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GRANT AMT: $2,822,422 **GRANT YR:** 2012
AWARD TOTAL: $6,723,311
INITIAL AWARD YEAR: 2009

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MANAGEMENT OF ZEBRA CHIP TO ENHANCE PROFITABILITY AND SUSTAINABILITY OF US POTATO PRODUCTION

NON-TECHNICAL SUMMARY: The U.S potato industry had farm-level sales of nearly $4 billion in 2008, and constitutes a vital segment of American agriculture. However, the economic sustainability of this industry is threatened by a new emerging disease named Zebra Chip (ZC). Zebra Chip affects all market classes of potato, such as the potato chip, fresh market, and French fry industries, by reducing both yield and quality. It was first identified in the US from Texas in 2000, but now has been detected in several other major potato production regions across the US. It is imperative to identify the major factors that impact disease incidence, severity, and spread, and to develop research and educational programs that will help producers deal with this new threat. Containment of the disease is especially important since Korea recently placed a quarantine on importation of potatoes from areas where Zebra Chip is present, an act that quickly could escalate into a cascade of countries placing restrictions on importation of US potatoes Specific deliverables of this project will include 1) Best management practices (BMP) for ZC, 2) A ZC risk assessment/disease forecasting model to trigger BMP, 3) Germplasm with tolerance to ZC, 4) an Economic cost/benefit analysis and economic models for best case/worst case scenarios, 5) Publications, and educational and training programs dealing with all aspects of ZC, and 6) Dependable scientific data that will be useful to US regulatory agencies in development of a Pest Risk Assessment for ZC, which will be needed to address the recent Korean quarantine on US potatoes. These deliverables will directly impact and enhance environmental quality through more controlled and targeted pesticide application, economic sustainability for potato producers and processors, and overall consumer confidence in the safety and quality of US potatoes and potato products.

OBJECTIVES: Our goal is to reduce losses from ZC to economically sustainable levels by development of a comprehensive, environmentally responsible disease management program. An Advisory Board and participating scientists identified seven Priority Focus Areas (Disease Etiology and Vector/Pathogen Diversity, Epidemiology, Pest Management, Breeding, Economics, Risk Assessment and Technology Transfer), each with a number of specific objectives: PFA 1. Pathogen Detection, Vector/Pathogen Diversity and Disease Etiology - (Gudmestad) Objective 1.1. Identify non-rRNA loci from the ZC Liberibacter genome for use in conventional and real-time PCR. Objective 1.2. Culture ZC Liberibacter bacterium and confirm its pathogenicity. Objective 1.3. Determine genetic variability among strains of `Candidatus Liberibacter' sp. Objective 1.4. Determine variability in the potato

psyllid population and investigate the impact variability has on acquisition and transmission of ZC Liberibacter sp. PFA 2. Epidemiological Investigations and Sampling Strategies - (Henne) Objective 2.1 Compare psyllid sampling strategies to develop accurate sampling techniques. Objective 2.2. Survey overwintering and reservoir hosts for potato psyllid and Liberibacter. Objective 2.3. Determine time required for psyllids to acquire or transmit Liberibacter. Objective 2.4. Determine impact of plant growth stage and psyllid numbers on ZC development. Objective 2.5. Investigate environmental conditions that may influence ZC symptom expression. Objective 2.6. Spatial and temporal analysis of disease incidence and progression. PFA 3. Management Strategies - (Nansen) Objective 3.1. Investigate factors that impact efficacy of insecticides. Objective 3.2. Antibiotics and Systemic Acquired Resistance. Objective 3.3. Evaluate potential for biological control. Objective 3.4. Develop a within-field sequential sampling plan and economic action threshold. Objective 3.5. Evaluate cultural practices for impact on ZC incidence and losses. PFA 4. Breeding - (Miller) Objective 4.1. Resistance Screening. Objective 4.2. Breeding for resistance to ZC. PFA5. Economics - (Guenthner) Objective 5.1. Estimate impacts of Zebra Chip on grower profitability. Objective 5.2 Estimate impacts of Zebra Chip on state and/or regional economies. Objective 5.3. Evaluate the economics of alternative disease management strategies, including best/worst case scenarios and risk assessment modeling. PFA 6. Risk assessment of ZC - (Workneh) 6.1. Identification of factors which influence ZC development. 6.2. Analysis and development of a ZC forecasting model. PFA 7. Technology Transfer/Outreach - (Appel) Objective 7.1. Grower Education and Training. Objective 7.2. IPM/BMP Program Development. Objective 7.3. Accountability, Impact Assessment and Expected Outcomes. The outcome of this effort will be six deliverables: best management practices, a ZC risk assessment/model, disease resistant germplasm, economic models with cost/benefit analyses, publications and educational programs dealing with all aspects of ZC, and scientific data that will be useful to regulatory agencies in development of a Pest Risk Assessment for ZC.

