FINAL REPORT

PROJECT TITLE: Corn Protein for Agricultural Applications

PROJECT NUMBER: AIC207IN

REPORTING PERIOD: July 15, 2013-July 31, 2016

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1.) PROJECT SUMMARY

The deliverables of this project included:

1. Four SelfEco cropping pot products based on corn feed stock
2. SunGro product evaluation of fertilizer containing corn products
3. Four journal articles
4. Two conference papers/presentations
5. One ISU patent application
6. Two SelfEco patent applications
7. Final report highlighting corn-based plastic formulations for several applications:
    a. Pots
    b. Fertilizers
8. Progress reports detailing several corn-based plastic products
    a. Pots (commercialized)

    b. Fertilizer (in product acceptance study by Sungro)
    c. Golf tee (in product acceptance study by Evolve Golf)
    d. Erosion control (no significant market acceptance)
9. Progress reports detailing all corn-based plastic formulations

2.) PRODUCT DEVELOPMENT

Commercialization of Pots: Working with Laurel Biocomposites and SelfEco, several corn based plastics have been developed. In more detail, Laurel Biocomposites produces corn-based plastic pellets, a Polylactic acid (PLA) corn starch plastic, and dry distillers grains (DDGs) with solubles from the corn ethanol industry. These plastics were delivered to SelfEco, a company that produces several products for horticultural applications as seen in *Figure 1*.

Figure 1- Photograph of corn based plastic applications that are currently on the market

Commercialization of Fertilizers: After attempting to work with several fertilizer products, it was found that SunGro had a significant interest in commercializing bio-based fertilizers.

During this period, the PI engaged SunGro, a company founded in 1929. Their primary product was peat moss, but they have expanded into other growth media and fertilizers. SunGro is located throughout North America as seen in

North America Locations

Production/ Distribution Facilities	Anderson, South Carolina	Kent, New Brunswick	Santa Maria, California
	Burnt Church, New Brunswick	Marysville, California	Seba Beach, Alberta
	Colombier, Quebec	Orlando, Florida	Vassar, Manitoba
	Elma, Manitoba	Pine Bluff, Arkansas	Valdosta, Georgia
	Fillmore, Utah	Port Cartier, Quebec	Vilna, Alberta
	Floodwood, Minnesota	Portage, New Brunswick	
	Hubbard, Oregon	Quincy, Michigan	
	Inkerman, New Brunswick	Sacramento, California	

Distribution	Abbotsford, BC	Brantford, ON	Montreal, QC	Nogales, AZ

Customer Resource Centers		Phone Number	Fax Number
	Agawam, Massachusetts	1-800-732-8667	1-413-789-3425
	Elma, Manitoba	1-888-982-4500	1-888-982-4501
	Hubbard, Oregon	1-800-842-3256	1-888-896-3005
	Orlando, Florida	1-800-683-7700	1-800-231-5307
	Pine Bluff, Arkansas	1-800-255-9057	1-870-536-1756
	Sacramento, California	1-800-222-2551	1-916-999-8450
	Seba Beach, Alberta	1-888-797-7328	1-888-797-6497
	Vilna, Alberta	1-866-636-2006	1-780-636-3000

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Our Expertise is Growing

September 4, 2015

Figure

Figure *2*.

Figure

Figure 2- Details of Sungro's locations

SunGro has a long history of sustainability as noted in their documentation: "stewardship of the environmental, social and economic values of Canada's renewable peatland resource." SunGro has tested several formulations but indicated that initial nitrogen release rates were too low. To address this issue, additional corn-based fertilizer samples were prepared that were:

1) Fast nitrogen release (high in SPI)
2) Slow nitrogen release (high in corn PLA plastic)

This allowed SunGro to tailor the formulations to a range of needs. SunGro continues to test these products for possible commercialization and this testing will continue with ISU's support through 2016.

In order to characterize the nutrient values of a "standard" bio-based fertilizer developed by Iowa State University (ISU), materials were tested for standard nutrient content by Minnesota Valley

Testing Laboratory (MVTL). Nutrient analysis for fertilizers included content of nitrogen, phosphorus, and potassium (N-P-K). These three ingredients are the most important functional components of fertilizer applications with nitrogen having the most affect. MVTL supplied results of tested materials at 50/50, 40/60, and 30/70 PLA-SPA. Table 1 shows the analysis results.

