soil amendment trials.

2.1. Glasshouse plant growth trials grown in three soil types

In a glasshouse trial, three soil types were used to investigate the interactions between soil texture and SCG soil amendment, as demonstrated through changes in soil properties and plant species biomass growth. The three soil types were: (1) sand, (2) sandy clay loam and (3) loam, representing soils with differing percentage clay, C and N contents (Table 1). Common horticultural plants were selected to provide a range of known N requirements (N demands)

Table 1
Soil characteristics of the upper 10 cm for sand, sandy loam, clay loam soil textures in the glasshouse trial, sandy soil texture in the field trial and spent coffee ground (SCG) amendment in the glasshouse and field trials.

	Units	Glasshouse trial			Field trial	Coffee
		Sand	Sandy clay loam	Loam	Sand	SCG
Sand (20–2000 μm)	%	88.46	67.82	51.48	83.11	
Silt (2–20 μm)	%	3.47	11.57	28.27	8.20	
Clay (<2 μm)	%	8.07	20.61	20.26	8.69	
Total C	%	0.68	2.07	1.98	2.93	51.53
Total N	%	0.04	0.14	0.15	0.13	2.23
C:N ratio	%	17.00	14.79	13.20	22.54	23.11
pH (1:5 soil:water)		5.76	5.51	6.09	6.71	5.48
EC (1:5 soil:water)	dS m^{-1}	0.23	0.22	0.22	0.06	1.97