Developing and implementing field and landscape level reduced-risk management strategies for Lygus in Western cropping systems

RAMP Project Summaries & Updates
RAMP PI Meeting
Maricopa Agricultural Center
June 22, 2009

Arizona Pest Management Center

RAMP Report – Colin Brent, USDA, ARS, ALARC, Maricopa, AZ

Studies have been conducted with laboratory populations of *Lygus hesperus* to elucidate the endogenous and exogenous factors regulating the reproductive development and behavior of both sexes. Age progression studies have shown that there is a tight correlation between post-emergence gonadal maturation and the initiation of reproductive behaviors. Males will not initiate courtship until their seminal vesicles and accessory glands are sufficiently full of product to deliver an adequately sized spermatophore to females, which occurs 2-3 days after emergence. Females show no interest in mating until they have begun to produce fully chorionated oocytes, happening 5-6 days after emergence. It is also at this stage of female development that males will first begin to show interest in mating. Younger females are simply avoided or ignored by males. The means by which females may signal this change in their reproductive maturation is currently being investigated in collaboration with Juergen Liebig (Arizona State University), using GC-MS to determine the age-based changes to their cuticular hydrocarbon profile. The underlying hormonal regulators of these concurrent processes are being investigated, with titrations for both ecdysteroids and juvenile hormone being measured during nymphal and early adult development. The intermediary role in these processes of the liphorin transport system, a carrier of both hydrocarbons and juvenile hormone, will also be investigated.

Females appear to be capable of producing viable offspring without mating, but egg production rates increase two- to three-fold once they have mated. In collaboration with Tim Judd (SE Missouri State University), the macro- and micronutrient content of the spermatophore is being determined to investigate whether males can enhance female fecundity by delivering limiting resources. In addition to increasing female fecundity, mating also induced a refractory period in both sexes. For males, this is a short delay of 22.5 hours, which appears to be the minimum time need to produce another viably sized spermatophore. For females, the median delay is 5 days. Their delay is loosely correlated with the time it takes to deposit their first clutch of mature oocytes and the degradation of the spermatophore. The refractory period may be timed to ensure that no mating occurs until additional sperm are needed, reducing a female's exposure to environmental hazards. The delay may also be induced by factors in a male's spermatophore which inhibit females from remating, thereby reducing the chances of sperm competition. Results from the injection of spermatophore constituents directly into the abdomen of females indicate that the males are inducing female inhibition, at least for the first 24 hours. A similar approach is being used to pinpoint the production source of this inhibitory substance with the intent of isolating and identifying it. It was also observed that the delay in female remating is enhanced by a decline in their attractiveness to males shortly after mating. This could result from a change in the female's expression of factors signaling her reproductive status, or may be from factors transferred from a male via the spermatophore. The latter possibility is being investigated with the hope of finding a highly selective sprayable agent that can be used to disrupt mating in field populations.

The effects of several environmental influences on Lygus reproductive behavior and development are also being investigated. The effects on reproductive development and behavior of increased population density, decreased day length and nutrient availability are being studied. While population density had a significant effect on the duration and extent of nymphal development, nymphs reared under low density conditions then placed in high densities as adults experienced few negative consequences in terms of fecundity or longevity. Photoperiod response studies, conducted in collaboration with Dale Spurgeon (ARS, Shafter, CA), have helped to better define the morphological markers of diapause, with several robust trait associations identified. Additional research is being conducted to determine how individual showing a wide range of physiological responses to short day length may respond behaviorally.

Scott Bundy Research (Plant/Pest/Pesticide Interactions; Matrix section I):

1. Economic Injury Evaluations for *Lygus* in New Mexico Cotton

Data are currently under analysis for the 3 years of this project. The goal is to develop an economic threshold for *Lygus hesperus* on cotton in New Mexico. This corresponds closely with a sub-objective for better characterization of internal and external signs of boll injury due to feeding by nymph and adult plant bugs. Preliminary analyses showed that levels of between 4-6 adults and 2-4 nymphs of *L. hesperus* were needed per plant (not sweep samples) before significant yield loss was documented in the field. These data provide general information on economic thresholds for *L.hesperus* in western cotton and should be useful to fellow researchers, consultants, etc. There are currently no thresholds for cotton in New Mexico; our data should be of particularly interest to growers in the state. This research has been presented at the Beltwide Cotton Conference, branch and national entomological meetings, and state grower meetings. Anticipated publications: 4 proceedings, 2-3 extension bulletins, 3 research journal publications.

2. Plant Bug Injury to Chile Peppers

Baseline data are being developed for potential injury to chile peppers by *Lygus hesperus*. Various ages of fruiting structures are currently being evaluated. Analyses will be completed later in the year. A descriptive survey of injury is being compiled. *Lygus* definitely show the potential to cause economic loss under caged conditions in the field. However, preliminary population data show that peppers may not be a preferred host in southern New Mexico. This season will give us a better indication of what the *Lygus* are doing in the field. Our research will be the first descriptive evaluation of *Lygus* injury to chile pepper and should valuable to chile growers, researchers (possible link to landscape assessments), and consultants in the Southwest.

This research will be presented at state chile grower meetings, and branch and national entomological meetings. Anticipated publications: 1 extension publication, 1-2 research journal publications.

Lygus RAMP

Carrière and Dutilleul Report for 2008-2009

Accomplishments for the last period have been many.

1. We produced and analyzed GIS maps to determine the distribution and abundance of *Lygus* crops around the focal cotton fields sampled for Lygus density. We have used Google Hearth and other tools to add to these maps non-cultivated vegetation, which may act a source of *Lygus*. The GIS maps that have been completed and analyzed are AZ 2007, CA 2007 and 2008, and TX 2007 and 2008. We plan to finish AZ 2008 in the next month.

2. We have collaborated with P. Ellsworth to map the new 2009 study area in Arizona. The last field season is under way.

3. We have developed three new programs to analyze landscape data. All programs perform both parametric and non-parametric statistical analyses of landscape data. Analyses take into account spatial autocorrelation when assessing the significance of effects tested. The new programs perform multiple regression / partial correlation analyses of landscape data, stepwise regression / partial correlation analyses of landscape data, and path analyses of landscape data. The new programs and accompanying documentation will be freely available on the Web soon. A publication is under way to demonstrate how these statistical tools can be used to analyze landscape data.

4. We have made significant progress in performing statistical analyses of the data collected in 2007 and 2008 in AZ, CA and TX. We have not developed a final method of analysis yet. We are confident that we will be able to develop a method that can adequately handle a high degree of multicollinearity and spatial autocorrelation in landscape data.

SUMMARY REPORT
RAMP Workshop 22-23 June, 2009
Peter Ellsworth, University of Arizona, Maricopa, AZ

Plant/Pest/Pesticide Interactions

Objective 1b. ***Refinement of Yield-Density Relationships & Key Economic Information***

Cotton (for Lesquerella and guayule, See Naranjo report).
Four years of data were analyzed to determine when the last effective spray should be made to control Lygus in cotton. These data represent two planting dates, two dates of irrigation termination, three maturity classes and three nominal termination timings for Lgyus control relative to an UTC. All sprays were made according to a previously determined economic threshold of 15 total Lygus including at least 4 nymphs per 100 sweeps ('15:4'). Economic outcomes were impacted by all variables leading to a dynamic set of rules for terminating control in cotton. In general, earlier planted cotton was subjected to less risk and damage from Lygus, and smaller returns from Lygus controls than later plantings. Similarly, short-season varieties benefited the least in the extension of Lygus chemical controls later in the season. Conversely, long-season varieties, particularly those planted in a later window, were subject to major risks of loss to Lygus and greater net returns on later terminations of Lygus chemical controls. Irrigation timing was less influential, but in general irrigations extended beyond cut-out led to conditions requiring later Lygus control terminations.

A multi-color graphic was developed for each planting date scenario that depicted the impact of two factors (variety x irrigation termination timing) on the economic returns of Lygus control termination decisions. This graphic has been presented in a series of grower meetings where the concept of diminishing returns of Lygus controls were taught. One commercial grower demonstration was conducted in 2007 and dramatically showed the importance of all these factors in making control decisions. This grower elected not to extend control, but the "correct" decision called for one more spray (for a total of 1 sprays) with flonicamid and returned at least $18 / A in excess of input costs. The results of this demonstration have also been shared at grower meetings where they stimulated much discussion about the decision-making process for Lygus control. Additional grower demonstrations are planned for 2009.

Objective 2a. ***Isolating and Evaluating Effective Chemistry***

Cotton
Replicated small and large plot evaluations of candidate Lygus control chemistry, including reduced-risk options have been extensively tested each year in contrast to conventional standards (acephate and/or oxamyl). Acephate, the number one Lygus control product up to 2006, has in the past controlled Lygus very well. Acephate treatments generally yield as well or better than any alternative. However, in the 2008

evaluations, the acephate treatment was significantly lower yielding than the reduced-risk alternatives. Also, secondary pest problems (mites and whiteflies) were documented.