PLA-SPA (10%PEG) N-P-K Results			
	50/50	**40/60**	**30/70**
Nitrogen	3.99%	4.28%	5.19%
Phosphorus	0.83%	0.91%	1.10%
Potassium	1.27%	1.39%	1.71%

Table 1- Nutrient analysis reported from MVTL

In addition to SunGro's evaluations, testing of the formulations were conducted at the ISU Horticulture Research Farm turf grass plot. Turf plots were defined into grid patterns with each grid having dimensions of five square feet. Four replicates of each material type were used. The plots were marked and randomly assigned a treatment application. Treatments included the three formulations shown in Table 1, a negative control with no fertilizer (control average), and two commercially available fertilizers. The first commercial fertilizer was a traditional synthetic and the other fertilizer a common bio-based alternative known as milorganite. Milorganite is produced by harvesting wastewater treatment bacteria. All fertilizers were applied at a standard application rate of 2 pounds of nitrogen per $1000ft^3$.

The plots were visually evaluated weekly (as close to a week as possible, rain and fog occasionally delayed data collection). A rating scale from 1 to 10, with 1 being low (dead, brown grass) and 10 high (dark green, thick) was defined. A rating of 6 was considered the "least commercially acceptable", or the point at which the turf grass was considered high enough quality for commercial turf grass growers.

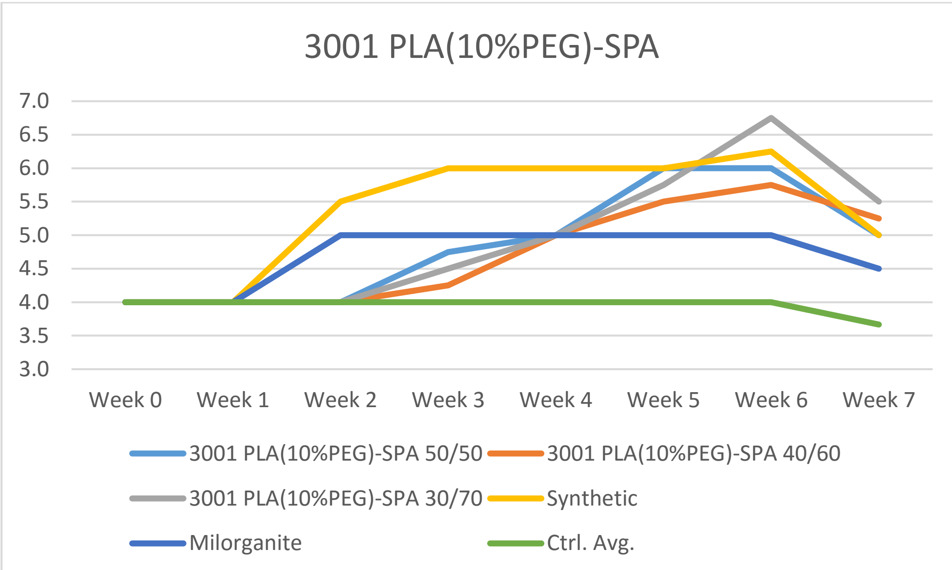

Figure 3 Fertilizer visual data through week 7.

Figure 3 is the data collected through week 7. It is important to note that the inflation at week 6 was the result of the grass beginning to enter its dormancy state for the season. The team will continue to collect data each week into the fall and next spring with anticipation of capturing data on any differences in “end of year” and “beginning of year” (emergence) effect of the fertilizers.

In addition, various fertilizers were tested with marigold plants. While several factors were studied, one of the most important was growth. In more detail, the average shoot dry weight (SDW) was one the key indicator (independent variables) for yield used in greenhouse experiments. With all other dependent growth parameter factors equal (light, water, soil type, and plant species), differences in SDW indicates effectiveness of the fertilizing nutrients made available to the plant.

Table 2 shows the average SDW in grams for different materials under the standard application rate of fertilizer. It is important to note that the negative control (no fertilizer) is given its own letter. This indicates that every material performed statistically better than applying no fertilizer, showing that soy based biocomposite fertilizers successfully work as fertilizers. Also, there are only two materials that did not statistically perform as well as the synthetic fertilizer; 2003 PLA/SF (60/40), and 3001 PLA (10%PEG)/SPA (30/70). Every other soy based composite showed no statistical difference in terms of SDW yield.

