Repairing the Break in the "Cycle" of "Re-cycle": Bio-plastic Container Cropping System

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Significance to the Industry: Agricultural businesses use 540 million tons of plastics with plastic containers (pots, flats, & trays) representing 59%. These plastics contribute to carbon emissions, represent 8% of the world's annual petroleum use (4% production, 4% transportation), create disposal issues (20% of solid landfill wastes by volume), are expensive, and remain in the environment indefinitely. Because recycling options for horticultural plastic containers are limited and reuse of plastic containers is not always economically feasible, our industry must take advantage of opportunities to reduce the volume of plastics used during crop production especially in honor of our name – "the green industry." The PolyAmide + PLA (70/40) container provided by Iowa State University (ISU) had some issues of remaining rigid in hot summer conditions. When picked up it could bend and spill substrate. The one and no coat paper fiber pots did not retain their structural integrity in the trial. Some had completed failed after the winter with their bottoms completely detaching from the remainder of the pot when picked up. The industry standard HDPE black pot used in this trial, performed extremely well, as expected. The two-coat polyurethane (partially derived from plants) paper-fiber pots; however, was statistically comparable for all measured variables to the control HDPE pot, for both species investigated. The paper fiber pots are also readily available, easily made, biodegradable and inexpensive.

Nature of Work: Alternatives to plastics include containers made of plant based fibers, plant or animal proteins (bioplastics), and recycled byproducts of various industries. Little information about the performance of modern biodegradable pots (pots that degrade in compost piles) or plant able pots (pots that degrade when planted directly in the ground) (or buried beside the plant) exists in the scientific literature. Many horticultural companies are successfully using such "Green" pots even though most alternative pots currently on the market are yet to be examined in an applied setting. This lack of information is a competitive disadvantage to nursery container producers and nursery growers and is *critical* if our industry wants to properly utilize sustainable plant containers on a long-term basis. The Society of the Plastics Industry (SPI) established a classification system based on the numbers 1-7, in 1988. The SPI code, or number, is placed on each plastic product and is usually molded into the bottom. The SPI number indicates what type of polymer was used to produce the item. Many nursery containers are made from High Density Polyethylene (HDPE) with an SPI code #2 or from Polypropylene (PP) with an SPI code #5. The nursery HDPE containers are blow-molded and usually have a hole in the bottom of the container. HDPE resists breakage in full sunlight which results in its utility in container nurseries. Many recyclers will not take #5 plastics or #6 (which is polystyrene). Therefore many #5 plastic containers will be discarded into landfill sites. Reusing HDPE containers can only be done with proper cleaning and sterilization. Most nurseries lack space required to store: 1) three types of containers, i.e., new unused, washed for reuse, and unwashed to be reused; and 2) to hold containers, often in a converted truck trailer feed by a steam generator for several days during the sterilization process. Only small, specialty nurseries with high profit margins can consider the investment in the storage area required and the expensive of cleaning and sterilization required for reuse. Another limitation to container reuse is return of the containers from end users. Nursery growers are not the end users of many of these containers, landscape, retail operations and the public are the end users thus there is a break in the "cycle" part of "re-cycle."

This research is in collaboration with ISU, and funded by USDA, Specialty Crop Research Initiative. ISU has lead for years in the development of corn and soy based plastics. The role of Ohio State University (OSU) in this project was to help understand the usefulness of biodegradable and plant able pots in production, landscape, and composting environments and to extend this information to the respective "green industry" sectors. The overall goal is to reduce commercial greenhouse and nursery reliance on environmentally unfriendly and increasingly expensive plastic plant containers through four assessments: 1) Biodegradation and pot impacts on plants growth and quality produced in nursery sites; Biodegradation, compostable and plant able ("Green") pots in nursery production settings; Windrow and backyard composting on the degradation of biodegradable pots; and, Plant able pot impacts on crop growth and pot degradation in landscapes. This paper deals with the first assessment.

Materials and Methods: Two species were evaluated in the bio-plastic study at OSU in 2013, *Sedum pachyclados* (dwarf stonecrop) and *Forsythia ovata 'Northern Gold'.* The sedum was obtained from Millcreek Gardens LLC**,** Ostrander, OH as one 80 cell seedling plug tray where each cell plug volume was 16cc, on April 24, 2013. The forsythia was obtained as bare root liners from North Branch Nursery Inc., Pemberville, OH, on April 24, 2013. The sedum and forsythia were potted into one gallon pots May 14, 2013. Eight one gallon containers of each of eight types of pots were shipped from Iowa State University (ISU), Ames, IA on June 10, 2014 and were received at Ohio State University (OSU), Columbus, OH, June 4, 2014. The bio-plastic trial was initiated on June 14, 2013 with 8 pot types at OSU in a retractable roof greenhouse (Cravo, Brantford, Ontario, Canada). The pots were placed on black geotextile ground fabric, laid on top of a gravel bed, to prevent rooting into the gravel. Each pot type was replicated 4 times in a completely randomized design. The pot types consisted of two Mirel composites, Mirel & lignin (80/ 20) (#11) and, Mirel P1008 (10% Starch) (#14-G); one polyamide composite and blend, PolyAmide + PLA (70/40) (#17); one Aspen Research Corporation, Maple Grove, MN pots, Recycled PLA # 2 (#24); one control, high density polyethylene pot (HDPE) (#26-G); and, three coated fiber containers, Paper-fiber (Polyurethane - one coat) (#27-G), Paper-fiber (Polyurethane - two coats) (#28-G) and Paper-fiber (Polyurethane – no coat) (29-G).

