OPTIMIZING PROTECTED CULTURE ENVIRONMENTS FOR BERRY CROPS

Report to Advisory Committee, December 2016

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BACKGROUND:

National demand for fresh raspberries and strawberries is strong and growing, but most domestic production occurs in select regions of the U.S with the most suitable climate. Concentrated production in specific regions can tax local resources such as water, increase costs of transporting produce to distant markets and perhaps elevate risks to supplies due to adverse local weather. Farmers in the upper Midwest and Northeast are keenly interested in supplying more berries to local markets, but producing profitable yields and consistently high fruit quality is difficult in a region with cold winters and short, humid growing seasons. Protective structures or tunnels appear to mitigate many aspects of our climate that hinder berry production. However, we learned through an earlier planning grant that producers need information on many topics including which type of structure and plastic to choose, how they should be managed and what benefits they can provide. An enormous array of protective structures and covering plastics is available, including specialty “smart” plastics that can diffuse light and alter the spectrum reaching plants. Modifying light quality and intensity – basic conditions to which all organisms have adapted – can directly impact the yield and quality of berry crops while presenting unique opportunities for non-chemical pest management methods. Our goal is provide growers with the knowledge necessary to select structures and plastics that optimize productivity and pest management, while increasing profits and minimizing the generation of plastic waste.

SUMMARY OF PROGRESS IN 2016

Objective 1. Evaluate/contrast diverse types of structures and plastics: To provide growers with information, an inventory of tunnel structures available on the market today along with twenty-two different tunnel films was published on the project website with links to film features, manufacturers and distributors. Current investigations are being conducted to assess plastic film performance over time. Plastic spectral characteristics in the field were monitored over time and changes in performance and physical condition were tracked. Solar powered tunnel venting systems were configured on stand-alone high tunnels using a ridge vent, roll-up roof, roll-up sides, and side baffles in various combinations for use in venting experiments and for comparison to a manually-vented control.

Objective 2. Describe effects of diverse plastics on tunnel microclimate, berry production and insect/disease management: Low tunnel experiments on research stations and commercial farms in four states using day neutral strawberries were conducted using various plastics for tunnel covers and mulches to understand how these structures alter environmental conditions and potentially impact yield and quality. Data was collected on tunnel coverings and mulch treatments compared with open field
conditions and consisted of microclimate, production and economic data, specifically: light conditions, temperature, relative humidity, plant vigor/runner production, crop yield, fruit quality/marketability, sugar content, fruit color and insect/disease incidence. The effect of fertilizer rates and planting dates on crop yield was also evaluated. Preliminary results suggest that disease incidence is reduced on plants growing under low tunnels and that mulch type affects both yield and incidence of fruit anthracnose.

High tunnel experiments evaluated various plastics for tunnel covers to determine how these structures alter environmental conditions and impact yield and quality of raspberries and strawberries. Studies on research stations and commercial farms were established on plants growing under tunnels either in-ground or in pots and compared with plants growing outdoors. Data was collected on fruit yield, quality/marketability, runner production (strawberries only) and insect incidence. There was a reduction in severity of Japanese beetle feeding under high tunnels, with some differences among plastics.

Three raspberry cultivars were compared under high tunnels covered with plastics that were either completely transparent to or partially opaque to ultraviolet light. The plastics did not significantly affect berry color, size, or shelf life, or insect pest prevalence.

Ten raspberry cultivars were tested for high tunnel culture suitability and were grown in containers under a partly UV transparent film. Differences in fruit yields, quality and fruiting times were documented. The new cultivars Imera, Kweli and Kwanza performed very well and have high commercial potential. Three raspberry cultivars were grown under organic culture in a high tunnel with partly UV transparent film. Results indicate that total yields of marketable fruit range from 12,000 to 18,000 pounds per acre, which appears to be profitable on a commercial scale.

A high tunnel strawberry experiment was conducted to evaluate two fertilization regimes (fertilizer incorporated into media or as constant-feed fertigation) and 4 types of media (coir, 2:1:1 peat:coir:perlite, 2:1 peat:perlite, Metromix 360). Data were collected on air and soil temperature, plant size, root growth, and vegetative growth. Overall, 2:1 peat:perlite with constant-feed fertilization resulted in the best plant growth.

In high tunnels, a two-year dataset has been collected of insect pests, natural enemies, and pollinators from high tunnel grown raspberries under different plastic types and compared to field-grown raspberries at multiple Michigan farm locations. Exclusion netting on high tunnel grown raspberries were utilized as an innovative approach to control spotted wing Drosophila. Two years of data has been collected from a pesticide degradation study under different plastic types. Ten different insecticides representing commonly used chemicals for raspberry pest management were tested and pesticide analysis results are forthcoming.

Different plastic film tunnel covers on low tunnel structures in combination of various bio-insecticides have been assessed for their effect on insect pest density and damage on 'Albion' day neutral strawberries.

Seven biological and natural fungicides were evaluated for control of powdery mildew, Botrytis gray mold, and late leaf rust. Disease pressure was evaluated in different raspberry cultivars growing under different plastic films and using the various training systems. Fungal spore viability, sporulation capacity and the breakdown of five fungicides was assessed under the different plastic films.

**Objective 3. Optimal Methods for Plastic Recycling:** Best practices for handling agricultural plastics have been developed and continue to be updated. Ground work has been laid for a stakeholder organization
with specific objective to increase recycling networking. Work is progressing on the database of plastic recycling market information being developed with Moore Recycling Associates which will identify reclaimers willing and able to process agricultural plastics. A website containing information on recycling agricultural was developed and published. Project participants have been monitoring plastic degradation with the goal of determining if tunnel plastics in various stages of degradation can still be recycled.