APPROACH: The ZC research and extension team is composed of twenty scientists, representing a variety of disciplines, areas of expertise, and institutions. Each was selected to participate in this project because of their specific research/extension expertise, and all are unified in commitment to our common goal: Reducing losses from ZC to economically sustainable levels by development of a comprehensive, environmentally responsible disease management program. Scientists and members of the Advisory Board (AB) discussed ideas concerning the SCRI Zebra Chip project, and identified and agreed on a common long term goal and seven research and extension areas that most needed attention. Scientists were asked to consider specific research objectives, which when accomplished would help achieve our project goal. Later, team scientists were asked to write a detailed approach they would follow to achieve their specific research/extension objectives, and to provide a brief rationale for why the objective was critical to the ZC project. Each scientist will be involved with specific research/extension objectives within one or more of the seven Priority Focus Areas. One scientist will be designated as lead for each specific objective. Lead scientists will have responsibility for coordinating efforts of other scientists who are collaborating in that objective, and for compiling and reporting research results for that objective. Project Leaders also have been identified for each PFA: PFA 1- Pathogen Detection, Vector/Pathogen Diversity and Disease Etiology, Neil Gudmestad, PFA 2 - Epidemiology, Don Henne, PFA 3 - Pest Management, Christian Nansen, PFA 4 - Breeding, Creighton Miller, PFA 5 - Economics, Joe Guenthner, PFA 6 - Risk Assessment/Disease Forecasting, Fekede Workneh, and PFA 7 - Technology Transfer and Outreach, Dave Appel. The lead scientist for each objective within a PFA will report to the Project Leader for that PFA. Project Leaders for each of the seven PFAs, and the Project Director (PD), Charlie Rush, and co-PDs, Neil Gudmestad and John Trumble, will meet at least quarterly by conference call to discuss

progress or problems within their respective areas of responsibility. The Project Director, co-PDs and Project Leaders will comprise an informal project management team.

PROGRESS: 2009/09 TO 2014/08
Target Audience: The target audience was primarily potato farmers, processors and the agricultural scientists who were working on various aspectszebra chip and other related diseases, such as citrus greening. Changes/Problems: During this reporting period, two of the lead PIs were diagnosed with cancer and had to undergo treatment and recover and this significantly impacted their programs. However, due to previous training of highly qualified personnel and team contributions, project objectives were still completed. In addition, one PI, Dr. Don Henne with Texas A&M AgriLife Research, Weslaco, Tx took another position and left the program in mid summer. Again however, due to highly trained personnel all research objectives were completed. What opportunities for training and professional development has the project provided? A significant number of undergraduate, graduate and post doctoralstudents, were exposed to and trained in the basic procedures of scientific research. This included specific training in insect identification, field plot design, simple data collection and statistical analysis, disease and insect management, IPM concepts, general laboratory skills, and basic training in molecular biology. A number of students were also taken to field dayts and grower meetings where they had the opportunity to see aspects of real production agriculture, visit with growers and make presentations concerning their activities in the ZC SCRI project. Students also had the opportunity to attend professional meeting, take part in development of research presentations and make oral and poster presentations. A number of students were given the opportunity to visit other research facilities and labs to meet peers and learn alternative ways of addressing research problems. How have the results been disseminated to communities of interest? Results of this program were disseminated through publication of a number of extension publications, conference proceedings, journal publications, presentations at field days and grower meetings and during the annual Zebra Chip Reporting Session. In order to facilitate reaching an expanded audience, the Annual Reporting Session was held in the Pacific Northwest (Portland, OR) this year instead of San Antonio, TX. What do you plan to do during the next reporting period to accomplish the goals? Nothing Reported

IMPACT: 2009/09 TO 2014/08
What was accomplished under these goals? The Zebra Chip SCRI has been an exceptionally successful program. Close to a thousand farmers and industry representatives have been educated about the disease and recommended management practices. These recommendations have been put to use at the farm level, with the result that no devastating epidemic of ZC has occurred in the last three years. Growers understand the nature of the disease, what causes it and how it spreads and the necessary steps to keep losses at a minimum. A large number of undergraduate, graduateand post doctoral studentshave been trained and a number have been placed in professional positions as university faculty and withthe potato agri-industry. DIspite changes in program personnel, individual projects continued,objectives were met and farmers currently rely on research and survey results to make disease and pest management decisions. Texas has been one of the major beneficiaries of thesuccessfulZC SCRI. When ZC was first identified in Texas in 2000 approximately 20,000 acres of potatoes were grown in the state. Half were grown in south Texas and half in the panhandle region in north Texas. From 2004 through 2006, ZC was at epidemic levels and costing growers in all production regions of the state millions of dollars in losses. Many believed the Texas potato industry would not survive. However, soon after the ZC SCRI program was initiated and the potato psyllid verified as the vector of 'Candidatus Liberibacter solanacearum', team members developed an insecticide program that was rapidly adopted by Texas growers. The same program has been the basis for all ZC management programs in the US. However, the expense of this program is significant and

