

## **PROJECT SUMMARY**

### **HABITAT AND RESOURCE MANAGEMENT TO ENHANCE BIOLOGICAL CONTROL IN GREENHOUSES**

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This is a Research project. Biological control holds the promise of sustainable and safe control of the most important greenhouse arthropod pest, western flower thrips. Release of the mite predator *Amblyseius swirskii* can lead to biological control, but often does not. Even though growers and extension educators have shown broad interest in biological control, a lack of consistent and reliable effectiveness impedes widespread adoption. We hypothesize that a solution is available and propose through a one-year effort to demonstrate this and set the stage for commercial-scale trials. Research has revealed that the predator, *A. swirskii*, quickly leaves plants that lack both leaf hairs (leaf trichomes) and a supplemental food source (pollen) and many greenhouse-grown plants are trichome free. We propose to mitigate this limitation by applying artificial leaf hairs (low densities of tiny fibers) and pollen to the canopy of plants lacking these resources. Over a twelve month period we will complete three objectives: (1) We will determine the influence of several types of artificial leaf trichomes and of several species of pollen on retention of and oviposition by *Amblyseius swirskii* and determine the influence of these pollens on oviposition by western flower thrips (WFT). (2) Based on these results we will determine the influence of select artificial leaf trichomes and pollen on the short-term dynamics of interacting populations of *A. swirskii* and WFT. (3) This will set the stage for conducting small greenhouse trials to determine the influence of artificial trichome and pollen augmentation on the effectiveness of biocontrol of WFT using *A. swirskii*.

## PROJECT NARRATIVE

### HABITAT AND RESOURCE MANAGEMENT TO ENHANCE BIOLOGICAL CONTROL IN GREENHOUSES

#### **i. Problem:**

Biological control offers the potential for sustainable and benign control of western flower thrips *Frankliniella occidentalis* (Pergande) in greenhouses. Predaceous phytoseiid mites, *Amblyseius swirskii* (Athias-Henriot) and *Neoseiulus cucumeris* (Oudemans) can, when released in greenhouses, provide effective thrips control. However, control is not consistent and multiple inundative releases are needed. Because of this, adoption of biological control is low. Recent advances in our understanding of interactions between these phytoseiids and the plants on which they reside provide a potential avenue for greatly enhancing the effectiveness of thrips biological control. It is very likely that plant habitats in greenhouses can be manipulated to ensure the persistence and growth of predatory phytoseiid mites. Our own research has revealed that these natural enemies quickly leave the foliage of plants that lack both leaf hairs (leaf trichomes) and a supplemental food source (pollen). We propose to mitigate this limitation of leaf habitat in greenhouses by applying artificial leaf hairs (low densities of tiny fibers) and pollen to the canopy of plants lacking these resources and thereby greatly enhance biological control in this important crop habitat.

Greenhouse and nursery crop production is the second most valuable agricultural commodity in most states of the Northeastern U.S. The USDA/NASS Floriculture Crops 2008 Summary only reports data for 15 U.S. states, but four are in the Northeast. In MD, NJ, NY and PA 2,229 producers grew crops in 1,611 acres of greenhouses for a wholesale value of \$641,757,000.

A complex of pests challenge greenhouse growers nationwide, but the western flower thrips is the most damaging. Feeding by this tiny insect not only causes severe aesthetic damage that leaves plants unsaleable but also transmits impatiens necrotic spot virus (INSV) to a number of widely grown greenhouse crops. Plants infected with the virus must be discarded at significant financial loss and the only effective control measure is to control the thrips. Resistance has developed to the previously most effective insecticide and no effective replacement products are currently available. Growers are now actively interested in biocontrol of thrips primarily due to a lack of alternatives. An indication of this interest is attendance at recent extension workshops on greenhouse biocontrol across NY that reached more than 300 growers, two years in a row.

Most growers who have been successful with thrips biocontrol make weekly or biweekly releases of commercially-purchased predaceous mites (*Neoseiulus cucumeris* or *Amblyseius swirskii*) in inundative numbers onto the crop foliage to target first instar thrips. These predators remain on foliage longer, live longer, and oviposit more in plant habitats with trichomes and pollen. Because many important greenhouse crops, such as garden impatiens, New Guinea impatiens, begonias, ivy geraniums, pansies, some vegetable transplants and herbs, are glabrous (i.e., lack leaf hairs), adding a tiny amount of fibers and pollen to the foliage along with the mites should substantially increase the effectiveness and reliability of predaceous mite releases. We expect that increased retention of mites in these glabrous crops will allow growers to reduce predatory mite release rates and/or release frequency, thus lowering the cost of biological control

while increasing the effectiveness of thrips biological control. Thus, the goal of our proposed work is to test the concept that the addition of artificial leaf trichomes and pollen to a variety of greenhouse crops can assure effective biological control of western flower thrips.

### **Background:**

Greenhouse crop producers are interested in using biological control for thrips and extension personnel request reliable, science-based guidelines for advising growers on development of biological control programs (see attached letters). The Pest Management Strategic Plan for Greenhouses in the Northeastern U.S. (<http://www.nysipm.cornell.edu/pmsp/>) includes western flower thrips among the unranked list of top 10 pests and diseases of greenhouse crops. “Development of banker plant biological control systems for a broader range of insect pests” is ranked first of nine top priority issues for Research Needs out of a total of 75 submitted issues. “Guidelines on what, when, how many, and how to apply biological control organisms taking into consideration the variations in greenhouse operations – size, environmental conditions, crops, etc.” is ranked eighth of 11 priority issues for Education Needs out of 67 submitted issues. The proposed research would directly address both of these priorities. A “banker plant” provides resources to support natural enemies when the target pest population is scarce. Our project applies the banker plant concept to every plant in the crop to enhance the establishment and persistence of predatory mites. The addition of artificial leaf trichomes and pollen should greatly increase the robustness of predatory mite releases and simplify strategies for releasing mites.

