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Wool-waste as organic nutrient source for container-grown plants

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ABSTRACT

A container experiment was conducted to test the hypothesis that uncomposted wool wastes could be used as nutrient source and growth medium constituent for container-grown plants. The treatments were: (1) rate of wool-waste application (0 or unamended control, 20, 40, 80, and 120 g of wool per 8-in. pot), (2) growth medium constituents [(2.1) wool plus perlite, (2.2) wool plus peat, and (2.3) wool plus peat plus perlite], and (3) plant species (basil and Swiss chard). A single addition of 20, 40, 80, or 120 g of wool-waste to Swiss chard (*Beta vulgaris* L.) and basil (*Ocimum basilicum* L.) in pots with growth medium provided four harvests of Swiss chard and five harvests of basil. Total basil yield from the five harvests was 1.6–5 times greater than the total yield from the unamended control, while total Swiss chard yield from the four harvests was 2–5 times greater relative to the respective unamended control. The addition of wool-waste to the growth medium increased Swiss chard and basil tissue N, and NO_3–N and NH_4–N in growth medium relative to the unamended control. Scanning electron microscopy (SEM) and energy dispersive X-ray (EDX) microanalysis of wool fibers sampled at the end of the experiments indicated various levels of decomposition, with some fibers retaining their original surface structure. Furthermore, most of the wool fibers' surfaces contained significant concentrations of S and much less N, P, or K. SEM/EDX revealed that some plant roots grow directly on wool-waste fibers suggesting either (1) root directional growth towards sites with greater nutrient concentration and/or (2) a possible role for roots or root exudates in wool decomposition. Results from this study suggest that uncomposted wool wastes can be used as soil amendment, growth medium constituent, and nutrient source for container-grown plants.

1. Introduction

The use of waste or by-products as nutrient sources for crop plants has a long history. However, there are some widely available waste products that have not yet been utilized and that may have potential value as nutrient sources for crops. Examples include sheep wool-waste generated during the process of cleaning raw wool (Kroening et al., 2004) and human hair-waste generated by hair salons. According to our preliminary calculations, the production of human hair and the amount of sheep wool-waste in the US can supply more than half of the N and perhaps all the P and K for US grown container plants. Worldwide, initial wool processing generates waste materials such as woolscour sludge (Duppong et al., 2004; Williamson et al., 2000) or other unused materials that are currently landfilled or composted. Sometimes due to price fluctuations, wool production may become uneconomical. Landfilling or surface disposing of the excess or low-grade wool is environmental concern.

Our preliminary study of samples of various hair and wool wastes found that the two waste products have distinct elemental compositions (Table 1, Supplementary data). The two waste materials differed in their mineral composition with wool-waste containing much more K, Na, Fe, and P than hair-waste, and human hair-waste containing more N, S, Ca, C, and Cu than the wool-waste (Table 1, Supplementary data). The very high concentration of K in wool is due to suint (a wool grease excreted from the roots of the wool fibers). Suint has been used as K fertilizer in the past, because K concentration in this product could be as high as 187,500 mg kg^{-1} (Burns et al., 1964).

Hydrolysed wool has been tried as fertilizer source for plants (Nustorova et al., 2006) or as binding agent for heavy metals (Evangelou et al., 2008). There are no publications on the potential use of wool-waste as a potting medium constituent, although prior research (Zheljazkov, 2005; Zheljazkov et al., 2008a) has demonstrated that uncomposted wool could be used as plant nutrient

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source. Therefore, we undertook this study to evaluate uncomposted wool-waste as nutrient source and potting media for greenhouse crops, a use that may offer an alternative nutrient source for crops to farmers and divert this material from waste sites. Being a N-rich source, wool has been used as a feedstock for composting (Das et al., 1997; Plat et al., 1984; Verville, 1996) and as mulch for weed control (Duppong et al., 2004; Hartley and Rahman, 1997; Hartley et al., 1996). Composted wool has been used as a N source for crop plants such as chickpea and wheat (Tiwari et al., 1989a,b). However, research has demonstrated that composting of protein-rich feedstocks usually results in a significant loss of N (Epstein, 1997).

The objective of this study was to evaluate uncomposted wool-waste as nutrient source, potting medium constituent, and as soil amendment for container-grown crops. Swiss chard (*Beta vulgaris* L. 'Fordhook Giant') and basil (*Ocimum basilicum* L. 'Mesten') were used as model crops in this study. Swiss chard is a known heavy N feeder and trace element accumulator and is a good reference plant (Basta and Sloan, 1999; Cancet et al., 1997; Handreck, 1994a,b; Hettiarachchi and Pierzynski, 2002; Luo and Christie, 1998; Warman et al., 1995; Zheljazkov and Warman, 2003). Basil is an aromatic crop that is not polyploid (Ryding, 1994; Zheljazkov et al., 1996) as are most agricultural crops, and hypothetically could be more sensitive to adverse environmental conditions. Both plants have been grown either in greenhouse (in pots) or field production systems as high-value crops.

