

Title: Verification of Web-based Pest Real-time High-Resolution Weed and Insect Predictive Models for Northeast IPM Programs

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State(s) involved: Pennsylvania

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Non-technical Summary:

Mathematical models that generate state-wide maps to predict the timing of eight weed species emergence periods and key times when three important insect species are present were tested in three distinct climatic zones of Pennsylvania. The goal of the research was to determine whether the models could provide reasonable predictions of when the weeds and insects were present as an early warning system for crop consultants, farmers, and other agricultural professionals. The first objective of the study was to test the models at six geographic locations in Pennsylvania for reliability by monitoring the period of weed emergence and when the insect pests entered key life stages (egg, larvae, pupae, and adult) and then compare the observations with the model's predictions. The second objective was to provide educational programs on the use of these models for pest management. Objective number one tested two aspects of the model: 1) whether the temperature predictions of ZedX, Inc. were adequate to drive the insect and weed models and 2) whether the observations at the site match the models predictions.

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Introduction:

Integrated Pest Management is defined as the use of multiple management tactics to maintain pest populations below economic levels in an environmentally and socially acceptable manner (Stern et al. 1959). Historically, however, synthetic pesticides have been the dominant tactic of choice, both to prevent and rescue crops from injury. Their relatively low cost has lead growers to use them as cheap insurance rather than when needed, but their overuse has lead to increased risk of adverse affects on the environment and human health and lower farm profits. The overuse of pesticides has lead to increased risk of adverse affects on the environment and human health and lower farm profits. By properly timing management activities these risks can be reduced.

Spatially explicit high-resolution temperature dependent models (i.e. models that predict when a pest will occur at a specific site) have been developed at Penn State, in collaboration with ZedX, Inc¹, for eight weed and three insect species to provide early warnings of the emergence of weeds and entrance into key insect life stages. Maps of percentage emergence of weeds and 5% entrance of insect pests into each life stage (i.e. egg, larval instars, pupae, and adult) are provided to Pennsylvania agricultural professionals. The maps are not intended to provide exact timing of key events but to provide an early warning of upcoming events so professional crop scouts, farmers, and other agricultural professionals can anticipate when they need to deploy insect monitoring tools, gear up for herbicide applications, and time field scouting activities. To test the predictions, plots were set up at six locations each year and the emergence periods of each weed species was monitored along with the stage structure and the period of occurrence of each insect species.

The alfalfa weevil is the most important pest of first cutting alfalfa, requiring 5 to 20% percentage of acres to be sprayed in Pennsylvania annually (Crop Management Association Records). Nationally, the European corn borer and the corn rootworm together cause about \$2 billion in annual lost of corn yield (Tollefson and Calvin 1995). Relative to weeds, more recent data is difficult to find, but Bridges (1992) estimated that annual losses from weeds for 46 major commodities in the U.S. was \$4.1 billion in 1991. Losses would have amounted to \$19.6 billion had herbicides not been available for use in these crops. More recently, Pimentel et al. (2001) estimated that weeds cause a reduction of 12% in potential crop yields and in economic terms, this reduction represents about a \$33 billion loss in crop production annually. In the northeast, yield losses from annual weed competition are important for all major commodities and particularly for those that rely less on herbicides for weed management.

Objectives of Study:

1. Verify and demonstrate each phenology model's reliability for timing key weed emergence periods and insect life stages across climatic regions of Pennsylvania.

The data on weed emergence and insect stage structure were collected at all locations in Pennsylvania as planned. The quality of these data however, varied

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depending on the number of weed species present at each location and the density of insects at each location. Because of data quality issues, some locations could not be used, but there was ample data to address the research questions.

2. Conduct educational training sessions with farmers, consultants, and agricultural professionals to demonstrate the use of the phenology model tools.

Educational training on the models' use was provided over the period of the grant. Evaluations of these educational programs suggest that participants increased their knowledge of the models and how degree days are used to predict timing of insect and weed occurrence.

Approach:

Objective #1 – Model Verification.

Insect Validation Procedures - Model verification data was collected at six locations in the four major climatic and crop production zones of Pennsylvania, as identified by average seasonal degree day accumulations: western central, central, northeast, and southeast/south central. For alfalfa weevil monitoring, fields were sampled using a 15-inch insect sweep net to collect alfalfa weevil larvae and adults. In each field, five sets of 20 sweeps will be collected weekly until pupation of the population is predicted. Alfalfa weevil larvae collected in the samples will be placed in 70% alcohol and sent to Penn State, where the age class of each individual will be determined in Dr. Calvin's lab. The weekly collections will then be used to compare the field observation developmental stages with the model's predictions. Pheromone traps were established at each of the test locations for both New York and Iowa races of the European corn borer and observed daily during the summer season beginning when the model predicts 5% adult flight at the site. Two methods were used to verify the corn rootworm models. Stage structure of corn rootworm populations were determined by collecting corn root systems weekly and then placed in burlap funnels with a container of alcohol under them. Larval samples in alcohol were then labeled with the date of collection, location and sent to Dr. Calvin's laboratory for instar determination. To test the model's ability to predict the timing of adult emergence, adult emergence cages were placed in cornfields and monitored twice weekly for new adults. Each location was monitored with two cages. Temperature sensors were placed at a 3 inch soil depth and at five feet above soil level to measure ambient temperature to drive the alfalfa weevil, corn rootworm and European corn borer models and compare to prediction using ZedX, Inc. spatially interpolated temperature data.

Weed Monitoring Procedures. Weed emergence by species was monitored at six locations in Pennsylvania. Four areas within a field, 2-m² in size areas were established in the spring as soon as conditions permitted. Half of each 2-m² quadrant was left crop free,

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while the other half was planted to no-till Roundup Ready soybeans. Soybeans were removed in the seedling stage from the no-crop plots by use of a nonselective herbicide (i.e. glufosinate or Liberty) to test the impact of the crop on weed species emergence periodicity. The naturally occurring weed seed-bank was assessed by collecting weed density by species information every 14 days until emergence ceases in mid to late summer. The total number of emerged seedlings, by species, was subjected to analysis of variance to compare the effect of crop vs. no crop, emergence over time, and the interaction. Means were separated using the Fisher's protected LSD tested at $p \leq 0.05$. In addition, the weed emergence data was compared by fitting a logistic growth model to the data and comparing the emergence rates and period to the eight weed species models (Myers 2003). Temperature sensors were placed in the soil at a 1 inch depth to compare against spatially interpolated temperatures provided by ZedX, Inc.