Flonicamid (Carbine @ 2.8 oz / A) has consistently led our trials in terms of Lygus control and yields. Metaflumizone (@ 0.25 lbs ai/A), still unregistered for cotton, has provided comparable control of Lygus and protection of yield. Novaluron (Diamond) has failed to provide commercially acceptable Lygus control and has been associated with secondary pest outbreaks (whiteflies) and natural enemy destruction. V10170 (clothianiden or Belay) has produced mixed results. At times, Lygus control and yields have been excellent; however, other times this compound has not performed as well as the reduced-risk alternatives. This compound will be tested in a large plot format in 2009 for the first time.

See OUTCOMES on last page

Regional Ecology, Movement & Modeling

Objective 3a.

Regional Ecology Lygus Project – Central Arizona (Also see Carriere report)
We have completed two years of regional mapping and sampling of Lygus in commercial grower fields and other habitats (alfalfa, guayule and weeds). More than 50 cotton fields were sampled weekly for Lygus and associated natural enemies. We are just completing summary of the 2008 data and preparing for delivery to Carriere et al. Our first season's sample processing was slowed by a freezer break-down, which degraded samples and led to major increases in processing times and costs. As a result, our processing investment in 2008 had to be reduced to conserve budget and has led to a delay in delivery of these data for processing by Carriere's and Dutilleul's groups. In 2009, we have again selected over 50 fields and began sampling last week. Our goal this year is to process Lygus from these samples contemporaneous to collections, rather than awaiting winter processing. We hope to deliver data for processing in the fall of this year.

Grower Education

Objective 2a, 3b, 4b, 4c.

On Farm Demonstrations – Arizona Cotton

Already noted above, but to summarize, we have run one commercial grower demonstration of flonicamid and Lygus control termination timing, one demonstration of the impact of natural enemy exclusion using conventional standard Lygus chemistry, and plan to run 3 grower demonstrations in 2009. We have also held Extension meetings and one field day where these demonstrations have been highlighted. One major popular press article was published on the natural enemy exclusion study. Two growers have reported that they finally "get IPM" and see the benefits of natural enemy conservation as this related to Lygus chemical controls and whitefly management.

Teaching Lygus Sampling Techniques

One supplementary grant was submitted, but denied, to the Cotton Foundation to help support the development of a video on proper sweeping techniques in Western cotton. Preparations have been made with the UofA Educational Communications and Technologies (ECAT) videographer to develop this video in 2009. The basic techniques for accomplishing a proper sweep sample have been written up as part of PCA training materials and will be adapted into a one-page bulletin to support the training process. Live demonstrations and workshops (3–6 in central Arizona) are planned during the 2009 cotton season, where proper sampling techniques will be shown and discussed.

International Forum for Lygus Scientific Exchange

In 2007, the 2nd International Lygus Symposium was organized by RAMP PIs (Ellsworth & Goodell) and held in Asilomar, CA, where over 50 Lygus scientists convened and shared research results. Survey responses were positive, and plans will be initiated in 2009 to solicit interest and organizational leads for a follow-up meeting during 2010.

Game Training Simulation

Preparations are being made to build a game training simulation to emphasize the regional relationships among source and sink crops and the advantages to adjusting crop placement to avoid damaging levels of Lygus. Results from movement studies may give some insight on how to build the simulation. A mechanistic simulation approach was developed by Andrew Corbett, but may not be reflective of actual movement dynamics. A probabilistic model based in part on results from the regional ecology project may be a better basis for a simulation. Corbett's other job responsibilities have precluded his continuation on this project. He has helped identify a private resource, Cadre, out of NSW, Australia, which may be capable of developing the game training simulation. Two conference calls have been initiated with the Aussies to solicit a proposal from them. Resources that were allocated for Andrew Corbett to work on this (in the CA budget) will be needed to support this effort, whether the Aussies successfully bid for it or not.

OUTCOMES

Research results have been routinely delivered to growers through presentations and informal publications. Carbine has been taught to growers as the only reduced-risk, selective option for Lygus control and therefore as the first chemical option for Lygus control as a way of extending the utility of natural enemy conservation (especially when adopted with Bt cotton and Integrated Control of whiteflies).

The last 3 years have been the lowest insecticide use in AZ cotton on record (30 years), at less than 1.5 sprays season-long. Growers have sprayed less than twice for all insect pests of cotton over the last 3 seasons, averaging just 0.56 sprays against Lygus, less than 45% of the 13-yr average. In 2007 and 2008, growers reported much untreated acreage.

Our results on metaflumizone, a selective chemistry for Lygus control, have been used in a Public Interest Document (PID) submitted to EPA in support of its registration in cotton. They have also been used to support registration processes in Canada. The only reduced-risk alternative currently on the market for Lygus control is Carbine, registered in 2006. One grower demonstration was conducted and showed excellent activity on Lygus (when sprayed by air) and excellent yield protection with no evidence of secondary problems.

Adoption rates have been remarkable. In just 1–2 years (2007-08), growers chose to use the reduced-risk insecticide alternative (i.e, Carbine) instead of standard and effective broad-spectrum options (from 0% in 2006, 52% in 2007, 64% in 2008 of Lygus applications), despite their lower per application costs. Clients and other stakeholders credit our research and outreach as one of the major reasons for this rapid change-over.

Our 2008 random survey of grower pesticide use practices in central Arizona revealed the following adoption rates for flonicamid (Carbine) use for Lygus control and its first use, i.e., deferring broad-spectrum insecticides.

- 1.86 sprays were made to control Lygus in 2008
- 86% of fields were sprayed for Lygus

The remainder of these data are of those that did spray for Lygus:

- 12% of fields were not sprayed with Carbine
- 64% of all Lygus-targeted insecticides were Carbine
  - 15% were endosulfan, often directly at a co-target (i.e., whiteflies)
  - 21% were acephate
- 77% of fields elected Carbine first before any other Lygus insecticide
- 86% of fields were treated at least once with Carbine

One grower alone reported adopting this compound in 2007 on 1200 A resulting in 0% loss to Lygus, based in part on this research and the pilot guidelines. Two Arizona PCAs reported using nymphs exclusively for timing Lygus chemical controls on cotton, overturning a long-standing practice of spraying based on Total Lygus and/or adult Lygus counts only. This reflects a change in behavior and recognition of the role nymphs play in the damage dynamic and in our threshold guidelines.

Research Initiatives in Fabrick Lab on Lygus pest management

1) Establish RNA interference (RNAi) mechanism in *Lygus*. Long term goal is to utilize RNAi technology using novel genes towards pest management strategies. We are working on designing and developing experiments to establish initial "proof of concept" of RNAi in *Lygus* using marker genes. We are also concurrently mining for novel genes to design and conduct studies that can effectively be utilized in pest control strategies.

2) Germ-line transformation of *Lygus* using green florescent protein as a tool towards functional studies of relevant genes and/or as marker insect for effective pest management. We have created original research thrust and initiated new collaboration to foster research in that direction.

RAMP Project Summary: Fournier

Section IV: Extension / Outreach / Education / Evaluation

Extension & Outreach

Objectives:
(1) Provide a clearinghouse for RAMP project information, resources and presentations.
(2) Create a listserv to facilitate ongoing two-way communication among RAMP partners.

Project Status:

- We have developed a website to host all RAMP-related publications, presentations, reports and other deliverables at http://cals.arizona.edu/apmc/RAMP.html. There is a section "Publications and Outputs" where I have posted all publications, presentations, etc., as RAMP PI's let me know about them. I expect we will have more Extension publications, presentations, journal articles, etc in the near future. **Please send me any RAMP-related publications or other outputs for posting.** As more outputs accumulate, we will create a single page focused on Lygus research outreach.
- We have set up a Lygus-RAMP listserv at lygusramp@CALS.arizona.edu. The listserv has been a good communication tool, but has been under-utilized, serving mainly for one-way communication from Peter or I to the group. **I strongly encourage everyone to keep the listserv in mind and use it to share research results, new publications and presentations, or to post questions to the group.**

Evaluation of RAMP

Objectives:
(1) To measure delivery of practical RAMP-generated information to clientele.
(2) To measure client adoption of new crop/pest management recommendations and the economic and environmental impacts of this adoption.

Project Status:

- There are 4 main things we need to measure: activities (what we do), results (what we learn), products (how we share what we learn) and outcomes & impacts (what we change or influence)
- We have several tools / methods available for documenting our productivity and impact.
- **Tracking Matrix.** *Thanks to everyone for submitting your tracking matrix reports on time each year.* This has been a valuable tool for collecting basic information on research activities, outreach activities and products, and leveraged resources, which is included in annual RAMP reports. The matrix has been less useful for reporting *research results*, as we found out in Year 2. Leveraged resources were also a bit confusing to compile, since some people listed the same resource across multiple projects. For the coming year, we will still use the matrix but will send out a separate form for reporting on research results, leveraged resources, and project outputs.
- **Lygus Survey.** The RAMP Evaluation Team (Fournier, Ellsworth, Goodell, Parajulee, Bundy and Kerns) has developed and implemented a Lygus Survey to measure changes

in clientele knowledge, skills and behaviors related to Lygus management. It also measures their knowledge and use of existing Lygus management information resources across the 4 states. The survey has been conducted at face-to-face meetings with PCAs and other clientele in Arizona, California, New Mexico and Texas. 144 surveys have been completed (2008 & 2009, 67AZ, 12NM, 28CA, 37TX) and data are currently being entered for analysis. The idea of the survey is to capture "before" and "after" data on lygus knowledge, management practices and use of resources. So far as I know, no new education resources have been released based on RAMP research, but when they are it will allow us to track the adoption and use of these resources. Data will be analyzed on a state-by-state basis, then pooled for combined analysis.