**Objective 4. Understand grower use of protective structures, consumer attitudes toward crops harvested, and evaluate economic viability of using structures for commercial production:** A grower survey was developed to obtain baseline data on grower attitudes towards tunnels plastics purchases, use, and recycling. Economic data were collected on labor required for various aspects of tunnel construction, plant establishment and management for use in economic analyses.

**Objective 5. Develop diverse outreach vehicles to ensure that all generated information is disseminated to stakeholders and the Extension and research community:** Forty meetings such as field days, seminars, workshops and conference presentations took place across multiple states and in Quebec, Canada. Extension activities also included dozens of communications and farm visits with growers across participating states. Print and online publications include journal and newsletter articles, weekly pest reports and an extension bulletin. The number of growers, researchers, extension personnel and other stakeholders reached is conservatively estimated to be at least 8,000.

The project website with accompanying project blog was populated to disseminate information primarily to growers and extension educators and now has 300-400 unique users per week. Also developed, published and regularly updated are a project Facebook page, a blog on low tunnel strawberry research, and a website on recycling agricultural plastics. Other online educational materials developed: four videos and a webinar covering aspects of growing brambles under high tunnels. A video series detailing tunnel construction was outlined and work on this series is progressing.

A stand-alone (20 by 36 feet) high tunnel was constructed on a vacant lot in East Orange, NJ in collaboration with the NJ Farm Bureau and a USDA Block-grant. The high tunnel will be operated by the local YMCA and used as an outreach tool to educate and train local youth and adults in urban agriculture.

**STATE-BY-STATE PROGRESS REPORTS AND PLANS FOR 2017**

**Michigan** (Eric Hanson, Rufus Isaacs, Heather Leach, Annemiek Schilder: Michigan State University)

**Raspberry cultivars for tunnels and double cropping.** Eric Hanson and Josh Moses. Our goal is to assess new primocane fruiting (PF) raspberries for production in tunnels. We are concentrating on the potential for double cropping, where one crop is produced in the fall on one year-old primocanes and a second harvest occurs in the summer on over-wintered floricanes. Double cropping costs more to prune and train, but is appealing to many growers because higher yields can be achieved and the summer floricane crop matures before populations of spotted wing drosophila increase to severe levels. We are assessing relative harvest times and fruit yields and qualities in both the summer and fall.

**Potted plants.** We have been studying these characteristics using potted plants under Haygrove high tunnels in Benton Harbor, MI. Plants were grown in composted pine bark/peat (70/30) media in 3 gallon
Gro-bags. Potted plants include the FF varieties Encore, Nova and Prelude for comparison and are pruned to retain two canes per plant.

Observations of primocane production from newer raspberry cultivars:
BP-1: early season, smaller, medium red, good flavor, somewhat soft, moderate gray mold incidence
Kwanza: late season, very large, glossy light red, flavor very good. Very firm. Very little gray mold.
Crimson Night: late season, small-medium, glossy very dark red, excellent flavor, firm, moderate gray mold.
Double Gold: mid- to late season, medium size, glossy yellow-pink, excellent flavor, less firm, little gray mold.
Imara: mid-season, medium size, bright glossy medium red, excellent flavor, medium firm, moderate gray mold
Kweli: mid-season, large, glossy red, excellent flavor, very firm, little gray mold
Nantahala: later season, large, dull darker red, good flavor, soft to medium firm, extensive gray mold.
Vintage: mid-season, medium size, uniform shape, glossy light red, somewhat soft, prone to gray mold.

<table>
<thead>
<tr>
<th>Cultivar</th>
<th>2015 FL</th>
<th>2015 PR</th>
<th>2015 Total</th>
<th>2016 FL</th>
<th>2016 PR</th>
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<td>--</td>
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<td>--</td>
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<tr>
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<td>--</td>
<td>--</td>
<td>--</td>
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<td>1720</td>
<td>2950</td>
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<td>300</td>
<td>900</td>
<td>1050</td>
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<td>--</td>
<td>--</td>
<td>1560</td>
<td>1680</td>
<td>3240</td>
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<tr>
<td>Kwanza</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>1430</td>
<td>930</td>
<td>2360</td>
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<td>740</td>
<td>640</td>
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<td>1760</td>
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<td>40</td>
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<td>1790</td>
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<td>Prelude</td>
<td>340</td>
<td>--</td>
<td>340</td>
<td>820</td>
<td>1260</td>
<td>2080</td>
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Effects of cultivar on primocane berry weight, appearance (1=non-salable to 5=excellent), and percentage of berries that were soft or leaky, or moldy, after 48 h at 18C. Berries were grown in pots under a high tunnel in southwest Mich., 2016. Most are means of four replications on four dates.

<table>
<thead>
<tr>
<th>Cultivar</th>
<th>g/berry</th>
<th>Appearance</th>
<th>% soft/leaky</th>
<th>% moldy</th>
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<td>10.1</td>
<td>11.3</td>
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<td>Crimson Night</td>
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<td>3.6</td>
<td>10.9</td>
<td>5.9</td>
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<tr>
<td>Double Gold</td>
<td>2.7</td>
<td>3.7</td>
<td>11.4</td>
<td>2.8</td>
</tr>
<tr>
<td>Josephine</td>
<td>3.6</td>
<td>2.9</td>
<td>8.7</td>
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</tr>
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<td>Vintage</td>
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<td>7.6</td>
<td>13.7</td>
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In-ground plants in East Lansing MI include the varieties Himbo top, Joan J, and Polka, planted in a high tunnel in 2009 and managed organically. In 2015, plots were pruned to retain 0, 0.7 or 1.4 canes per foot. This was a low number due to winter injury. In 2016, we retained 0, 1.5 or 3.0 canes per foot. Floricane and primocane harvests ran from roughly 22 June to 22 July, and 4 Aug to 14 Oct, respectively. Depending on the year and variety, there were about three weeks between the end of floricane picking and the beginning of the primocane harvest. Himbo Top harvest began and ended the latest. Floricane yields (Table 1) across the two years were proportional to the number of canes retained. Highest yields were reached with 3.0 canes per foot, and were equivalent to about 9,000 lb per acre. Primocane yields ranged from 7,000 to 13,000 lb over varieties and years. Floricane fruiting did not appear to affect primocane yields except perhaps with the highest number of floricanes were retained in 2016. Total yields (primocane plus floricane) were highest with the greatest number of floricanes retained, and were often equivalent to 16,000 and 20,000 lb per acre.