The mechanisms governing phytoseiid response to leaf hairs (non-glandular trichomes) and pollen in plant habitat are well understood. The presence of leaf hairs (see Loughner et al. 2008, 2009 and reviews by Walter 1996; Sabelis et al. 1999; Agrawal 2000; Romero and Benson 2005) and availability of pollen (see Nomikou et al. 2009; review in discussion of Arthurs et al. 2009) strongly and consistently increase the retention, survival and reproduction of many phytoseiids.

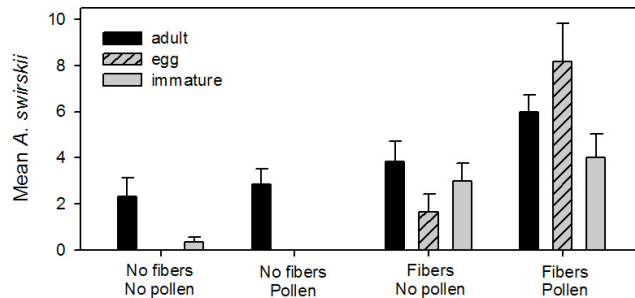
Loughner et al. (2009) conclude that a behavioral response of phytoseiids to the presence or absence of leaf trichomes drives phytoseiid densities. In the absence of leaf hairs, the mite population as a whole moves from the plant leaves to the plant stem, and subsequently disappears from the plant habitat; these predators disperse rapidly (within 72 hours) and simply do not establish on glabrous plants. Natural trichomes and cotton fibers applied to glabrous plants to mimic leaf hair structures both elicit a strong increase in phytoseiid retention. Only a small quantity of fibers is necessary; retention with ten tiny cotton fiber patches (total area of 0.75 cm<sup>2</sup> spread over a leaf) was comparable to retention with a 6 cm<sup>2</sup> fiber patch of fibers. Placing fibers on the upper leaf surface yields phytoseiid retention levels equivalent to when fibers are located on the leaf underside. The later finding is critical as the process for distributing fibers onto greenhouse crops will likely result in greater fiber adherence to the upper leaf surface.

Pollen acts in an additive manner with trichomes to increase phytoseiid retention (Loughner et al. 2009). Although there is the potential of thrips to benefit from pollen resources (Hulshof et al. 2003), *Amblyseius swirskii* substantially reduces thrips populations (van Rijn et al. 2002; Arthurs et al. 2009; Messelink 2006) and can control thrips commercially (communication with growers who have successfully established thrips biocontrol programs). A light level of pollen (200-300 grains per leaf) is sufficient to increase phytoseiid oviposition and rate of immature development

(McMurtry and Scriven 1966); minimizing the amount of pollen applied should increase phytoseiid retention and reproduction without excessively benefiting thrips populations.

The released phytoseiids and essential habitat resources (leaf hairs, pollen) must co-exist spatially. Banker plant systems intersperse resource-rich plants to benefit natural enemies in adjacent plants that lack such habitat resources. Use of such a system with phytoseiid mites is not viable. The mites are not only slow to move across a crop because of their size, but also fail to move from resource-rich plants and establish on glabrous neighbors (Loughner et al. in review). Successful enhancement of phytoseiid populations requires that every plant in the system become a “banker plant” with both fibers and pollen added.

Preliminary work indicates that up to 75-80% of *A. swirskii* leave plants within 72 hours if no leaf hairs are present and no food source is available (Figure 1) and clearly illustrates the potential effect of leaf hair presence on predatory mite establishment. Adding fibers almost doubles the retention of adults and retention rate triples when both fiber and pollen are added. In the absence of leaf hairs, there simply is no reproduction. Reproduction, measured by the number of eggs and immature, increases substantially when pollen is added along with fibers. Clearly, both pollen and fibers are important; the lack of trichomes, in particular, is almost certainly a major limitation to successful biocontrol in a greenhouse environment.



**Figure 1.** Mean adult, egg, and immature *A. swirskii* on leaves 72 h after 10 adult females were released on bean seedlings with or without added cattail pollen (*Typha* sp.) and with or without added cotton fiber trichome mimics.

### **Justification:**

Grower interest in biological control of thrips is largely driven by increasing resistance to a chemical that has provided high levels of control in recent years and the lack of any effective replacements. This presents an opportunity for increased adoption of biological control. Biocontrol is environmentally benign and sustainable, however for widespread adoption and growers to continue using phytoseiids after new insecticides are introduced, biocontrol must be simple, reliable, and cost-effective. The Northeastern IPM Center identifies one of the challenges to implementing IPM as “lack of science based information for Extension staff to make pest management recommendations.” That is precisely the limitation for increased use of predatory mites to control western flower thrips in the Northeast.

Our one year project is intended to catalyze a larger commercial trial the following year(s). The objectives outlined in this proposal are most effectively addressed with small scale trials that minimize variation in environment and application technique. It is this type of research that is most needed to address gaps in current knowledge and that is necessary before commercial trials are appropriate to pursue. Recommendations from this work are immediately relevant to thrips

biocontrol in the Northeast, in the U.S. and internationally. We have identified collaborators for this later commercial scale testing in other Northeastern states (see letters in Appendix). Scaling the project up from research trials to commercial trials will be a multi-disciplinary collaboration involving engineering expertise to develop a commercial apparatus that adequately distributes fibers, pollen, and/or phytoseiids, similar to designs that already exist for phytoseiid applications.