Mirel^{TM} was obtained from Metabolix ® it is a bio-based Polyhydroxyalkanoaste (PHA). The Mirel products used in this study are PHA/ lignin – cellulose fiber composites. The cellulose and fibers are supplied from corn stover and Dried Distillers Grains with Solubles (DDGS). DDGS is a co-product of the ethanol production process and is a high nutrient feed valued by the livestock industry. When ethanol factories make ethanol, they use only starch from corn and grain sorghum. The remaining nutrients -

protein, fiber and oil - are the by-products used to create livestock feed called DDGS. A third of the grain that goes into ethanol production comes out as DDGS. Each bushel of grain used in the ethanol-making process produces 2.7 gallons of ethanol; 18 pounds of DDGS and 18 pounds of carbon dioxide. The Poly lactic acid or polylactide (PLA) used in this study is a thermoplastic aliphatic polyester produced from renewable resources, such as corn starch through fermentation process. PLA is the most widely used bio-based and biodegradable polyesters. Polyamides are biodegradable poly-ester-amides (PEAs) which are biomaterials derived from α-amino acids, diols, and diacids. PEAs are promising materials for biomedical applications such as tissue engineering and drug delivery because of their optimized properties and susceptibility for either hydrolytic or enzymatic degradation. Because of their use in medicine these were also the most expensive material used in the trial. The paper fiber pots used consist of no, one or two coatings of polyurethane. The polyurethane used was manufactured in part with bio-materials.

Three evaluations were conducted at one month after potting (1 MAP), 2 MAP and 4 MAP. Evaluations consisted of rating the quality of the pots (including a measure of integrity and rigidity), and plant quality (including a measure of growth and appearance), on a scale of 0 to 10, where 10 is perfect and $\geq$7 is commercially acceptable. Dry weights of plant roots and shoots were not taken at 4 MAP as an evaluation of plant and pot was to be conducted post-overwintering in May, 2014.

Results and Discussion: One coat polyurethane statistically was the lowest quality pot compared over all evaluation dates, when containing *Forsythia* (Table 1); however, the no-coat fiber container was the worst when *Sedum* was containerized (Table 1). The low pot quality of the one and no-coat polyurethane fiber containers included assessing integrity (by lifting) and rigidity (by lifting). We hypothesized the no-coat container would be the least able to endure regardless of species. We also hypothesized that species would be non-significant for pot appearance. With the *Sedum*, the plants were small and using less water early in the trial. The species ratings were much lower for *Sedum* (Table 2) in date 1 and 2 evaluations versus *Forsythia* (Table 3). The *Forsythia* were larger and used more water and thus the container media was kept less saturated versus the *Sedum.* We speculate this is why species was significant for pot appearance and why *Sedum* performed poorly with the no-coat (Table 1). The *Forsythia's* poor performance in the one-coat polyurethane containers (Table1) we speculate was the result of a low rating in the date 4 evaluation (Table 3). *Forsythia* on the last date was growing statistically poorer in the no- and one- coat pots, but not statistically different from one another. Because of the growth decline in the *Forsythia* in the no- and one-coat pots the no-coat performed worse than expected probably due to higher saturated conditions for the pot (Table 1). PolyAmide + PLA (70/40) container had some issues with rigidity in hot summer conditions. Although note-worthy, it did not severely impact the pot appearance rating combined over dates (Table 1). When picked up the PolyAmide + PLA (70/40) container would bend and spill substrate. This was more of an issue for the *Sedum pachyclados* (dwarf stonecrop) than for the *Forsythia*. *Sedum pachyclados* is a ground cover sedum and true to this group is very shallowly rooted. The *S. pachyclados* has long horizontal trailing stems that grow along the surface of the soil and produces roots and shoots at the nodes or tips (The Stonecrop Page, 2014). This shallow creeping root habit was prone to damage when the PolyAmide + PLA (70/40) container would bend and spill when temperatures were highest (Table 2). The disruption is growth was quite damaging to the *Sedum* (Table 2) versus the *Forsythia* (Table 3). However, by the trial end, once the structural integrity of the pot was stronger in the cooler temperatures of fall, the stonecrop (Table 2) was growing comparatively well to the *Forsythia* (Table 3). The one and no coat paper fiber pots did not retain their structural integrity in the trial. Some had completed failed after the winter with their bottoms completely detaching from the remainder of the pot when picked up. All plants in the trial died in the unusually severe winter conditions of 2013-2014. Dwarf Stonecrop which was hardy to only -10°F experienced temperatures of -11°F overwintering in January 2014. The "northern Gold was developed by Agriculture Canada and is known to have the hardiest of flower buds. However, roots are far less hardy than shoots. Steponkus (1976) found shoots of very hardy plants can be as much as 15 degrees Fahrenheit hardier. The lack of hardiness of the roots systems and subsequent death of all trial plants rendered plant growth evaluations impossible for spring 2014 (as originally planned). The containers with acceptable structural integrity, however, were retained and repotted with new species for 2014 evaluations. Pots that had failed with their bottom collapsing when lifted were recorded and discarded.