economically unsustainable. A Delphi survey was conducted to obtain expert opinion from Texas potato experts knowledgeable about Zebra Chip. In order to estimate an "average annual cost" of Zebra Chip to the Texas potato industry, the Delphi survey results were applied to 2010-2012 USDA-NASS marketing year average price data, 2010-2012 USDA NASS Production estimates, and 2010-2012 insecticide and application costs collected from Texas A &M's custom rate guide, input cost surveys, personal communication (price sheets) from Texas pesticide dealers, and Texas potato grower surveys. During this survey, it was discovered that US potato growers spent a total of $35,000 on insecticides for control of the potato psyllid in the year 2000. However, by 2013 US potato growers spent in excess of $10M dollars on insecticides targeted at psyllid control. Some estimates suggest that if Zebra Chip alonedid not exist, insecticide use across the entire US coulddecrease by25%. For the time period evaluatedby the Delphi survey, it was estimated that ZC was costing Texas growers statewide approximately $26M/year. However, despite the high cost for control of ZC, in every region where the insecticide program has been adopted, the incidence of ZC has been maintained atsustainable levels. The ZC management program saved the Texas potato industry and continues to save Texas growers an estimated $23M - $32M dollars/year. The majority of this savings has been in the lower Rio Grande Valley where the potatopsyllid overwinters and incidence of Lso positivepsyllids is high. However, the program has also savedmoney forproducers in all Western potato producing regions of the USA. Although it is difficultto predict with certaintyhow many millions of dollars have been saved due to adoption of the ZC management program, ithas been estimatedthat even in the PNW where disease pressure has been relatively low, growers have avoided losses that would have exceeded $10M dollars/year since the introduction of the disease in 2011. The most solid evidence of the ZC SCRI program's value is the increase in potato acres planted in Texas since the ZC management program was developed. When ZC first entered Texas in 2000, approximately 20,000 acres of potatoes were planted each year. By 2007, planted acres had declined to approximately 15,000, but in 2014 approximately 30,000 acres had been planted. Such a significant increase would not have been possible if growers were not confident of being able to manage ZC. Team members have nearly completed the sequence of three Lso haplotypes, which show considerable diversity in phage insertion sequences. This work has improved pathogen detection and differentiation andwill help to understand biological differences that exist among haplotypes. The team also discovered that over an eight year period, haplotype A has become the dominant type in the environment. Preliminary data suggest differences in temperature sensitivity and in acquisition and transmission success. Furthermore, it has been observed that haplotype A and B have differential effects on seed germination and in aggressiveness in tomato and that haplotype B is the more aggressive of thetwo. Surveys of non crop areas verified that psyllid haplotypes exhibit temporal shifts within a givenarea or region. In West Texas, the Southwestern haplotype was displaced during thesummer by the Western haplotype and this is highly significant because none ofthe southwesternhas tested positive for Lso, whereas the highest percentage of positive psyllids have been of the Western haplotype. Also, the recent discovery that potato psyllid successfully overwinters in the Pacific Northwest has led to studies which suggest that residency is a consequence of an apparently new adaptation by one psyllid haplotype (Northwestern) to a recently introduced and invasive nightshade, Solanum dulcamara. Late-season access to this plant prompts a cold-hardening response by the Northwestern haplotype not observed for the other (non-resident) haplotypes. An insecticide rotational program that allows growers to reliably produce potatoes in the presence of bacteriliferous potato psyllids was developed. While the rotation is not sustainable because of the limited number of materials, it cut pesticide use substantially, thereby allowing growers to produce an economically-viable crop with much less potential for pesticide residues and farm worker safety concerns. In a related study, baselines for psyllid resistance to key compounds were determined and it was documented that, at least in Texas populations, resistance has developed to a neonicotinoid. It also was