## **ii. Objectives and Anticipated Impacts:**

The goal of the proposed one-year project is to rigorously test whether the addition of artificial leaf trichomes and pollen to greenhouse crops will improve the effectiveness of biological control of western flower thrips. This work will set the stage for commercial trials throughout the northeast region and for the development of devices that will enable simultaneous application of artificial trichomes, pollen and phytoseiids over an entire greenhouse. We have chosen to limit the proposed research to a “proof of concept” so that the work can be done at minimal cost in an incremental manner. Provided this one-year effort is successful, funding will be requested to complete the project by conducting commercial-scale trials.

Three objectives will be pursued during the year-long research:

- 1) Determine the influence of several types of artificial leaf trichomes and of several species of pollen on retention of and oviposition by *Amblyseius swirskii* (AS) and determine the influence of these pollens on oviposition by western flower thrips (WFT).
- 2) Based on the results from Objective (1), determine the influence of artificial leaf trichomes and pollen on the short-term dynamics of interacting populations of AS and WFT.
- 3) Based on the results from Objective (2), conduct small greenhouse trials to determine the influence of artificial trichome and pollen augmentation on the effectiveness of biological control of WFT using AS.

### *Potential Impacts:*

1) Safeguarding human health and the environment- Insecticides are inherently biologically active compounds and have attendant human health and environmental risks. Because biological control reduces insecticide use, there is concomitant reduction in human health and non-target risks. Multiple releases of *N. cucumeris* in crops of ornamental bedding plants reduced the number of pesticides needed for WFT control from 5 to 0.4 (Gill 1994). We will use *A. swirskii* as a natural enemy rather than *N. cucumeris* because *A. swirskii* is considered a better, though more expensive, thrips predator and *A. swirskii* also feeds on whiteflies, another important pest in greenhouses. Thus, effectiveness of this biologically-based pest control tactic will be greatly enhanced which will in turn obviate the need for applying insecticides to control WFT.

2) Economic benefits- Because weekly releases of predators will not be necessary with a successful trichome and pollen augmentation technology, cost of the predators themselves and labor to apply them will decrease. It may also be possible to decrease predator release rates, further reducing the cost of thrips biocontrol.

3) Implementation of IPM- The immediate impact of the proposed research is generation of the knowledge required to pursue commercial-scale trials. Objective (1) will identify the most effective types of artificial trichomes and types and densities of pollens for enhancing the abundance of *A. swirskii* while minimizing benefits to the target pest (WFT). Objective (2) will determine what combination of artificial leaf trichomes and pollens is most likely to enhance the effectiveness of thrips biological control. Objective (3) will evaluate whether trichome and pollen augmentation increase the effectiveness of WFT biological control on a small scale and thereby set the stage for the development and testing of commercial applications. The ultimate impact of the proposed work will be to make biological control of thrips a reality in many, and perhaps most, greenhouses in the northeast, particularly given the current interest in thrips biocontrol among growers (see letters in Appendix).

### **iii. Approach and Procedures:**

Objective 1: We know that the addition of artificial trichomes and cattail pollen (*Typhus spp*) to glabrous plants greatly increases the retention of and oviposition by adult phytoseiids, including *A. swirskii*. Artificial trichomes created by hand cutting cotton batting cannot be applied to large areas in commercial greenhouses. Fortunately, several types of commercially available plant-based fibers are well suited to function as trichome mimics and could be applied to plants using either a water carrier or via directed air pressure. These fibers include jute, several cellulose-based products (e.g., Cellu-Flo®, Tencel® and Viscose®) and cotton fibers used in paper production. While cattail pollen is a good food source for phytoseiids, and can be collected from wild plants, it is not readily available commercially. There are however several pollens including those from fruit trees, pines, corn and rapeseed that are available commercially and might be useful as a food supplement for *A. swirskii*. Our first objective is therefore to measure the influence of several trichome mimics and pollens on the retention of and oviposition by *A. swirskii*, and to measure the influence of the tested pollens on WFT survival and oviposition.

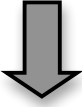

The experiments with *A. swirskii* will all be conducted on small bean plants that have two leaves and in greenhouses with conditions conducive to plant and arthropod growth and survival. We have previously used bean plants in similar experiments with great success (Loughner et al. 2009). Bean plants are inexpensive and easy to grow, are glabrous and are good host plants for thrips. In objectives 2 and 3 we will use crop plants typically grown in greenhouses.


For experiments with *A. swirskii* the basic protocol will be to add trichome mimics and pollen to the two leaves on each plant, place 10 adult female phytoseiids on each plant (5 on each leaf) and after 72 hours to record the number of adults remaining on the plants and the number of phytoseiid eggs produced. Previous work has clearly shown that these parameters are good indicators of phytoseiid population size and persistence over a longer time frame (Loughner et al. 2009). In each experiment, each treatment will be replicated 7 to 10 times. Trichome mimics will be applied using either a small paint brush or by suspending the fibers in water and brushing or misting the suspension onto the leaf surface. Preliminary work with one of the candidate fibers has shown that either methodology will work. Pollen will be applied using a DeVilbiss® glass powder blower powered by a small compressor. By regulating air pressure and duration of application, the amount of pollen applied to the leaf surfaces can be reasonably regulated.

Quantifying fiber density will be done by counting fibers on two 1-cm<sup>2</sup> areas of each leaf on a plant with a dissecting scope. Data will be analyzed using a mixed model with a binomial error structure for the adult counts and a Poisson error model for the egg counts. Specific experiments and their sequence are described in Table 1, though these are subject to change based upon results obtained.

Experiments will be conducted with WFT to measure the influence of pollen type and density on fecundity. Pollen will be applied to the surfaces of the two leaves on a bean plant and the plant will be placed in a thrips-proof cage. Five female thrips will be placed in the cage and egg production will be assessed after 7 days. Thrips eggs cannot be easily counted; however, counts of 1<sup>st</sup> instar thrips are a good surrogate. To obtain repeatable different levels of pollen on the leaf surfaces we will regulate the airflow and duration of pollen application with the DeVilbiss® glass powder blower. Prior to the experiment we will develop a relationship between air pressure, application duration and pollen density on the leaf. Pollen density will be estimated using the methods described by Roda et al. (2001). Data from the experiment will be analyzed using a mixed model.

