Funding Request 2019: State Horticultural Association of Pennsylvania

Title: *Investigating Codling Moth Phenology Model and Management*

Personnel:

Dr. Anne L. Nielsen
Associate Extension Specialist in Tree Fruit Entomology
Department of Entomology
Rutgers University
96 Lipman Dr.
New Brunswick, NJ 08302
nielsen@njaes.rutgers.edu
856-455-3100

Dr. Clement Akotsen-Mensah
Postdoctoral Researcher
Rutgers Agricultural Research & Extension Center
121 Northville Rd.
Bridgeton, NJ 08302
ca555@scarletmail.rutgers.edu

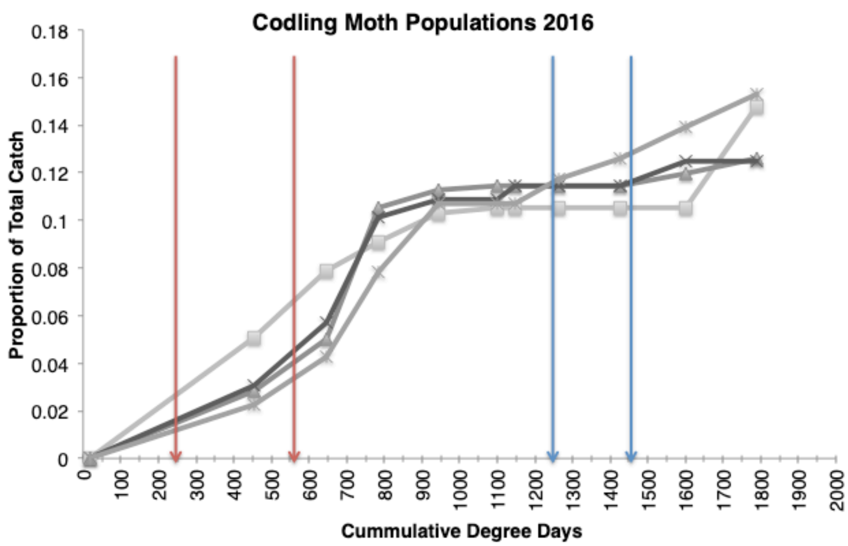
Duration of Project: 2 years

Justification: Codling moth, *Cydia pomonella,* is a critical pest of pome fruit production globally, especially in North America (Witzgall et al. 2008). The economic injury level for apples is 1% damage given the high value of the crop and direct impact on the fruit itself. Damage can vary greatly in its appearance. The juvenile stage burrows into developing fruit leaving behind anywhere from a small external bite mark to a frass-filled apple. Further, the juvenile stage, or larvae, presents a contamination risk if still present at harvest. Tree fruit production in Pennsylvania and New Jersey are at risk from coding moth injury from post-bloom through harvest due to 2-3 codling moth generations. A 2017 survey of NJ growers ranked codling moth as the second most important tree fruit pest overall and the top pest in pome fruit (https://plant-pest-advisory.rutgers.edu/results-from-the-tree-fruit-priorities-survey/). The State Horticultural Association of Pennsylvania also lists "internal feeder management" as a top 2019 entomology research priority, demonstrating the importance of internal worms such as codling moth to growers within this region.

As a critical and long-term pest of apple, many IPM tactics are available. This includes insecticides applied based on a combination of degree-day timing and abundance in pheromone monitoring traps and/or alternative strategies such as mating disruption. The degree-day (DD) or phenology model describes and predicts adult flight, egg laying, and egg hatch in order to help growers synchronize treatments with critical stages of codling moth development. Codling moth eggs and larvae are susceptible to a broad range of insecticides including organophosphates, pyrethroids, neonicotinoids, diamides, insect growth regulators, and viruses or bacteria in insecticide form. However, resistance to organophosphates, pyrethroids, and insect growth regulators has been reported throughout the United States. Thus, two connected problems are occurring with codling moth management causing injury to increase. First, the DD models are not lining up with codling moth flight activity. The ability to predict emergence of codling moth in the Spring defines the biofix and is related to management decisions. Male moth catches in pheromone traps define the biofix – or the time at which degree-days start accumulating. From the biofix, degree-days are accumulated based on weather to predict the timing of codling moth egg hatch for each generation. Applications of insecticides are based on these phenology predictions. The same is true in an orchard with mating disruption if the monitoring traps exceed a threshold for treatment.