2. Materials and methods

2.1. Experimental design and plant growth conditions

The experimental design was a randomized complete block design with four replicates. The wool-waste consisted of unprocessed and unwashed low-grade wool from Texel and Rideau Arcott ewes. Plants were grown in 8-in. (851 cm^3 volume) plastic pots. Each 8-in. pot received exactly the same volume of the growth medium before the application of the waste-wool. Plastic trays were used under each pot to avoid leaching of N or other nutrients from the system. The wool-waste was incorporated into the soilless medium or soil as is, without additional cutting or drying, or any other treatments such as hydrolysis (Evangelou et al., 2008; Gousterova et al., 2003; Nustorova et al., 2006).

2.2. Growth medium container experiment

The objective was to evaluate the uncomposted waste-wool as N source and growth medium constituent (mix of wool plus perlite, wool plus peat, or wool plus peat plus perlite) for container-grown crops. Perlite has been widely used as an inert substrate in studying soil-plant relationships with respect of essential and trace elements (Hernandez et al., 1995; Iorio et al., 1996; Lieten and Roeber, 1997). Both perlite and peat (Canadian peat moss) are standard growth medium constituents for container-grown plants. The treatments consisted of: (1) rate of wool-waste application (0 or unamended control, 20, 40, 80, and 120 g of wool per 8-in. pot), (2) growth medium constituents [(2.1) wool plus perlite, (2.2) wool plus peat, and (2.3) wool plus peat plus perlite], and (3) plant species (basil and Swiss chard). All wool treatments were added to all potting mixes and the two crops. The unamended control consisted of commercial growth substrate (Metromix 300, Sun Gro Horticulture, Bellevue, WA). We used a commercially available potting medium in the unamended control because our preliminary study indicated very poor to no growth of plants in medium consisting of peat plus perlite only. In all treatments, peat and perlite were mixed in ratio of 3:1.5, as recommended for container-grown plants. To improve the degradation of wool wastes, we added 300 g of municipal solid waste (MSW) compost to every pot including the unamended control. Compost was added to all treatments because preliminary experiments with peat, perlite, or peat plus perlite without addition of compost did not produce marketable yields. The MSW compost had 66.2% dry matter content, pH of 7.2, 1.52% N, 22.5 g kg^{-1} Ca, 3.1 g kg^{-1} P, 57 g kg^{-1} K, 1.75 g kg^{-1} Mg, 2.8 g kg^{-1} Na, 2829 mg kg^{-1} Fe, 353 mg kg^{-1} Mn, 24.8 mg kg^{-1} Cu, 91.2 mg kg^{-1} Zn, and 14.6 mg kg^{-1} B. The rates of wool-waste application were based on preliminary experiments.

Basil and Swiss chard seeds were started in Metromix growth medium and then transplanted into 8-in. pots with the growth medium that included wool. The experiment was initiated in mid-March and conducted for 250 days. The plants were grown in a greenhouse with an average day temperature of 24 °C and a night temperature of 18 °C, under natural light during the summer period and with supplemental artificial lights during the winter to provide 14/10 day/night periods. Swiss chard and sweet basil were harvested 4 or 5 times, respectively, each time when basil plants reached flowering and Swiss chard reached what growers consider technical maturity (four fully developed and extended outer leaves).

The first harvest of Swiss chard was done 47 days after transplanting. Three subsequent harvests of Swiss chard were taken at 103, 137, and 250 days after transplanting. The first harvest of basil was taken 57 days after establishment when the plants were flowering. Four subsequent basil harvests were taken at 103, 138, 187, and 247 days after transplanting. Plants were cut at approximately 3–4 cm above soil level or 3–4 cm above the nodes with care not to damage the small inner chard leaves or basil nodes in order to allow for re-growth. Fresh weight and height of the harvested sample were recorded. The entire Swiss chard sample and a sub-sample from each of the basil treatments were dried at 68 °C oven temperature for 72 h and dry weight recorded. The rest of the basil plants were air dried to avoid loss or compositional changes of the essential oil (Bowes and Zheljazkov, 2004). The essential oil of air dried basil from the first, second, and third harvests were extracted using a Clevenger type apparatus and analyzed for composition by Gas Chromatography (GC) as described previously (Zheljazkov, 2005).

Immediately after the final harvest, growth medium samples were taken from each pot using soil core probes (5 cores per pot). Half of the growth medium sample was air dried, then sieved through a 2 mm soil sieve for Mehlich 3 extraction (Mehlich, 1984), to characterize the concentration of phytoavailable nutrients. The other half of the fresh growth medium was stored in a plastic bag at 4 °C for NO_3–N and NH_4–N measurements and processed within 10 days.

2.3. Total N, apparent N recovery (ANR), NO_3–N and NH_4–N determination

The C and N content of the wool or hair-waste and plant tissue were measured using a Leco (LECO, St. Joseph, MI) CNS analyzer. Apparent N recovery (ANR) was calculated by difference as: ANR% = (N uptake for treatment − N uptake for unfertilized control)/N applied × 100

To determine the concentrations of soil NO_3–N and NH_4–N, fresh soil samples were extracted with 2.0 M KCl (Bremmer, 1965; Sanderson and MacLeod, 1994). Extracted NO_3–N and NH_4–N samples were measured on a Technicon (Technicon Instruments Corp., Tarrytown, NY) TRAACS 800 AutoAnalyzer (Technicon Industrial Systems Corp., 1986).

2.4. Essential oil analysis of basil

Basil herbage samples (200 g of leaves, flowers, and stems) were steam distilled for 2 h in a Clevenger type apparatus (Furnis et al.,