Objective #2 – Demonstration and Education.

Several methods will be used to increase farmer and agricultural professional adoption of the web-based maps. First, the maps will be made available on the web at the Department of Entomology website (http://www.ento.psu.edu/extension/field_crops/default.htm). These maps will be updated daily and used biweekly in the Field Crops News (state field crop newsletter) and local county extension newsletters. In the newsletters, the map information will be interpreted for the users. Field days will be hosted at each location during the summer to explain and discuss the value of pest prediction. Field days will be conducted at times when the educational message is most clearly seen in the field. Since county agents are playing a pivotal role in this project, the educational component will clearly reach out from the local county office. In addition, an educational circular will be developed and used at each field day to discuss the merits of pest predictions.

Progress:

During FY 2005/2006 was the last summer validation data sets were collected and aggregated into Excel databases. These data sets included 1 and 3 inch soil temperatures and 5 feet ambient temperature data collected with HOBO temperature sensors at each location, weed emergence data and insect data. In addition, ZedX, Inc. provided simulations of degree days, weed emergence and insect life stages for each location for the 1 inch soil, 3 inch soil, and 5 feet ambient at each location of the study for 2004 and 2005. The data in the Excel databases were manipulated to provide both predicted and observed weed emergence periods, the observed and predicted stage structures of insect pests, and the observed and predicted periods of entrance into key life stages. Statistical analyses were then run on these data sets to determine the degree to which model predictions and on-site observations agreed.

Results:

The results of this project are divided into four components: 1) evaluation of the ZedX, Inc. spatially interpolated temperature predictions relative to on-site HoboTM

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temperature data recorders, 2) a comparison of weed emergence timing and rate predicted using the Zedx, inc. temperature data and on-site observed emergence rates, 3) a comparisons of key insect life stage timing predicted by the models and on-site observations and 4) examples and evaluations of educational meetings about the use of the weed and insect models for pest management.

The basic outcome of the temperature data comparison was that the ZedX, Inc. data tended to predict weed emergence slightly later than observed in the field (appendix I). The degree of deviation in estimated percentage weed emergence increased from early to late season weed species (appendix II). The results of the high-resolution spatially interpolated weed predictions help support the accuracy of our previous emergence models, but also show the need to more accurately determine how soil moisture or rainfall and perhaps preplant tillage play a role in developing more accurate weed emergence models. The results of the insect predictions indicate that the model is providing estimates key insect life stage timing to provide early warning to agricultural professional (appendix III). However, there is still a need for further model refinement and in a couple of cases the predictions were outside the range desired to provide early warnings. Without local monitoring networks, these predictions should not be used to help timing of control efforts. Educational programs were well received and help improve the participate's understanding of degree day models and their value for pest management (appendix IV).

Impacts:

This project has helped further the development of high-resolution spatially explicit development models designed to predict both key insect life stages and weed emergence periods. These data will help promote IPM practices that base decisions on specific pest species timing and severity. Relative to weeds, being able to predict weed emergence will help growers make decisions about altering planting date, timing of in row cultivation, and post herbicide applications based on weed emergence periodicity. Relative to insects, being able to predict the time of key life stages provides a method of reducing the window for scouting and management.

The weed emergence and insect development models are currently providing guidance to crop consultants, county educators, and other agricultural professions. These model predictions are updating every day and provide an early warning of when to expect weed emergence and key insect life stages. This is very important to consultant and agricultural professionals with clients distributed over large geographic areas. Simulation of both insect and weed development show that the timing of key pest occurrence can vary across Pennsylvania by as much as five weeks due to great topographic variation in the state. Using the information provided by the models, these individuals can better anticipate when to spend time in a given area scouting for weeds and insects and when to start gearing up for weed and insect control. Because the models are driven by spatially interpolated temperature data generated by ZedX, Inc., they have the potential for use on all crop acres in the United States, although additional validation and improvements are needed before extending the utility beyond Pennsylvania. The models do not offer any

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new pest management approaches but they do provide an expanded capability for prediction of pest timing and eliminate the need for on-site weather sensors. This eliminates the issues of improperly working or calibrated sensors and the purchase of expensive equipment.

By having a better method of timing insect and weed activity, farmers can more precisely time herbicide and insecticide applications, maximizing their effectiveness and minimizing environmental contamination through the need for additional applications. The economic benefits of these models is hard to quantify at this time, however, time loss to scouting during the wrong time period and improperly timed pest management tactics account for a significant loss of resources. Cutting out one or two weeks from the window of scouting by forecasting the period of pest activity would allow the agricultural professional or farmer to focus their time on other important business aspects. By helping to target the windows of key pest activity, pest management actions should be more effective. Objective #2 (appendix IV) provides information on educational materials and numbers of growers/personnel trained. Additional insect model validation data sets have been collected by colleagues in Delaware, New York and private industry. These individuals have been beta testing the models and providing their access of accuracy, as well as using the models for their clientele.