**Table 1.** Sequence of experiments for completing Objective 1.

Experiment 1: Objective is to determine how well various fibers function as trichome mimics.		
<b>Treatments</b>	<b>Controls</b>	<b>Comments</b>
<ul style="list-style-type: none"> <li>• Jute fibers</li> <li>• Cellu-Flo® fibers</li> <li>• Tencel® fibers</li> <li>• Viscose® fibers</li> <li>• Cotton fibers for paper</li> </ul>	<ul style="list-style-type: none"> <li>• No trichomes – this will be a negative control</li> <li>• Hand-cut cotton trichome mimics – this is a positive control to allow comparison with previous work</li> </ul>	<ul style="list-style-type: none"> <li>• Cattail pollen will be applied to all treatments.</li> <li>• Replicates blocked on date to keep the size of the experiment manageable.</li> </ul>
 Two candidate fibers will be identified (e.g., Cellu-Flo, jute) and used in the second experiment.		
Experiment 2: Objective is to determine whether fiber position (dorsal or ventral leaf surface) is important. Previous work indicates that position is unimportant.		
<b>Treatments</b>	<b>Control</b>	<b>Comments</b>
<ul style="list-style-type: none"> <li>• Candidate fibers applied to dorsal leaf surface</li> <li>• Candidate fibers applied to ventral leaf surface</li> </ul>	<ul style="list-style-type: none"> <li>• No trichomes</li> </ul>	<ul style="list-style-type: none"> <li>• While previous work has shown that location of trichome mimics is unimportant, this must be confirmed and is important because application technologies must account for this factor.</li> <li>• Cattail pollen will be applied to all treatments in the same location as fibers are applied.</li> </ul>
 One of the two candidate fibers identified in experiment (1) will be used in the third experiment and applied to the leaf surfaces as dictated by the results from experiment (2).		

Experiment 3: Objective is to determine whether commercially available pollens are suitable food sources for <i>A. swirskii</i>		
Treatments	Control	Comments
<ul style="list-style-type: none"> <li>• Pine pollen</li> <li>• Corn pollen</li> <li>• Apple pollen</li> <li>• Rapeseed pollen</li> </ul>	<ul style="list-style-type: none"> <li>• No pollen (negative control)</li> <li>• Cattail pollen (positive control)</li> </ul>	<ul style="list-style-type: none"> <li>• A factorial experimental design will be used.</li> <li>• Pollen will be dusted with a DeVilbiss® powder blower resulting in pollen on the upper and lower leaf surfaces.</li> <li>• Replicates will be blocked on time.</li> </ul>
 <p>One fiber type will be used in the fourth experiment and applied to the leaf surfaces as dictated by the results from experiment (2). Two pollen species, as determined from experiment (3) will be used</p>		
Experiment 4: Objective is to determine the influence of pollen density on <i>A. swirskii</i> and WFT fecundity.		
Treatments	Control	Comments
<ul style="list-style-type: none"> <li>• Two pollen species</li> <li>• Pollen densities of 1x, 2x, 4x and 8x</li> <li>• <i>A. swirskii</i> and WFT</li> </ul>	<ul style="list-style-type: none"> <li>• No pollen</li> </ul>	<ul style="list-style-type: none"> <li>• Experiment will provide the basis for trying to balance the benefits of pollen augmentation to <i>A. swirskii</i> without advantaging WFT.</li> <li>• A factorial experimental design will be used.</li> <li>• Replicates will be blocked on time.</li> </ul>

Objective 2: The results obtained under Objective (1) will provide knowledge of the types of artificial leaf trichomes and pollens that can be used to enhance habitats for *A. swirskii* and where on the leaf and at what densities these resources should be deployed. The next step is to build on this knowledge by testing whether the addition of these resources results in lower densities of WFT when *A. swirskii* is released for biological control. It is also necessary to determine whether single applications of trichome mimics and pollen are sufficient because plant growth will result in foliage devoid of trichome mimics and pollen may degrade in quality over time. Previous research (Loughner et al. 2009) has shown that trichome mimics need not be

distributed over all leaves on a plant to increase the abundance of some phytoseiids. This needs to be verified for *A. swirskii* and there remains the question of whether spatial asynchrony between leaf trichome mimics and WFT, which often inhabit the youngest leaves and flowers, will impact biological control.

Flats (ca 0.5m x 0.3m) of basil, impatiens and pansies will serve as experimental units in these studies. These plants were selected because they are representative of the types of glabrous plants found in commercial greenhouses and because they are good hosts for WFT. The general experimental design will be to inoculate the flats of plants with female WFT, to apply *A. swirskii* and any habitat enhancements (e.g., trichomes and pollen), and to monitor the populations of pest and natural enemy over a 30 day period. Treatments will be replicated 5 times.