<table>
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<td>Floricanes</td>
<td>Yield (1000 lb/acre)</td>
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<td>FL</td>
<td>PR</td>
<td>Total</td>
<td>FL</td>
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<td>6.4</td>
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<td>18.5</td>
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<td>0</td>
<td>11.2</td>
<td>0</td>
</tr>
<tr>
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<td>13.2</td>
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</table>

Rotating cross-arm trellis for blackberries under high tunnels. Eric Hanson and Josh Moses, MSU. Columbia Star, Natchez, Obsidian and Triple Crown blackberries were planted in May 2015 to determine if the trellis and row cover will protect less hardy cultivars from winter cold. Three rows were planted in a 26 ft wide high tunnel. The highest 2016 yields were from Triple Crown (12,000 lb/acre equivalent), followed by Natchez (5,000 lb), Obsidian (3,000 lb) and Columbia Star (2,000 lb). Harvest occurred from late June to mid-July (Columbia Star, Obsidian), to late July (Natchez) and late July to mid-Aug (Triple Crown). The trellis system required considerable labor to train and tie canes. Row cover was installed and removed several times in the winter and early spring to prevent heat buildup and early plant development. Average daily temperature under the cover from 1 Dec to 29 Feb was 4.2°F warmer than outside, and the average daily minimum was 2.2°F warmer. On the coldest day of the winter (14 Feb), temperatures reached -8°F outside and only 8°F at the same height under the cover.

Effect of UV transparent and partly transparent plastic on fruit color. Eric Hanson and Josh Moses. One tunnel each of the raspberry varieties (Himbo Top, Joan J and Prelude) were covered in 2016 with of UV transparent (Lumisol) and partly transparent (Luminance) plastic. The tunnels were in Coloma MI, and were planted in 2009. Floricane and Primocane fruit samples were harvested on each of three dates and color was measure on 10 berries with a Minolta colorimeter. Plastics had no discernable effect on color. Reduce exposure to UV light was expected to reduce the red pigmentation.
Effect of UV transparent (Lumisol) and partly transparent (Luminance) plastic on fruit color of three raspberry cultivars, Coloma, MI, 2016. Means are of three replicate tunnels and 3 dates (n=9). L scale ranges from no reflection (L* = 0, black) to perfect diffuse reflection (L* = 100, white); the a* scale ranges from negative values for green to positive values for red, and the b* scale ranges from negative values for blue to positive values for yellow.

<table>
<thead>
<tr>
<th>Plastic</th>
<th>Cultivar</th>
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<th>Primocane fruit</th>
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<td></td>
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<td>L*</td>
<td>a*</td>
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Michigan Entomology (Heather Leach and Rufus Isaacs)

**Effects of Plastic Selection on Insects/Pesticides**

Pests, natural enemies, and pollinators on raspberries were monitored under high tunnels covered in either Lumisol or Luminance plastic season-long in 2015 and 2016. Under both of these plastics, no consistent trends have been noted for insect activity or damage, including spotted wing Drosophila.

In 2016, sixteen mini tunnels were constructed and covered in Luminance (partial blocking), clear UV-blocking, clear UV-transparent, or left uncovered. Potted raspberries were grown in them season long. Three applications containing a mix insecticides were made to determine the degradation of pesticides on leaves and fruit under the different plastic types. The mix contains 10 different insecticides representing commonly used chemicals for raspberry pest management. These samples have been sent to a pesticide analytical lab to compare residue decline curves after application. We are waiting on the results.

**Photo 1.** The mini tunnels, used to test insecticide degradation under different plastic types.
Figure 1. The average percent reduction in UV light (±SEM) under each of the mini tunnels covered in different plastic types.

Harvest Frequency

In 2015 & 2016, we conducted a trial to determine how harvest frequency in raspberry affects *D. suzukii* infestation. We found that harvesting every day or every 2 days significantly reduces larvae found in the fruit, especially the larger 3rd instars (which are visible to the naked eye) (Figure 2). We also found that yield per effort was highest in the plots harvested every 2 days, so this may be the most economically feasible harvest schedule for growers while also reducing *D. suzukii* larvae.

Figure 2. The number of eggs, undetectable larvae (1st and 2nd instars) and detectable larvae (3rd instar) (±S.E.) per kilogram of raspberries when harvested every 1 d, every 2 d, and every 3 d in 2015 (A) and 2016 (B). Bars marked with the same letter within each life stage are not significantly different at α=0.05.
Waste Fruit Removal
In 2016, we conducted a trial to determine the best bagging method for disposing of heavily infested and overripe fruit. We found that leaving fruit in the open can exacerbate *D. suzukii* populations and using clear bags (compared to white or black) results in the greatest temperature increase (Figure 3). By 32 hours, all bag colors killed 99% or more of the larvae present.