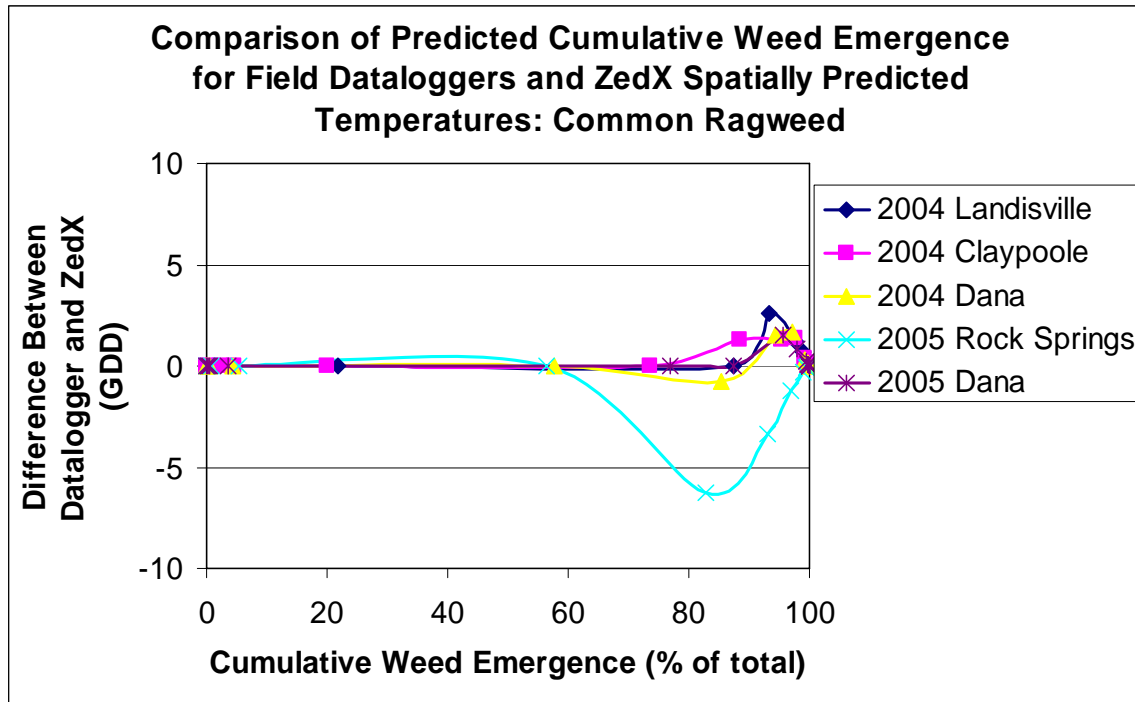
Appendix I: Comparison of spatially interpolated and locally measured temperature data for use as input into weed emergence models.

Self contained button type Hobo™ temperature dataloggers were buried at a one-inch depth in fields where weed emergence was observed. Accumulated growing degree days (GDD) for weeds were calculated from these data (48 F base temperature) and compared to similar data derived from spatially derived, spatially interpolated data generated by ZedX, Incorporated. The cumulative emergence of three weed species known to emerge relatively early (common ragweed), during mid season (common lambsquarters), and later (eastern black nightshade) were compared using the two temperature sources (on-site and ZedX, Inc. spatially interpolated) as inputs into the weed emergence equations. These comparisons were conducted for three sites during 2004 and two sites during 2005.

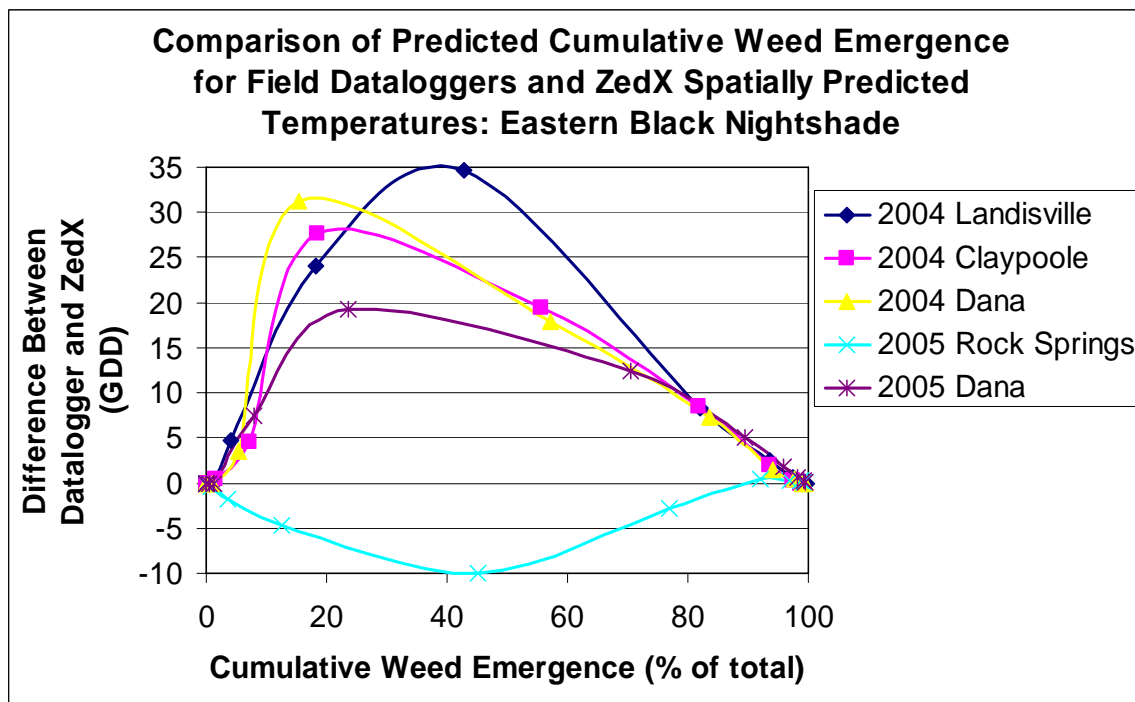
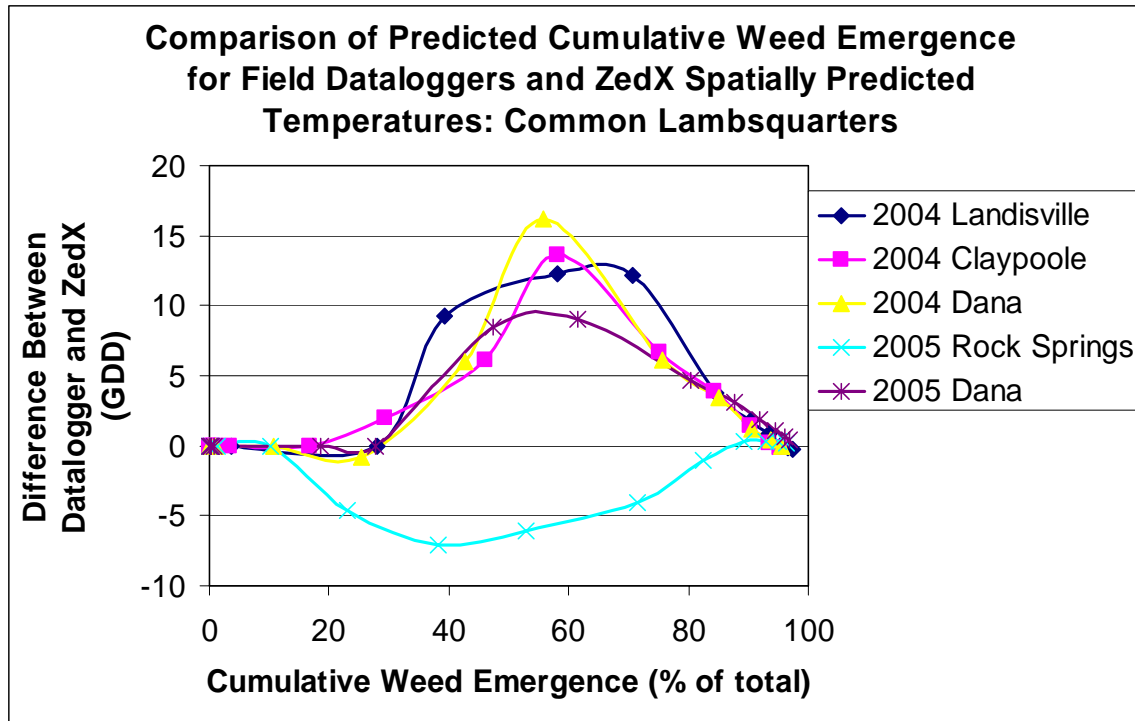
The difference between the two methods of calculating weed GDD and cumulative weed emergence was small until early May when dataloggers began accumulating degree days much faster than the ZedX predictions. This advantage, frequently 200 degree days or greater, remained for most locations through late June when the differences were greatly reduced, often to zero. The consequence of deviations in degree day accumulated using on-site measured and ZedX predicted temperatures on predicted percentage emergence are illustrated in the following graphs. The small differences (-6.2% to 2.6%) occurred for the early emerging common ragweed, with the greatest deviation occurring late in the emergence period. For the mid and late season emerging weeds these deviations were greater (mid – 16.2% to -7.0%; late – 34.7% to -10.1%) and they occurred earlier in the weed emergence period. Based on these findings, the value of spatially interpolated data for use in the weed models will be dependent on how the predictions are used. For instance, if the models are used to provide early warning of impending weed emergence,