- **Tracking Practical Impacts.** Quantifying environmental & economic impacts of our project is the biggest challenge. We cannot measure these directly, but we do have data sources that can be used to measure trends or changes in grower management practices over time.
    A. **Pesticide use data.** In AZ and CA we have access to pesticide use reporting data that will be used to measure changes over time in adoption of selective Lygus chemistries and reductions in the use of broad-spectrum chemistry. From this we can infer environmental benefits. While this is only a general trend, we can also measure adoption of new chemistries for Lygus control that were field-tested as part of the RAMP. *Progress:* In AZ, we have hired a database specialist, Richard Farmer, who is developing a historical pesticide use database (19 years of data). The shortcoming of this approach is that we do not have similar data sources available for NM and TX. I am open to ideas from the group on this. Perhaps similar information can be gathered in those states using a survey.
    B. **Random Field Survey.** Another data source that will provide insights into community level pest management practices is the Regional Ecology sampling project. Peter Ellsworth, Pete Goodell and Megha Parajulee are collaborating on large-scale regional sampling of Lygus in the different crop communities of TX, AZ and CA. As part of that study, they are collecting field-level pesticide use data from the cooperators. Because of the size of the study (e.g., over 50 fields in central AZ) and the random sampling design, these data should reflect the practices of the larger communities, and are already telling us much about changes in pest management practices. (e.g., Peter's data on the adoption of Carbine.)
    C. **Crop Pest Losses survey.** In AZ, we have been conducting crop insect loss surveys in cotton, melons and head lettuce for several years. PCAs estimate yield losses in their crops as part of a post-harvest face-to-face survey each season. They apportion total yield loss among the different insect pests and also provide detailed information on insecticide use and target pests. With this data, we can track changes in Lygus pest status from year to year and changes in the control measures that are used. We ran a pilot Crop Insect Losses meeting in Lubbock, TX, in June 2007, but I do not believe the survey has been repeated there.
- **Scientific Outputs & Impacts** should be documented by each of us. Research presentations & publications, abstracts, etc., have previously been reported in the matrix. However, starting in 2009 we will collect data on research results, products and leverage through a separate process yet to be finalized. PIs should try to be sensitive to, and

definitely report, any impacts of your work that you identify. There is a space on the matrix to report "impact nuggets." A good impact nugget is any bit of information you can provide, even anecdotally, that shows some influence of your RAMP work on someone—it could be a grower or a fellow scientist. One example of an impact nugget might be an influence your research has had on peers, or the initiation of a new collaboration to build on RAMP results. A good impact nugget links one of your activities to someone else's action or behavior.

Key Findings:
Because data analysis is pending, I have no findings to report. The analysis of Y1 data will provide a baseline against which progress will be measured.

Project Modifications:
The reporting process will change this year. While all PIs will still be asked to fill out the project reporting matrix to provide brief summaries of their activities, some of the information gathered via the matrix in the past will be collected using a separate "Results and Outputs" form. This will allow PIs to articulate their research results in more detail, including graphs and tables if desired, and will provide direct citations for all publications, presentations and other RAMP outputs. In addition, this will streamline the reporting of leveraged resources.

Relevance of these projects to all RAMP PIs: We are quickly approaching the homestretch for this grant. Our success will be measured, in large part, by how well we communicate the outcomes and the impacts of our project to the granting agency, growers and the public. The perception of our success will influence our competitiveness for future RAMP or other grants. For this reason, both the delivery of practical Lygus management information and the evaluation of its adoption and impact are important to all of us.

Other Comments: These projects are outreach oriented, so no information related to the gaming simulation will be generated.

Summary from Larry Godfrey, UC-Davis

(1) Plant/Pest/Pesticide interactions

Project Title: *Strengthening research and extension in Pima cottons*
Project Directors: Goodell, Hutmacher and Godfrey

- What is the current status of the project?
    - Goodell has been spearheading this part of the project; I observed the plots in 2008 but it appeared that the Lygus population overwhelmed the plot
- Summarize your key findings to this point (preliminary data is okay).
    - None from me
- How will the information from this study be useful to other RAMP PIs or other components of the RAMP project?
    - Not clear at this time
- Specifically, how might the results contribute to the RAMP gaming simulation?
    - Not clear at this time
- How will information from this study be useful to growers or other target audiences in the public (i.e., what is the anticipated application for the findings)?
    - Clearly Pima is highly susceptible to injury from lygus bugs but the exact yield loss relationships have not yet been determined.
- What are the existing and anticipated outputs of this work (presentations, papers, extension publications, newsletters, websites, new grants or projects, etc.)?
    - The UC-IPM Pest Management Guidelines is the primary source of IPM "recommendations" from UC and will be used. The possibility of other more scientific publications is unclear at this time.
- Explain any modifications to the project including any setbacks or barriers to completion of the original objectives specified in the grant.
    - The study relies on "cooperating" insect populations which is not always a reality.

Project Title: *Refining pest management guidelines for Lygus in dry beans*
Project Directors: Godfrey

- What is the current status of the project?
    - Small Baby Lima Bean research at UC-Davis – 2007 and 2008: Very high lygus populations were seen (up to 10x the existing threshold); populations were manipulated with insecticides
    - Cowpea research at Shafter REC – 2007 and 2008: subeconomic populations of lygus, in 2007 confounding factor of spider mite outbreak
- Summarize your key findings to this point (preliminary data is okay).

    - Small Baby Lima Bean: Significant relationship between lygus numbers and bean yield on the commonly-grown bush variety ('Luna'); even with three applications during the season (which is not economical for these growers) not able to produce top grade beans due to lygus "stings"; however, this must be considered in light of the abnormally high populations encountered; a new variety has been developed by the bean breeder that has a moderate to high level of resistance (tolerance?) to lygus; even under this high lygus pressure, yields were unaffected and one to two applications of a "soft" insecticide protected the crop quality
    - Cowpea: Lygus pressure has not been high enough to impact yield, some bean quality effects seen but not consistent
- How will the information from this study be useful to other RAMP PIs or other components of the RAMP project
    - New information regarding management in two bean types.
- Specifically, how might the results contribute to the RAMP gaming simulation?
    - Probably will not
- How will information from this study be useful to growers or other target audiences in the public (i.e., what is the anticipated application for the findings)?
    - Information has been presented annually at two summer field days and in a winter production meeting
    - Pest Management Guidelines for Dry Beans
- What are the existing and anticipated outputs of this work (presentations, papers, extension publications, newsletters, websites, new grants or projects, etc.)?
    - Development of revised Pest Management Guidelines for dry beans
    - Bean progress report
    - Handouts at field days
    - New bean variety pedigree has been submitted for publication with a proposed name('Haskel')
- Explain any modifications to the project including any setbacks or barriers to completion of the original objectives specified in the grant.
    - None
    - Observations – I can use 4-row wide plots (35' long) and maintain plot integrity between a plot with high lygus numbers and a neighboring one with low numbers in beans; cannot do this in cotton with plots 3x this size
    - Question – Lima growers are growing more vine lima bean varieties, any ideas how to sample lygus in this viney bean "jungle" – difficult to walk, power a sweep net through it, etc.

(2) Individual Behavior & Local Movement -

Project Title: *Evaluating efficacy of registered and experimental insecticides for Lygus management in cotton*

Project Directors: Godfrey, Parajulee

- What is the current status of the project?
    - In 2007 and 2008 up to 20 treatments were evaluated; 3 applications were used; lygus populations were very high in 2008 and moderate in 2007; cotton yields were evaluated; plant mapping data were collected; impacts of the insecticides of populations of natural enemies were evaluated; propensity of insecticides to flare populations of secondary pests (cotton aphids and spider mites) was evaluated
- Summarize your key findings to this point (preliminary data is okay).
    - In 2008 under the very high lygus pressure, flonicamid (alone and in combinations) clearly showed advantages in terms of yield protection; oxamyl also shows some utility for lygus management; pyrethroid insecticides were only slightly to moderately effective (3-5 days of suppression); other experimental insecticides showed poor to moderate (at best) activity, susceptibility was monitored in 2008 via bioassays of field-collected adults with clear levels of pyrethroid resistance detected
- How will the information from this study be useful to other RAMP PIs or other components of the RAMP project?
    - Although there are recognized differences in lygus response to insecticides in various areas, some of these data should be useful to others working in cotton IPM
- Specifically, how might the results contribute to the RAMP gaming simulation?
    - Not clear to me
- How will information from this study be useful to growers or other target audiences in the public (i.e., what is the anticipated application for the findings)?
    - Growers are always interested in findings on insecticide efficacy, especially new, reduced-risk products
- What are the existing and anticipated outputs of this work (presentations, papers, extension publications, newsletters, websites, new grants or projects, etc.)?
    - UC Pest Management Guidelines, Beltwide cotton conferences
- Explain any modifications to the project including any setbacks or barriers to completion of the original objectives specified in the grant.
    - None

Project Title: *Evaluating efficacy of registered and experimental insecticides for Lygus management in dry beans*
Project Directors: Godfrey

- What is the current status of the project?
    - In 2007 and 2008, 8 to 12 treatments were evaluated; up to 3 applications were used as well as 3 application timings (early bloom, pod fill and bean maturation); lygus populations were very high in the baby lima bean site and moderate in cowpea studies (this reflects the location of these studies and not the susceptibility of the bean type)
- Summarize your key findings to this point (preliminary data is okay).