SHOOT DRY WEIGHT (SDW) OF LOW TREATMENT RATE							
MATERIAL						**Mean**	**Std Dev**
MILORGANITE	A					3.857	0.695
2003 PLA/SF (50/50)	A	B				3.552	0.362
SYNTHETIC FERTILIZER		B	C			3.374	0.387
2003 PLA/SF (40/60)		B	C	D		3.211	0.704
3001 PLA/SPA (50/50)			C	D		3.137	0.419
3001 PLA(5%PEG)/SPA (30/70)			C	D		3.081	0.455
3001 PLA/SPA (30/70)			C	D		3.031	0.635
2003 PLA/SPA (50/50)			C	D		3.002	0.547
2003 PLA/SF (60/40)				D		2.856	0.429
3001 PLA(10%PEG)/SPA (30/70)				D		2.842	0.645
NEGATIVE CONTROL					E	2.378	0.335

Table 2 - Shoot dry weight (SDW) averages, displayed in grams, for each fertilizer type using standard application rate.

Commercialization of Golf Tees: Working with Evolve Golf, several formulations of golf tees produced from a range of bioplastics, including corn based plastics, are under product testing, see ??. Samples were sent to Evolve Golf as well as other customers for testing. The testing consisted of appearance ratings as well as durability during multiple use and ability to survive 3-4 impacts during a typical “tee-off.” Several of the formulations performed sufficiently for commercial consideration and Evolve Golf is evaluating the development of a marketing plan.

Figure 4 Photograph of corn based golf tee

Commercialization of erosion control: Alternative erosion control products (ECP) for use at construction sites, including road construction, were evaluated to replace current petroleum based polymer options. There are commercial additives to promote degradation of conventional plastics by UV radiation, however these are relatively expensive and their performance is not widely accepted. Straw from wheat production is an alternative. However wheat production decreased in total acres in the 2015/16 fiscal year. It is believed that a corn/soy formulation would be viable alternative.

After engaging several companies for commercialization of corn-based ECP, there was insufficient industry support to justify commercialization. Some of the possible products include those seen in Figure 4, an example sheet of ECP created with 60% PHA and 40% DDGS (by weight). Figure 5 shows the rough texture of the ECP as discussed.

Figure 5- PHA/DDGS ECP sheet at 60/40 formulation.