Although, the Polyamides (PEAs) + PLA pots did will in this study for both species the PEAs are becoming very expensive. The standard HDPE black pot used as the industry standard, also performed extremely well as expected (Fig. 4). The two-coat polyurethane was comparable to the control HDPE pot for both species. Trials in 2014, will focus more on the paper-fiber pots with two coatings. The paper fiber pots are also readily available, easily made, biodegradable and inexpensive. We are continuing these trials in 2014 at OSU and will be doing pot degradation and composting studies as well.

Treatment	***Forsythia ovata* 'Northern Gold'**		***Sedum pachyclados***	
Mirel & Lignin	10.0≠	a∗	9.0	a
Mirel 1008	10.0	a	10.0	a
PolyAmide + PLA	10.0	a	9.4	a
Recycled PLA#2	8.0	b	9.8	a
HDPE trade-gallon (check)	10.0	a	10.0	a
Paper-fiber (polyurethane) (1coat)	4.8	c	6.0	b
Paper-fiber (polyurethane) (2coat)	8.4	b	7.2	b
Paper-fiber (polyurethane) (no coat)	7.0	b	4.4	c

Table 1. Container appearance mean ratings for seven bio-plastic container types developed at Iowa State University, Ames, IA evaluated for appearance and averaged over evaluation dates for two species of plants grown in 2014 at Ohio State University, Columbus, OH compared to an HDPE (industry standard) trade gallon container.

∗Means with the same letters are not statistical different from one another using at $p > 0.05$, lsmeans.
≠ Rating of container appearance is 0-10, where 10 is no visible appearance problems, $\geq$ 7 is commercially acceptable and 0 is a disintegrated container.

Table 2. Plant injury means for *Sedum pachyclados* grown in seven bio-plastic container types developed at Iowa State University, Ames, IA evaluated at three dates in the 2014 growing season at Ohio State University, Columbus, OH compared to an HDPE (industry standard) trade gallon container.

Treatment	**Date 1**		**Date 2**		**Date 4**	
Mirel & Lignin	7.4≠	a∗	9.8	a	4.0	b
Mirel 1008	4.4	ab	4.4	abc	7.7	ab
PolyAmide + PLA	2.8	ab	2.5	c	7.4	ab
Recycled PLA#2	5.8	ab	6.5	abc	4.0	b
HDPE trade-gallon (check)	2.4	b	4.0	b	8.8	a
Paper-fiber (polyurethane) (1 coat)	5.0	ab	7.8	abc	4.5	b
Paper-fiber (polyurethane) (2 coat)	6.6	ab	9.6	ab	6.0	ab
Paper-fiber (polyurethane) (no coat)	4.5	ab	5.0	abc	6.5	ab

∗Means with the same letters are not statistical different from one another using at p> 0.05, lsmeans.
≠Plant injury rating is 0-10, where 10 is no phytotoxicity, $\geq$ 7 is commercially acceptable and 0 is a dead plant.

Table 3. Plant injury means for *Forsythia ovata* 'Northern Gold' grown in seven bio-plastic container types developed at Iowa State University, Ames, IA evaluated at three dates in the 2014 growing season at Ohio State University, Columbus, OH compared to an HDPE (industry standard) trade gallon container.

Treatment	**Date 1**		**Date 2**		**Date 4**	
Mirel & Lignin	10.0	ns∗	10.0	ns	5.8	ns
Mirel 1008	10.0	ns	10.0	ns	5.4	ns
PolyAmide + PLA	10.0	ns	10.0	ns	6.5	ns
Recycled PLA#2	10.0	ns	10.0	ns	**7.0**	ns
HDPE trade-gallon (check)	10.0	ns	10.0	ns	6.8	ns
Paper-fiber (polyurethane) (one coat)	9.8	ns	10.0	ns	4.4	a
Paper-fiber (polyurethane) (two coat)	10.0	ns	10.0	ns	6.8	ns
Paper-fiber (polyurethane) (no coat)	10.0	ns	10.0	ns	4.7	a

∗Means with the same letters are not statistical different from one another using at p> 0.05, lsmeans; ns signifies non-statistically different
≠Plant injury rating is 0-10, where 10 is no phytotoxicity, $\geq$ 7 is commercially acceptable and 0 is a dead plant.

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