Codling moth phenology based on these model predictions has been found to be variable throughout the country in apple growing regions and highly variable weather during Spring emergence around apple bloom time leads to erratic trap results. Research primarily on the West Coast tried to address model prediction mismatch with trap data and identified that 100 DD_{10} from January 1 best predicted first emergence ('biofix') and avoids low population estimates from trap captures that are common early in the growing season, however the authors stressed that validation in other geographic areas was needed (Jones et al. 2013). However, researchers in North Carolina found that the January 1 biofix didn't match their populations likely due to variations in elevation or other exogenous factors (Chappell et al. 2015). Data from the Rutgers IPM program also suggests that the trap-based biofix provides inaccurate estimation of codling moth activity. Given the importance of codling moth, the appropriate biofix needs investigation in the mid-Atlantic region.

Figure 1. *Codling moth populations in 2 NJ apple orchards (2 blocks each) in 2016 represented as the percent total trap catch by degree-day. The red lines indicate model predictions for 1st generation insecticide application. The blue lines indicate model predictions for 2nd generation insecticide application. Predictions are not inline with codling moth flight*



Codling moth management on two southern New Jersey apple farms was evaluated as part of a BMSB management program in 2016 and 2017 with one 5-acre plot on each farm using standard insecticide-based management and a paired plot using Isomate CM/OFM TT mating disruption (Akotsen-Mensah *in prep*). Codling moth pressure was high in both years. In 2016, a single trap had 45 moths in a week during the 2nd generation flight in the undisrupted block. Injury in 2016 ranged from 2-14% in the standard blocks and 1-2% in the mating disruption blocks, despite multiple management applications during the second and third generation (Figure 1). In 2017, traps consistently were at or above threshold in both insecticide and mating disrupted blocks, at time points not consistent with flight activity. Injury was high with 2-24% of injured fruit at harvest in the insecticide managed plots and 1-9% in the mating disruption blocks. The cause of the management breakdown is unknown but moth activity as measured in the pheromone traps did not match with the phenology model predictions. New Jersey tree fruit growers have expressed specific interest in codling moth management as growers seek to reduce insecticide use and increase mating disruption.

Further confounding the problem with accurate model predictions of activity is that phenological differences occur in insecticide resistant populations in North Carolina (Chappell et al. 2015). Specifically, resistant moths in the 2nd generation emerge slower than insecticide susceptible ones. Canada, Michigan, Washington, and North Carolina all report insecticide resistance in codling moth populations and New Jersey has suspected pyrethroid resistance (Mota-Sanchez et al. 2008, Magalhaes and Walgenbach 2011, Chappell et al. 2015, Grigg-McGuffin et al. 2015). Knowledge of resistance is critical in both predicting phenology as well as insecticide selection. During critical codling moth management time periods, other critical pests are present, specifically plum curculio following bloom and brown marmorated stink bug in the late season through harvest. Increases in pyrethroid use against brown marmorated stink bug may have exacerbated pyrethroid resistance and growers need to know which materials are efficacious at these critical time periods. Identification of efficacious materials for these critical pests is needed, especially given use restrictions, selectivity of various insecticide classes, and pre-harvest intervals.

Given the two primary issues with management in the United States appear to be inaccuracies with the predictive model and insecticide resistant populations, we propose to address both problems in NJ apples. We will re-evaluate codling moth phenology and identify the best phenology model to predict management timings. We will document injury levels and screen populations for insecticide resistance to commonly used materials. This information will be widely shared and beneficial to all growers within the mid-Atlantic region to improve internal worm management and increase fruit quality.

