Entomology

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Section Editor

Seasonal Pest Activity Patterns, Observations and Recommendations from a Tennessee Phenology Garden Pilot Study

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Significance to Industry: Monitoring seasonal activities, including egg hatch, scale crawler emergence, and adult flight and feeding incidence will be facilitated once they can be correlated with visual cues from flowering or other phenological event on selected ornamental plant species. Identifying uniform and effective plant taxa for use in pest monitoring should increase user efficiency and reduce frustration of scouts who would also maintain the garden system. Once developed, this resource can promote landscape manager and grower adoption of IPM by simplifying pest scouting efforts. In turn, better understanding about pest activity and interactivity across a broad region will help direct and optimize timing and use of increasingly expensive pesticides. We expect that use of plant flowering phenology data can be enhanced when assessed against real-time, on-site weather data collections. Finally, established gardens will function as a durable training resource for hands-on experience with scouting and nursery and landscape IPM programs. This long-term effort supports and will advise a multi-regional SNIPM Working Group objective seeking to initiate and monitor phenology gardens across the southeastern U.S.

Nature of Work: There are several demonstrated systems in which ornamental flowering plant phenology can serve as reliable pest management tools for localized prediction of seasonal pest activity in both the eastern U.S. (6,7,9) and Europe (3,11). Regional initiation of plant flowering has also been shown to occur geographically, from south-to-north, creating a sort of a seasonal phenological wave event (7). This phenomenon is expected to function across an even wider geography, though it may become less fixed or apparent farther south in the eastern U.S. (12).

In conjunction with MS thesis work directed by Dr. David Held and undertaken by Raymond Young at Auburn University (12), a collaborative phenology garden project was initiated in Tennessee starting in 2010. Plant species that were selected by D. Held and R. Young (Auburn Univ.) for the thesis project were chosen to provide a seasonal flowering continuum (e.g., 3,11). In addition, plants were either clonally propagated or resulted from division. Plant materials for these studies were purchased from the same source nurseries or propagated from a known parent plant then distributed by Dr. Klingeman.

In Tennessee, three different phenology gardens were planted between March and November 2010 in Nashville (*data not shown*), at the Knoxville Botanic Garden & Arboretum and at the UT Forest Research & Education Center in Oak Ridge, TN. Within each garden, four plots with each of the 13 key plants were laid out on approx. 0.5 ac (0.20 ha) and mulched. Irrigation was only supplied the first year by hose and as needed to sustain plants. At planting, specimens were located in full sun and spaced to limit competitive shading as plants matured.

Across seasons in Tennessee, key plant flowering activity for each of 13 test plants was visually estimated (to the nearest 10%) for each plant at least once per week. When possible, as flowering periods approached more frequent observations were taken. Flowering data were partially collected during 2011 yet are not included due to exposure to non-regional climates prior to harvest and shipping as well as storage in overwintering houses and nursery holding areas prior to planting. Flowering data for 2012 and 2013 are presented. Yields of insect traps with pheromone and aggregation lures (deployed each spring and replaced mid-season) and larvae from egg masses were counted weekly or throughout egg hatch (eastern tent caterpillar, *Malacosoma americanum*) or at start of hatch (bagworm, *Thyridopteryx ephemeraeformis*) across all three seasons. Downloaded weather data were entered into DegDay software (10) and assessed using a January 1 biofix date with a 50^{o}F (10^{o}C) base temperature assumption (6).

Results and Discussion: The two eastern Tennessee phenology garden locations were about 25 mi (40.2 km) apart. Regardless of year, GDD accumulated faster at the KBGA location than at the UT Arboretum site. By early March in each year, KBGA had accumulated about 20 more GDD than were logged at the UT Arboretum, with about 100 GDD more by early June (Table 1). There was considerable variability in seasonal plant flowering date both across locations (Table 2) and up to 2 wk variation in mean flowering of individual plants, though they were genetically identical. In part, direct comparison with flowering state to accumulated GDD was confounded both by gaps in periodic observation within each season and also by differences in the rating that different estimators gave to flowering state.

Despite this variability, eastern tent caterpillar egg hatch and first adult maple shoot borer (*Proteoteras aesculana*) captures occurred reliably in conjunction with ‘Lynwood Gold’ *Forsythia* flowering (Table 2). Bagworm egg hatch, as well as powdery mildew of dogwood (*Erisyphe pulchra*) (*data not shown*), were both observed when *Deutzia scabra* ‘Flore Pleno’ was beginning to flower. In several locations during 2012 and 2013, first adult Japanese beetles (*Popillio japonica*) were caught when ‘Crown of Rays’ Goldenrod began flowering. The first adult green june beetles (*Cotinus nitida*) were captured at about the same time that ‘Hummingbird’ *Clethra* began to flower (Table 2).

Landscape managers and commercial nursery growers in the southeastern U.S. report limited adoption of IPM practices and use of degree days in pest monitoring. In part, surveyed respondents felt they had limited understanding about how degree days are calculated and how such data are best used within an IPM program (1,2,5,8). To address this knowledge gap, members of the Southern Nursery IPM working Group (SNIPM, http://wiki.bugwood.org/SNIPM) have initiated efforts to expand and extend use of functional pest monitoring gardens across the southeastern U.S. and to integrate dynamic data capture and regional forecasting.

