Evaluating Performance and Stability of Polyethylene Terephthalate (PET) and Cellulose Polymer as Soilless Mix Components

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Abstract

In the U.S., concerns over the long-term sustainability of peat, perlite, and other media components have led to searches for alternative materials. FiberFill, a synthetic fiber made of recyclable polyethylene terephthalate, and Tencel, a cellulose fiber, are new materials with potential as substrate components. FiberFill blocks have already been used for hydroponic vegetable production, but its suitability as well as the suitability of Tencel has not yet been tested as soilless mix components. The growth of several floriculture crops was tested using substrates containing different proportions of the two polymers. Furthermore, the long-term stability of the materials was tested by measuring respiration rates of the different components by themselves or as blends with peat. A peat- or coir-based mix was amended with the polymers up to 100% of the final volume and fertigated with water-soluble fertilizer as needed. Visual observations of plants, dry weight (DW), leaf area (LA), and consumer preference were measured. Plants grown in 100% FiberFill or Tencel were shorter and had smaller DW and LA than plants grown in partially-amended substrates with the exception of begonia, which were largest in 100% and 75% FiberFill. Substrates containing 50% FiberFill produced plants that were equal to or larger than substrates containing less polymer. Plants grown in Tencel-containing mixes were consistently smaller than plants grown in substrates containing an equal amount of FiberFill. Initial respiration rates of Tencel were lower than those of peat or peat:perlite blends, but after only ten days, respiration rates of Tencel increased after saprophytic organisms colonized the material. These results indicate that FiberFill has potential as soilless mix component, but the high respiration rates suggest Tencel would not be suitable for long-term (>6 months) production. However, the movement of the U.S. floriculture industry towards sustainability likely favors the adaptation of the cellulose-based component, Tencel.

INTRODUCTION

The ornamental and nursery industry in the U.S. has a reported wholesale value of nearly $10 billion (U.S. Dept. of Agr., 2007). Sphagnum peat, pine and Douglas fir bark, perlite, and vermiculite are the primary substrates used in container production for this industry. There is growing concern, however, over the long-term sustainability and availability of these materials, which has led many to search for alternatives to these materials (McNalley, 2003). The hydroponic vegetable industry relies on the use of rock wool as a substrate, which is known to have disposal problems. Coconut coir has been widely adapted in some areas as a peat replacement (Meerow, 1994). Par boiled rice hulls hold promise as a perlite replacement (Evans and Gachukia, 2004), minimally processed wood chips have shown to be useful in replacing bark for some crops (Fain et al., 2008), and composted material of various origins have value in the horticulture industries (Raviv, 2005).

FiberFill, a synthetic fiber made of polyethylene terphthalate (PET), is a lightweight, porous material that can be made from recycled materials such as plastic drinking bottles. As a block material, it is gaining in popularity for the hydroponic

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vegetable industry as a rockwool replacement since it can be recycled or incinerated after use. When loose, the material resembles cotton or padding in pillow stuffing. The lightweight, porous nature of the material may also make it suitable as a peat or perlite replacement in potted crops.

Tencel is cellulosic polymer (CP) that has been used primarily in the clothing and furniture industries. Made from processing eucalyptus tree in a pulping process, it is organic and potentially can be produced in a sustainable manner. It too resembles small cotton balls in its loose form, and because of the lightweight nature of the material, it may make a suitable replacement for peat or perlite. Neither FiberFill nor Tencel have been tested, however, for their use in potted ornamental cropping systems as soilless mix components.

The goal of this study was to test the suitability of both FiberFill and Tencel as complete or partial replacements of the currently used substrate components peat and perlite. We sought to determine 1) the fraction of PET that could be used for the most marketable crop, 2) how PET and CP impacted the growth of begonia grown in a more sustainable, coir-based substrate, and 3) the long-term stability of the materials as determined by respiration measurements and weight change in unplanted, fertilized samples when incubated for eight weeks.