Objectives:

1. Evaluate codling moth phenology to identify the best predictive model for management decisions
2. Document levels of injury from codling moth
3. Conduct laboratory testing of insecticides to evaluate product efficacy

Procedure:

Location: Four farms within Southern and Central New Jersey will be sampled. This will include three commercial farms with moderate codling moth populations and reported injury at harvest and one research farm with a history of codling moth pressure where plots will be unsprayed. Management approach and spray records will be collected from each site.

Objective 1: Pheromone traps baited with Codling Moth L2 and Codling Moth DA lures (6 of each lure type per farm) will be deployed to monitor for codling moth males and females, respectively in 2019 and 2020. For each lure type, 4 traps will be used to optimize trap catch within the orchard and two will be placed on the orchard edge. A line of four pheromone traps has recently been suggested to improve estimation of flight and population pressure by researchers at Michigan State University. Trapped moths will be sexed and counted daily until biofix is reached, and then twice weekly there after until frost or trap numbers are consistently zero. Daily temperature data will be accessed through onsite weather stations or the nearest NEWA site and degree days calculated using the sine wave method with minimum and maximum threshold set at 10 and 31^{o}C. To determine which predictive model best fits codling moth populations, trap data will be calculated using two 'biofixes' with first consecutive trap catch (Riedl et al. 1976) or January 1 (Jones et al. 2013) and compared using a modified SD_{DD} (revised from Snyder et al. (1999), in Nielsen et al. (2017)) method. The SD_{DD} method allows for best estimation of a biofix through field data and importantly allows for statistical comparison between the other two approaches. All trap data will be modeled as cumulative trap catch per generation (564 and 584 for 1st and 2nd generation, respectively) by degree day (Chappell et al. 2015). Careful tracking of codling moth phenology and updating model estimates will improve the accuracy of predictive models to time insecticide-based management.

Objective 2: Fruit injury will also be assessed weekly beginning mid-June by collecting 100 fruit/site and holding them within the laboratory for larval emergence and fruit injury at the four farms. Coordinating with the Rutgers Fruit IPM program, codling moth pressure (seasonal total counts) and injury within key varieties will be documented statewide. Larvae emerging from fruit will be put into a "NJ" colony and used for insecticide testing (see below).

Objective 3: Two colonies of codling moth will be used for testing, a laboratory "susceptible" colony originating initially from Michigan and a "wild" colony originating from NJ orchards. Larvae that emerge from collected fruit as well as cardboard bands placed on tree trunks to collect pupae during the season will be used to create the "wild" colony. Moths will be reared using standard rearing techniques.

Commonly used insecticides against codling moth include Intrepid (methoxyfenozide), Altacor (cholantraniliprole), Delegate (spinetoram), Warrior II (lambda-cyhalothrin), and Imidan (phosmet). Danitol (fenpropathrin) will also be included as it is commonly used against brown marmorated stink bug, a late-season apple pest. Efficacy tests against neonate larvae will be performed using formulated products at four dosage rates in a dietary bioassay per Mota-Sanchez et al. (2008). Briefly, 200 ul of formulated insecticide is applied to the surface of diet cups. Diet cups are 20 ml plastic cups filled partially with artificial bean diet. After a brief drying period, 3-5 larvae that are less than 12 h old will be added to the diet and held in an incubator at 25^{o}C. Ten replications per insecticide rate will be performed. Mortality of the larvae is assessed 5 days after treatment. Probit analysis on codling moth larvae survivorship will calculate the LC_{50} and LC_{95} values. We will calculate resistance ratios (LC_{50} of the resistant/LC_{50} of the susceptible population) by comparison of the susceptible and wild populations for each insecticide.

All research results will be shared with growers in the region through annual fruit meetings, within season twilight meetings, Plant Pest Advisory blog posts, and presentations at the Mid-Atlantic Fruit and Vegetable Expo. Further, changes to management recommendations will be shared broadly with Extension Educators within the region.