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then the discrepancy may not be significant, but if used to time weed management activities they may not be adequate. The trade off is the cost of maintaining temperature sensors versus accuracy of prediction needed.



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Appendix II: Evaluation of weed model predictions using ZedX, Inc. spatially interpolated temperature data as an input compared to on-site measurements of weed emergence periods.

A total of 11 weed species were documented across the six locations over two years. Of these 11, seven species were recorded in high enough numbers to allow for further analysis. Several species and locations were omitted due to poor data sets resulting from low weed density or sporadic emergence. The data analysis was included for common lambsquarters at 4 locations, smooth pigweed, smooth crabgrass, eastern black nightshade, common ragweed, and yellow foxtail from three locations and giant foxtail at two locations. In addition, fall panicum was identified at several locations, however as this was a newly recorded species, an emergence model was not previously developed.

In general, the impact of planting a crop had a minimal effect on weed emergence compared to the no crop treatment. Rapid corn growth and development generally occurs after peak weed emergence, so crop canopy closure or other potential crop impacts on weed emergence likely were not a factor in this study. In the two seasons that data was collected, we experienced both higher than average rainfall in some areas (2004) and severe drought in others (2005). These variable weather events certainly increased emergence variability and should be considered in developing future research activities. This report will discuss the results for three representative weed species; the other species will be reported in more detail in future publications.

For Pennsylvania, from April 15 to May 30, daily degree day (DD) accumulations (base = 48F) are generally between 5 and 15 and increase to between 20 and 30 DD from June 1 to June 15 depending on location and year. For common ragweed, almost 100% emergence occurred by 500 DD. The difference between the observed and predicted percent emergence for the three locations averaged 50 to 120 DD (Table 1). The Wyoming County location was somewhat delayed compared to the predicted and other locations. For common lambsquarters, the difference between the observed and predicted percent emergence for the four locations averaged between a positive 50 to a -140 DD (Table 2). In general, the first half of the emergence curve followed the predicted curve more closely than the later emerging cohorts, especially for the Wyoming County location. For smooth pigweed, the difference between the observed and predicted percent emergence for the three locations averaged 10 to 42 DD and emergence was similar across the three locations (Table 3).

The results of this research help support the accuracy of our previous emergence models, but also show the need to more accurately determine how soil moisture or rainfall and perhaps preplant tillage play a role in developing more accurate weed emergence models.

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Table 1. Difference between observed and predicted percentage for common ragweed at three locations in Pennsylvania.

County		Difference (observed – predicted) in percent emergence in degree days for 25, 50 and 75% cumulative emergence		
		25%	50%	75%
Centre	2004	90	120	155
Centre	2005	50	90	155
Wyoming	2004	10	40	50
Average		50	83	120
SE mean		28	29	43

Table 2. Difference between observed and predicted percentage for common lambsquarters emergence at four locations in Pennsylvania.

County		Difference (observed – predicted) in percent emergence in degree days for 25, 50 and 75% cumulative emergence		
		25%	50%	75%
Centre	2004	80	65	-120
Lancaster	2004	20	70	-55
Lancaster	2005	90	-40	-340
Wyoming	2005	80	65	-120
Average		52	14	-177
SE mean		22	36	71

Table 3. Difference between observed and predicted percentage for smooth pigweed emergence at three locations in Pennsylvania.