Based on experiences and observations in these eastern Tennessee pilot gardens, plants selected to function within a regional phenology garden system should be relatively easy to acquire, replant and replace. Weather data collected on-site should include soil-moisture and soil temperature probes, placed at uniform depths, which should help better predict seasonal activity of soil-inhabiting pests and weed seed germination. Their growth and flowering and other phenological characters should provide clearly recognized parameters, with discrete flowering periods (are not prone to re-flowering), which facilitates data collection and seasonal maintenance. Additionally, plants in a regional phenology garden system will best fit if they are: 1) small-statured trees or slow-growing shrubs and hardy perennials, 2) genetically-identical (clonal) plants, on their own roots that may be freely and easily propagated, 3) unlikely to proliferate by seed or rhizomes, 4) native plants, as were requested by several Master Gardener volunteers and garden visitors, 5) broadly adapted across USDA Plant Hardiness Zones 5 – 8, and 6) are non-preferred or resistant to deer browsing. Browsing by deer and pruning of vigorous shrub growth has confounded seasonal flowering incidence in all Tennessee locations. Finally, data based on visual estimates of plant flowering will be more consistent when taken by a select few, cross-trained individuals. Variability among estimators will be mitigated if plant pictorial guides are used.

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Table 1. Seasonal GDD accumulations from 2011-2013 at both eastern Tennessee locations projected across Julian dates at 10 day intervals from to March to October.

julian date	calendar date	KBGA GDD[1]	UT Arboretum GDD	KBGA GDD	UT Arboretum GDD	KBGA GDD	UT Arboretum GDD
		2011		2012		2013	
50	19 Feb	10	0	0	0	43	25
60	1 Mar	27	0	27	12	43	25
70	11 Mar	34	4	37	12	43	25
80	21 Mar	96	34	190	143	76	52
90	31 Mar	127	62	326	267	76	52
100	10 Apr	226	140	434	369	145	89
110	20 Apr	288	202	503	407	248	182
120	30 Apr	437	327	598	496	270	203
130	10 May	540	424	828	715	382	308
140	20 May	676	551	989	853	508	438
150	30 May	923	785	1234	1089	693	613
160	9 Jun	1231	1080	1422	1265	932	845
170	19 Jun	1475	1324	1672	1509	1183	1089
180	29 Jun	1737	1582	1954	1798	1439	1346 (*est.*)
190	9 Jul	2023	1861	2302	2136	*	*
200	19 Jul	2311	2155	2581	2414	*	*
210	29 Jul	2637	2472	2892	2726	*	*
220	8 Aug	2960	2782	3177	3011	*	*
230	18 Aug	3243	3053	3420	3251	*	*
240	28 Aug	3531	3332	3662	3487	*	*
250	7 Sept	3786	3574	3956	3771	*	*
260	17 Sept	3958	3743	4169	3980	*	*
270	27 Sept	4153	3931	4297	4111	*	*
280	7 Oct	4234	3986	4471	4276	*	*

Table 2. Preliminary observations of flowering plant phenology coincident with seasonal egg hatch and adult pest activity of key nursery and landscape pests in eastern Tennessee.