demonstrated that field failures occur if pesticides such as organophosphates, pyrethroids and carbamates are used, and that these have an extremely detrimental impact on the primary parasite of the psyllid.Selected biorational insecticides were evaluated for the repellency or control of B. cockerelli. Results indicated >50% suppression of some psyllid stages, suggesting these materials may be useful in IPM programs. In a related study, the benefit of psyllid natural enemies was determined for the western haplotype of the psyllid in CA, and results will serve as a template for how to assess beneficial insects in other production regions. Breeding germplasm was screened for resistance to B. cockerelli and Lso. Compared to the susceptible control, several breeding clones exhibited reduced psyllid feeding and resting, suggesting resistance to the vector, and several clones displayed significantly reduced Lso infection. In a related study, 35 advanced breeding lines were screened by challenging with bacteriliferous psyllids. All lines developed typical foliar symptoms of ZC but nine lines had no, to only light, symptom development in tubers.

PUBLICATIONS (not previously reported): 2009/09 TO 2014/08

1. Type: Journal Articles Status: Published Year Published: 2014 Citation: Arp, A., Munyaneza, J.E., Crosslin, J. M., Trumble, J.T., and Bextine, B. 2014. A global comparison of Bactericera cockerelli (Hemiptera: Triozidae) microbial communities. Environmental Entomology 43(2): 344-352.
2. Type: Journal Articles Status: Awaiting Publication Year Published: 2014 Citation: Clark, N.E., Frigulti, T., Zheng, Z., Wallis, C. M., Bushoven, J. and Chen, J. 2014. Pyrosequencing analyses of bacterial populations in tomato leaves infected by ?Candidatus Liberibacter solanacearum?.
3. Type: Journal Articles Status: Accepted Year Published: 2014 Citation: Cooper, W.R., Sengoda, V.G., and Munyaneza, J.E. 2014. Localization of ?Candidatus Liberibacter solanacearum? in Bactericera cockerelli (Hemiptera: Triozidae). Annals of the Entomological Society of America 107: 204-210.
4. Type: Journal Articles Status: Published Year Published: 2014 Citation: Diaz-Montano, J., Vindiola, B.G., Drew, N., Novy, R.G., Miller, J.C., Jr., and Trumble, J.T. 2014. Resistance of Selected Potato Genotypes to the Potato Psyllid (Hemiptera: Triozidae). Amer. J. Potato Res. 91:363-367.
5. Type: Journal Articles Status: Published Year Published: 2014 Citation: Hao, G., Pitino, M. Ding, F. Lin, H. Stover, E. and Duan, Y. 2014. Induction of innate immune responses by flagellin from the intracellular bacterium, ?Candidatus Liberibacter solanacearum?. BMC Plant Biology. doi:10.1186/s12870-014-0211-9.
6. Type: Journal Articles Status: Awaiting Publication Year Published: 2014 Citation: Horton, D.R., Miliczky, E., Munyaneza, J.E., Swisher, K.D. and Jensen, A.S. 2014. Absence of photoperiod effects on mating and ovarian maturation by three haplotypes of potato psyllid, Bactericera cockerelli (Hemiptera: Triozidae). Journal of the Entomological Society of British Columbia
7. Type: Journal Articles Status: Published Year Published: 2014 Citation: Ibanez, F., L?vy, J., and Tamborindeguy, C. 2014. Transcriptome analyses of ?Candidatus Liberibacter solanacearum? in Its Psyllid Vector, Bactericera cockerelli. PLoS ONE 9(7)
8. Type: Journal Articles Status: Published Year Published: 2014 Citation: Kogenaru, S., Yan, Q., Riera, N., Roper, C., Deng, X., Ebert, T., Rogers, M., Irey, M., Pietersen, G., Rush, C., and Wang, N. 2014. Repertoire of novel sequence signatures for the detection of Candidatus Liberibacter asiaticus by quantitative real-time PCR. BMC Microbiology. 14(39):1-11.
9. Type: Journal Articles Status: Published Year Published: 2014 Citation: L?vy, J. and Tamborindeguy, C. 2014. Solanum habrochaites Resistance Against Bactericera cockerelli Does Not Protect Against Transmission of ?Candidatus Liberibacter solanacearum. Journal of Economic Entomology 107(3): 1187-1193
10. Type: Book Chapters Status: Published Year Published: 2014 Citation: Lin, H. and