County		Difference (observed – predicted) in percent emergence in degree days for 25, 50 and 75% cumulative emergence		
		25%	50%	75%
Armstrong04	2004	-65	-60	-130
Armstrong05	2005	130	160	110
Westmoreland04	2004	-190	-130	-10
Average		-42	-10	-10
SE mean		114	107	85

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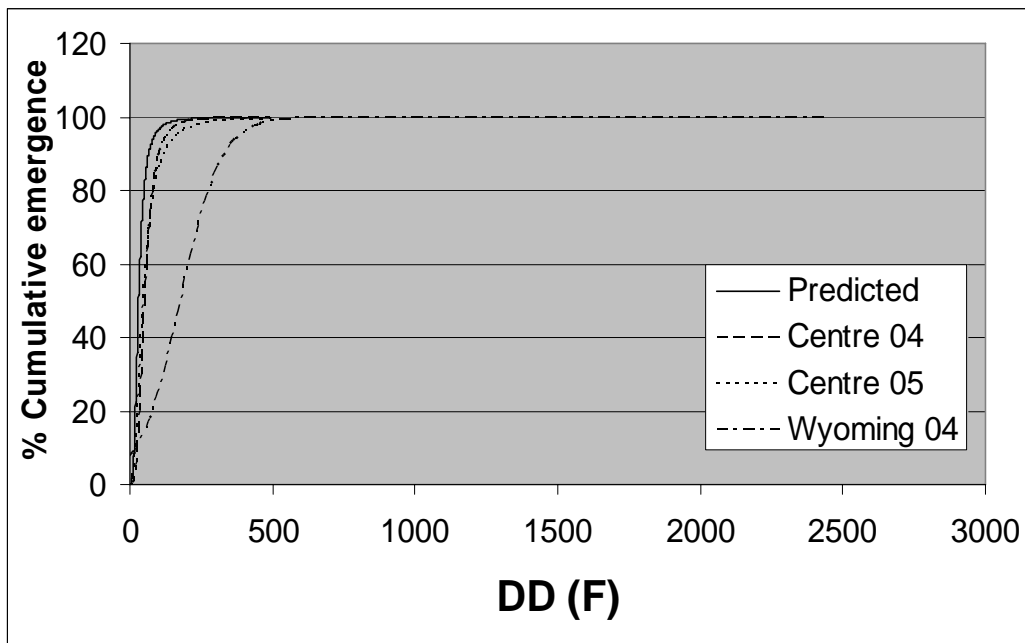


Figure 1. Cumulative common ragweed emergence at Centre County in 2004 and 2005, and Wyoming County in 2004. Predicted emergence is based on the emergence model developed by Myers et al., 2004.

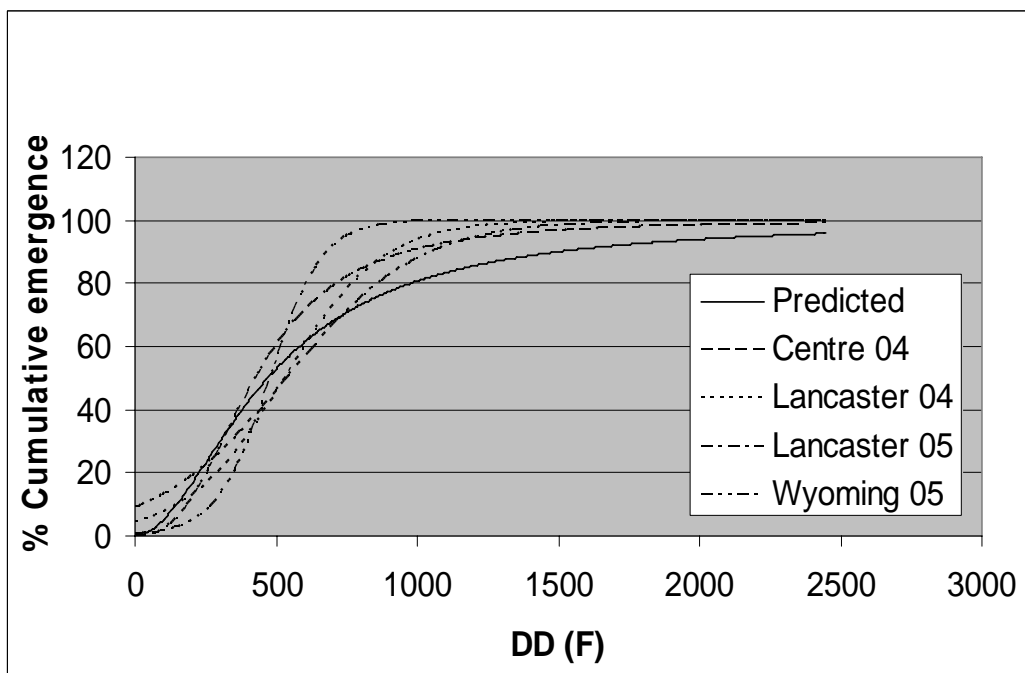


Figure 2. Cumulative common lambsquarters emergence at Centre County in 2004, Lancaster County in 2004 and 2005, and Wyoming County in 2005. Predicted emergence is based on the emergence model developed by Myers et al., 2004.