MATERIALS AND METHODS

Growth Experiments

In the initial growth experiment, rooted cuttings of geranium (*Pelargonium ×hortorum*) 'Americana Dark Red' and coleus (*Solenostemon scutellarioides*) were planted into 11-cm diameter plastic pots containing (by volume) 0%, 25%, 50% 75% or 100% PET with the remainder consisting of a 70:30 (by volume) peat:perlite mixture. Additionally, there was a treatment that was 100% commercial mix (trade name Fafard 3-B, FF3B containing sphagnum peat, perlite, vermiculite, processed pine bark, and starter fertilizer charge). The plants were grown in a glasshouse in Columbus, OH from 3 March to 23 May 2007 and were fertigated with a soluble fertilizer mix (Peter's Cal-Mag 15-5-15, Peter's Maryville, OH) at a rate of 150 mg/L N each time the plants required irrigation. There were three replicate plants for each treatment. At the end of the experiment, consumer preference was measured by asking a group of 17 Master Gardener volunteers to rate them on a scale of 1 to 5 with 5 being high preference and 1 being lowest. After scoring, the plants were harvested by separating leaves and measuring leaf area with an area meter (LICOR 3100, LICOR, Lincoln, NE). After measuring leaf area, leaf dry weight and the leafless stem was measured after drying the leaves in a forced-air drying oven for 72 hours.

The second growth experiment evaluated both PET and CP as complete or partial substrate components with a coconut coir substrate. Rooted cuttings of begonia (*Begonia semperflorens*) 'Bayou Rose' were planted into mixes consisting of 0%, 25%, 50%, 75% or 100% PET or CP with the remainder of the volume coconut coir. Additionally, there was a treatment that was 100% commercial mix (FF3B) that served as a negative control. The plants were grown in a glasshouse in Columbus, OH from 9 November 2007 to 5 February 2008 and were fertigated with a soluble fertilizer mix (Peter's 20-10-20, Marysville, OH) at a rate of 150 mg/L N each time the plants required irrigation. There were six replicate plants for each treatment. At the end of the experiment, leaf area and dry weight were measured by the above method.

Long-Term Stability

The stability of the CP material was measured by determining instantaneous respiration rates of the material alone or mixed with a sphagnum peat:perlite (70:30 by volume) mixture and by measuring the change in weight after incubation of the material for two months. For respiration measurements, approximately 1.5 g samples of CP, a 50% CP 50% peat:perlite mixture, peat:perlite, and 100% PET were air dried for 72 hours and weighed with a microbalance. Each sample was placed in a 250 ml Erlenmeyer flask with a rubber stopper containing a sealed Neoprene tube. Fertilizer solution (Peter's 20-10-20) was added to each substrate mixture until the substrates were saturated. The flasks were sealed and placed in a light-free cabinet. Twice weekly, the flasks were vented and air was blown into the flasks to prevent oxygen deprivation. At 0, 1.5, 6 and 8 weeks after hydration, respiration rate tests were performed using the closed system approach to CO_2-gas exchange (Wheeler, 1992). A 3 ml syringe was used to mix the air inside the sealed flasks for about 30 s. At that time, a 3 ml sample was drawn from the flask and injected into a CO_2 gas analyzer (LICOR model 6262). The signal was measured with a datalogger (CR10X, Campbell's Scientific, Logan, UT) and compared with the signal from standard, pre-calibrated CO_2:Air tanks (Airgas Great Lakes, Inc, Royal Hill, MI). Samples were drawn periodically until respiration rates could be determined for each flask. At the end of 8 weeks, the samples were removed from the flasks, air dried for 72 hours, and weighed with a microbalance.

Statistical Analysis

Each plant growth variable measured in these experiments as a response PET or CP concentration were analyzed using the general linear model procedure in SAS (SAS Institute, Cary, NC). Mean comparisons by LSD were used to compare PET or CP amended substrates with the standard soilless mixes used as a comparison.

Respiration rates were compared using the general linear model procedure in Statistix (version 9.1) as a two-way analysis of variance (ANOVA) with substrate mixture and period of time after the start of the respiration tests the two main effects. Any significant differences ($P<0.05$) were further tested using Tukey's multiple comparison of means.

RESULTS

Growth Experiments

No significant differences in geranium dry weight or leaf area were found between plants grown in peat/perlite and Fafard 3-B mixes without PET (Fig. 1A, B). Significantly larger plants were obtained when 25% by volume of PET was added to the peat/perlite mix. Increasing PET in the mix from 25 to 100% reduced dry weight of geranium plants. Consumers did not indicate any difference in their preferences between geranium grown at any percent PET addition except the 100% PET (Fig. 1C).