  - The pyrethroid insecticides definitely gave the best control in the lima studies and were among the most effective in the cowpea studies; dimethoate is the other registered material and was a poor performer, experiential products were marginally effective.
- How will the information from this study be useful to other RAMP PIs or other components of the RAMP project?
  - Although there are recognized differences in lygus response to insecticides in various areas, some of these data should be useful to others working in lygus management
- Specifically, how might the results contribute to the RAMP gaming simulation?
  - Not clear to me
- How will information from this study be useful to growers or other target audiences in the public (i.e., what is the anticipated application for the findings)?
  - Growers are always interested in findings on insecticide efficacy, especially new, reduced-risk products
- What are the existing and anticipated outputs of this work (presentations, papers, extension publications, newsletters, websites, new grants or projects, etc.)?
  - UC Pest Management Guidelines, grower meetings
- Explain any modifications to the project including any setbacks or barriers to completion of the original objectives specified in the grant.
  - None

(3) Regional Ecology, Movement & Modeling

Project Title: *Influence of surrounding crops on Lygus infestation in cotton*
Project Directors: Goodell, Rosenheim & Godfrey

I have been available if needed but Pete G. and Jay have handled the activities; I have discussed the results and aided in the interpretation

(4) Game Training Simulation

No activity.

(1) Plant/Pest/Pesticide interactions

Project Title: *Strengthening research and extension in Pima cottons*
Project Directors: Goodell, Hutmacher and Godfrey

- What is the current status of the project?
  - 2008 experiments lost due overwhelming pressure
  - 2009 experiments at KAC are in place and populations building. Sampling of plant and insect populations underway
- Summarize your key findings to this point (preliminary data is okay).
  - Observations suggest Pima cotton far less elastic in being able to compensate for early fruit loss. Pima appears to be extremely attractive to Lygus, with populations spreading uniformly across plots, regardless of availability of alfalfa
  - Adults caused majority of damage, little to no reproduction in field

- How will the information from this study be useful to other RAMP PIs or other components of the RAMP project?
  - Different plant response to Lygus,

- Specifically, how might the results contribute to the RAMP gaming simulation?
  - No suggestions at this point
- How will information from this study be useful to growers or other target audiences in the public (i.e., what is the anticipated application for the findings)?
  - Expected outcome is an increased understanding of Lygus population density on Pima yield.
  - The output will be updated information into existing management guides.
  - Long term outcome is improved Lygus management decisions, optimized use of pesticides against the pest and management of risk to yield form pest.

- What are the existing and anticipated outputs of this work (presentations, papers, extension publications, newsletters, websites, new grants or projects, etc.)?
  - The output will be updated information into existing management guides.

- Explain any modifications to the project including any setbacks or barriers to completion of the original objectives specified in the grant.
  - High populations in 2008 at KAC resulted all plots being overwhelmed and no differential population densities

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Project Title: Developing eggplant pest amangement guidelines for Lygus in eggplant
Project Directors: Goodell, Molinar & Jimenez

- What is the current status of the project?

- 2008: Organic site, introduction of alternate hosts within field to reduce threat to eggplant, five species incorporated in single row, replicated plots
- 2009: attempting to find interest in introducing Flonicomid into control options. Industry slow to pick up on new registration

- Summarize your key findings to this point (preliminary data is okay).
  - Alfalfa and buckwheat provided strong habitat sinks for Lygus.

- How will the information from this study be useful to other RAMP PIs or other components of the RAMP project
  - New information regarding management in eggplants.

- Specifically, how might the results contribute to the RAMP gaming simulation?
  - None envisioned

- How will information from this study be useful to growers or other target audiences in the public (i.e., what is the anticipated application for the findings)?
  - Organic grower interested but production constraints may limit introduction of habitat diversification
  - Experimental trials with new conventional products will be include in recently developed Pest Management Guidelines for Eggplant
- What are the existing and anticipated outputs of this work (presentations, papers, extension publications, newsletters, websites, new grants or projects, etc.)?
  - Development of new Pest Management Guidelines which include Lygus management .

- Explain any modifications to the project including any setbacks or barriers to completion of the original objectives specified in the grant.
  - None

Project Title:
Project Directors:

- What is the current status of the project?
- Summarize your key findings to this point (preliminary data is okay).
- How will the information from this study be useful to other RAMP PIs or other components of the RAMP project?
- Specifically, how might the results contribute to the RAMP gaming simulation?
- How will information from this study be useful to growers or other target audiences in the public (i.e., what is the anticipated application for the findings)?
- What are the existing and anticipated outputs of this work (presentations, papers, extension publications, newsletters, websites, new grants or projects, etc.)?

- Explain any modifications to the project including any setbacks or barriers to completion of the original objectives specified in the grant.

(2) Individual Behavior & Local Movement -
No projects listed

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(3) Regional Ecology, Movement & Modeling

Project Title: *Documenting the value of alfalfa in the cotton ecosystem*
Project Directors: Goodell

- What is the current status of the project?
  - No progress
- Summarize your key findings to this point (preliminary data is okay).
  -
- How will the information from this study be useful to other RAMP PIs or other components of the RAMP project?
  -
- Specifically, how might the results contribute to the RAMP gaming simulation?
  -
- How will information from this study be useful to growers or other target audiences in the public (i.e., what is the anticipated application for the findings)?
  -
- What are the existing and anticipated outputs of this work (presentations, papers, extension publications, newsletters, websites, new grants or projects, etc.)? Explain any modifications to the project including any setbacks or barriers to completion of the original objectives specified in the grant
  -

Project Title: *Influence of surrounding crops on Lygus infestation in cotton*
Project Directors: Goodell, Rosenheim & Godfrey

- What is the current status of the project?
  - 2007: 40+ focus fields and surroundiong crops sampled
  - 2008: 40+ fields and surrounding crops sampled
  - 2009: 50+ focus fields identified, initial sampling of fields and surrounding crops
  - 2007-08 data summarized and available for analysis
  - 2009 landscape maps available
- Summarize your key findings to this point (preliminary data is okay).
  - 2007: low populations, key sources tomato, seed alfalfa, sugar beet
  - 2008: extreme populations due to shift in landscape to unmanaged safflower

  - 2009: reduction in cotton aceage required portion of focus fields to be on Tulare Lake Bottom, section sized production units
- How will the information from this study be useful to other RAMP PIs or other components of the RAMP project?
  - Shared info will provided valuable contrasts from various landscapes
  - Natural enemies information being examined
- Specifically, how might the results contribute to the RAMP gaming simulation?
  - Landscape maps could provide risk analysis opportunities
  - Understanding of key crop mixes will provide some opportunity for teaching and application of knowledge

- How will information from this study be useful to growers or other target audiences in the public (i.e., what is the anticipated application for the findings)?
  - Sampling of safflower has verified 40 yr old management guidelines
  - Project has opened dialog with farmers to serious consider landscape planning
  - Inquiries have occurred from other cropping systems pest manager regarding application to their system (e.g. almonds)

- What are the existing and anticipated outputs of this work (presentations, papers, extension publications, newsletters, websites, new grants or projects, etc.)?
  - Anticipate papers
  - Project has lead to small grant to compare and contrast shift in cotton landscape between Kern and Fresno county using PUR data as evidence of Lygus pressure

- Explain any modifications to the project including any setbacks or barriers to completion of the original objectives specified in the grant
  - None

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(4) Game Training Simulation

Project Title: *Grower Training in group processes using gaming*
Project Directors: Ellsworth & Goodell

- What is the current status of the project?
  - Unaware about progress.
- Summarize your key findings to this point (preliminary data is okay).
  -
- How will the information from this study be useful to other RAMP PIs or other components of the RAMP project?
  -
- Specifically, how might the results contribute to the RAMP gaming simulation?
  -

- How will information from this study be useful to growers or other target audiences in the public (i.e., what is the anticipated application for the findings)?
    -
- What are the existing and anticipated outputs of this work (presentations, papers, extension publications, newsletters, websites, new grants or projects, etc.)? Explain any modifications to the project including any setbacks or barriers to completion of the original objectives specified in the grant
    -

Hagler, Naranjo, Blackmer

Subject Area: Local Movement of Lygus

Status of the Project(s):

1. We completed the field portion of a two year study designed to quantify the temporal and spatial dispersal patterns of *Lygus* and predaceous natural enemies between a cotton, alfalfa, lesquerella and guayule cropping system. Specifically, 11 separate one week mark-capture trials were conducted from April through August in 2007 and 2008. The resident population of arthropods inhabiting the central portion (400-m^2) of 1.5-ha alfalfa, lesquerella, and cotton fields were marked with casein from bovine milk, egg albumin from chicken egg whites, and soy trypsin from soy milk; respectively. Then, arthropods were collected in each crop using two different trapping methods. The population density of the arthropods inhabiting each crop was estimated and the trapped arthropods were examined for the presence of each protein mark to determine their dispersal patterns. We assayed >40,000 insects over two years for the presence of the three protein marks (n=120,000 ELISAs). These data are being compiled and imported into ArcGis for analysis. Ultimately, spatial and temporal dispersal patterns of *Lygus* and natural enemies will be quantified (Hagler, Naranjo, and Blackmer).
2. We have completed a two year, large scale dispersal study of *Lygus* moving between alfalfa and cotton using the protein mark-capture methodology described above. A description of this research is provided by Rosenheim (Rosenheim, Sheller, and Hagler).
3. We are in the second year of a study designed to examine the intercrop dispersal patterns of *Lygus* and associated natural enemies (predators and the *Lygus* parasitoid, *Peristenus relicutus*) between an organic strawberry and alfalfa (strip) crop using the protein mark-capture methodology described above (Swezey, Pickett, and Hagler).