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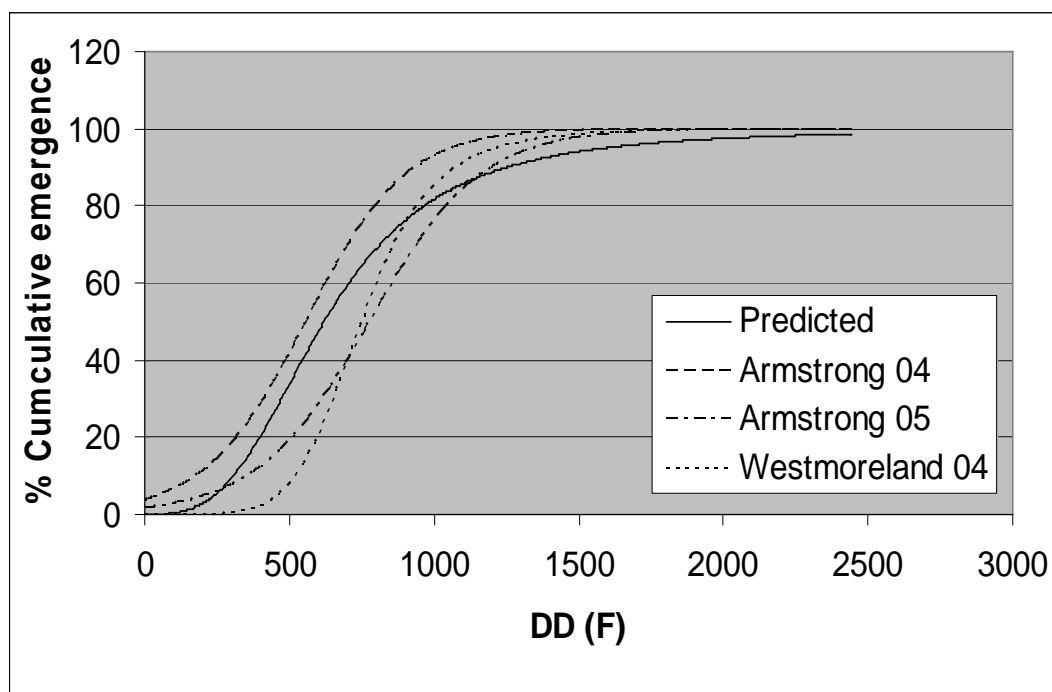
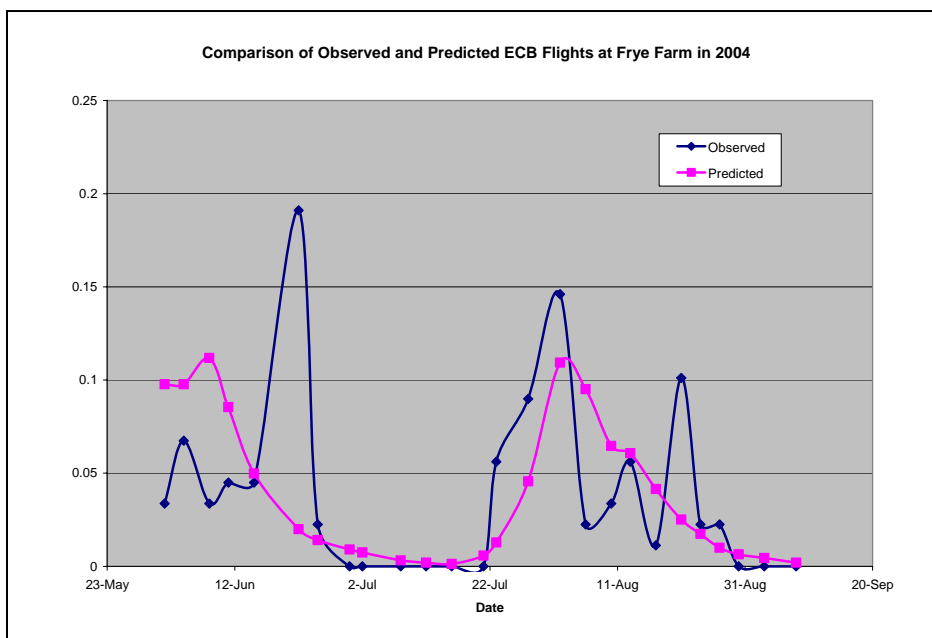


Figure 3. Cumulative smooth pigweed emergence at Armstrong County in 2004 and 2005, and Westmoreland County in 2004. Predicted emergence is based on the emergence model developed by Myers et al., 2004.

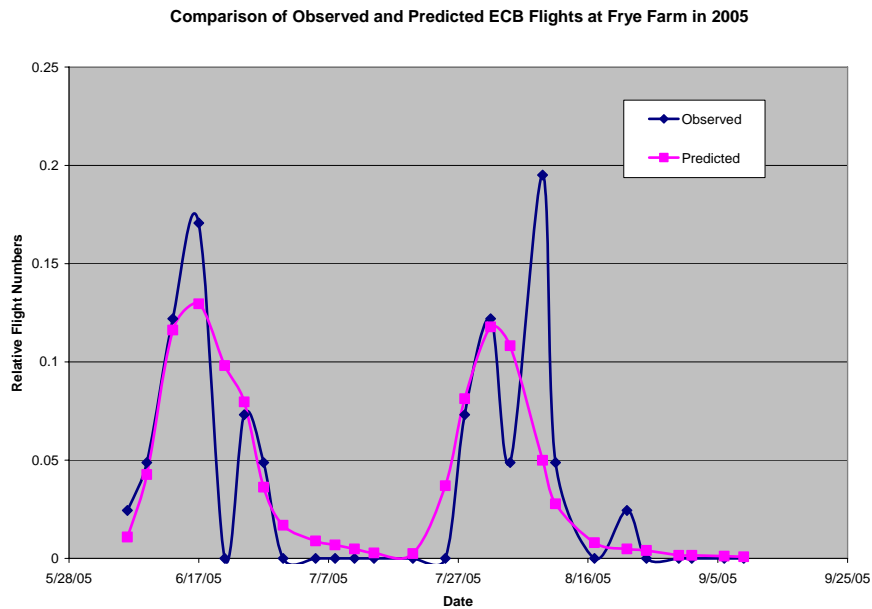
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Appendix III: Evaluation of insect prediction models relative to on-site observation of European corn borer adult flight periods and corn rootworm age structure.

Below are two examples of European corn borer flight predictions compared to on-site observed flights. Predictions of European corn borer flights closely followed the observed flights at the Frye Farm in Indiana, County Pennsylvania in both 2004 and 2005. However, the agreement between the predicted and observed second flight were typically better than for the first flight. The predicted corn rootworm stage structure tracked the observed stage structure at Landisville, PA well in 2004, but appeared to trail the observed emergence period in 2005. The 5% entrance into the 3rd and 4th instar was predicted for 2005. Frye farm data was 1 May and 6 May, respectively. Additional data analysis remains for the other locations, but preliminary analysis suggests that the predictions are within the window needed to provide an early warning for agricultural professionals of impending key life stages. Further analysis will be conducted and mean deviations between the predicted and observed data will be estimated as research papers are developed.