Civerolo, E. L. 2014. Comparative Genomics of the Liberibacteral Plant Pathogens. In Gross, DC. et al. (ed) in Genomics of Plant-Associated Bacteria, Springer-Verlag Berlin Heidelberg. P: 203-233. ISBN:978-3-642-55377-6.
11. Type: Journal Articles Status: Published Year Published: 2014 Citation: Michels, Jr., G. J., Jones, E. N., and Rush, C.M. 2014. Susceptibility of Selected Perennial Small Grain Cultivars, to Greenbug, Schizaphis graminum (Rondani) (Hemiptera: Aphididae). G. J. Michels, Jr., E. N. Jones, and C. M. Rush. Southwestern Entomologist 39(1):9-22.
12. Type: Journal Articles Status: Published Year Published: 2014 Citation: Munyaneza, J.E., Sengoda, V.G., Sundheim, L., and Meadow, R. 2014. Survey of ?Candidatus Liberibacter solanacearum? in carrot crops affected by the psyllid Trioza apicalis (Hemiptera: Triozidae) in Norway. Journal of Plant Pathology 96: 397-402.
13. Type: Journal Articles Status: Published Year Published: 2014 Citation: Nachappa P., Levy, J., Pierson, E., and Tamborindeguy, C. 2014. Correlation between ?Candidatus Liberibacter solanacearum? infection levels and reduction in fecundity in its psyllid vector. Journal of Invertebrate Pathology 115:55-61.
14. Type: Journal Articles Status: Published Year Published: 2014 Citation: Nelson, W.R., Swisher, K.D., Crosslin, J.M., and Munyaneza, J.E. 2014. Migration of the potato psyllid Bactericera cockerelli into potato crops. Southwestern Entomologist 39:177-186.
15. Type: Journal Articles Status: Awaiting Publication Year Published: 2014 Citation: Nwugo, C.C., Sengoda, V.G., Munyaneza, J.E., Tian, L., and Lin, H. 2014. Characterizing the global molecular processes associated with the response of aboveground and belowground potato tissue to ?Candidatus Liberibacter solanacearum? infection. Journal of Proteome Research
16. Type: Journal Articles Status: Published Year Published: 2014 Citation: Pearson, C.C., Backus, E.A., Shugart, H.J., and Munyaneza, J.E. 2014. Characterization and correlation of EPG waveforms of the psyllid Bactericera cockerelli (Hemiptera: Triozidae): variability in waveform appearance in relation to applied signal. Annals of the Entomological Society of America 107: 650-666.
17. Type: Journal Articles Status: Published Year Published: 2014 Citation: Prager, S.M., Butler, C.D., and Trumble, J.T. 2014. A binomial sequential sampling plan for the psyllid Bactericera cockerelli Sulc (Hemiptera: Triozidae) in tomato (Solanum lycopersicum). Journal of Economic Entomology 107(2): 838-845.
18. Type: Journal Articles Status: Published Year Published: 2014 Citation: Prager, S.M., Esquivel, I., and Trumble, J.T. 2014. Factors influencing host plant choice and larval performance in Bactericera cockerelli. PLoS ONE 9(4): e94047. doi:10.1371/journal.pone.0094047.
19. Type: Journal Articles Status: Accepted Year Published: 2014 Citation: Rashed, A. Workneh, F., Paetzold, L. and Rush, C.M. 2014. Candidatus Liberibacter solanacearum?-infected seed potatoes in relation to the time of infection. Plant Disease.
20. Type: Journal Articles Status: Awaiting Publication Year Published: 2014 Citation: Rashed, A., Workneh, F., Paetzold, L., and Rush, C.M. 2014. Emergence of ?Candidatus Liberibacter solanacearum?-infected seed potatoes in relation to the time of infection. Plant Disease
21. Type: Journal Articles Status: Published Year Published: 2014 Citation: Rashed, A., F. Workneh, J. Gray, L. Paetzold and C.M. Rush. 2014. Zebra Chip Disease Development in Relation to Plant Age and Time of ?Candidatus Liberibacter solanacearum? Infection. Plant Disease 98: 24-31.
22. Type: Journal Articles Status: Accepted Year Published: 2014 Citation: Wallis, C.M., Rashed, A., Chen, J., Paetzold, L., Workneh, F., Rush, C. M. 2014. Effects of potato psyllid-vectored ?Candidatus Liberibacter solanacearum? infection on potato leaf and stem physiology. Phytopathology
23. Type: Journal Articles Status: Published Year Published: 2014 Citation: Sengoda, V.G., Cooper, W.R., Swisher, K.D., Henne, D.C., and Munyaneza, J.E. 2014. Latent period and