Key Findings:

1. The efficacy of two types of sticky card traps for collecting *Lygus* and associated natural enemies were compared. Clear circular traps trapped significantly more arthropods than clear rectangular traps. The rectangular traps were more user friendly, time efficient, and provided information on the directional flight of the arthropods. The data obtained from both types of traps will be useful for quantifying the intercrop dispersal patterns of the arthropod assemblage.

   The protein marking method consistently yielded well-marked insects. These data are being compiled and imported into ArcGIS for statistical analysis. Ultimately, the spatial and temporal distance travelled by every marked insect will be precisely pinpointed and quantified.
2. Key findings for objective 2 are provided by Rosenheim.
3. Preliminary data indicate that the vast majority of marked insects are located in the alfalfa trap crop and not in the strawberry fields. These data suggest that alfalfa is an effective refuge for *Lygus*. Ultimately, the efficacy of using a highly desirable host plant (alfalfa) as a lure for *Lygus* will be determined

Usefulness to other RAMP PIs: The protein mark-capture methodology provides researchers associated with the RAMP project an effective method to monitor *Lygus* and natural enemy dispersal patterns. The methodology is being used to study various aspects of *Lygus* dispersal by Hagler and Naranjo in Arizona, Parajulee in Texas, and Rosenheim in California. Moreover, *Lygus* dispersal projects outside of the RAMP proposal have been established. Specifically, collaborations with Sean Swezey (UC, Santa Cruz) and Charlie Pickett (CDFA) in California and Greg Loeb (Cornell) in New York have been established to study various aspects of *Lygus* dispersal patterns in strawberry fields.

Contribution to RAMP Gaming Simulation: We envision that knowledge of *Lygus* and natural enemy dispersal patterns as they pertain to host plant preference and host plant phenology will be a critical component to gaming simulation models. Such knowledge will enable gamers to create simulated cropping scenarios. The data generated from the dispersal studies will then be incorporated into such scenarios and used to generate predictive models of pest invasion and natural enemy conservation.

Usefulness to Growers and Public: Knowledge of *Lygus* spatial and temporal dispersal patterns and host plant preferences are key to growers. Such knowledge will enable growers to better control *Lygus* by habitat manipulation, selective (spot) insecticide application, or a combination of these factors.

Anticipated Outputs: Numerous invited presentations have been made at national and international meetings. This research has fostered two additional collaborations on *Lygus* dispersal research. Additional funding is being sought for these projects. We anticipate that this research will yield at least five peer-reviewed publications. The information gained by this research can be incorporated into extension publications.

Barriers: The major challenge to this project is processing and analyzing the large amount of data generated from these studies. We are currently exploring the use of ArcGIS for the data analysis. The analysis will require a collaborative effort with an expert in dispersal statistics. A major goal for the upcoming RAMP group meeting will be to identify such an individual.

SUMMARY REPORT

RAMP Workshop 22-23 June, 2009

Steve Naranjo, USDA-ARS, ALARC, Maricopa, AZ

Plant/Pest/Pesticide Interactions

Objective 1b.

Naranjo
Observational studies were conducted to quantify and characterize the feeding behavior of *Lygus hesperus* on lesquerella plants. On average, bugs spent about 64% of their time in nominal activities such as resting, walking and grooming. They spent about 7% of their time in probing various plant parts and about 29% in feeding on various plant structures. The majority of time spent in feeding was on fruiting structures followed by feeding on stems, flowers, flower buds and leaves. Patterns were similar between females and males. A similar set of studies have been conducted for 4-5th instar nymphs and results are pending.

Survey results indicated that lesquerella harbors large reproducing populations of lygus bugs and a wide diversity of natural enemies common to many crops in the western USA including alfalfa and cotton. Immature and adult stages of several natural enemy species were noted indicating in-crop reproduction. Lesquerella probably acts as a sink of lygus bugs from overwintering hosts and alfalfa and may act as a source to other susceptible crops such as alfalfa during its late winter and spring production cycle. As cotton is not suitable for Lygus spp. in the late spring when lesquerella is harvested the crop may not be a direct source of Lygus for cotton. Lesquerella may, however, be a potential source of natural enemies providing biological control in the region.

Observational studies were conducted to quantify and characterize the feeding behavior of *Lygus hesperus* on guayule plants. On average, bugs spent about 60% of their time in nominal activities such as resting, walking and grooming. They spent about 8% of their time in probing various plant parts and about 32% in feeding on various plant structures. The majority of time spent in feeding was on flowers followed by feeding on leaves, stems and flower buds. Patterns were similar between females and males. A similar set of studies have been conducted for 4-5th instar nymphs and results are pending.

Field survey studies demonstrate that lygus bugs are present in and reproduce guayule over an extended portion of the season but are most abundant during late spring and early summer. Guayule flowers over an extended portion of the spring, summer and fall. A wide diversity of natural enemies (some reproducing) are also present in guayule with spiders abundant most of the year but winter and predatory beetles and predatory bugs present mainly during spring and summer. Guayule probably acts as a sink of Lygus bugs from overwintering hosts but does not appear to be an overwintering host. Guayule in turn may act as a source to other susceptible crops such as alfalfa and cotton during portions of the season.

Development and survival of *L. hesperus* was examined on lesquerella, guayule and alfalfa at 27C. Nymphal development times were similar on alfalfa, a common host, and lesquerella (ca. 11 days) but slightly longer on guayule (ca. 12 days). Resulting adult females were largest on lesquerella and smallest on guayule. Male size was similar on alfalfa and lesquerella and smaller on guayule. Survivorship was similar on all host plants and averaged between 73-85%.

Naranjo/Ellsworth
Replicated field studies have been conducted for 3 years to examine the potential impact of *Lygus* spp. on lesquerella yield and seed quality. To date results have only been summarized for the first two years. These studies have shown that damage to flower buds and fruit are positively correlated with lygus bug density. In turn, damage to these structures led to negative correlations between yield and plant bug density in one year, and between seed oil quantity and bug density in two years. A third and final year of study was recently completed and analyses are pending.

Field and greenhouse studies are planned to examine the relationship between Lygus bug density and plant damage and yield. Given that the yield of guayule (latex) is produced in the woody stems, it seems unlikely that Lygus bugs will have a measureable impact on latex production; however, they could be important in guayule nursery operations for seed production.

Objective 2b.

Naranjo/Ellsworth
Community analyses of data from a replicated large plot field study indicate that both flonicamid and metaflumizone selectively impact Lygus and other problematic plant bugs such as cotton fleahopper while having little or no impact on a wide diversity of predaceous arthropods that can contribute significant levels of suppression to other pests such as the sweetpotato whitefly. These findings provide growers and consultants with effective options for the management of Lygus bugs. In addition, along with transgenic Bt cotton for selective control of caterpillars, insect growth regulators and other selective insecticides for management of whitefly, these compounds have the potential to equip producers with a complete arsenal of selective options that will contribute to more biologically-based management of all key pests of cotton in the region.

Individual Behavior & Local Movement

Objective 3c.

Blackmer/Naranjo
Based on flights of ca. 1300 male and female lygus (age range 1-11 day old, mated and virgin) in a vertical flight chamber, flight initiation and orientation relative to wind speed was influenced by age and sex. Mating status had no effect on either flight initiation or orientation to a vegetative cue. Flight initiation of both sexes declined with increasing wind speed but less so for males. Both males and females showed a steep decline in orientation to vegetative cues with increasing wind speed. The youngest and oldest females were less likely to initiate flight at any wind speed while only the youngest males initiated flights less frequently compared with older males. Males and females less than 5 days of age were essentially non-responsive to vegetative cues while there was no difference in this orientation behavior for both genders ≥ 5 days of age.

New circular flight mills were constructed and refined to fly small insects. Software was developed to monitor and record data from the flight mills. Studies were initiated to measure flight behavior parameters relative to temperature. Studies at 20 and 25C have been completed to date. Females approximately 7-15 days of age, took a greater number of flights and flew greater total distances at 25C (38 flights, 2445m) compared with 20C (14 flights, 382m). Males flew less frequently and covered less distance than females at 25C (24 flights, 593m) and 20C (4 flights, 9.2m). Females flew more frequently and covered a great total distance than males at both temperatures. However, males flew faster on average at both temperatures (1.83-1.90 km/hr) than females (1.56-1.66 km/hr).

Collectively, these studies will help to characterize the flight behavior of Lygus bugs relatively to important environmental variables and will be of value to other members of the proposal team that are developing simulation models of Lygus movement on local and regional scales.