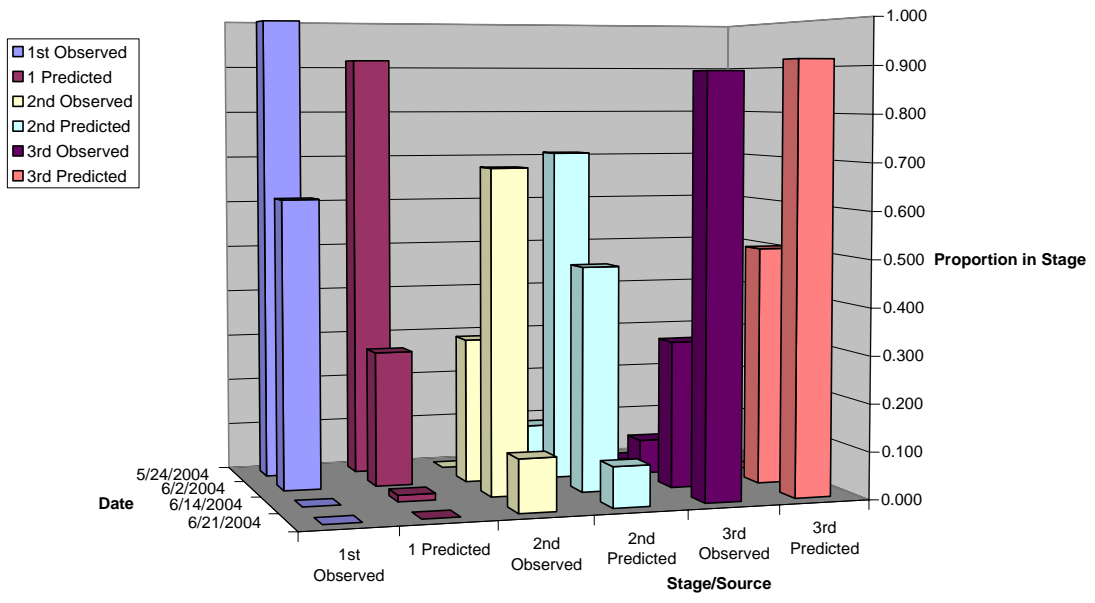


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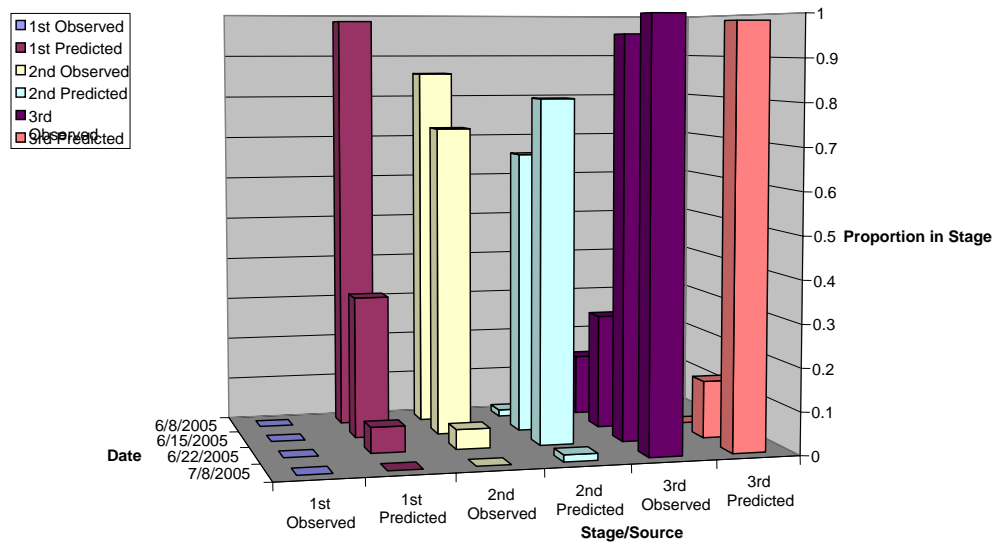


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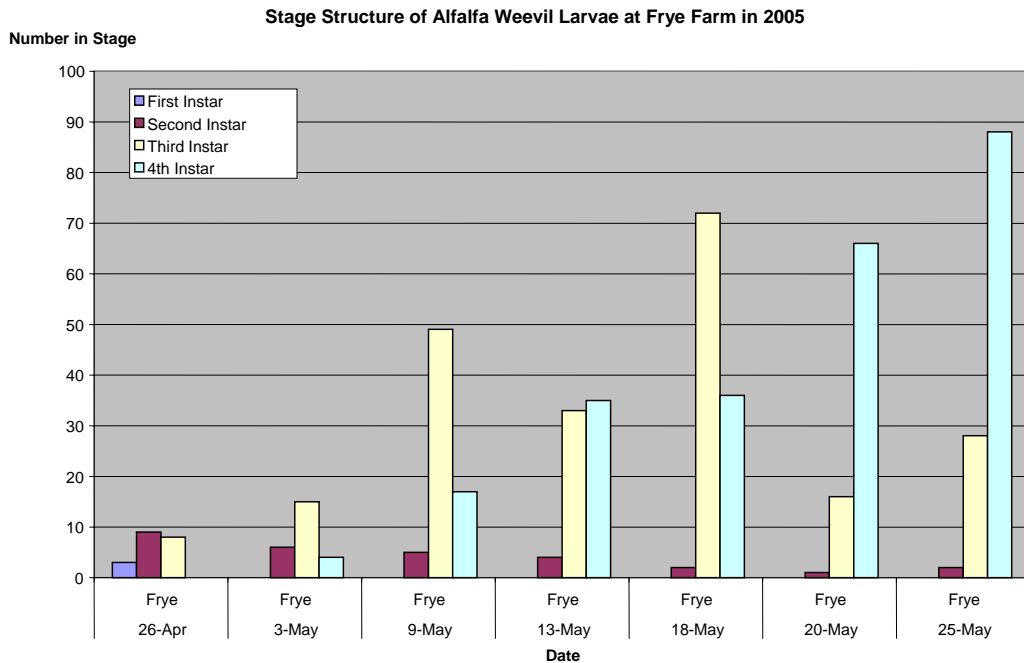
Landisville 2004



Lansdisville, PA 2005



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Appendix IV: Feedback from participants in field days.