A single female thrips will be introduced onto each plant in a flat when plants attain a height of 6-10 cm. Three to five days later, trichome mimics and pollen will be added to the plants. These resources will be applied to the leaf surfaces at a density derived from results obtained for Objective (1). The trichome mimics will be applied one of three ways based on outcomes from preliminary experiments; as a suspension in water that is sprayed or brushed on the leaves, as dry fibers dispersed using air pressure, or as dry fibers dispersed via a mechanical shaker. Pollen will be applied using the DeVilbiss® powder blower procedure described under Objective 1. Following application of the trichomes and the pollen, 30 *A. swirskii* will be released per flat, which is about three to four times the commercially recommended rate of 50 per m<sup>2</sup> of habitat, to ensure sufficient mite presence for these initial trials. For each of the three plant species the following treatments will be used in the experiments: 1) only thrips added to the plants; 2) thrips and *A. swirskii* added to the plants; 3) thrips, *A. swirskii*, trichome mimics and pollen added to the plants and 4) thrips, *A. swirskii*, trichome mimics and pollen added to the plants twice (at the beginning of the experiment and then again after two weeks). Each treatment will be replicated 6 times and replicates will be blocked over two time periods. Densities of *A. swirskii* will be estimated by collecting 15 leaves per flat, three times during the experiment (ca 10, 20 and 30 days following release of the predators) and counting egg and motile (adult and immature) *A. swirskii* on each leaf. Western flower thrips damage will be estimated on a visual scale at each sampling date, and thrips densities (adults and nymphs) will be estimated three times (ca. 10, 20 & 30 days) by placing 15 flowers into alcohol and extracting thrips from dissected flowers, or counting thrips on leaf samples, under a microscope; taking leaf or flower samples will depend on the crop. Data will be analyzed using a mixed model that accounts for the correlations inherent in repeated measurement of the same experimental unit. At the end of the experiment, five randomly selected plants from each flat will be destructively sampled to estimate final population densities of WFT and predators. The number of motile WFT and egg and motile *A. swirskii* will be counted on all leaves and flowers of each plant and total numbers on each type of plant tissue analyzed used a mixed model.

Objective 3: The results obtained under objectives (1) and (2) will provide the knowledge required to conduct an experiment, under conditions that mimic those found in commercial greenhouses, to assess the extent to which thrips biological control is improved by the addition of leaf trichome mimics and pollen. This experiment will be relatively large scale and long in duration, will be done with three species of plants, and target thrips populations will be spatially aggregated, a characteristic of thrips populations found in commercial greenhouses. As a result,

this experiment will provide a “proof of concept” for applying trichome mimics and pollen to improve the success of thrips biological control.

The experiment will be conducted in four small greenhouses approximately 5m x 4m in size; each greenhouse will be considered an experimental replicate. Two treatments will be used in the experiment; 1) thrips and release of *A. swirskii* as a control and 2) thrips, application of trichome mimics and pollen, and release of *A. swirskii*. We will do a single predator release in the control treatment at the same time as the release in the other treatment however because all plant species in the control will not have trichome mimics, we do not expect the mite predators to persist. A complete factorial design was not used because the number of greenhouses available for the experiment is limited and our goal is test the overall combined effect of trichomes and pollen prior to commercial trials. Treatments will be replicated in two greenhouses during each of two 50 day periods, for a total of four replications in the experiment. Because each replicate is run over a 50 day period, further replication is impractical and probably unnecessary because we expect the influence of the trichome mimics to be large and easily measured.

At the start of each experiment each greenhouse will be stocked with eight flats each of basil, impatiens and pansies. The flats of the three plant species will be randomly distributed within the house so that plant species can be considered a factor in the experiment. Plants will be cared for based on recommendations for commercial greenhouses. When the plants are approximately 6 cm tall they will be inoculated with WFT at an average rate of one thrips per plant. However, rather than uniformly introducing the thrips, one half of the flats (4 flats per plant species per house) will receive 2x thrips and the other half of the flats will receive none. This will create an aggregated thrips population that is characteristic of commercial greenhouses. Five days following release of thrips, the trichome mimics, pollen and *A. swirskii* will be added to the plants.

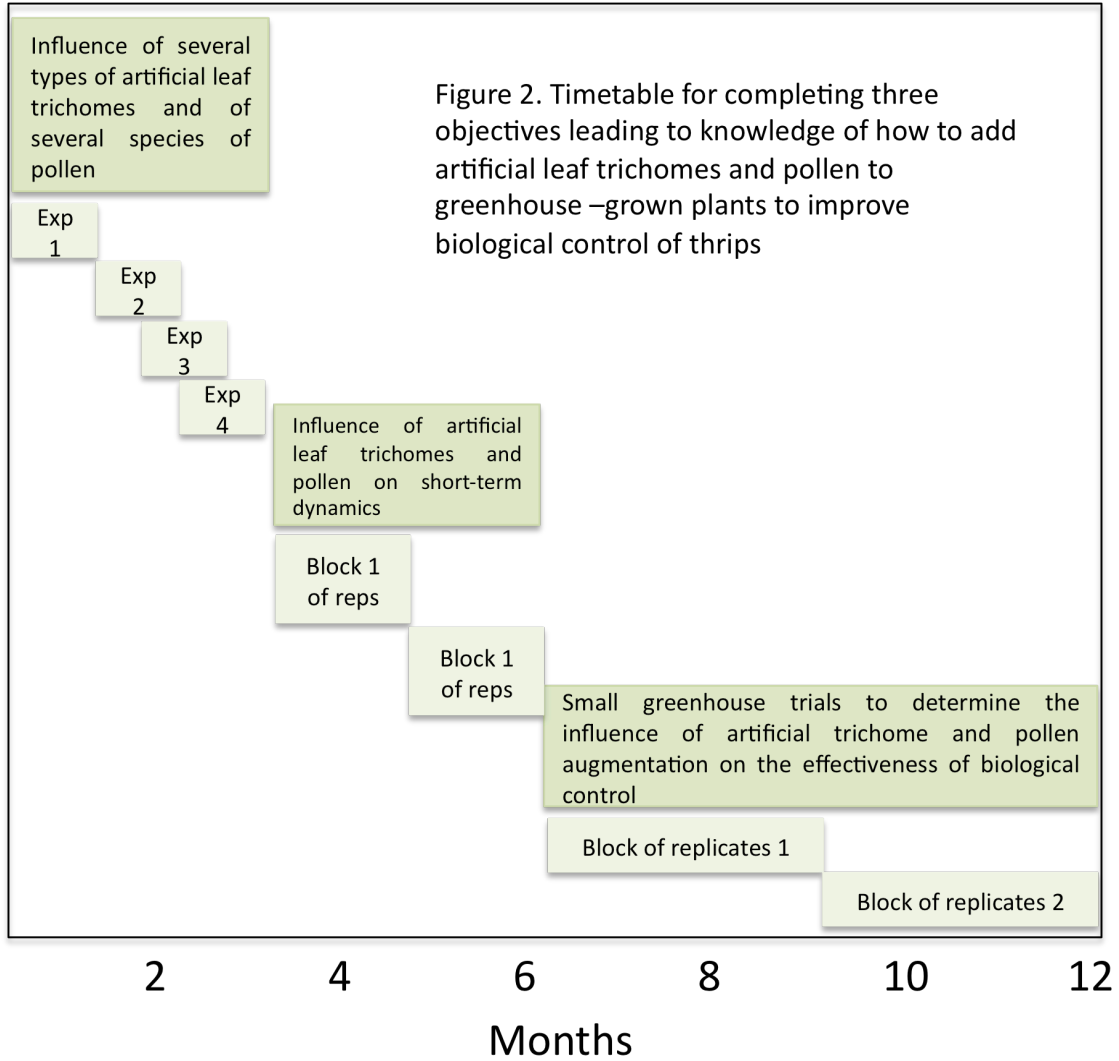
Trichome mimics used will be based on results obtained in objectives (1) and (2). These will be applied using either a water-based suspension, as air-directed dry fibers, or via a mechanical shaker. Results from experiments under objective (2) will indicate which application method is appropriate. The pollen species to be used and frequency of application will be based on results from objectives (1) and (2). The appropriate pollen will be applied using either the DeVilbiss® apparatus previously described or a Firman® power duster. The Firman® power duster has the capacity to disperse pollen over a wide area; however, the precision of this apparatus is unknown. We will conduct preliminary experiments to determine whether this application device can be used. These experiments will consist of using the device to apply pollen to flats of plants and then estimating the density of deposited pollen using previously described methods. The DeVilbiss® method is proven to work and while time consuming, it can be used even for the scale of this experiment. *Amblyseius swirskii* will be released throughout the plants in the greenhouse at a rate of approximately 30 mites per flat.