Plant/Pest Interactions

Megha Parajulee, Stanley Carroll, Ram Shrestha, David Kerns, Texas High Plains

Three separate projects were undertaken to examine the plant-insect interaction behavior of *Lygus* and cotton in the Texas High Plains. The RAMP project picked two ongoing projects that were designed to quantify the ability of cotton to compensate for *Lygus*-induced fruit loss. Both projects were completed in 2008 and publication manuscripts are being developed on those studies. A third project, which began as a new project under RAMP, is evaluating the role of *Lygus hesperus* as a late season pest of cotton in the Texas High Plains. This project will continue through 2010. See below for the summary of each of those three projects.

Project #1. Cotton Compensation for Lygus-Induced Pre-flower Fruit Loss. A 3-year field study was conducted in the Texas High Plains to quantify the compensatory ability of cotton to pre-flower fruit loss induced by *Lygus hesperus*. Experiments were designed to achieve different levels of pre-flower square loss by augmenting natural populations of *Lygus* bugs with laboratory reared nymphs, including 3 bugs per plant augmented (3PP), 1 bug per plant augmented (1PP), naturally occurring background density or untreated control (UC), and 0 bug achieved through insecticide spray applications (SC). Percent fruit loss due to the highest infestation level of bugs (3 per plant) was 48, 30, and 37% in 2005, 2006, and 2007, respectively. Pre-bloom fruit loss was not compensated through lint yield in 2005, but 30 and 37% pre-flower fruit loss in 2006 and 2007 were fully compensated. The reduction in yield (significant reduction in 2005 and numerical reduction in 2007) was primarily due to plant's inability to compensate lost first fruiting positions. These data clearly demonstrate that the plants have potential to compensate about a third of the pre-flower square loss (up to 37% in 2007) caused by *Lygus* injury. While one needs to consider plant compensation potential, protection of 30% fruit shed during early squaring may not be necessary for the Texas High Plains. RAMP project picked this ongoing project and completed in 2007.

Project 2. Cotton Compensation for Lygus-Induced Fruit Loss in a High Input Drip Production System (pre-flower vs. early flower stage fruit loss). The objective of this study was to quantify the compensatory ability of cotton to insect-induced fruit loss in a high input production system utilizing subsurface drip irrigation. Experiment consisted of four *Lygus* augmentation treatments [3 *Lygus* bugs per plant (3PP), 1 *Lygus* per plant (1PP), natural control or untreated control (UC), and spray control with no *Lygus* augmentation (SC)] to generate four levels of fruit loss during pre-flower and early flower stages, and all potential plant growth and reproductive parameters were measured. Percent fruit loss due to the highest infestation level of bugs (3 per plant) in the pre-flower and early-flower studies was 25 and 20% in 2006 and 33 and 26% in 2007, respectively. Both pre-flower and early-flower fruit loss were fully compensated through yield in 2006, indicating that a full irrigation such as the one applied through a drip system enables plants to compensate up to 25% fruit loss. In 2007, plants fully compensated the 29% pre-flower fruit loss (1PP), but the 33% fruit loss in 3PP could not be compensated fully. Both years UC (low density) and 1PP (medium density) plots had lower lint yield compared with that in SC, but the 3PP showed an "over-compensatory" response and had numerically higher lint yield than in SC in 2006, but could not fully compensate the fruit loss in 2007. These preliminary results suggested that the plant could compensate pre-flower square loss slightly better (25-30%) than the early flower fruit loss (20-25%) when environmental conditions were favorable. If conditions were not favorable, 25-30% of the fruit will be shed physiologically, therefore an insecticide intervention to save early squares may not be necessary. Consequently, it is important to consider plant compensation potential, input variables (fertility, moisture), and environmental stress while making insect management decisions. However, control costs and efforts to protect less than a 30% and 20% fruit shed during early squaring and during early flowering, respectively, may not be necessary under full irrigation production in the Texas High Plains region. We plan to conduct one or two more years of research to understand the cotton compensation behavior in a high input production system.

Project 3. Understanding Western Tarnished Plant Bug as a Late Season Pest of Cotton in the Texas High Plains. The objectives of this study were to: 1) determine when cotton bolls are safe from western tarnished plant bug (WTPB) feeding injury using heat units as the indicator of boll maturity, 2) determine how much pressure is required to penetrate the carpel wall of bolls of different ages using a commercial penetrometer, and 3) compare the damage potential of adult and late instar WTPB to maturing cotton bolls. The experimental treatments consisted of cotton bolls of different maturities [150, 250, 350, 450, and 550 heat units (HU) past white flower]. A total of 60 bolls were infested per boll age group based on HU accumulation. When the bolls from each age group reached the treatment HU, a single WTPB adult per boll was confined for 48 hours. Infested bolls were collected for each heat unit accumulation period and examined for internal and external damage. Internal damage parameters included warts, lint staining and seed damage that develop due to the WTPB punctures. A subset of infested bolls from each HU that were left on the plant until maturity was harvested by hand to determine lint quality and yield. A separate subset of 30 bolls per HU treatment were caged at white flower but were not infested. *Lygus hesperus* caused external lesions on bolls at all ages, with 90% bolls infested with *Lygus* at 150 HU and as high as 60% external injury at 550 HU. However, *Lygus* were unable to cause significant internal damage in bolls >350 HU. It appears that cotton bolls are safe from *Lygus* damage when 0.69 lb/ft^2 pressure is required to puncture the boll (>350 HU). This project will continue for 2009 and 2010 growing seasons.

Lygus Host Preference, Movement Behavior, and Landscape Ecology

Ram Shrestha, Megha Parajulee, William McSpadden, Stanley Carroll, Texas High Plains

Project 1. Influence of non-cotton hosts on life history characteristics of Lygus hesperus. Four selected host plants from the field choice test in 2005-2006 [alfalfa (*Medicago sativa*), pigweed (*Amaranthus palmeri*), Russian thistle (*Salsola iberica*), and cotton (*Gossypium hirsutum*)], green beans (*Phaseolus vulgaris*)], and artificial diet were used to conduct a no-choice feeding trial. The study was conducted in an environmental growth chamber at 27±1 ^{o}C, 65±10% RH, and a 12:12 (L:D) photoperiod. Newly eclosed *L. hesperus* nymphs were caged individually on each host substrate and recorded development and survivorship through the adulthood. Lifetime fecundity was evaluated for artificial diet, green beans, cotton, and alfalfa. Total nymphal development was longest for cotton bolls (<2 d old bolls) followed by cotton squares and alfalfa. Nymphal development was shortest in Russian thistle. Together with the longest developmental period, nymphal survivorship was lowest on cotton bolls indicating that the young bolls were not satisfactory host substrate for *L. hesperus* development. Both squares and bolls were inferior hosts to other host substrates evaluated. Preliminary fecundity data suggest that artificial diet, green beans, and alfalfa are superior substrates compared with cotton squares. Data from choice field test and no-choice laboratory test collectively suggest that cotton may be a much less preferred host than other non-cotton hosts for *L. hesperus*.

Project 2. Characterization of intercrop movement behavior of Lygus in alfalfa-cotton system. The intercrop movement behavior of *Lygus* in an alfalfa-cotton system has been evaluated by field studies where the movement of *Lygus* from one crop to another was monitored weekly throughout the cotton growing season. For this test we planted an alfalfa strip (about 40 x 600 ft) in the middle of a cotton field near Lubbock, Texas. We sprayed 10% EW in the alfalfa and 10% NFDM in the cotton field weekly for 10 weeks beginning from when cotton was at the 3-4 true leaf stage. The *Lygus* were sampled from both crops after 24 h of foraging every week. We used a blower sampler on a 100 ft long patch replicated three times for both crops. The *Lygus* numbers were undetectable in the cotton but when the cotton started squaring and flowering *Lygus* started moving into the field. The specimens collected from these alfalfa and cotton plots are being stored at -20 ^{o}C in the laboratory until processed by ELISA. So we do not have needed data available at this time to make the inference about the direction and quantity of net movement. We have also evaluated the effect of alfalfa mowing height in the intercrop movement of *Lygus* in cotton blooming and boll maturing stage. We had 3 levels of alfalfa (not mowed, 2-inch mowed height, and 6-inch mowed height) replicated 3 times. We sprayed the alfalfa with EW in 2-inch mowed plots and NFDM in 6-inch mowed plots and the *Lygus* were sampled from all plots including nearby cotton after 24 h following the alfalfa mowing. *Lygus* collected are being processed by ELISA. With this season-long intercrop movement research we will be able to predict the time and direction of movement. This approach can be used in evaluating different crop management practices (irrigation, soil fertility, insecticide spray, herbicide spray, etc.) and other ecological and environmental factors in the movement of *Lygus* into cotton in the future. Such data will be useful in developing a model to predict the intercrop movement behavior of *Lygus* by incorporating the major factors in a single model.