Budget:

Year 1		**Year 2**	
Salaries	$2400	Salaries	$2400
Hourly wages	$3456	Hourly wages	$3456
Fringe Benefits	$1430	Fringe Benefits	$1430

Supplies	$3311	Supplies	$3311
Travel	$918	Travel	$918
Miscellaneous	$1000	Miscellaneous	$1000
Total	*$12,515*	*Total*	*$12,515*

Budget Justification: In both years, salary (5% FTE) plus fringe for a post-doctoral researcher to conduct the laboratory insecticide bioassays is requested. Additionally, we request hourly wages to check traps at $12/hr plus fringe for 18 weeks at 16 hours per week. Mileage to and from farm sites to check traps and collect fruit is calculated at $0.545/mile for 94 miles weekly for 18 weeks. Plot charges ($1000) for the Rutgers Cream Ridge Fruit Research Station to maintain apple plots is requested. Supplies including laboratory incidentals, codling moth diet ($500), monitoring traps including delta traps, liners, and lures ($3,311) are requested annually. All budgetary needs are identical in Year 2 of the project.

Literature Cited:

Chappell, T. M., G. G. Kennedy, and J. F. Walgenbach. 2015. Predicting codling moth (*Cydia pomonella*) phenology in north carolina on the basis of temperature and improved generation turnover estimates. Pest Manag. Sci. 71: 1425-1432.

Grigg-McGuffin, K., I. M. Scott, S. Bellerose, G. Chouinard, D. Cormier, and C. Scott-Dupree. 2015. Susceptibility in field populations of codling moth, *Cydia pomonella* (L.) (Lepidoptera: Tortricidae), in Ontario and Quebec apple orchards to a selection of insecticides. Pest Manag. Sci. 71: 234-242.

Jones, V. P., R. Hilton, J. F. Brunner, W. J. Bentley, D. G. Alston, B. Barrett, R. A. Van Steenwyk, L. A. Hull, J. F. Walgenbach, W. W. Coates, and T. J. Smith. 2013. Predicting the emergence of the codling moth, *Cydia pomonella* (Lepidoptera: Tortricidae), on a degree-day scale in North America. Pest Manag. Sci. 69: 1393-1398.

Magalhaes, L. C., and J. F. Walgenbach. 2011. Life stage toxicity and residual activity of insecticides to codling moth and oriental fruit moth (Lepidoptera: Tortricidae). J. Econ. Entomol. 104: 1950-1959.

Mota-Sanchez, D., J. C. Wise, R. V. Poppen, L. J. Gut, and R. M. Hollingworth. 2008. Resistance of codling moth, *Cydia pomonella* (L.) (Lepidoptera: Tortricidae), larvae in Michigan to insecticides with different modes of action and the impact on field residual activity. Pest Manag. Sci. 64: 881-890.

Nielsen, A. L., S. Fleischer, G. C. Hamilton, T. Hancock, G. Krawczyk, J. C. Lee, E. Ogburn, J. M. Pote, A. Raudenbush, A. Rucker, M. Saunders, V. P. Skillman, J. Sullivan, J. Timer, J. Walgenbach, N. G. Wiman, and T. C. Leskey. 2017. Phenology of brown marmorated stink bug described using female reproductive development. Ecology and Evolution: 1-11.

Riedl, H., B. A. Croft, and A. J. Howitt. 1976. Forecasting codling moth phenology based on pheromone trap catches and physiological-time models. The Canadian Entomologist 108: 449-460.

Snyder, R. L., D. Spano, C. Cesaraccio, and P. Duce. 1999. Determining degree-day thresholds from field observations. Int. J. Biometeorol. 42: 177-182.

Witzgall, P., L. Stelinski, L. Gut, and D. Thomson. 2008. Codling moth management and chemical ecology. Annu. Rev. Entomol. 53: 503-522.