Following release of *A. swirskii*, the experiment will run for a period of 50 days. During this period, *A. swirskii* densities will be monitored on each plant species in each greenhouse by collecting 5 leaves from each flat of plants of each species (40 leaves per species) and counting the number of motile *A. swirskii*. Western flower thrips damage will be estimated on a visual scale at each sampling date. For the flowering crops, 5 flowers per species per flat will be

collected into alcohol vials and later dissected to count all motile stages of thrips. Leaves will also be scored for pollen and artificial leaf trichomes. Densities of predatory mites will be monitored on a 10 day schedule resulting in 5 density estimates for each experimental unit. The design of this experiment is complex and the statistical model used to analyze the data will reflect this. Plant species are nested within greenhouses and hence within the 2 treatments that will be used. Replication will be achieved by repeating the experiment in two houses over two blocks of 50 days. Because repeated counts are taken from the same experimental units (greenhouses), the error structure for the model will account for temporal correlation in the data. At the end of the experiment, five randomly selected plants from each flat will be destructively sampled to estimate final population densities of WFT and predators. The number of motile WFT and egg and motile *A. swirskii* will be counted on all leaves and flowers of each plant and total numbers on each type of plant tissue analyzed used a mixed model. At the completion of this experiment we will have a clear indication whether the application of trichome mimics and pollen augmentation can make thrips biological control more effective, resilient and predictable, all needed to advance adoption of this important pest management tactic.

Timetable:

The timetable for completing objectives 1, 2 and 3 is depicted in Fig. 2

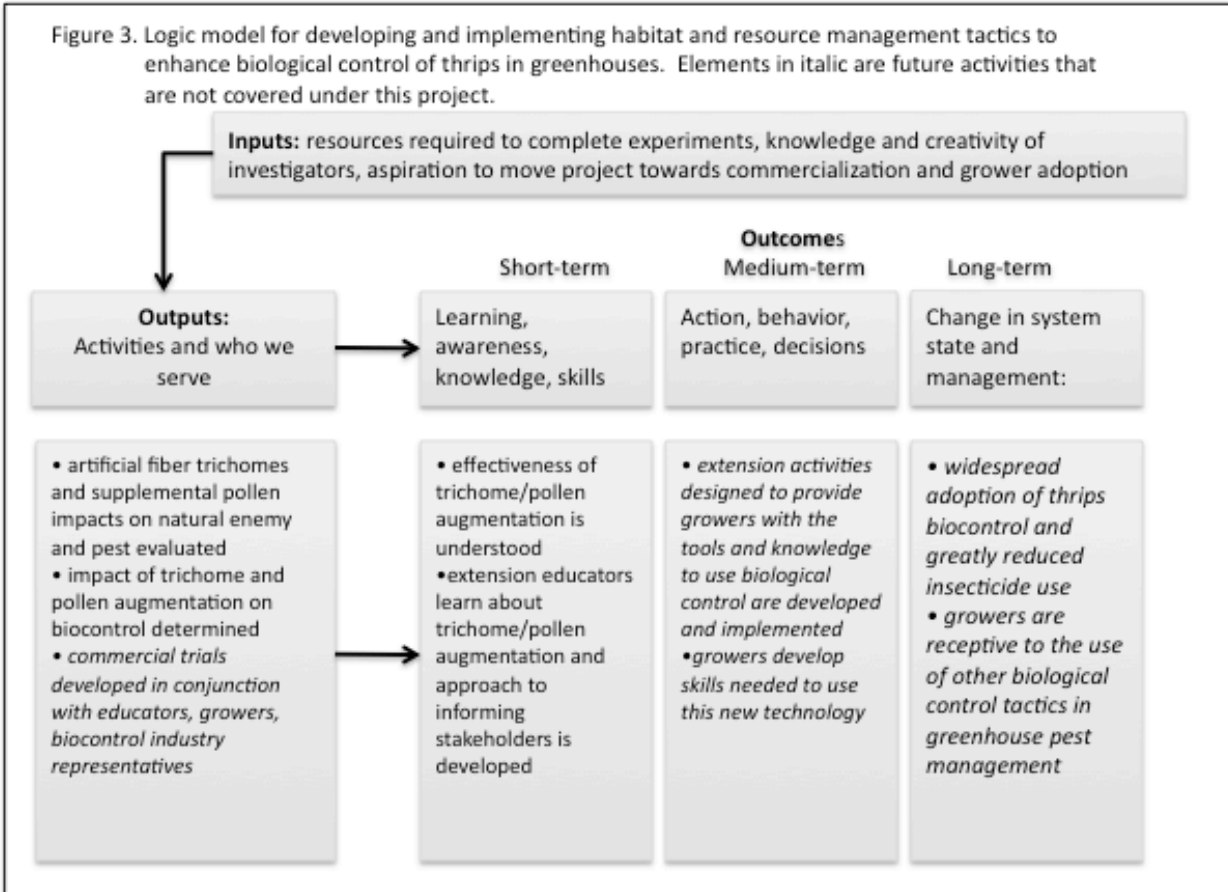


**iv. Evaluation Plans:**

The proposed experiments are inherently designed for evaluation and “proof of concept.” We have outlined expected outcomes from each objective (see the Objectives and Anticipated Impacts section), a projected direction for future work following this one-year proposal, and possible ways to measure the long-term impact of recommendations developed from the Proposed work (see Logic Model below). Two major directions for future work will be 1) developing and/or improving existing devices for application of artificial trichomes (fibers), pollen, and predatory mites in commercial greenhouse facilities and 2) engaging with cooperators in multiple states in the Northeast to quantify the impact of adding artificial trichomes and pollen on thrips biocontrol effectiveness at the scale of commercial greenhouses. Recommendations for use of phytoseiids in thrips management from the proposed project and future work will be shared through presentations and publications, but more significantly, through the extension educators we have communicated with as part of this proposal. Betsy Lamb (see attached letter) has been actively organizing workshops and other events to increase grower awareness and adoption of biological control in greenhouses; Betsy and others provide a direct link for this information to reach the target audience of greenhouse crop producers.

**Logic Model:**

The logic model used to guide this project is depicted in Fig. 3. Note that the proposed one-year project covers only the first part of the logic model and further research and extension planning and activities are needed to attain the long- term outcomes identified.



**v. Key Personnel:**

Project Directors Jan Nyrop and John Sanderson will be responsible for all aspects of the proposed project.

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## RELEVANCE STATEMENT

**(a) PD's:** J.P. Nyrop, Dept. of Entomology, Cornell University, NYS Agric. Expt. Station., Geneva, NY and J.P. Sanderson, Dept. of Entomology, Cornell University, Ithaca, NY

**(b) Title:** Habitat and Resource Management to Enhance Biological Control in Greenhouses

**(c) Project Type:** Research

**(d) Project Summary:** Biological control holds the promise of sustainable and safe control of the most important greenhouse arthropod pest, western flower thrips. Release of the mite predator *Amblyseius swirskii* can lead to biological control, but often does not. Even though growers and extension educators have shown broad interest in biological control, a lack of consistent and reliable effectiveness impedes widespread adoption. We hypothesize that a solution is available and propose through a one-year effort to demonstrate this and set the stage for commercial-scale trials. Research has revealed that the predator, *A. swirskii*, quickly leaves plants that lack both leaf hairs (leaf trichomes) and a supplemental food source (pollen) and many greenhouse-grown plants are trichome free. We propose to mitigate this limitation by applying artificial leaf hairs (low densities of tiny fibers) and pollen to the canopy of plants lacking these resources. Over a twelve month period we will complete three objectives: (1) We will determine the influence of several types of artificial leaf trichomes and of several species of pollen on retention of and oviposition by *Amblyseius swirskii* and determine the influence of these pollens on oviposition by western flower thrips (WFT). (2) Based on these results we will determine the influence of select artificial leaf trichomes and pollen on the short-term dynamics of interacting populations of *A. swirskii* and WFT. (3) This will set the stage for conducting small greenhouse trials to determine the influence of artificial trichome and pollen augmentation on the effectiveness of biocontrol of WFT using *A. swirskii*.

**(e) Brief Description of the Problem, Background, and Justification:**

Problem: Biological control offers the potential for sustainable and safe management of western flower thrips *Frankliniella occidentalis* (Pergande) in greenhouses. The predaceous phytoseiid mite *Amblyseius swirskii* (Athias-Henriot) can provide effective thrips control; however, control is not consistent and multiple releases are often needed. As a result, adoption of biological control is low. Recent advances in our understanding of interactions between these phytoseiids and the plants on which they reside provides an avenue for greatly enhancing the effectiveness of thrips biological control. Research has revealed that these natural enemies quickly leave plants that lack both leaf hairs (leaf trichomes) and a supplemental food source (pollen) and many greenhouse-grown plants are trichome free. We propose to mitigate this limitation by applying artificial leaf hairs (low densities of tiny fibers) and pollen to the canopy of plants lacking these resources and thereby greatly enhancing biological control in this important crop habitat.