Project 3. Development of landscape-level pest management guidelines to reduce Lygus infestations in cotton. The project involves surveying and sampling the agricultural landscapes of several sub-regions within the West Texas High Plains for *Lygus hesperus*. Geographic information from the 2007 study has been compiled using a software-based geographic information system. In June and July of 2007 and 2008, 50-55 cotton fields (the majority of which were under irrigation) were selected as "focal fields". A goal was set to sample fifty fields each week, with the remaining extra fields designated as auxiliaries. This effort included the sampling, via sweep net, of up to six occurrences of non-cotton target insect habitats within a three-kilometer radius of ten of the aforementioned fields. We surveyed for nine weeks in 2007 and 11 weeks in 2008 and sample data have already been sent to Yves' lab for both years. In contrast to 2007 efforts, our ability in 2008 to confine our weekly efforts to a period of five days per week was not compromised, however, at times, the mission to sample fifty fields, with ten involving adjacent non-cotton habitat sampling, was not 100% met due to circumstances which were primarily climatic in nature, and which ultimately precluded physical access to "missed" fields. Processing of retrieved samples was performed in tandem with weekly surveying and sweeping activities. Third year of survey has already begun with focal field selection and planning for other logistics. Our goal is to begin the survey during the first week of July. We do not foresee any problem in conducting this survey project for this year.

Evaluation of Insecticide Chemistry: Laboratory Bioassays and Field Screening

Abhilash Balachandran, David Kerns and Megha Parajulee, Texas High Plains

Project 1. Insecticide Bioassays on adult Lygus hesperus. Glass vial bioassays were performed with three technical grade insecticides, cypermethrin (94.3% AI), acephate (97% AI) and flonicamid (99% AI). Sweep nets were used to collect *Lygus* adults from an alfalfa field near Levelland, TX. The live adults were returned to the laboratory and used to conduct the acephate and cypermethrin bioassays. For flonicamid, *Lygus* from lab colony were used. Mortality observations for the analyses were taken at 24 h after exposure (HAE) for acephate and cypermethrin, whereas for flonicamid, the mortality evaluations were taken at 72 HAE due to a different mode of action which extends the time required to kill the insects. Results indicated the LC_{50} value for acephate was 1.29 μg/mL and for cypermethrin, 0.19 μg/mL. Flonicamid showed an LC_{50} of 22.46 μg/mL. A probit regression analysis will be used to determine the sublethal doses of these insecticides to be used in future experiments to study the sublethal effects on life history parameters and behavioral changes in *Lygus*. This and the following studies will continue in 2009 and 2010.

Project 2. Laboratory Assay: Effects of sublethal doses of flonicamid on oviposition of Lygus hesperus. Laboratory glass vial assays were conducted with females during the oviposition stage. Sublethal doses of flonicamid were dissolved in an ethyl alcohol solvent and then the solution was applied to the vials at rates of 10, 25, 50, 100, 250 ug/mL were tested. The selected control treatment was ethyl alcohol (99% molecular grade). A total of 25 females were tested for each concentration and a fresh green bean piece was provided to serve as a food source plus an oviposition substrate. At 48 h HAE, observations were made to count the number of eggs and mortality. Surviving adults were then moved to fresh untreated glass vials with a similar food/oviposition substrate. Observations for oviposition and mortality were taken on the fresh vials after 48 h (total 96 HAE). This was done to check whether the effect on oviposition after exposure to flonicamid caused a permanent suppression of oviposition or not. Results indicate that flonicamid suppressed oviposition. There were significant differences in the mean number of eggs at both 48 HAE and 96 HAE. At 48 HAE, the mean number of eggs laid per female was 15.9 in the untreated control whereas, in the other treatments mean values were <1.0. At 96 HAE, females in the untreated control again laid significantly more eggs than the females previously exposed to flonicamid. Increases in mortality were positively correlated with increases in flonicamid concentration and time which might be due to starvation. Ovipositional capacity was regained in 50% of the surviving individuals at 96 HAE when transferred to non treated vials held under the same conditions.

Project 3. Plant Bioassay: Effects of sublethal doses of flonicamid on oviposition of Lygus hesperus. Potted cotton plants of two varieties, Bt (DP141B2RF) and Non Bt (DP174RF), were sprayed at the 2-4 true-leaf stage with three different solutions. The replicated treatments included: 1) a sublethal dose of Carbine® 50 WG (flonicamid) in a concentration of 1.72g/L, 2) water as a control, and 3) Ammo 2.5 EC (cypermethrin) at 4ml/L as a positive control. Five pots with two plants each were treated with each treatment solution. Plants were caged 3 days after spraying. Two adult females in their oviposition phase (7-10 day old) were selected at random from a laboratory colony and then released into each cage. Five days after the releases, mortality observations were made and surviving adults were removed. Plants were dissected and eggs counted using a stereomicroscope at 20X magnification. The results indicated that *Lygus* oviposition on cotton plants treated with the sublethal doses showed significant differences on the Bt cultivar plants, whereas with the non Bt cultivar, Carbine® and the untreated plants were not different. The control Bt plants were found to have a mean of 17 eggs/female whereas, plants treated with Carbine® and Ammo possessed 10.2 and 0.7 eggs, respectively. The results of this study are preliminary and additional research is needed to validate the findings.

Project 4. Chemical Management of Lygus in Late-Season Cotton and Impact on Yield, 2008. Overall, western tarnished plant bug, *Lygus hesperus* (Knight), populations were low across the High Plains of Texas in 2008. However, where ever alfalfa – cotton systems exists, there is high chance of an infestation of Lygus. Being a highly mobile insect, Lygus exhibits back and forth movement between alfalfa and cotton depending on phenological stage of the crop. Since our study was conducted in such a system where the adjacent field of alfalfa acted as the major source of Lygus; even in late season cotton (8 NAWF), it was evident that yield could be affected if not managed in a timely manner. We observed a 239 lbs-lint/acre reduction beween the highest yielding treatment and the untreated. All insecticides except Centric and Diamond had a significant impact in reducing Lygus populations below threshold at 3 DAT, continuing until 13 DAT. Centric and Diamond showed activity at 6 DAT. Percentage of bolls (at 150-200 HU maturity) with external and internal injury did not vary among insecticides initially, but after treatment showed a sharp decline relative to the untreated beginning at 6 DAT. Holster recorded the least amount of Lygus injury to the bolls. The currently recommended threshold of 4 Lygus/6 ft-row appears to follow the yield response curve, adding validity to the threshold. Additionally, because of the tight linear relationship where approximately 50% of 150-200 HU aged bolls with external injury resulted in internal injury, a threshold based on external injury using this boll age cohort is may be possible. With further evaluation, an action threshold of 25% bolls with external injury could be used as a scouting measure for the population threshold of 4 Lygus/6 ft-row. Orthene proved to be the best insecticide considering the lint yield, overall effect in reducing the Lygus population, injury to bolls, and net return.

RAMP Report – USDA, ARS, WICSRU, Shafter, CA

Individual Behavior & Local Movement

During the 2008 cropping season we conducted studies to develop and validate improved techniques for evaluating sampling methods for *Lygus* in cotton. Our efforts focused on a mark-release-recapture method for adult *Lygus hesperus* in Pima cotton. Adult bugs were marked with fingernail polish to facilitate their identification and prevent flight. Marked bugs released in sample rows at known population densities were then sampled with the standard 38-cm sweep net. Recovery of marked bugs from 1-m row sections suggested a large proportion (> 85%) of released bugs remained in sample rows. Based on two sets of pooled regressions relating numbers of collected adult bugs to expected numbers (assuming 100% collection efficiency), estimated collection efficiencies of the sweep net changed with cotton crop development from approximately 21.4% in smaller, less developed plants (plant heights < 50 cm on most dates) to 7.7% in more developed plants (plant heights > 52 cm). Increasing the sample unit size from 10 to 20 sweeps improved fit of regression models for both sets of samples, but fit of the model corresponding to less developed plants was still better than for more developed plants. These results illustrate the utility of the mark-release-recapture approach for sampling studies of adult lygus in cotton, and suggest opportunities for its use in quantifying the influence of factors such as time of day, plant development, and variation among samplers on population indices provided by the sweep net in cotton. A manuscript describing this work was accepted by the Journal of Cotton Science and should be included in the volume published in July.

We are currently using the mark-release-recapture method to evaluate differences among samplers and the influence of bug release times (7:00 PM vs 7:30 AM) on sweep net collection efficiency in both Upland (Acala) and Pima cottons. These efforts have been hampered by inadequate acreage and poor plant stands in the study fields. In addition, high population levels of native lygus combined with unusually cool and cloudy weather have resulted in very poor square retention. Data collected as of June 18 does not suggest differences among samplers using the same sweeping technique (one sweep across a single row, about 7 sec per 10 sweep sample). However, poor square retention resulting in a concentration of available squares in the plant terminal combined with cloudy conditions at the time of sampling appear to have caused a corresponding concentration of marked and native bugs near the top of the plant canopy. This apparent change in lygus distribution yielded initial estimates of sweep net efficiency ranging from 35-50%, compared with 21.4% observed last year. Our most recent sampling indicated square development has progressed more rapidly in the Acala than in the Pima cotton, and temperatures and cloud cover were more representative of those normal for the region. Sweepnet efficiency in the Acala was about 22% (which was similar to that from 2008), while efficiency in the Pima was still somewhat inflated (about 33%). Data from studies of time-of-release indicate plant phenology-related trends in collection efficiency similar to those observed in the study of among sampler differences. Recovery of bugs released 2 h before sampling has been numerically higher than recovery of bugs released on the evening before sampling, but these differences are probably not statistically significant. Hand recovery of bugs from designated 1-m of row sections suggest any differences observed are not from mortality or movement of released bugs. Instead, observations suggest that 2 h may not be a sufficient time interval between release and sampling.