![Photo 2. Infested and overripe raspberries contained in a black, clear, or white bag.](image)

*Figure 3.* Average internal temperature of raspberries held within three different colors of plastic bags or in an open plastic container, compared to the ambient temperature.

*Publications:* A paper entitled “Exclusion Netting Delays and Reduces *Drosophila suzukii* (Diptera: Drosophilidae) Infestation in Raspberries” has been published in the *Journal of Economic Entomology*. This and other high tunnel raspberry research has also been used to create an extension bulletin to provide growers with new management guidelines for spotted wing drosophila in berry and fruit crops.
Minneapolis (Heidi Anderson, Mary Rogers, Emily Hoover: Department of Horticultural Science, University of Minnesota)

Accomplished in 2016:
The objective of our experiment was to determine if UV-blocking plastic covering low tunnels influenced strawberry yield, fruit quality and marketability.

During the 2016 growing season, we planted ‘Albion’ on raised beds with white on black plastic mulch and landscape fabric installed in the aisles between rows. Each row contained 35 feet of planted length (including “buffer zones” between experimental sections) divided into 4 subplots randomly assigned. Main plot treatments were the type of plastic covering the plot. Subplot treatments were application of bio-pesticides. Of the 12 main plots, 4 were covered with a UV-blocking plastic (red, in the diagram below), 4 were covered with a UV-transparent plastic (green) and 4 were left uncovered as control plots (blue). Below is a diagram of the field layout.

North

The 4 subplot treatments were applications of the bio-pesticides Mycotrol, Entrust, PFR and water as a control. These applications were made twice during the growing season. We monitored pest presence and microclimate within tunnels including air temperatures and humidity and light quality and quantity (Image 1). We collected data on yield, marketability, sugar content and color of the harvested fruit.

Image 1: A [HOBO RX3000 Station](https://www.hobo.com/products/rx3000) data logging device installed in the field. The sensors gathered information on air temperature, humidity and light quality and quantity within the plots.
Images 2 and 3: Practical challenges arose in the construction and maintenance of our low tunnels covered with the experimental plastics. These plastics were thicker and less stretchy than standard low tunnel plastics. Therefore pulling these plastics taut over the metal hoops and keeping them taut, was difficult. As can be seen in Image 2 (on the left) heavy rainfall events this summer collected on the plastics and collapsed them. To help increase the tautness, we attached a 15-foot length of thinner plastic film from Dubois Agrinovation to either end of the experimental plastics. This allowed us to tie the plastics off to anchors in the ground on both ends of each tunnel. Image 3 (on right) shows the plastics splitting where the plastics were attached together thus requiring frequent repairs (image on right).

Yield and marketability: Flowers were removed until July 1 in order to prevent the plants from fruiting earlier than desired. Harvesting began on July 21 and ended on November 8. Cumulative yield over the growing season totaled 217 kg (about 479 pounds) of fruit from all plots. For marketability, during the peak harvest period, fruit was sorted into USDA Grade A, Grade B, and lower grade/unmarketable. Data for these two parameters are in Table 1.

Table 1: Yield and *marketability of the three plastic treatments. In this table, yield was totaled over the entire growing season. In the third column, if letters following the data point are different then there is a significant difference at p<0.05.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Cumulative yield (kg/34m)</th>
<th>Marketability (%)* (grade A + grade B)</th>
</tr>
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<tbody>
<tr>
<td>UV-blocking plastic</td>
<td>69.5</td>
<td>54.8b</td>
</tr>
<tr>
<td>UV-transparent</td>
<td>81.4</td>
<td>70.8a</td>
</tr>
<tr>
<td>Control</td>
<td>66.2</td>
<td>41.5c</td>
</tr>
</tbody>
</table>
A comparison test for significance of average yield as a factor of tunnel covering revealed that yield did not vary significantly between plastic types, but yield from plots with either plastic covering was significantly greater than uncovered plots at p<0.05. These differences are denoted with different letters in Table 1. Statistical analysis of fruit marketability revealed significant difference among the main treatments at p<0.05.

\[ ^0 \text{Brix/sugar content:} \] Overall, the sugar content of the fruit did not vary significantly from one treatment to another. However, \(^0 \text{Brix} \) values did vary significantly across date. A higher value signifies higher sugar content. Because there were no statistical differences among treatments within date, we averaged across treatments within date then analyzed the data across dates (Table 2). Data analysis is ongoing to determine correlations among data collected.

**Table 2:** \(^0 \text{Brix} \) values averaged across treatments within a date and then analyzed across date. If letters following the data point are different that indicates significant difference at p<0.10.

<table>
<thead>
<tr>
<th>Date of harvest</th>
<th>Average (^0 \text{Brix} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>August 5, 2016</td>
<td>7.81ab</td>
</tr>
<tr>
<td>August 12, 2016</td>
<td>8.09a</td>
</tr>
<tr>
<td>August 18, 2016</td>
<td>7.09b</td>
</tr>
<tr>
<td>August 29, 2016</td>
<td>8.27a</td>
</tr>
<tr>
<td>September 13, 2016</td>
<td>7.25b</td>
</tr>
</tbody>
</table>

**Insect and Disease presence:** The insect causing the greatest amount of observable damage to fruit was the tarnished plant bug. The two-spotted spider mite was also observed in high numbers early in the season, but was not present by September. Spotted wing drosophila traps caught male and female flies as early as June, indicating they were present in the area before harvest. However, no obvious SWD damage was noticed until late September, when clearly infested fruit was harvested two weeks in a row. We also noted that the incidence of Botrytis fruit rot increased late in the season and was noticeably higher in uncovered plots than in either the UV-blocking or UV-transparent covered plots.