In coleus, there was no difference in plant size between the substrate without PET and 100% PET (Fig. 1D, E). As with geranium, the 25% PET addition to the substrate produced plants that were larger than control plants. In spite of similar sizes between control and 100% PET-grown plants, consumers did not prefer the plants grown in 100% PET (Fig. 1F). Plants grown in the commercial substrate had similar preference scores as those grown in 0, 25, 50, and 75% PET.

Roots of plants grown in mixes having 0, 25, 50, and 75% PET were well distributed in the substrate (data not shown). On the other hand, roots of plants grown in 100% PET had the roots concentrated only in the lower third to quarter of the substrate.

In the second growth experiment, begonia plants grown in only the commercial mix were significantly larger than those grown in only coconut coir (Fig. 2A, B). Increasing PET concentrations in the coconut coir mixes increased dry weight and leaf area above that of coir alone. On the other hand, adding CP to the coir mix had no effect on plant dry weight or leaf area.

Long-Term Stability

Initially after hydration, respiration rates of the peat:perlite substrates were greater than the other substrate mixtures (Table 1). It was observed that the CP clumped together within days of hydration whereas the PET remained in its original loose form for the duration of the experiment. After ten days, respiration rates did not change significantly in the peat:perlite substrate. Also evident at this time was colonization of the CP by saprophytic fungi. None were observable on the PET. Subsequent identification of these micro-organisms revealed *Penicillium* spp. and *Fusarium* spp. These colonizations resulted in increased respiration rates that were sustained for the duration of the tests. The respiration rate of the peat:perlite:CP mixture was the highest 10 days after hydration, but by 6 weeks had decreased to rates similar to the CP alone. If the respiration rates in the peat:perlite:CP mixtures were expressed on a per gram CP basis (approximately double the rate reported in Table 1), the peat:perlite:CP mixture would have had respiration rates greater than those of CP alone. If the CP remained respiring at the peak measured rate, 50% loss of substrate would occur in 1.5 years. The change in weight after 8 weeks days was greatest for CP (Table 1), while the weight change in PET was negligible. If this weight loss rate persisted, the CP would be consumed in a little over a year.

DISCUSSION

Based on these results, PET can be used as a component for soilless substrates as long as it is utilized between 25 and 75% by volume. Different plants will respond differently as indicated by the geraniums and coleus results. Before generalization of these results, more experiments using different species and cultivars are recommended. Data from these experiments were collected on mature plants. It is possible that more obvious differences can be found if measurements are taken on younger plants.

When PET was blended with a peat:perlite base, plants were largest (dry weight and leaf area) when PET was used at a rate of 25% by volume. We speculate that this was due to improved porosity. The roots of these plants grew densely throughout the center of the container as well as along the sides of the container whereas the control plants roots grew predominately along the edge of the container. Much more PET was needed to produce large plants (relative to the commercial substrate) when coconut coir was used instead of the peat:perlite mixture.

In spite of similar appearances, the CP- and PET-containing mixtures produced very different plants. The tendency of the CP to clump after wetting and growth of fungi after a week of wetting suggests that the air space of dry CP disappears or is significantly reduced as it is used. Physical testing needs to be done to confirm this. It is possible that incorporating a porous substrate such as perlite with CP would allow for CP to serve as a peat replacement.

After six weeks, a fungus was observed on the rubber stoppers used to seal the respiration flasks. While the colonies were small, these may have been respiring enough to result in non-zero, positive respiration rates in the PET. If it is assumed that respiration from these fungi were uniform (as was observed) in each of the flasks, and these rates are subtracted from each treatment, then both PET and peat:perlite had negligible respiration rates by the end of the 8 weeks. The initially high respiration rates of the peat:perlite substrate may be due to a physical effect since the pH of the peat:perlite mixture is low enough (pH ~ 4.5) to drive off the CO_2 dissolved in the fertilizer solution upon initial hydration. The sustained respiration rates of the CP substrate and the visible fungal colonies indicated that the fungi could use the CP as a carbon source. Still, calculated longevities of CP indicate this substrate would not decompose during production of annual floriculture crops.