	KBGA	UT Arboretum	KBGA	UT Arboretum	KBGA	UT Arboretum
	2011		2012		2013	
Eastern Tent Caterpillar	*2117*	*1887*	*1680*	*1518*	*434*	*605*
First date of egg hatch [GDD]	3/3 [0]	2/28 [27]	2/25 [14]	2/25 [0]	3/10 [43]	3/15 [25]
Last date of egg hatch [GDD]	3/22 [52]	3/22 [115]	3/12 [37]	3/9 [12]	3/30 [76]	4/5 [52]
'Lynwood Gold' Forsythia						
First flowers [GDD]			3/2-4 [37]	3/2-4 [12]	3/12-14 [43]	3/16-17 [40-52]
approx. 50% flowering [GDD]			3/11 [37]	*na*	3/22-23 [76]	3/24 [52]
'Yoshino' Cherry						
First flowers [GDD]			3/10-11 [37]	3/19 [104]	3/21-24 [76]	3/25-4/3 [52]
approx. 50% flowering [GDD]			3/13-14 [46-63]	*na*	4/1-4/3 [76]	4/5 [52]
'Flore Pleno' Fuzzy Deutzia						
First flowers [GDD]			4/4 [400]	*na*	5/10 [382]	4/30-5/18[2] [203-487]
approx. 50% flowering [GDD]			4/26 [527]	*na*	5/20 [508]	5/18-22 [401-487]
Maple Shoot Borer	*41*	*0*	*401*	*1*	*147*[4]	*3*[4]
First date of capture [GDD]	4/17 [249]	*na*	3/11 [37]	3/13 [21]	4/7 [90]	4/20 [182]
Last date of capture [GDD]	7/7 [1964]	*na*	8/27 [3064]	*na*	*na*	*na*
Lilac borer	*28*	*20*	*81*	*20*	*60*	*21*
First date of capture [GDD]	4/17 [249]	4/26 [309]	4/13 [433]	5/6 [537]	4/20 [248]	4/26 [182]
Last date of capture [GDD]	6/21 [1378]	6/21 [1532]	6/15 [1568]	6/20 [1535]	6/25 [1331]	6/6 [774]
'Annabelle' Oakleaf Hydrangea						
First flowers [GDD]			4/27-5/3 [541-673]	5/21 [1011]	5/13-19 [424-489]	5/25-6/1 [508-664]
approx. 50% flowering [GDD]			5/8 [791]	*na*	5/24-26 [600-634]	6/4-6 [728-774]
Dogwood borer	*1*	*28*	*16*	*8*	*2*	*9*
First date of capture [GDD]	9/15[1] [3232]	4/29 [328]	4/26 [527]	8/3[1] [2869]	5/4 [330]	3/24 [52]
Bagworm						
First date of egg hatch [GDD]	4/30 [437]	5/1 [345]	4/20 [503]	4/21 [420]	5/18 [468]	5/15 [343]
Peachtree borer	*318*	*53*	*213*	*47*	*354*	*204*
First date of capture [GDD]	6/15 [1232]	5/1 [345]	5/4 [698]	5/21 [875]	5/27 [634]	6/6 [774]
Last date of capture [GDD]	10/10 [4282]	10/7* [3985]	8/27 [3064]	8/24 [3384]	*na*	*na*
'Red Heart' Hibiscus syriacus						
First flowers [GDD]			5/21 [875]	6/9 [1265]	6/23-7/8 [1279-*na*]	6/28-7/2 [1303-*na*]
approx. 50% flowering [GDD]			6/25 [1853]	6/25 [1688]	7/27-30 [*na*]	7/27-30 [*na*]
'Natchez' Crapemyrtle						
First flowers [GDD]			5/22-30 [1032-1234]	*dnf*	6/8-9 [907-932]	6/13-24 [952-1219]
approx. 50% flowering [GDD]			6/1-8 [1287-1401]	*dnf*	6/19-7/1 [1183-1492]	7/2 [*na*]
Japanese Beetles	*30*	*299*	*1005*	*1931*	*3254*	*4824*
First date of capture [GDD]	6/15 [1232]	6/21 [1532]	5/21 [1101]	5/21 [875]	6/6 [859]	6/12 [925]
Last date of capture [GDD]	7/20 [2637]	8/11 [3053]	8/17 [3397]	8/3 [2869]	*na*	*na*
'Crown of Rays' Solidago						
First flowers [GDD]			5/23 [1051]	5/17-21 [791-875]	7/10-17 [*na*]	6/10[3] [870]
approx. 50% flowering [GDD]			6/8-10 [1401-1443]	5/25-30 [955-1089]	7/27-30 [*na*]	6/25[3] [1246]
'Lemon Queen' Sunflower						
First flowers [GDD]			5/20 [988]	6/11-16 [1308-1433]	7/19-25 [*na*]	*na*
approx. 50% flowering [GDD]			6/8-15 [1401-1568]	8/3-8 [2869-3011]	*na*	*na*
Green June Beetles	*6*	*2*	*13*	*9*	*1054*	*844*
First date of capture [GDD]	7/7 [1964]	6/25 [1631]	6/25 [1852]	6/4 [1167]	7/1 [*na*]	7/9 [na]
Last date of capture [GDD]	7/29 [2637]	6/25[3]	8/2 [3004]	7/18 [2386]	*na*	*na*
'Hummingbird' Clethra						
First flowers [GDD]			6/25-7/1 [1688-1867]	6/25 [1853]	7/1-8 [1492-*na*]	7/7 [*na*]
approx. 50% flowering [GDD]			*na*	7/1-10 [1867-2167]	7/18 [*na*]	7/10-17 [*na*]
Lilac/Ash borer	*226*	*6*	*41*	*15*	*na*[4]	*na*[4]
First date of capture [GDD]	7/15 [2200]	7/20[3] [2345]	7/13 [2405]	7/18 [2386]	*na*	*na*
Last date of capture [GDD]	9/28 [4169]	7/20[3]	8/27 [3034]	7/27 [2664]	*na*	*na*
'Autumn Joy' Sedum						
First flowers [GDD]			8/17 [3227]	8/20 [3299]	*na*	*na*
approx. 50% flowering [GDD]			8/30-9/20[2] [3753-4216]	9/1-5 [3601-3713]	*na*	*na*

[1] no individuals from the first generation were collected
[2] data presented across a gap of missing data
[3] data presented for a single plant at that location; all specimens collected on single date
[4] individuals still being collected; not collected yet

Temperature Affects Maple Spider Mite Development and Survival

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Index words: *Acer* x *freemanii, Acer rubrum, Acer saccharinum, Oligonychus aceris*

Significance to Industry: We investigated the effect of temperature on maple spider mite, *Oligonychus aceris* Shimer, development and survival. This is significant to the industry because spider mites are among the most common, damaging, and difficult to control pests of nursery crops (1, 4). Warmer temperatures are known to increase survival and reduce development time in many arthropods (8). Global temperatures are increasing annually (3) and nursery-grown plants often experience elevated temperatures (6). *Oligonychus aceris* host plants are maple trees, which are the most commonly planted landscape tree in the eastern United States (7). These pests are difficult to manage because their small size and short development time allows them to avoid control measures and build up populations quickly. Understanding how temperature affects maple spider mites will allow us to better manage these pests in nurseries.

Nature of Work: Maple spider mites are key pests of maple trees, most commonly red maple (*Acer rubrum*), silver maple (*Acer saccharinum*), and Freeman maple (*Acer x freemanii*) (10, 2). These spider mites feed on the leaves, causing yellow stippling and browning which leads to premature leaf drop. This damage reduces photosynthesis and aesthetic quality, which directly affects tree vigor and marketability (9). Many spider mite species thrive in hot, dry conditions where they experience decreased development time and increased fecundity and survival (5, 11). However, maple spider mite response to temperature increase is unknown. Our objective was to determine how temperature affects the development and life history of *O. aceris*. Results from this will help us understand the biology of these pests in both nursery and landscape settings.

Maple spider mites were obtained from landscape trees in Raleigh, NC and kept in a lab culture at North Carolina State University. To determine how temperature affects spider mite development and life history, we conducted a laboratory experiment within controlled environment chambers. Sixteen mated, adult females were placed in each chamber and reared at three constant temperature treatments (25°C/77°F, 30°C/86°F, 35°C/95°F). Each individual was kept on a 1.5 cm (0.59 in) red maple leaf disc placed on a water-saturated cotton pad within a petri dish. Leaf discs were monitored every 24 hours.