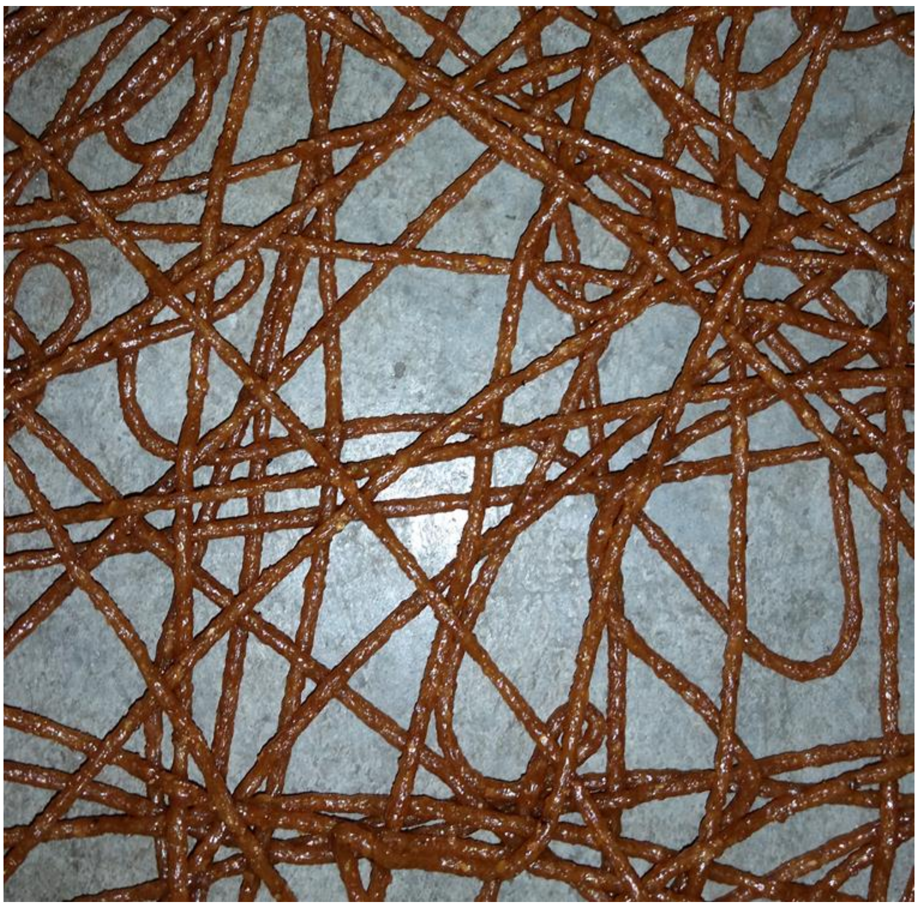

Figure 6- ECP close-up

While many formulations were characterized, three materials that were considered as typical formulations are detailed for mechanical properties. The materials were compounded in a twin screw extruder, pelletized and injection molded into ASTM dog-bone samples. In addition, a petrochemical plastic, polypropylene (PP) was studied as a control group. The samples were tested for tensile strength and maximum strain at failure, see Figures 6 and 7.

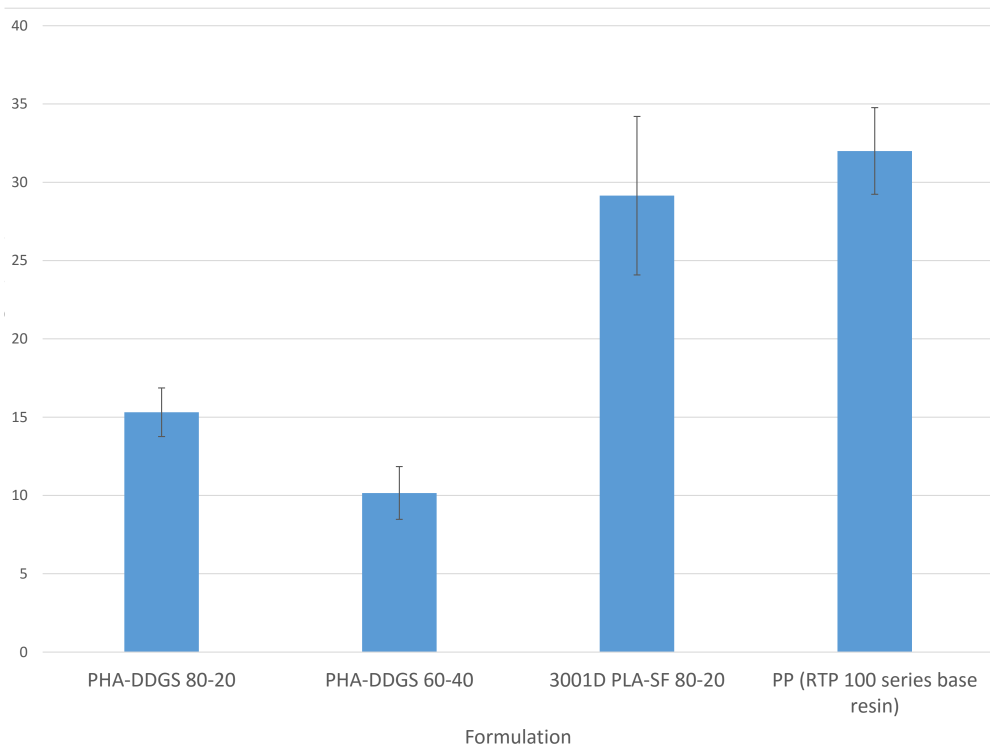

Figure 7. Tensile strength of three corn-based resins compared to petrochemical plastic (PP)