Regional Ecology, Movement & Modeling

We have been conducting studies of *Lygus hesperus* response to photoperiod to better define the morphological criteria used to distinguish diapause. Some of this work was reported at the 2009 Beltwide Cotton Conferences. We are collaborating in our current work with Dr. Colin Brent (ARS, Maricopa, AZ). While studies at Shafter feature bugs reared to adulthood and held singly on green bean pods, work at Maricopa is using artificial diet and bugs held in mixed-sex groups. Both locations are using a rearing temperature of 26.6°C. Preliminary results at both locations indicate that a 10-h photoperiod induces a significantly lower rate of diapause than was suggested by previous reports. Both locations are also observing much shorter pre-oviposition periods and faster reproductive development than is indicated in the published literature. For diapausing males and females reared at both locations, the fat body continues to develop (based on visual perceptions of volume) for 10-14 d after adult eclosion, providing a useful categorization criterion. Additional characteristics of diapause include inhibited ovarian development and limited male accessory gland activity. For females older than 7 d, the presence of follicular remnants (yellow bodies) in the ovarioles, indicating recent oviposition, is also a useful indicator. However, the content of the seminal vesicles is not a useful gauge of status, because diapausing males continue to produce sperm. Observations at both Shafter and Maricopa suggest color of the ventral surface of the abdomen (reflecting primarily fat body color) may be a useful non-destructive indicator of diapause. The degree of cuticular pigmentation on this surface may also be useful for categorizing older males. If the color criterion proves sufficiently accurate, it would facilitate studies of host-free longevity that would have implications to studies of ecology and spatial distribution of overwintering adults.

Jay Rosenheim – RAMP Report – June 2009

Cooperators:

at UC Davis: Frances Sheller, Yao Hua Law, Andrew Forbes

at USDA Phoenix: James Hagler

Section 1:

In original grant proposal:

1. Incorporating the key predator *Geocoris* into thresholds for *Lygus* control in cotton (Rosenheim; Ellsworth collaborator)

- What is the current status of the project?
  - We are beginning our third year of field experimentation
- Summarize your key findings to this point (preliminary data is okay).
  - *Geocoris pallens* is an effective predator of eggs and nymphs, resulting in improved square retention and yield. However, *Geocoris* populations appear to reach an upper density 'ceiling' that is imposed by strongly density-dependent cannibalism. This means that *Geocoris* can contribute to control, but often do not generate full control. Still unresolved: how can growers use data on *Geocoris* presence to modify control decisions?
- How will the information from this study be useful to other RAMP PIs or other components of the RAMP project?
  - Biocontrol of *Lygus* from *Geocoris* is measurable, but limited.
- Specifically, how might the results contribute to the RAMP gaming simulation?
  - Unclear.
- How will information from this study be useful to growers or other target audiences in the public (i.e., what is the anticipated application for the findings)?
  - Unclear, really. Worth discussing. How likely are growers to be willing to collect data on *Geocoris* density?
- What are the existing and anticipated outputs of this work (presentations, papers, extension publications, newsletters, websites, new grants or projects, etc.)?
  - Manuscripts are being prepared for scientific journals.
- Explain any modifications to the project including any setbacks or barriers to completion of the original objectives specified in the grant.
  - No major setbacks, although it is clear that the potential control contributions from *Geocoris* are limited

Not in original grant proposal (or, emerging from complementary grants):

2. *Lygus* thresholds for upland and Pima cotton: data from growers/PCA's

Summary: This is work coming from a complementary USDA-funded project. We have built a database with data collected from private pest management consultants and growers. The data suggest that *Lygus* management on cotton in California can be improved. On upland cotton, growers have apparently been more aggressive in controlling *Lygus* than was needed to protect yield: upland cotton has remarkable abilities to compensate fully (i.e., no yield loss) for low to moderate densities of *Lygus* during all parts of the growing season. On Pima cotton we have the opposite outcome: growers have been incurring yield losses without recognizing it, because Pima exhibits linear declines in yield across the full range of *Lygus* densities. Only preliminary analyses have been completed to date. Final analyses are expected to be completed within a year. This work should have direct relevance to growers, and should flow into the training simulation. Reports to the scientific community and in extension publications are anticipated.

3. **Influence of phosphorus on cotton (upland and Pima) sensitivity to *Lygus* ('decisions' to abscise squares).**

   Summary: We are making progress on understanding a long-standing riddle in the management of *Lygus* on cotton in California: growers have long reported that the impact of *Lygus* on short-term crop damage (square shed) was unpredictable. Growers said that some fields had few *Lygus* but heavy square shed, and other fields have many *Lygus* but light square shed. Previous work had suggested one candidate for a factor that might 'sensitize' the cotton plant to *Lygus* herbivory (petiole phosphorus content), but without any *a priori* reason to expect a role for phosphorus and without any experimental confirmation of the effect, we remained skeptical. We have two results to report. First, we have a second, independent data set that confirms the same correlation (higher petiole phosphorus levels are correlated with higher square abscission, after controlling for *Lygus* density). Second, recent (and little recognized) findings suggest that phosphorus may play a general role in regulating abscission responses in a broad array of plants. We are now conducting a greenhouse experiment to produce a definitive test of this effect. If confirmed, this result could be relevant to managing *Lygus* on cotton (and perhaps on other crops).

Section 2: (not reporting on any projects)

Section 3:

1. **Long-distance dispersal of *Lygus* and crop colonization from native plant over-wintering sites (Rosenheim & Hagler)**

   - What is the current status of the project?
     - We have completed 3 years of field experimentation using James Hagler's protein-based mark-capture techniques; all sample processing is complete.

We are not planning to conduct additional field trials, and are instead focusing on data analysis and writing.

- Summarize your key findings to this point (preliminary data is okay).
    - We encountered a series of interesting and challenging procedural and statistical challenges in this project. In particular, because we had special interests in quantifying the incidence of (rare) long-distance dispersal events, we needed to be able to detect a very low frequency of marked individuals in an 'ocean' of background, unmarked individuals. As a result, we needed to have an extremely low rate of false positive readings on the ELISA assay, and we needed to be able to quantify the false positive rate so that we could correct our data for false positives. We have worked hard to figure out how best to do this. We have now essentially completed the statistical work (I'll be happy to go into the nitty gritty for anyone who is interested), and are ready to apply our new protocols to the data to start asking the biological questions once again.
- How will the information from this study be useful to other RAMP PIs or other components of the RAMP project?
    - The statistical tools may be useful to others working with protein marking, and we're happy to share our ideas. We should have estimates of *Lygus* dispersal distances within the year. We should also have data on dispersal for some of the key predators in the cotton system (*Geocoris*, *Hippodamia*, *Nabis*, etc.).
- Specifically, how might the results contribute to the RAMP gaming simulation?
    - Dispersal data could be used to simulate *Lygus* spread within and between fields.
- How will information from this study be useful to growers or other target audiences in the public (i.e., what is the anticipated application for the findings)?
    - These data should help us to understand how field locations within ranches can assist growers with managing *Lygus*, and in particular avoid situations in which sensitive crops are placed near major sources of *Lygus*.
- What are the existing and anticipated outputs of this work (presentations, papers, extension publications, newsletters, websites, new grants or projects, etc.)?
    - The methods development is currently being written for a scientific journal.
- Explain any modifications to the project including any setbacks or barriers to completion of the original objectives specified in the grant.
    - The main modification was that we will not attempt to quantify movement from natural areas into cotton. We may be able to approach this question using the database.

2. A landscape-scale, research level simulation model for *Lygus* (Corbett, Rosenheim, Bancroft)

- What is the current status of the project?
    - Corbett developed the framework for the model. It is likely that I will bring new personnel on board to finish the project.
- Summarize your key findings to this point (preliminary data is okay).
    - Early explorations with the model have shown that, depending on the mobility of the herbivore (e.g., *Lygus*), the mobility of any effective natural enemies, the quality of the crop for herbivore reproduction, and whether the herbivore and natural enemy can over-winter in the crop (or must re-colonized each year), we can obtain quite variable pictures regarding how to 'design' a ranch to minimize herbivore damage. In some cases, clumping vulnerable but low-quality crops together provides protection (this is likely the case for *Lygus* attacking cotton.
- How will the information from this study be useful to other RAMP PIs or other components of the RAMP project?
    - The simulation should complement the study being conducted by Carriere, Goodell, and others, on the influence of the agricultural landscape on *Lygus* colonization of cotton.
- Specifically, how might the results contribute to the RAMP gaming simulation?
    - A version of the model could certainly be adapted for use as a gaming simulation for farmers who wish to do 'virtual experiments' with different spatial arrangements of their fields.
- How will information from this study be useful to growers or other target audiences in the public (i.e., what is the anticipated application for the findings)?
    - Findings should inform recommendations regarding ranch design.
- What are the existing and anticipated outputs of this work (presentations, papers, extension publications, newsletters, websites, new grants or projects, etc.)?
    - Too early to have concrete plans for outreach.
- Explain any modifications to the project including any setbacks or barriers to completion of the original objectives specified in the grant.
    - No substantial modifications of the project. Substantial changes in personnel (Corbett and Bancroft).

<u>Section 4</u>: (not reporting on any projects)