transmission of ?Candidatus Liberibacter solanacearum? by the potato psyllid Bactericera cockerelli (Hemiptera: Triozidae). PLoS ONE 9(3): e93475. doi:10.1371/journal.pone.0093475.
24. Type: Journal Articles Status: Published Year Published: 2014 Citation: Swisher, K.D., Sengoda, V.G., Dixon, J., Munyaneza, J.E., Murphy, A.F., Rondon, S.I., Thompson, B., Karasev, A.V., Wenninger, E.J., Olsen, N., and Crosslin, J.M. 2014. Assessing potato psyllid haplotypes in potato crops in the Pacific Northwestern United States. American Journal of Potato Research 91: 485-491.
25. Type: Journal Articles Status: Published Year Published: 2014 Citation: Tahzima, R., Maes, M., Achbani, E.H., Swisher, K.D., Munyaneza, J.E., and De Jonghe, K. 2014. First report of ?Candidatus Liberibacter solanacearum? on carrot in Africa. Plant Disease 98: 1426.
26. Type: Journal Articles Status: Accepted Year Published: 2014 Citation: Wallis, C. M., Rashed, A., Wallingford, A. K., Chen, J., Paetzold, L., Workneh, F., and Rush, C. M. 2014. Effects of potato psyllid-vectored ?Candidatus Liberibacter solanacearum? infection on potato leaf and stem physiology. Phytopathology.
27. Type: Journal Articles Status: Published Year Published: 2014 Citation: Wallis, C.M., Rashed, A., Paetzold, L., Workneh, F., and Rush, C.M. 2014. Similarities and differences in physiological responses to ?Candidatus Liberibacter solanacearum? infection among different potato cultivars. Phytopathology 104: 126-133.
28. Type: Journal Articles Status: Published Year Published: 2014 Citation: Wallis, C.M., Rashed, A., Wallingford, A.K., Paetzold, L., Workneh, F., and Rush, C.M. 2014. Similarities and differences in physiological responses to ?Candidatus Liberibacter solanacearum? infection among different potato cultivars. Phytopathology 104:126-133.
29. Type: Websites Status: Published Year Published: 2014 Citation: Zheng, Z., Clark, N., Lee, R., Keremane, M., Wallis, C., Deng, X., and Chen, J. 2014. Whole-genome sequence of ?Candidatus Liberibacter solanacearum? from California. Genome Announcements. GenBank assembly: http://www.ncbi.nlm.nih.gov/assembly/GCA 000756225.1
30. Type: Conference Papers and Presentations Status: Awaiting Publication Year Published: 2014 Citation: Paetzold, L., Rashed, A., Workneh, F., and Rush, C.M. 2014. Temporal and spatial variation of psyllid haplotype occurring in indigenous vegetation of Texas. 14th Annual SCRI ZC Reporting Session, Portland, OR. Nov. 9, 2014.
31. Type: Conference Papers and Presentations Status: Awaiting Publication Year Published: 2014 Citation: Rashed, A., Wallis, C.M., Paetzold, L., Woodell, L., Olsen, N., Workneh, F., Rashidi, M., Wenninger, E.J., and Rush, C.M. 2014. ?Candidatus Liberibacter solanacearum? development in Russet Norkotah under commercial storage conditions. 14th Annual SCRI ZC Reporting Session, Portland, OR. Nov. 9, 2014.
32. Type: Conference Papers and Presentations Status: Awaiting Publication Year Published: 2014 Citation: Rush, C.M. 2014. Impact of vine-kill on Lso and zebra chip symptom development in tubers following late season psyllid infestations. 2014 SCRI Zebra Chip Annual Reporting Session. Portland, OR. Nov. 9-12.
33. Type: Conference Papers and Presentations Status: Awaiting Publication Year Published: 2014 Citation: Rush, C.M., Workneh, F., Paetzold, L., Olsen, N., Henne, D., and Rashed, A. 2014. Impact of vine-kill on Lso and zebra chip symptom development in tubers following late season psyllid infestations. 14th Annual SCRI ZC Reporting Session. Portland, OR. Nov. 9, 2014.
34. Type: Conference Papers and Presentations Status: Awaiting Publication Year Published: 2014 Citation: Villanueva, R., Esparza ,G., Henne, D., Paetzold, L., and Rush, C.M. 2014. The Mexican conundrum of hot potato psyllids: commercial hosts, and surveyed sites. 14th Annual SCRI ZC Reporting Session. Portland, OR. Nov. 9, 2014.
35. Type: Conference Papers and Presentations Status: Awaiting Publication Year Published: 2014 Citation: Wallis, C., Rashed, A., Workneh, F., and Rush, C.M. 2014. Effects of ?Candidatus Liberibacter solanacearum? infections on the physiology of tubers at different