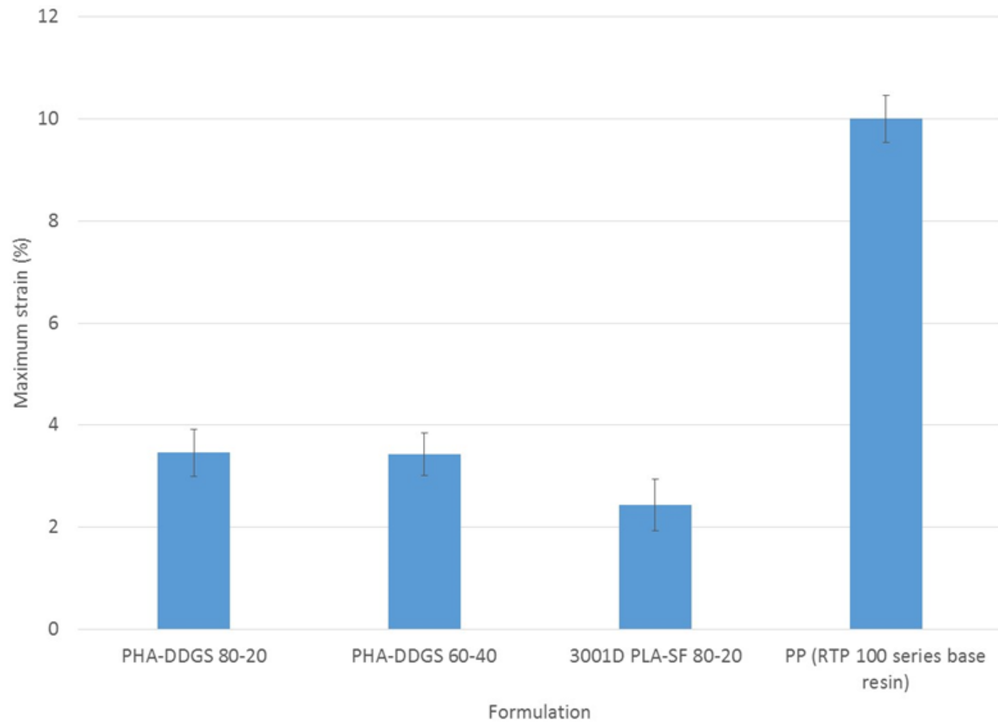

Figure 8. Tensile strength of three corn-based resins compared to petrochemical plastic (PP)

It is seen that tensile strengths between 15 and 29 MPa are possible (Figure 1?), and that the stronger of the biobased material PLA-SF is similar to PP. However, the maximum strain at failure (stretch) for the biobased materials is significantly less compared to PP. It is believed that this may be a benefit as it will promote mechanical failure during degradation after the product is placed into soil and degradation is desired.

Other Deliverables

There were four journal articles and one conference paper/presentation detailing the results of this study. These included:

JOURNAL ARTICLES

James Schrader , Kenneth McCabe , Gowrishankar Srinivasan , David Grewell, William Graves. Performance and Biodegradation in Soil of Novel Horticulture Containers Made from Bioplastics and Biocomposites, HortTechnology February 2015 vol. 25 no. 1 119-131.

S. Madbouly, J. Shrader, D. Grewell, W. Graves, K. McCabe, M. Kessler, G. Srinivasan. Characterization and Biodegradation Behavior of Bio-Based Poly(lactic acid) and Soy Protein Blends for Sustainable Horticultural Applications, Green Chemistry, 2015,17, 380-393.

K. G. McCabe, J. A. Schrader, S. Madbouly, D. Grewell, W. R. Graves. Evaluation of Biopolymer-coated Fiber Containers for Container-grown Plants, HortTechnology, 2014, 24(4).

S. Madbouly, J. Shrader, D. Grewell, W.Graves, K. McCabe, M. Kessler, J. Behrens. Pelletized Soy-based Bioplastic Fertilizers for Container-crop Production, submitted March 2016, HortScience.

Conference papers/presentations:

D. Grewell, Bioplastics in Cropping Systems, Agricultural Plastics Recycling Conference & Trade Show, San Diego, CA, August 2015.

D. Grewell, G. Srinivasan, J. Schrader, W. Graves, M.Kessler. Sustainable Materials for Horticultural Application, 100th Annual Technical Conference for the Society of Plastic Engineers Proceedings (2013), Society of Plastic Engineers, Brookfield, CT.

Outreach:

The team had a 20’x20’ booth at NPE2015, North America’s largest plastics trade show (+65,000 attendees). Figure 10 shows the booth with a 20’ tower and new booth display. It is important to note that the team shared the booth with Laurel Biocomposite, a company that is commercializing one of the corn based bioplastic formulations developed at ISU. Mark Laurenzo from the Iowa Economic Development Authority visited the booth and Dr. Grewell walked him to the five center member companies that had booths at the show.

Figure 9. Photograph of NPE booth where PLA/DDGs pots were molded

During the show, the group molded 1,400 pots/day for ?? days that were made from corn derived PLA and DDGs from the corn/ethanol industry on a 110-ton injection molding machine that was on loan from Wittmann/Battenfeld. This loan arrangement was secured by Dr. Grewell. In addition, a mold from VistaTek, a CB^2 member, was used to make the pots. The pots were given to booth visitors.