When one or more eggs were found on a disc, the corresponding female was placed onto a new leaf disc and her eggs were monitored every 24 hours until eclosion. Each juvenile mite was observed every 24 hours to record survival and life stage until they became adults. Of those adults, ten females were selected, placed onto leaf discs and monitored for egg deposition. Five deposited eggs per female were then monitored every 24 hours until they became adults. Since virgin maple spider mites produce only males, we stopped the experiment after completion of the second generation. There were 160 replications per treatment for the first generation and 50 replications per treatment for the second generation.

Results and Discussion: Survival from egg to adult was not significantly different between treatments in the first generation (X^2_2=3.82, p= 0.1479) (Figure 1). In the second generation, significantly fewer spider mites survived to adult at 35°C than those reared at 25°C and 30°C. Our data suggests that at 25°C and 30°C, second generation male spider mites have acclimated to their respective temperatures. Male survival increased by over 100% from the first to second generation at both 25°C (X^2_1=28.45, p<0.0001) and 30°C (X^2_1=34.54, p<0.0001) (Figure 1). However, survival at 35°C decreased by nearly 84%. These data may indicate that *O. aceris* is acclimating to temperature at 25°C and 30°C but that sustained temperatures of 35°C are above their thermal development threshold.

Our results suggest that as temperature increases, spider mite development time decreases. Development time of the first generation significantly decreased for each treatment as temperature increased ($F_{2,100}$=278.55, p<0.0001) (Figure 2). Second generation spider mites reared at 30°C developed significantly faster than those at 25°C ($F_{2,83}$=90.52, p<0.0001) but did not differ from 35°C. Development time also differed between generations for males. Second generation males reared at 25°C and 30°C developed significantly faster than males in the first generation ($F_{1,59}$=17.23, p<0.0001; $F_{1,51}$=23.99, p<0.0001). This provides additional evidence suggesting that second generation maple spider mites are acclimating to their respective rearing temperature.

These results have important implications for spider mite management in nurseries. As the global climate warms, spider mites will be exposed to higher temperatures. Nursery-grown plants experience warmer summer temperatures than plants in natural conditions (6). Based on our findings, these warmer temperatures may result in increased survival and faster development. Our research suggests that maple spider mite abundance in nurseries and urban landscapes may be partially explained by elevated temperatures in nurseries and may become a more significant problem in the future. While temperature isn't the only factor regulating spider mite abundance, it is a significant one. Other factors such as natural enemy populations also regulate spider mite abundance. Next, we plan to determine the effects of temperature on natural enemies of *O. aceris* and then examine the effects of temperature on predation.

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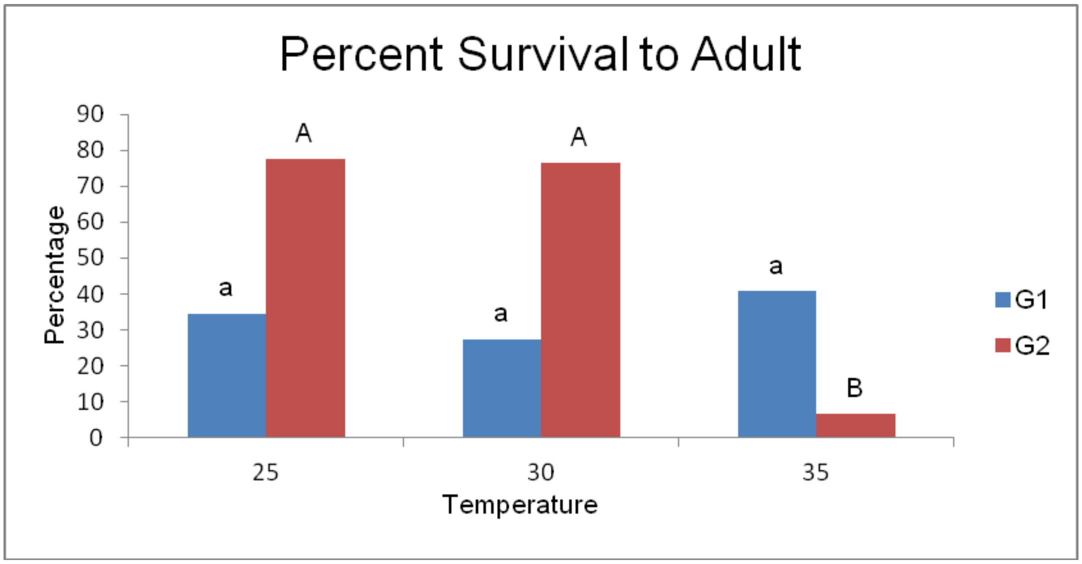

Figure 1. Percentage of mites that survived from egg to adult. X-axis represents the three temperature treatments (°C) and y-axis represents percent survival. Blue bars represent the first generation and red bars represent the second generation. Letters designate treatment differences within generations.