Several outreach educational activities were conducted during the life of the project explaining objectives and goals of the project as well as how to use the information to better manage insects and weeds. An extension publication was developed titled “When Do Weeds Wake Up.” This publication was used at several educational events across the state. Educational meetings occurred in Armstrong, Centre, Mifflin, and Lancaster Counties at summer field days. In addition, an educational workshop was offered to crop consultants during the Pennsylvania Agronomic Education Society annual conference in State College. Results from a survey conducted at Armstrong meeting showed that 79% of those attending had large gains in knowledge and 21% had moderate gains in knowledge in understanding the concept of growing degree days (DD). In the same survey, 74% had large gains and 26% had moderate gains in understanding how to use insect and weed prediction maps. Finally, 53% of those attending were highly likely and 42% were moderately likely to use the web-based insect and weed emergence maps to help better manage insects and weeds on their farms or for their farm customers. (Figures 4 and 5).

Outreach photos



Image 1&2. Educational meeting with Ag Teachers at Rock Springs during July, 2006 (left). Dr. Dave Mortensen, Penn State discusses the “when weeds wake up” concept and publication. Field day conducted at the Village Acres Farm in Mifflin County, PA (June, 2006) where weed emergence periodicity was addressed.

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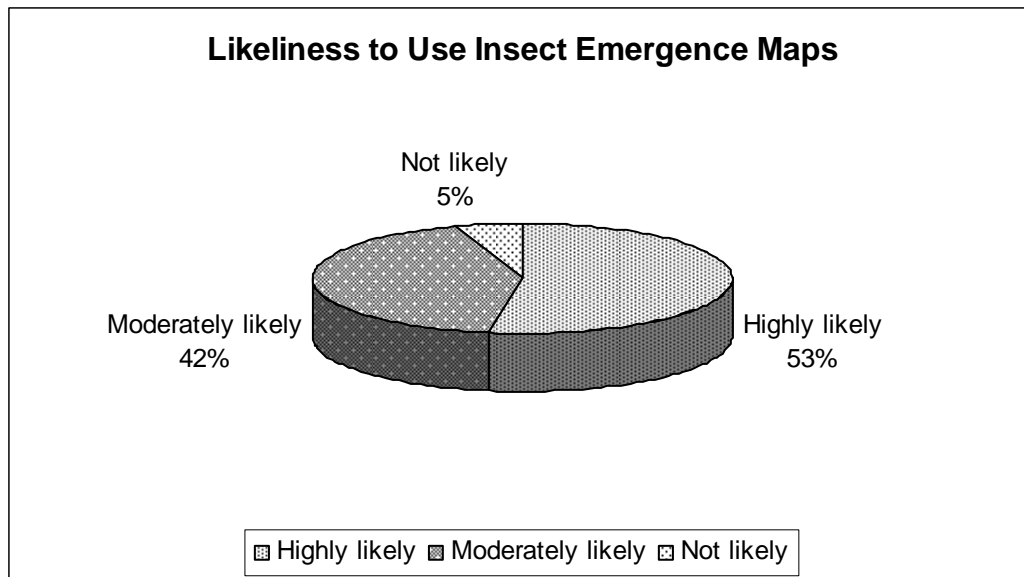


Figure 4. Survey results from a grower/consultant meeting conducted in Armstrong County, PA in 2005. Participants were asked their likeliness to use the web-based insect emergence maps.

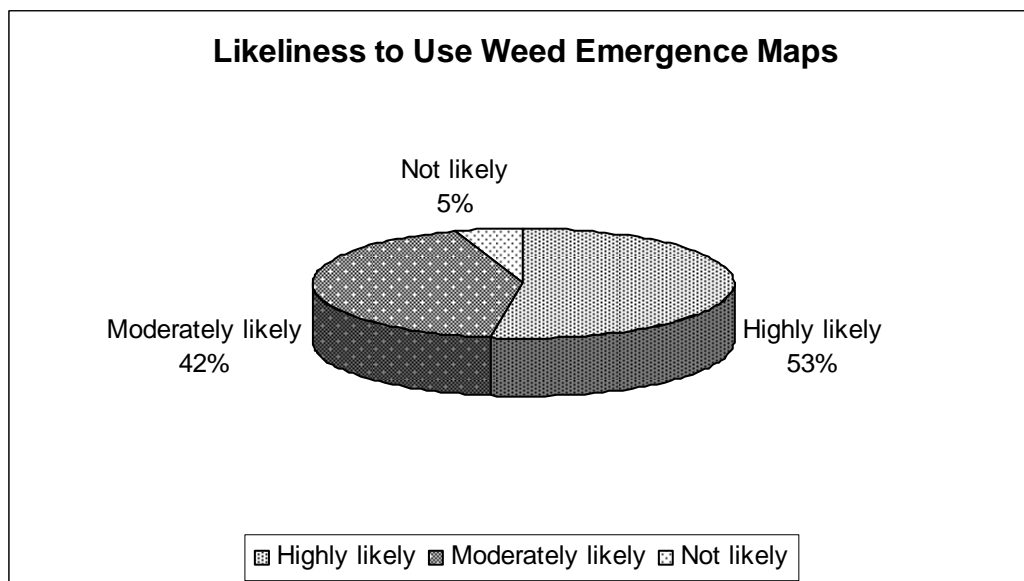


Figure 5. Survey results from a grower/consultant meeting conducted in Armstrong County, PA in 2005. Participants were asked their likeliness to use the web-based weed emergence maps.

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Appendix V: Publication resulting from work

Curran, W.S. and D. D. Calvin. 2004. Monitoring and predicting weed emergence. *Field Crop News* 04:02. College of Agricultural Sciences, University Park, PA 16802.

Mortensen, D., W. Curran, M. Ryan, A. Hulting, and S. Mirsky. 2006. Weed germination periodicity: When do weeds wake up? Dept. Crop & Soil Sciences, College of Agricultural Sciences, University Park, PA 16802.

Myers, M.W., W. S. Curran, M. J. VanGessel, D. D. Calvin, D. A. Mortensen, B. A. Majek, H. D. Karsten, and G. W. Roth. 2004. Predicting Weed Emergence for Eight Annual Species in the Northeastern United States. *Weed Sci.* 52:913-919.

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