storage temperatures. 14th Annual SCRI ZC Reporting Session. Portland, OR. Nov. 9, 2014.
36. Type: Conference Papers and Presentations Status: Awaiting Publication Year Published: 2014 Citation: Workneh, F., Henne, D., Paetzold, L., Warfield, B., Silva, A., Bradshaw, J., and Rush, C.M. 2014. Psyllid survey results for 2014. 14th Annual SCRI ZC Reporting Session. Portland, OR. Nov. 9, 2014.
37. Type: Conference Papers and Presentations Status: Awaiting Publication Year Published: 2014 Citation: Workneh, F., Henne, D.C., Bradshaw, J., Paetzold, L., and Rush, C.M. 2014. Progress in regional assessments of zebra chip incidence and associated factors. 14th Annual SCRI ZC Reporting Session. Portland, OR. Nov. 9, 2014.
38. Type: Conference Papers and Presentations Status: Awaiting Publication Year Published: 2014 Citation: Trumble, J. and Prager, S. 2014.Resistance evaluation and insecticide rotation programs for control of potato psyllids. 14th Annual SCRI ZC Reporting Session. Portland, OR. Nov. 9, 2014.
39. Type: Conference Papers and Presentations Status: Awaiting Publication Year Published: 2014 Citation: Shjerve, R., Johnson,C. , Wen, A., Johansen, V. , and Gudmestad,N. 2014. Effect of haplotype on the transmission of Lso in eight potato cultivars. 14th Annual SCRI ZC Reporting Session. Portland, OR. Nov. 9, 2014.
40. Type: Conference Papers and Presentations Status: Awaiting Publication Year Published: 2014 Citation: Munyaneza,J., Mustafa, T. , Swisher K., Horton D.,and Zack, R. 2014. Liberibacter transmission efficiency among potato psyllid haplotypes. 14th Annual SCRI ZC Reporting Session. Portland, OR. Nov. 9, 2014.
41. Type: Conference Papers and Presentations Status: Awaiting Publication Year Published: 2014 Citation: Munyaneza, J., Bester, G., Ronis, D., Novy, R., van Hest, P., J. , Nordgaard, Buchman, J. , and Thompson, S. 2014.Update on the 2014 zebra chip variety screening trial. 14th Annual SCRI ZC Reporting Session. Portland, OR. Nov. 9, 2014.

PROGRESS: 2012/09/01 TO 2013/08/31
Target Audience: Our target audience primary included farmers, crop consultants, representatives from agri-industry and commodity groups, and other researchers working on Zebra Chip and related diseases, such as Citrus Greening. Changes/Problems: Nothing Reported What opportunities for training and professional development has the project provided? Numerous post docs, graduate students and undergraduate student workers have been trained this year and during the course of this program. Researchers frequently visit other PI's labs to learn specific techniques and methods. How have the results been disseminated to communities of interest? Research results have been publishedboth as refereed journal articles and non-refereed technical articles. Research results have also been presented at national and international scientific meetings, field days, grower meetings, and at the 2013 SCRI ZC Reporting Session. Numerous radio and television interviews and broadcasts have been conducted, outlining results of research from this program. What do you plan to do during the next reporting period to accomplish the goals? Nothing Reported

IMPACT: 2012/09/01 TO 2013/08/31
What was accomplished under these goals? In the SCRI ZC Program, part of the 1:1 requiredmatch of Federal grant dollars was in the form of cash contributions from farmers, processors and agri-industry. Originally, these groups pledged $238,000 per year as part of the ZC program required match, and these funds were in turn were awarded as minigrants to bring in new researchers into the ZC program or to enhance or introduce areas of particular research need. This program has grown over the years and in2013 the ZC Advisory Board approved $360K in funding for 13 proposals. As evidenced by its growth, this program has been popular among the researchers and all clientele groups, and has ensured that the program remains open to new ideas and continually addresses the most critical research needs. Another unique aspect of the SCRI ZC program has been its annual