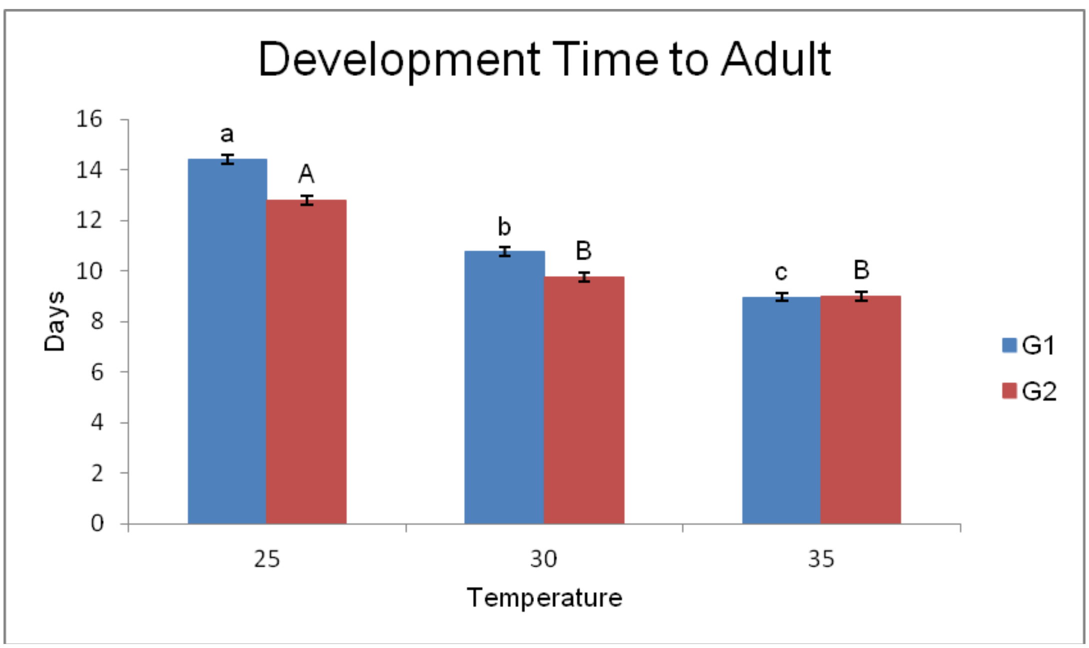

Figure 2. Development time from egg to adult in days. X-axis displays the three temperature treatments (°C) and y-axis represents time (days). Blue bars represent the first generation and red bars represent the second generation. Letters designate treatment differences within generations.

The Effect of Banker Plant Species and Mixtures on Aphid and Parasitoid Abundance

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Index words: *Aphidius colemani*, banker plant system, greenhouse biological control, mixture vs. monoculture

Significance to Industry: Increased consumer demand for organic products and pest resistance to insecticides have increased grower demand for effective biological control tactics (6). Aphids such as *Aphis gossypii* and *Myzus persicae* are important pests of many greenhouse crops. These aphids can be controlled by the parasitoid *Aphidius colemani* (2). However, this system requires growers to monitor continually and react to pest aphid abundance ordering by and releasing parasitoids or to making routine preventive releases.

Banker plant systems were developed to maintain a constant population of the biological control agents by providing them with suitable alternate hosts. When the biological control agents significantly reduce pest abundance the biological control agents are able to remain in the greenhouse feeding on the alternate host (1, 3). This way, pest aphid numbers are kept low and growers do not have to worry about continually ordering more parasitoids.

Banker plant systems targeting aphids such as, *Aphis gossypii*, and *Myzus persicae* consist of the biological control agent *Aphidius colemani* supplemented with the alternative host *Rhopalosiphum padi* grown on grain banker plants.
To improve the efficacy of aphid banker plant systems we investigated how different grain species and interspecifc mixtures affect alternative host aphid and parasitoid abundance. Our results will help growers select the banker plant species or mixture which produces the most parasitoids.

Nature of Work: Increasing plant diversity can reduce pest abundance and damage through associative resistance, while also attracting a larger more diverse natural enemy community (4). Along with these general plant trends in grains, increasing diversity can also lead to increased plant productivity (5). Based on these components we predicted banker plants grown as mixtures would have fewer alternative host aphids, *R. padi* but more parasitoids per capita. This would be an ideal banker plant, the low number of alternative host aphid would allow for the banker plant to remain healthy for an extended period of time and the high per capita parasitoid abundance would allow for a sustained population of biological control agents.

We conducted a greenhouse experiment to determine how grain monocultures and mixtures affect aphid and parasitoid abundance on banker plants. The experiment had 4 monoculture treatments: barley *(Hordeum vulgare),* oat (*Avena sativa),* cereal rye *(Secale cereale),* and wheat *(Triticum* spp.*)* and 1 mixture treatment. To avoid presenting a single cultivar as a representative for an entire species, monocultures consisted of 3 different cultivars each replicated 3 times (9 replicates per monoculture treatment). The mixture treatment consisted of 12 different randomly generated cultivar combinations made from the four species of monoculture host plants (36 replicates of mixtures) (Table 1). On 24 January 2013 each treatment was planted from seed (24 seeds per pot mixture, which included six seeds of each cultivar). Plants were randomly distributed across two greenhouse benches which received equal light. On 11 February 2013 (18 days after planting) 30 *Rhopalosiphum padi* aphids were added to each pot. Parasitoids were not released for this experiment; instead we allowed the resident parasitoids of our test greenhouse to attack the aphids. On 4 March 2013 the total number of aphids and mummies (pupal form of parasitoids) were recorded for each pot. Data were analyzed with ANOVA followed by LSD means comparisons in the Mixed procedure of SAS 9.3. Mummy and per capita parasitoid abundance (mummies/aphids) were log(x+1) transformed to correct normality.