PET appears suitable as a perlite replacement given its tendencies to hold its form and not degrade over time. It is this stability, however, that likely limits its market acceptability. PET does not degrade and the floriculture industry is moving into a direction of sustainability and “Earth Friendly” materials and practices. The adaptation of different forms of this material into the hydroponics industry as a rockwool replacement is accepted due to the fact that the rooting substrate is more readily re-usable or combustible. The bedding plant portion of the floriculture industry relies on transplanting plants and substrates into consumers yards and landscapes, so PET would persist in the environment. There is a possibility that PET in a similar form could be used for cutting production since those parent plants are not transplanted into the landscape and have a long production life. The results with begonia are encouraging in that regard.

Both materials' fibrous nature makes them difficult to mix with other substrate components. Once mixed, the resulting substrate is not "flow-able" so mechanical and automated container filling would not be possible. Recently formulated classes of CP (kernels, grains, or pellets) are pourable yet retain some water reducing the mechanical barrier to commercial adaptation.

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Tables

Table 1. Respiration rates of polyethylene terephthalate (PET), cellulose polymer (CP), peat:perlite blend, and a 50% peat:perlite/CP blend at four time points after hydrating with a fertilizer solution. After eight weeks of incubation at room temperature (23°C), the materials were dried and weighed to determine the total amount of material lost through respiration.

	Time (weeks)				Weight lost mg (SD)[1]
	0	1.5	6	8	
	μmol CO_2/h/g material				
PET	0.06 f[2]	0.71 ef	0.41 ef	0.97 cdef	3.6 (9.1)
CP	0.12 ef	4.40 b	3.35 bc	3.22 bcd	129.2 (60.2)
Peat:perlite	2.55 bcde	3.31 bcd	0.85 def	0.93 cdef	45.2 (16.2)
Peat:perlite:CP	0.12 ef	10.79 a	2.15 bcdef	1.70 cdef	117.5 (11.3)

[1] weight lost shown with standard deviation.

[2] numbers followed by different letters indicate significant differences ($P < 0.05$) between respiration rates based on Tukey's multiple comparison of means.