**Goals for 2017:**
In the 2017 growing season, this experiment will be repeated. We intend to increase the number of bio-pesticide applications and to analyze the residue of these bio-pesticides, post-application, in order to determine whether or not the type of tunnel covering has an impact on how long the bio-pesticides persist on the plants and therefore, how long after an application they remain potentially effective. We intend to gather more data on fruit color and firmness to better assess differences in berry quality among main plot treatments. Additionally, we will incubate a small percentage of marketable fruit each week to quantify the levels of spotted wing drosophila infestation.
New Hampshire (Kaitlyn Orde and Becky Sideman: University of New Hampshire)

Overview
Field research at UNH began in 2016, focusing on mulch color and low tunnel cover options for day-neutral strawberry production in the Northeast. We evaluated three mulching possibilities for raised beds: 1.25 mil black plastic (“black”), mil while-on-black plastic (“white”), and un-mulched/bare ground (“bare ground”). In addition, we assessed five cover treatments. These included four plastics for use as low tunnel covers (all 6 mil): Kool Lite Plus (KL+; Klers Greenhouse Films, Chester, SC), Tufflite IV (TIV; Berry Plastics Corporation, Evansville, IN), Lumisol Ultraviolet-Opague and Lumisol Ultraviolet-Transparent (UV-O & UV-T; British Polythene Industries, Colne, UK), and a fifth uncovered/no low tunnel treatment, included to represent a typical annual production/plasticulture system. One day-neutral variety, ‘Albion,’ was used in the experiment (Nourse Farms; Deerfield, MA).

A split-plot experimental design was utilized. Mulch served as the main plot and cover treatment as subplot. The experiment contained four complete blocks, resulting in a total 60 subplots that resembled short mini-tunnels (Picture 1). Each subplot measured approximately eleven feet in length and contained 16 plants, installed in staggered double rows 12” apart with in-row spacing of 16”. Each subplot was equipped with three galvanized steel low tunnel hoops (BROCH28-tunnel: Dubois Agrinovations, Quebec, Canada) at a 5’ spacing and covered with their respective cover.

Dormant bare-rooted ‘Albion’ plants were planted on 9 May 2016. Tunnels were constructed over plants on 18-19 May 2016. Plastics covering low tunnels were raised to just below the eave of the tunnel on both sides, providing overhead protection from rain and light. Sides were lowered on three occasions throughout the season: once in August for protection from heavy rain, and on two nights in September for frost protection. They were permanently lowered for the season on 10 October, and raised only for harvesting purposes after this date. Harvesting began 14 July and concluded 21 November, for a total of 19 consecutive weeks of production.

Data were collected on the innermost 12 plants of each subplot, and included: fruit yield (marketable & unmarketable), average berry size, runner production, °Brix and skin color measurements from ten fruit per plot on six occasions (3,600 samples), plant diameter height, early season plant vigor, berry storability, and air and soil temperature under each treatment.
Findings
Preliminary but notable findings are as follows:

1. **Peaks in production**: We observed two distinct peaks in production in New Hampshire, 13 July through 14 August (week 1-5) and 4 September through 2 October (week 8-12) (Figure 1).

2. **Mulch color**: Mulch color had a significant effect (p<0.05) on yield (by weight) during four of the 17 weeks of production analyzed for this report (Figure 1; weeks 7-10). During this period, white mulch produced significantly higher yields than bare ground during all four weeks, and black mulch produced significantly higher yields than bare ground during three of the four weeks. During these three weeks, white and black mulch were not significantly different from each other.

3. **Cover treatment**: Cover treatment had a significant effect (p<0.05) on cumulative yield. Replicates with no low tunnel cover produced higher total yields than those covered with KL+ and TIV plastics (Figure 2). However, when only marketable fruit yield is considered, no differences existed among any of the five cover treatments. This can be attributed to the larger quantity of unmarketable fruit from plots lacking low tunnel cover. Average cumulative marketable yield per plant was 338.5 grams, or approximately ¾ lb per plant.
In fact, we found in many instances the uncovered plots produce a smaller percent of marketable fruit than the covered plots. This was particularly true for KL+ covering black and white mulch, which produced a significantly higher (p<0.05) percentage of marketable fruit (~86%) than uncovered treatments on all mulches (~71-77%)(Figure 3).

![Graph showing percentage of marketable fruit](image1)

*Figure 2. Mean total yield per plant for 'Albion' grown under five different cover treatments during 2016 season. Error bars are Standard Error. Means sharing a letter within each yield category are not significantly different (p<0.05).*

![Graph showing cover and mulch treatment combinations](image2)

*Figure 3. Mean percent marketable yield per plant for each cover/mulch combination. Error bars are Standard Error. Means sharing a letter are not significantly different (p<0.05).*

![Fruit from a covered (left) and uncovered (right) treatment following a period of rain leading up to harvest.](image3)

4. **Runner Production**: Though we found a strong Cover x Mulch interaction (p<0.001), the black plastic with no cover treatment stood out in its prolific runner production. This treatment produced >10 runners per plant, compared to less than six in all other treatments (Figure 4).

![Image of runner production](image4)

*Picture 4. Prior to runner removal, 23 September 2016*
Pest Notes: In late June, aphid populations built up in the planting to a level that warranted treatment. A single application of Assail (acetamiprid) was made on 26 June 2016, and was effective at reducing populations. We experienced a high infestation of Oriental Beetle (*Anomala orientalis*) late summer in 2016. This resulted in visible stunting and discoloration of plants, and certainly compromised yields and fruit size. Many plants died, and we determined that keeping the plants overwinter was not viable. We assessed stunting, discoloration, and wilting symptoms to determine whether there was any association between treatment and degree of oriental beetle infestation.