Results and Discussion: After five weeks there were significant differences in aphid abundance ($F_{4,67}$ = 4.17; P = 0.0045) between treatment wherein rye monoculture banker plants had 35% more aphids than the next closest treatment (Figure 1). Contrary to what we predicted, the mixture treatment did not have greater per capita parasitoid abundance (Figure 2). In fact, there were no significant differences in per capita parasitoid abundance ($F_{4,67}$ = 1.15; P = 0.3411) between treatments. Ultimately, after five weeks we saw significantly ($F_{4,67}$ = 2.88; P = 0.0291) more parasitoids formed on rye, while no other treatments showed any significant difference (Figure 3).

We did not see the beneficial characteristics we expected in the mixture treatments. Previous research found that natural enemies are more attracted to grain mixtures than monocultures (4). Although our data suggest rye supported the most parasitoids and may the most beneficial species of banker plant among the species we tested, we do not know the sex ratio of the parasitoids. In future research, we will determine how plant species and cultivars affect parasitoid life history traits and fitness. Because banker plants did not die after five weeks of aphid feeding, these systems should be useful for at least 5 weeks and probably longer. Of all tested treatments, our data suggest rye banker plants allow for the largest population of *R.padi*, and in turn produce the largest population *A.colemani.*

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Table 1. Treatments used and which varieties were used to make up the mixture treatments.

Monoculture			Mixture				
				Barley	Oat	Rye	Wheat
1	Price	b - 1	1	Price	Cat grass	Wrens Abrozzi	Roane
2	Throughbred	b - 2	2	Nomni	Cat grass	Matt time	USG 3209
3	Nomni	b - 3	3	Nomni	Cat grass	Wrens Abrozzi	Neuse
4	Cat grass	o - 1	4	Throughbred	Rodgers	Matt time	USG 3209
5	Brooks	o - 2	5	Price	Brooks	Wrens Abrozzi	Neuse
6	Rodgers	o - 3	6	Price	Rodgers	AGS 104	Roane
7	Matt time	r - 1	7	Nomni	Brooks	AGS 104	USG 3209
8	Wrens Abrozzi	r - 2	8	Throughbred	Cat grass	Wrens Abrozzi	Neuse
9	AGS 104	r - 3	9	Throughbred	Rodgers	Matt time	Roane
10	Roane	w - 1	10	Throughbred	Brooks	AGS 104	Neuse
11	USG 3209	w - 2	11	Nomni	Cat grass	Wrens Abrozzi	Roane
12	Neuse	w - 3	12	Throughbred	Brooks	AGS 104	USG 3209

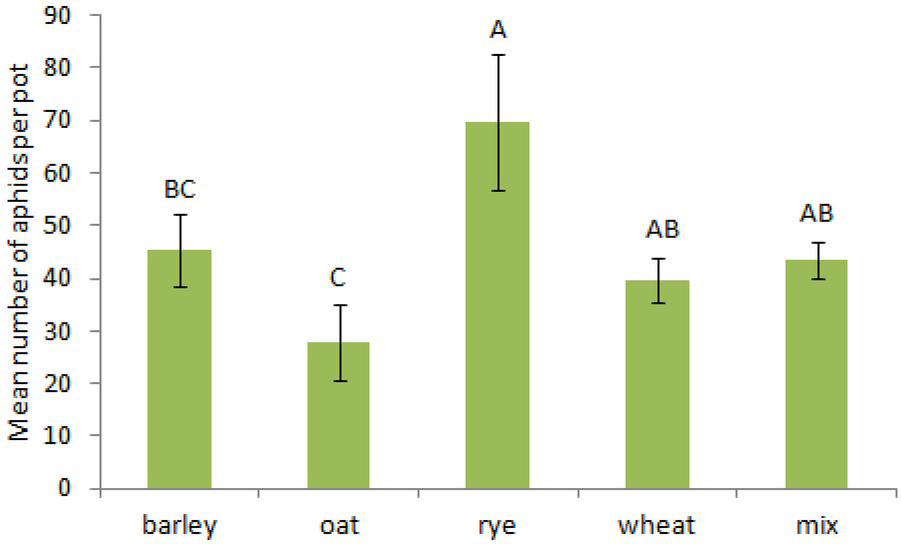

Figure 1. Average number of aphids on each treatment after five weeks. The x-axis represents the different treatments, while the y-axis represents the average number of aphids per pot (n=9 for each barley, oat, rye, and wheat, n=36 for the mix).

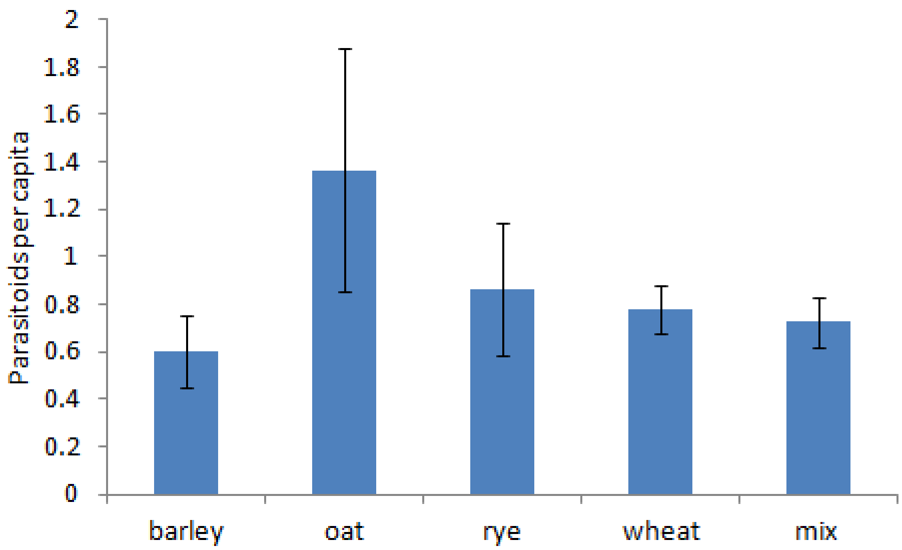

Figure 2. Average parasitoids per aphid (parasitoids per capita) after five weeks. The x-axis represents the different treatments, while the y-axis represents the number of parasitoids per aphid (n=9 for each barley, oat, rye, and wheat, n=36 for the mix).