Figures

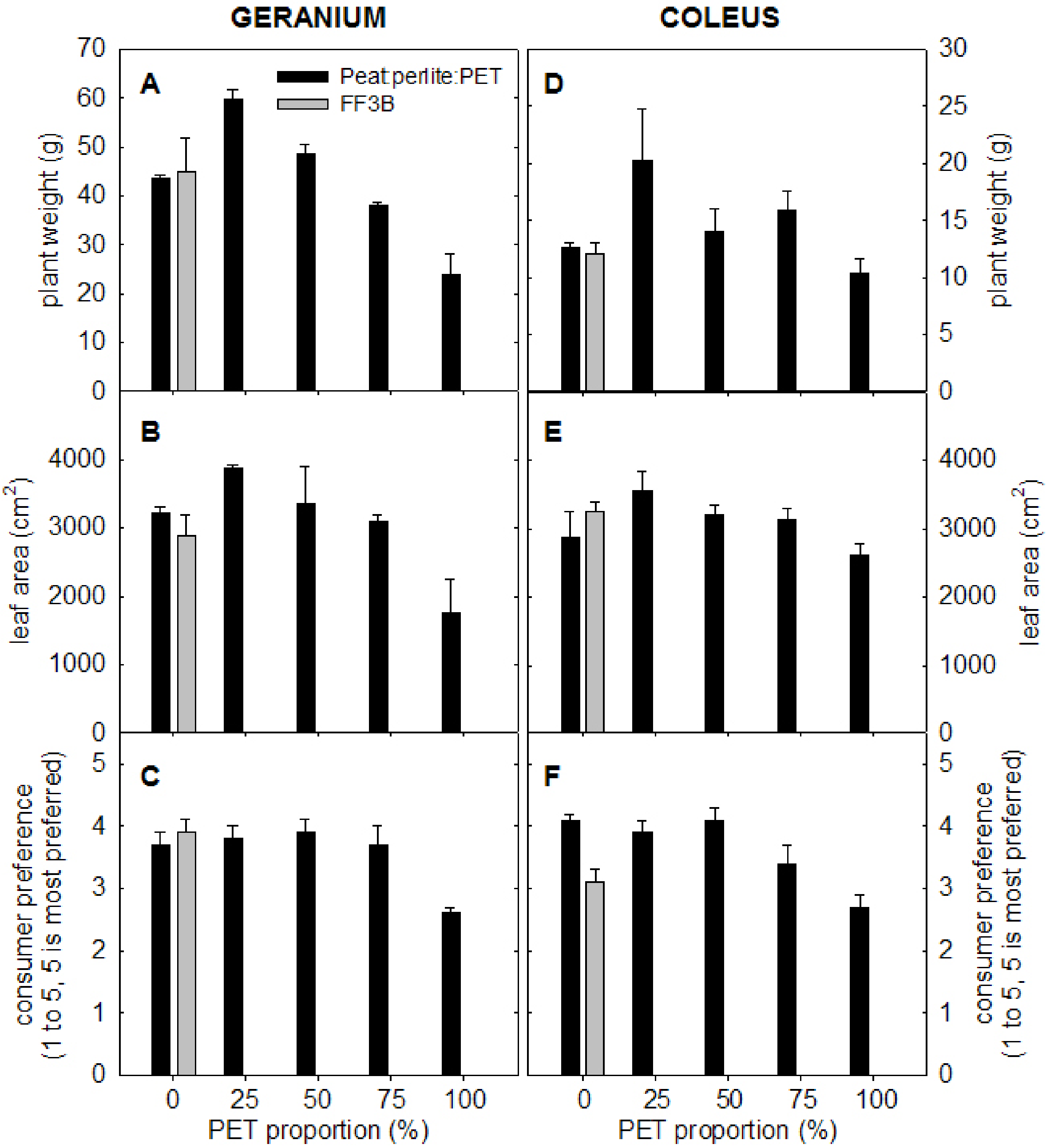

Fig. 1. Geranium and Coleus weight, leaf area, and consumer preference when grown in peat:perlite substrates containing different amounts of polyethylene terephthalate (PET). A commercial substrate (Fafard 3-B, FF3B) was grown as a negative control for comparison purposes. Error bars indicate on standard deviation of the mean.

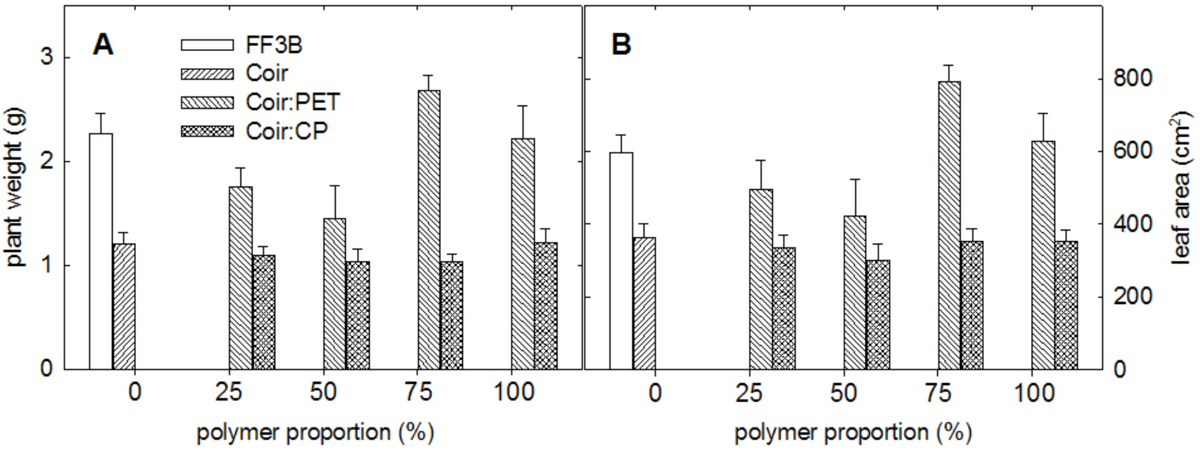

Fig. 2. Begonia weight (A) and leaf area (B) grown in a commercial mix (Fafard 3-B, FF3B), coconut coir (Coir), or coir blended with different amounts of polyethylene terephthalate (PET) or cellulose polymer (CP).