Background: Producers of greenhouse crops are interested in using biological control for western flower thrips and extension personnel request reliable, science-based guidelines for advising growers on this tactic. The Pest Management Strategic Plan (PMSP) for Greenhouses in the Northeastern U.S. includes western flower thrips among the unranked list of top 10 pests and diseases of greenhouse crops and strongly advocates for habitat and resource manipulation to enhance biological control as well as application for releasing natural enemies. Our project seeks to enhance the establishment and persistence of predatory mites and if successful, will result in technology for using predatory mites that yields reliable thrips control. Our preliminary research

indicates that up to 75-80% of *A. swirskii* leave plants within 72 hours if no leaf hairs are present and no food source is available. Adding fibers almost doubles the retention of adults on the leaves, and retention rate triples when both fiber and pollen are added. In the absence of leaf hairs, there simply is no reproduction. Reproduction, measured by the number of eggs and immatures, increases substantially when pollen is added along with fibers. Clearly, both pollen and fibers are important; the lack of leaf hairs, in particular, is almost certainly a major limitation to successful biocontrol in greenhouse flower crops.

Justification: Grower interest in biological control of thrips is currently high, driven in part by the lack of effective chemical pesticides. This presents an opportunity for increased adoption of biological control. Biocontrol is environmentally benign and sustainable; however, for widespread adoption and continued use, biocontrol must be simple, reliable, and cost-effective. Our proposed one-year project will provide technology that can assure simplicity, reliability and cost effectiveness and will catalyze a larger commercial trial. The proposed objectives are most effectively addressed with small-scale experiments that minimize variation in environment and application technique and will generate the knowledge needed to pursue commercial trials. Recommendations from these early trials are immediately relevant to thrips biocontrol not just in the Northeast, but also to the United States and internationally. We have identified potential collaborators for this later commercial scale testing in other Northeastern states. Scaling the project up from this project's demonstration trials in research houses to commercial trials will be a multi-disciplinary collaboration involving engineering expertise and partners in other Northeastern states.

1. Risks to the environment will be reduced by improving the cost-effectiveness and reliability of biocontrol of thrips in greenhouses, which in turn will reduce the number of pesticide applications from the current weekly rate to very occasional.
2. Risks to human health will be reduced by decreasing sprays (often weekly) of pesticides for thrips made by a large number of growers.
3. Stakeholders strongly support the project as witnessed by attached letters and by published state and region IPM priorities.
4. Western flower thrips are among the most serious pests in greenhouses worldwide. The results of this project would certainly be extended to Northeastern U.S. greenhouses, but would likely go far beyond.
5. Biological control of thrips is theoretically possible but often difficult to achieve. As a result, biological control is not widely used. There is no current technology that can improve this situation. The proposed work will fill this niche.
6. While the proposed work will only be done in New York, it is a required precursor to wide-scale commercial testing. We have identified extension educators in at least three NE states who are willing to trial/demonstrate our results in commercial greenhouses.
7. If successful, the proposed technology could be widely adopted in two years. We know growers who would immediately put this information to use. Also, commercial suppliers of natural enemies would almost certainly develop equipment to apply fibers and/or pollen.
8. The expertise needed to accomplish this project only requires entomological knowledge within a greenhouse IPM context. If the proposed work is successful, engineers will be asked to join further development efforts.

9. The technology developed in this project will reduce dependency on chemical pesticides by providing a simple, reliable, and cost-effective non-chemical approach to managing a key pest that currently requires nearly weekly sprays.
10. Nearly all of the 3,000+ NE greenhouse producers are currently making frequent pesticide applications to battle insecticide-resistant thrips. This project will greatly reduce this expense along with crop losses due to thrips damage and virus infections.
11. Growers of organic greenhouse crops, herbs, and other edible greenhouse crops would clearly benefit from this research, given the lack of pesticides for these crops.
12. The degree of resistance to chemical pesticides in Western flower thrips now makes it operationally a “new pest” in that there are no consistently effective control technologies.
13. Recent extension workshops on greenhouse biocontrol reached more than 300 growers in each of two years. There is currently tremendous interest in biocontrol and biocontrol would be widely adopted if results were more consistent and reliable.
14. Our research would lead to a reduction in the cost of biocontrol for thrips because a single rather than multiple releases of predators would likely be needed. This would make costs for biological control less than that now required for nearly weekly application of insecticides.

**(f) Project Objectives and Anticipated Outcomes:** The goal of the proposed one-year project is to rigorously test whether the addition of artificial leaf trichomes and pollen to greenhouse crops will improve the effectiveness of biological control of western flower thrips. Provided this one year effort is successful, funding will be requested for conducting commercial-scale trials. The immediate impact of the proposed research is the generation of the knowledge required to pursue the commercial-scale trials. The ultimate impact of the proposed work will be to make biological control of thrips a reality in many, and perhaps most, greenhouses in the northeast. Three objectives will be pursued during the year-long research:

- 1) Determine the influence of several types of artificial leaf trichomes and of several species of pollen on retention of and oviposition by *Amblyseius swirskii* and determine the influence of these pollens on oviposition by western flower thrips (WFT).
- 2) Based on the results from Objective (1), determine the influence of artificial leaf trichomes and pollen on the short-term dynamics of interacting populations of AS and WFT.
- 3) Based on the results from Objective (2), conduct small greenhouse trials to determine the influence of artificial trichome and pollen augmentation on the effectiveness of biological control of WFT using *A. swirskii*.

The impact of completing Objective (1) will be to know what are the most effective types of artificial trichomes and types and densities of pollens for enhancing the abundance of *A. swirskii* while minimizing benefits to the target pest (WFT). The impact of completing Objective (2) will be to know what combination of artificial leaf trichomes and pollens are most likely to enhance the effectiveness of thrips biological control. The impact of completing Objective (3) will be to know whether trichome and pollen augmentation increases the effectiveness of WFT biological control and thereby set the stage for development and testing of commercial applications.