Figure 3. Average number of mummies (pupal parasitoids) on each type of treatment after five weeks. The x-axis represents the different treatments, while the y-axis represents the average number of mummies per pot (n=9 for each barley, oat, rye, and wheat, n=36 for the mix).

The Escalating Cost of High Impact Invasive Pests

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Index Words: Emerald ash borer, impatiens downy mildew of garden impatiens, hemlock woolly adelgid, imported fire ants, Japanese beetle, gypsy moth, thousand cankers disease, walnut twig beetle, Japanese maple scale, granulate ambrosia beetle, camphor shot borer

Significance to Industry: Invasive pests and diseases of plants are nothing new. Accidental introductions have been occurring as long as humans have traveled to faraway lands. Two industries that have been especially negatively impacted by invasive pests and diseases are the forest and commercial nursery industries. Some of the trees and shrubs that have been negatively impacted by invasive pests or diseases include flowering dogwood, Fraser fir, all ash species, elm, Carolina and eastern hemlock, American chestnut, *Viburnum* spp., roses, redbay, and American beech. Pests such as emerald ash borer have destroyed the market for any of the ash species grown in our nurseries. Pests such as Japanese beetle and imported fire ant species have increased the cost of production and pesticide use in order to comply with regulatory requirements for shipping nursery plants.

Nature of Work: A study by Aukema et al. 2010 (1), noted that most non-native insects have insignificant impact on live trees. Those insects that do have a significant impact or a regulatory significance are considered high-impact pests. The study also noted that the detection frequency of high-impact forest pests increased fairly steadily from the late 1880s until the early 1990s. Then from 1990 to 2006, the detection of 19 high-impact forest pests, or an average of 1.2 per year, was nearly three times the rate of detections in the previous 130 years.

Results and Discussion: High-impact pests can negatively affect the green industry in several ways. Since its discovery in southeastern Michigan, the emerald ash borer has killed millions of ash trees in many states and in several Canadian Provinces. The certainty of ash trees dying from this pest was so great that the market for ash trees grown in Tennessee nurseries and elsewhere was effectively eliminated well before EAB was first detected in Tennessee in the summer of 2010. The Tennessee Department of Agriculture, Division of Forestry estimates that five million urban ash trees in Tennessee are potentially at risk with an estimated value loss of $2 billion. There are an estimated 261 million ash trees on Tennessee public and private timberland potentially valued as high as $9 billion. Another recent disease of garden impatiens, impatiens downy mildew (*Plasmopara obducens*) has already caused production of garden impatiens, *Impatiens walleriana*, to cease in Europe and this outcome will probably occur over the next few years in the U.S.

Other impacts on the green industry include the millions of dollars spent by growers each year to comply with regulations for the control of imported fire ants and Japanese beetles, *Popillia japonica* Newman, in order to ship nursery stock. These two pests have been in this country for many years and they continue to increase production costs for growers and management costs in the landscape for the general public. A Clemson University web site estimates imported fire ant costs at over $7 billion in the U.S. annually (2). The biggest cost is incurred by people (general public, local governments) trying to manage and control imported fire ants.

The movement of imported fire ants (red imported fire ant, *Solenopsis invicta* Buren, black imported fire ant, *Solenopsis richteri* Forel, and a hybrid of the two species) into nursery and sod production has greatly increased the use of insecticide needed to comply with shipping regulations. The following examples are not the complete list of regulatory options approved for treating sod or nursery stock for imported fire ant control. They are to demonstrate the extensive use of insecticides needed to meet regulatory rules for shipping sod and nursery stock. For instance, bifenthrin granular (Talstar Nursery Granular Insecticide, Bifenthrin Nursery Granular Insecticide, Up-Star Nursery Granular Insecticide, Wisdom Nursery Granular Insecticide) is mixed into potting media for container ornamental plants. Alternatively, bifenthrin flowable (Talstar S Select Insecticide, OnyxPro Insecticide, Up-Star SC Lawn & Nursery Insecticide, Menace GC 7.9% Flowable, Wisdom Flowable Insecticide, Quali-Pro Bifenthrin Golf & Nursery 7.9F) is used as a topical application only for nursery stock in 3- and 4-quart containers. Fipronil granular treatments (TopChoice, Chipco Choice, Fipronil 0.0143 G Broadcast, Fipronil 0.1G), which are applied in two sequential broadcast treatments made one week apart and irrigated with 1.5 inches of water, are used when shipping sod.

Drenching tree and shrub root balls (B&B) for imported fire ants with chlorpyrifos (Quali-Pro Chlorpyrifos 4E, Chlorpyrifos SPC 2, Chlorpyrifos SPC 4, Chlorpyrifos AG 4E, Chlorpyriphos 4E-AG) insecticide solution twice a day for three consecutive days is time consuming and expensive. Drenching chlorpyrifos at 0.125 lb active ingredient (ai)/100 gal has an estimated cost of $0.51/tree. Dipping B&B trees with chlorpyrifos at 0.125 lb ai/100 gal has an estimated cost of $0.73/tree. Dipping B&B trees with bifenthrin flowable at a 0.117 lb ai/100 gal has an estimated cost of $1.89/tree. Also, drenching and dipping trees can potentially increase worker exposure to insecticides in solution and dried residue on the burlap.