One patent application from ISU was submitted relating to the technology in this project:

United States Patent Application 20160102024

Kind Code A1

Schrader; James ; et al. April 14, 2016

BIODEGRADABLE FERTILIZER

Abstract

This invention relates to bio-renewable fertilizer compositions and methods of making and using the bio-renewable fertilizer compositions. In particular, the fertilizer compositions include biodegradable nutrient carriers, which have naturally derived bio-renewable nitrogen content. The fertilizer compositions also contain biodegradable stabilizer.

In addition, one of the industry partners, SelfEco has applied for two patents:

United States Patent Application 20160174470

Kind Code A1

June 23, 2016

BIODEGRADABLE HORTICULTURE CONTAINER

Abstract

The containment of plants and seedlings as such plants or seedlings are grown, transported, displayed and planted is provided. Containers are comprised of biodegradable materials that have the advantage of being formed into containers with various features, such as by an injection molding process, but that can be buried within the soil along with a plant's roots. Such containers allow for plant or seedling transplanting without having to separate the container from the plant's root system. More preferably, biodegradable plastics utilized in accordance with the present invention have properties such that the plastic can be injection molded and yet provide a stable structural container that will last in accordance with predetermined set needs, which needs may include environmental aspects, timing aspects and decompositional aspects. By utilizing injection molding, containers can be formed with many advantageous features.

United States Patent Application 20160174469

Kind Code A1

Shaffer; Chadwick Arron ; et al. June 23, 2016

BIODEGRADABLE HORTICULTURE CONTAINER

Abstract

The containment of plants and seedlings as such plants or seedlings are grown, transported, displayed and planted is provided. Containers are comprised of biodegradable materials that have the advantage of being formed into containers with various features, such as by an injection molding process, but that can be buried within the soil along with a plant's roots. Such containers allow for plant or seedling transplanting without having to separate the container from the plant's root system. More preferably, biodegradable plastics utilized in accordance with the present invention have properties such that the plastic can be injection molded and yet provide a stable structural container that will last in accordance with predetermined set needs, which needs may include environmental aspects, timing aspects and decompositional aspects. By utilizing injection molding, containers can be formed with many advantageous features.

In addition, a formal news release was prepared and released:

Researchers Develop Soy-based Turfgrass Fertilizer for Improved Sustainability

Growing a lush and environmentally friendly lawn might be easier thanks in part to some Iowa soybeans and some innovative research from the Center for Bioplastics and Biocomposites (CB^2).

David Grewell, CB^2 Director, and James Schrader, an associate scientist in horticulture, lead a team investigating the use of soy-based materials as a source of nitrogen in a fully biorenewable, slow-release fertilizer. Their goal was to develop a biobased turfgrass fertilizer that could perform as well as traditional synthetic fertilizers, while improving environmental sustainability.

Grewell said they wanted to design a fertilizer for residential and commercial use that also would minimize the effects of nitrogen run-off in waterways.

"The problem with most synthetic fertilizers is that they are water soluble and easily breakdown after a heavy rainfall, washing nitrogen downstream," he said. "Excess nitrogen in the waterways can cause negative environmental impacts including hypoxia and algae blooms."

Members from David Grewell's research team extrude soy flour and PLA using CCUR's pilot-scale extruder. Matt Blom, a student in industrial technology, (right) sets the extruder's controls as James Burkholder, a student in materials engineering, feeds the soy-PLA mixture into the hopper. Larger image

The fertilizers that Grewell and Schrader have developed are considered to be "slow released." The nitrogen that is found in the soy breaks down slowly, providing the lawn with nutrients for a longer period of time compared to typical water-soluble products.

The first stages of this research actually began much earlier while Grewell and Schrader were developing biobased horticulture pots made with a blend of soy, PLA (a polymer made from cornstarch) and other fillers. They found that during crop production in the greenhouse, nitrogen and other nutrients were slowly released, and nourished the plants growing in the containers. Grewell and Schrader took those findings and applied them to develop a bioplolymer-based turfgrass fertilizer.

A close-up view of the soy-PLA fertilizer. Larger image

Grewell's team, led by Jake Behrens, a graduate student in agricultural and biosystems engineering, began developing various formulations using a mixture of soy flour or soy protein isolate with a PLA matrix and other filler materials. They used the equipment in the Dry Processing Pilot Plant at the Center for Crops Utilization Research to compound the formulations and extrude and pelletize them into one-eighth-inch pieces. The pellets, also known as prills in the horticulture industry, were designed so they could be applied to turfgrass using standard fertilizer broadcast applicators or by hand.

Figure 10. Partial screen image of web-page news release of current project