Plans for 2017
Replicate low tunnel strawberry study for a second season:
Main Plot, three mulches: black plastic, white-on-black plastic, and bare ground
Subplot, five cover treatments: KL+, TIV, UV-O, UV-T and uncovered
Collect data on: fruit yield, average berry size, runner production, °Brix and skin color measurements from ten fruit per plot on six occasions (3,600 samples), plant diameter and height, early season plant vigor, and air and soil temperature.
Plant early and aggressively monitor for pests throughout the season
Wish to over-winter plants (as is done by several Northeastern growers) into the spring of 2018

**New Jersey** (A.J. Both: Rutgers University)

Past activities
Approximately a year ago, we started construction of a YMCA operated high tunnel on an abandoned housing lot in East Orange, NJ. The construction crew included several military veterans that are enrolled in a work training program organized by Rutgers Cooperative Extension. The 20 by 36 feet tunnel is part of a community garden project and was completed in the fall of 2016. The tunnel has roll-up sides, polycarbonate end-walls and polyethylene film as roof cover. Metal benches and raised beds will be used to grow plants inside. More raised beds were constructed outside the tunnel.
Photograph: Completed 20 by 36 feet high tunnel (Model EastPoint, Rimol Greenhouse Systems, Inc.) in East Orange, NJ.

Future activities
We advertised a student/Post Doc position to work on our main task: Evaluating ventilation systems and strategies for high tunnels. We are evaluating applications. The new hire will receive training in software techniques including computational fluid dynamics. Using field measurements and model simulations, different designs and strategies will be evaluated. In collaboration with Kathy Demchak at Penn State, we plan to work on a series of ventilation systems for high tunnels: roll-up sides, roll-down sides, side and end-walls openings, and ridge vents. These systems were installed at the Penn State High Tunnel Research and Education Facility during 2016.

New York (Marvin Pritts, Lois Levitan, Laura McDermott, Kasper Kuehn: Cornell University)

EXTENSION
1) We had a number of significant extension events in 2016 including the following:

a) January 14th, Catskill Regional Ag Conference, Delhi, NY on 1/14/16, 15 present
b) Empire State Producers EXPO, Syracuse, NY on 1/21/16, 128 present
c) Hudson Valley Small Fruit Session, Kingston, NY on 2/18/16, 34 present
d) CaroVail (industry) – Low Tunnel strawberry presentation in Salem, NY on 3/9/16, 29 present
e) CaroVail (industry) – Low tunnel strawberry presentation in Ghent, NY on 3/10/16, 48 present
f) Berry Production Workshop – with low tunnel presentation in Ballston Spa, NY on 3/24/16, 29 present
g) Geneva Fruit Field Day - A field day was held in Geneva, NY on July 20, 2016 with more than 100 growers attending. They viewed demonstrations of low tunnel strawberries and high tunnel raspberries.
h) FSA Train the Trainer Workshop – information on strawberry field worth vs tunnel production in Kinderhook, NY on 8/22/16, 25 present
i) BF 122: Berry Farming – Session 1 Site Selection (included info re: siting tunnels), On-line training on 11/08/2016, 25 present
j) BF 122: Berry Farming – Session 2 Business Management (included info on cost of protected culture as best we could), On-line training on 11/15/2016, 25 present
k) BF 122: Berry Farming – Session 3 Strawberries (included info on low tunnels), On-line training on 11/22/2016, 25 present
l) BF 122: Berry Farming – Session 4 Brambles (included info on high tunnel brambles), On-line training on 11/29/2016, 25 present
m) BF 122: Berry Farming – Session 5 Blueberries (included info on exclusion netting), On-line training on 12/6/2016, 25 present
n) BF 122: Berry Farming – Session 6 Post harvest and minor fruit (included info on post-harvest treatment and the benefits of tunnel culture), On-line training on 12/13/2016, 25 present

2) Worked with ~ 25 growers in 17 counties of eastern NYS to teach them about growing berries in both low and high tunnels
   a) Specifically worked with 3 growers to answer questions re: low tunnel production. Both of these growers are using low tunnels currently. Survey of these growers yet to occur. One grower gave testimony at a large funder sponsored event on November 14 in Albany, NY.
   b) Participated in a project with Dr. Marvin Pritts – final spring season of data collection in a low tunnel with 2nd season DN strawberries in production.

3) In conjunction with the NYS Berry Growers Association we are hosting 3 statewide workshops dealing exclusively with growing berries in ‘protected culture’.
   a) December 14, 2016 in Portland, NY
   b) January 17, 2017 in Syracuse, NY
   c) March 7, 2017 in Riverhead, NY

4) As part of these workshops we are creating a resource handbook that will be given to attendees.

5) Protected Culture information has been disseminated through newsletters etc. in the following publications:

   a) 3 different editions of the Weekly Berry newsletter that was sent to ~270 berry growers in eastern NY.
   b) Exclusion netting, a type of protected culture, was included in an article that was published this summer in the NY Fruit Quarterly and distributed to over 1000 growers throughout NYS.
RESEARCH
1) Side-by-side comparison research and demonstration plantings of low tunnel and open field strawberries were initiated. Three grower collaborator research and demonstration plantings were installed (eastern, south western, south central NY). Production and economic data were collected and evaluated from the 3 on-farm side-by-side comparison plantings for the 2015 and 2016 growing seasons.
2) Effect of planting date on total yield under a low tunnel day neutral production system was evaluated under New York conditions. Two research plantings were initiated at Geneva and Ithaca, NY. Treatments consisted of replicated low tunnel plots for varieties Seascape and Albion established every two weeks from April 15 through June 15.
3) Four fertilizer rates were used in a replicated trial to grow first-year Albion strawberries to determine which rate might be optimal.
4) High tunnel blackberries were trellised under two regimes – low vs. high density. Yield data were collected to determine if low density systems could be productive while providing easier harvesting.