Dipping the root balls of B&B trees to meet Japanese Beetle Harmonization protocols is also expensive. Estimates of treatment costs for dipping B&B trees with bifenthrin flowable (0.2 lb ai/100 gal) are $3.34 per tree. When using chlorpyrifos at 0.25 lb ai/100 gal, the estimated cost per tree is $1.12.

Some other select pests or diseases impacting forests and landscapes include hemlock woolly adelgid, *Adelges tsugae* Annand, gypsy moth, *Lymantria dispar* (Linnaeus), thousand cankers disease vectored by the walnut twig borer, Japanese maple scale, granulate ambrosia beetle, camphor shot borer, and rose rosette disease vectored by eriophyid mites. Hemlock woolly adelgid has been found in 36 Tennessee counties as of March 2013. Thousands of hemlock trees have died while many have been kept alive by treating them with soil applied systemic insecticides or foliar insecticide sprays. Imidacloprid applied as a soil drench is probably the most cost effective control option because of the low cost of the insecticide, ease in application, and its effectiveness for at least three years. One named brand of imidacloprid (Mallet 75 WSP) is available on-line for $98.99 (before sales tax) for an envelope (package) containing four of the 1.6 oz water soluble packets (WSP) (3). The application rate on the label is to use one 1.6 oz WSP per 24-48 cumulative inches of trunk diameter as a soil drench application. The highest rate (one 1.6 oz WSP per 24 cumulative inches of trunk diameter) should give at least 3 years of control. If we use one 1.6 oz WSP in a drench around a 24 inch diameter hemlock tree, it would cost $24.74 ($98.99 divided by 4) in insecticide (a little over $1.00 per inch of trunk diameter) to treat the tree and get 3 years control. Thus, the insecticide cost per year is $8.25 for the three year period on a 24 inch diameter hemlock tree.

Even though the cost to landscape managers to treat individual trees with insecticide is not great, it would be very costly to treat all the hemlocks in a forest or region. Biological control is one of the most cost-effective options to manage invasive pests over regions. A major effort has also been made by the University of Tennessee through the Department of Entomology and Plant Pathology and the Lindsay Young Beneficial Insects Laboratory (LYBIL) to rear and release predaceous beetles so they can feed on the hemlock woolly adelgids and over time help to stabilize hemlock populations in the wild. The cost of this program has been about $210,000 annually to rear predaceous beetles at the LYBIL (3.5 full time personnel position equivalents, travel, supplies, utilities, and overhead) although cost will be less in 2013 due to a reduction in personnel (Dr. James P. Parkman, Director, LYBIL, personal communication).

According to the Tennessee Cooperative Gypsy Moth Program report by Clint Stromeier (Division of Forestry, Tennessee Department of Agriculture) , a total of 14,214 traps were placed in Tennessee for gypsy moth in 2010 (12,509 detection and 1,705 delimiting traps). From 1992 to 2010, the Tennessee program has cost $10.2 million at an average annual cost of $534,815/yr). While the amount of money spent on this program is substantial, it has been effective in preventing gypsy moths from becoming established in the state. The substantial value of this program in undeniable, considering the huge potential for loss of hardwood trees in Tennessee. Hardwoods comprise 89 percent of the slightly > 14 million acres of forests in Tennessee and oak-hickory forest types represent 73 percent of Tennessee forests (4). Oaks are considered most preferred hosts while hickories are preferred hosts of gypsy moth (5).

Thousand cankers disease (TCD) of walnut is a serious threat to black walnut, *Juglans nigra* L. and other walnut species. It is caused by the pathogen *Geosmithia morbid*a which is vectored by the walnut twig beetle, *Pityophthorus juglandis* (Blackman). TCD was first found killing walnut trees in western states. In 2010, it was found in Knox County in East Tennessee which was the first report of this disease and vector in the eastern native range of the black walnut. Since then, TCD has been found in Pennsylvania, Virginia, and North Carolina while walnut twig beetles but not TCD have been found in Ohio.

Japanese maple scale, *Lopholeucaspis japonica* (Cockerell), has become an emerging nursery pest. This tiny armored scale is difficult to control in the nursery and it is showing up more in the landscape. Achieving proper insecticide spray coverage in nursery blocks is difficult when there are too many rows of trees between grassy roadways and spray rows. Growers are buying small 3 point hitch attached sprayers that will allow them to traverse down every row when spraying. Also, growers are increasing the number of grassy roadways per spray rows to allow better spray coverage using their current sprayers. An online UT Extension fact sheet has been developed for this pest (6)

Invasive ambrosia beetles continue to be a problem on stressed plants in the nursery and landscape. Ambrosia beetles chew galleries in the host tree that are inoculated with specific ambrosial fungi on which they feed. When ethyl alcohol is released by a stressed plant, the ambrosia beetles are attracted and attack the tree in mass. These attacks can cause limb die-back and even tree death. Thirty new Scolytinae species (bark beetles and ambrosia beetles) have been introduced into the U.S. from the 1980s to 2010 (7). In a trap study performed in Middle Tennessee during 2012, 17 Scolytinae species were captured, of which 10 were non-indigenous species. Two ambrosia beetle species of special concern in Tennessee are the granulate ambrosia beetle, *Xylosandrus crassiusculus* (Motschulsky) and the camphor shot borer, *Cnestus mutilatus* (Blandford). An online factsheet on camphor shot borer was published jointly by Tennessee State University and University of Tennessee Extension (8).

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