Recycling- Lois Levitan continues to pursue the recycling aspect of the ag plastics.

Communicating with plastic reclaimers and manufacturers of products with recycled content in order to flesh out information about the recycling options available to growers.* This work is in collaboration with Moore Recycling Associates (MRA). The information is being integrated with MRA's PlasticsMarkets.org online directory and behind-the-scenes database of information about plastics recycling markets. My contributions are in identifying reclaimers willing and able to process agricultural plastics, particularly the smaller, emerging processors, and in introducing sufficient detail about agricultural plastics (resin type, quality, color, etc.) to be useful to these markets.

* However, in reality, market information is likely of greater use to organizers of agricultural/horticultural plastic collection and recycling programs because the bigger stumbling block to recycling is in amassing sufficient volumes to be of interest to recycling markets.

Building the network of stakeholders in agricultural plastics recycling, to better connect suppliers (growers and grower organizations) with recycling markets, promote market development, and provide a platform for information exchange about innovations in materials, equipment and recycling infrastructure. In addition to carrying out this work in conjunction with developing the markets database described above, and continuing to develop a stakeholder networking database that has been a work-in-process for the past decade, I am laying groundwork for a new organization for stakeholders in plasticulture stewardship.

The stakeholder organization will be maintained under the auspices of either the Southern Waste Information Exchange (SWIX) and/or their Agricultural Plastics Recycling Conference (APRC). This effort is in collaboration with Gene Jones, CEO of SWIX and, since 2014, organizer of the annual APRC (which will likely become biennial after the 2016 meeting). The concept is to develop a means for communication/information exchange in the intervening periods between conferences, a role previously played by the Agricultural Plastics Workgroup of The Pesticide Stewardship Alliance (TPSA) and the American Society for Plasticulture (ASP), neither of which still exists. While the organization is envisioned as primarily US- or North America-based, I have also been building a network with European colleagues. Gene Jones and I represented the United States at the November 2015 RIGK/EPRO (European Plastics Recycling Organization) 1st International Recycling Forum on Agricultural Plastics,
where I met key European colleagues, gleaned much information about equipment, logistics and markets for recycling high tunnel plastic in Europe, and presented an Overview from the United States: Collection Systems & Markets for Domestic Recycling of Agricultural Plastics that is archived on eCommons, Cornell’s digital archive.

**Website and educational/outreach resources.** The website Recycle Agricultural Plastics [http://recycleagriculturalplastics.net/](http://recycleagriculturalplastics.net/) is under development as the repository for the body of knowledge developed over the 10-year history of the Cornell-based Recycling Agricultural Plastics Program. I am in process of updating and revising educational materials developed when we knew less and had fewer options. Resources pertinent to recycling tunnel covers will be posted to the Tunnel Berry website.

**Plans for 2017:**

- Continue to work with growers across the state that have expressed interest in trying protected culture production.
- A number of extension articles are planned for the 2017 season.
- Contribute to web-based outreach, newsletters and field days
- Repeat the fertilizer trial
- Examine waiting bed strawberry production under tunnels
- Initiate an experiment to examine methods of overwintering day-neutral strawberries
- Collect another year’s data on blackberry trellising systems under high tunnels
- Contribute to web-based outreach, newsletters and field days

**Pennsylvania (Kathy Demchak, Dennis Decoteau, William Lamont, Kathleen Kelley, Richard Marini: Pennsylvania State University)**

**High Tunnels – 2015-16**

In 2015, 5 plastic film coverings based on their spectral transmittance characteristics were chosen and used to cover single-bay high tunnels in a randomized complete block design with 3 replications. In the fall of 2015, an experiment was conducted evaluating two different fertilization regimes (fertilizer incorporated into media or as constant-feed fertigation) and 4 types of media (coir, 2:1:1 peat:coir:perlite, 2:1 peat:perlite, or Metromix 360) within each of the above 15 high tunnels. The purpose was to determine the optimum regime for growing strawberries in a soilless system. Air and soil temperature, plant size, root growth, and vegetative growth were measured. Data are being analyzed, but initial indications are that there may be some slight effects of plastic x media interactions, though overall, 2:1 peat:perlite with constant-feed fertilization appeared to result in the best growth.

Plant growth results from tunnels covered with a commonly-used plastic considered to be a grower standard are presented below.

<table>
<thead>
<tr>
<th></th>
<th>Total Fresh Wt. (g)</th>
<th>Total Dry Wt. (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Incorporated*</td>
<td>Constant Feed**</td>
</tr>
<tr>
<td>Coir</td>
<td>plants dead</td>
<td>18.6</td>
</tr>
<tr>
<td>Metromix 360</td>
<td>24.6</td>
<td>36.9</td>
</tr>
<tr>
<td>2:1 Peat:Perlite</td>
<td>26.2</td>
<td>58.9</td>
</tr>
</tbody>
</table>
### Table

<table>
<thead>
<tr>
<th>Media Type</th>
<th>Leaf Dry Wt. (g)</th>
<th>Root Dry Wt. (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Incorporated*</td>
<td>Constant Feed**</td>
</tr>
<tr>
<td>Coir</td>
<td>plants dead</td>
<td>2.0</td>
</tr>
<tr>
<td>Metromix 360</td>
<td>3.7</td>
<td>5.1</td>
</tr>
<tr>
<td>2:1 Peat:Perlite</td>
<td>3.7</td>
<td>7.2</td>
</tr>
<tr>
<td>2:1:1 Peat:Perlite:Coir</td>
<td>3.0</td>
<td>5.9</td>
</tr>
</tbody>
</table>

*Fertilizers incorporated into mix (dolomitic lime, potassium nitrate, triple superphosphate, micros)

** 100 ppm N using Peters Peat-Lite 20-10-20 plus micronutrients

### High Tunnels - 2016

In the spring of 2016, plantings of 2 cultivars of raspberries ('Polka' and 'Josephine) and one cultivar of strawberries ('Albion') were established using the media and fertilization regime that overall produced the best growth last year (2:1 peat:perlite with constant-feed fertilization) under all 15 high tunnels (5 plastics x 3 replications) plus outdoors.

Data were collected on Japanese beetle, two-spotted spider mite, and spotted wing drosophila incidence, potato leafhopper injury, yield, proportion of marketable fruit, soluble solids, and for strawberries only, runner production. Japanese beetle damage was significantly lower in all tunnels compared to outdoors, with slighter differences occurring among plastics. The experimental film that completely blocked UV light was very good at excluding Japanese beetles. Plants that had been growing outside and that were being devastated by Japanese beetles were rescued by moving them into the tunnels and they subsequently recovered. Plants were harvested 3 times per week from July 29 to Nov. 14, 2016. As this is being written, data are in the process of being entered, checked, and analyzed.

Watchdog dataloggers were installed in 2 replications of the tunnels, as Raspberry Pi dataloggers proved to require a tremendous amount of labor and were a little “fussy” regarding reliability of data collection. However, the Raspberry Pi’s have now been installed in most of the tunnels and are functioning well. Due to concerns about reliability, other options for micro-environmental monitoring are being considered.
Low Tunnels

A similar experiment, but with 4 replications, was conducted under low tunnels using the same plastic films plus open-field conditions on raised beds with ‘Albion’ strawberries. Beds were mulched with white plastic, black plastic, or no plastic mulch. Data were collected on potato leafhopper injury, yield, proportion of marketable fruit, reasons that fruit was unmarketable, soluble solids, and runner production.

In both high and low tunnel experiments in PA, some plants were lost to anthracnose crown rot, which means that the disease probably came in on plants received from the nursery.

High Tunnel Venting Study
Five high tunnels were either built or retrofitted with hardware to allow automated venting studies to begin next year with materials donated by Rimol Greenhouses and Advancing Alternatives. The different configurations consist of the following:
1) Ridge vent plus roll-up sides
2) Roll-up roof plus side baffles
3) Manual venting
4) Roll-up roof plus roll-up sides
5) Ridge vent plus side baffles
Venting can be automated based on temperature, and motorized components are powered from solar panels.
Videos
Based on advisory committee input at last year’s advisory committee meeting, the 3 planned videos were broken into a greater number of topics with more time being spent on each. There are currently 8 videos planned related to tunnel installation, with 1 completed, though close captioning will still needs to be done. The others are in various stages of development. The video topics now are:
1) Types of Tunnels
2) Tunnel Parts and Purposes
3) Site Selection and Tunnel Orientation
4) Squaring the Tunnel
5) Installing Collars to Cross-Braces
6) Installing Hipboards, Baseboards, and Track
7) Building End Walls
8) Installing and Securing Plastic

Economics
Data on material and labor costs were collected throughout the process of building the high tunnels, and establishing and harvesting the plantings under both the high tunnels and low tunnels. This data is being shared with David Conner. Questions we hope to answer, besides addressing the economic feasibility of high tunnel and low tunnel berry production, is whether containerized production is more or less feasible than in-ground production, and how high and low tunnels compare with regards to differences in cost, labor requirements and yields.

Outreach Efforts
Visitors consisted of 30 K-12 teachers, the PA Farm Bureau Board of Directors and their guests, and 111 growers who took part in a 2-hour tour of the facility during Penn State’s Ag Progress Days, along with a few additional individual visitors who have asked to see the site. Probably the greatest amount of grower interest during the Ag Progress Days tours was in the venting studies.

Plans for 2017:
High tunnels: A new high tunnel strawberry planting will be established, and raspberries overwintered and data collection continued in 2017. Additional data is needed on Japanese beetle incidence. There is a concern that because the outside plants were on grass, there may have been more pressure from Japanese beetles emerging from the grass than plants in tunnels received. Thus we’ll need 3 more tunnels in which plants can be grown using identical growing methods that those in tunnels receive, just without plastic.

The low tunnel strawberry experiment will be harvested in the spring if winter survival is acceptable. Another low tunnel field experiment will be established that will be identical to last year’s.

Grower and consumer surveys will continue to be developed and launched. Work on videos and data collection for economic analyses will be continued.

Vermont  (David Conner:  University of Vermont)

Accomplishments
Working with the Penn State team, we collected and analyzed data on the costs to construct a 17x96’ tunnel. Costs totaled about $9,300 including kit, hardware and labor
In addition, production costs and yields for raspberries and strawberries were collected on the Penn State farm. These data will be compared to existing tunnel berry budgets and adjusted to brad deviancies in research farm production. In addition, we will calculate break even costs and yields for tunnel production for each.

**Plans for 2017**
- Present 2016 results at Hershey growers’ meeting (MAFVC). Recruit farmers for qualitative and quantitative analysis. Measure and analyze data as available
- Continue measuring costs for strawberry and raspberry production on Penn State farm. Conduct two-year analysis of data
- Investigate and compare costs and profitability of high and low tunnel berry production using secondary data