reporting session. SCRI ZC program researchers are required to attend and participate in this meeting by presenting a poster or oral presentation of their current research progress. This program has become the undisputable source for the most current information on all aspects of ZC. Proceedings are published on the SCRI ZC website and in a hard copy proceedings that are given to all attendees.The 2013 meetingmeeting in San Antonio had approximately 125 in attendance, from 16 states and 6 countries and approximately 45 presentations were given during the 3-day meeting. The value of this meeting has been attested to by potato growers from the PacificNorthwest who were devastated by ZC in 2011, primarily because they were unaware of the true threat an unprepared to deal with it once it arrived. Many of these growers attended the 2011 Reporting Session and were able to hear about the latest in ZC management strategies and to talk with other farmerswho had experienced and survived previous onslaughts of ZC. Information gained at that meeting, and others since then, has contributed to the lack of any newregional ZC induced disasters. Over 20 PIs are currently involved in the SCRI ZC program and each of those has an aggressive research or extension program and have made significant contributions during 2013. The following are some of the more notable: Dr. Rush's program determined that plant infections as late as one week before harvest still allow adequate time for Liberibacter solanacearum (Lso) to travel to the tuber. At harvest, tubers from plants infected one week before harvest show no disease symptoms and the pathogen cannot be detected in the tuber. However, after storage a percentage of these same tubers will test positive for Liberibacter solanacearum. These results emphasize the importance of late season vector control and have very significant implications with regard to disease monitoring, storage and trade issues. After developing the tools used by most labs to distinguish between the Central and Western Potato Psyllid biotypes, ARS researchers from the Pacific Northwest joined into collaboration with Dr. Bextine, UT-Tyler, to work on identifying additional haplotypes. Going beyond the Biotype/Haplotype level of population genetic inquiry, they completed a large data set that differentiated populations within the Central Biotype. This provided evidence that psyllid populations found in Mexico and Central America are closely related to those found throughout the US during the growing season. Secondly, the Potato Psyllid Genome Project continues to progress and the first genome sequence was released in August 2013, with another release (with much greater coverage) scheduled for February 2014. Finally, collaborative relationships with researchers in several Central American countries were established resulting in identification of Lso in new geographic regions. John Trumble's program at UC-Riverside has long been recognized for their work on psyllid ecology, epidemiology and management. They recently determined that although some potato psyllid populations in Texas are quite resistant to imidicloprid, thiamethoxam is still efficaceous. This was surprising since these two neonicitinoids are in the same same IRAC class. However, these results will allow growers to use a material that still has a benefit of psyllid suppression rather than continue to use an ineffective material. It also was documented that both materials will still supress psyllid populations in California. In additional studies, working with breeders in Texas and Idaho, potato lines that have usable plant traits that provide reasonable resistance to the potato psyllid were identified. These lines are now undergoing additional selection for commercial attributes. Researchers at the USDA-ARS, Parlier, CA and Texas AgriLife Research, Amarillo examined three different potato cultivars to observe ZC progression and associated changes in biochemistry in potatoes infected with Lso. It was observed that few differences existed in ZC progression and tuber physiological shifts after Lso infection. It was concluded that breeding programs should target sources of Lso tolerance in currently uncultivated species of potato, as little variation was discovered among major cultivated potatoes. Dr. Rich Nove, USDA-ARS, Aberdeen, ID found that potato breeding germplasm derived from the intercrossing of wild relatives of potato with cultivated potato impacted psyllid behavior. Germplasm derived from Solanum etuberosum and S. berthaultii displayed antibiotic and antixenotic effects to potato psyllid. Liberibacter transmission also was reduced in this germplasm, with potato

germplasm derived from S. guerreroense also displaying reduced Liberibacter transmission. This species-derived germplasm is being utilized in further hybridizations to cultivated potato for the development of resistance to potato psyllid and possible resistance to Lso. The Texas Potato Breeding and Variety Development Program continued to evaluate germplasm for tolerance/resistance to ZC. Over the past several years, some 800 varieties/selections have been evaluated and several promising selections have been identified. In 2013, several of these were utilized in a hybridization program and progeny are under evaluation. Because of relatively low natural psyllid populations in recent years and improved pesticide spray programs, evaluation work is now almost exclusively conducted in caged mini-plots where psyllid pressure can be regulated. Tolerant varieties/selections tend to continue to increase tuber size after psyllid infection, as opposed to susceptible lines where yield is arrested with infection. Symptom expression of tolerant varieties/selections also tends not to be as severe as in susceptible varieties/selections. Importantly, Dr. Creighton Miller has solidified a partnership with Dr. Antonio Rivera Pena, the INIFAP potato breeder in Toluca, Mexico who is believed to have important germplasm relative to the ZC problem.

PUBLICATIONS: 2012/09/01 TO 2013/08/31

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2. Type: Book Chapters Status: Awaiting Publication Year Published: 2014 Citation: Wang, N., Rashed, A., Workneh, F., and Rush, C. 2013. Candidatus Liberibacter spp. and related diseases. In: Virulence Mechanisms of Plant Pathogenic Bacteria (eds. N. Wang, J. Jones, G. Sundin, F. White, S. Hogenhout, C. Rober, L. De La Fuente, and J. Ham). APS Press (in press)
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23. Type: Conference Papers and Presentations Status: Published Year Published: 2013

Citation: Munyaneza, J.E., Buchman, J.L., and Henne, D.C. 2013. Effects of potato psyllid and zebra chip disease on potato seed and postharvest. American Journal of Potato Research 90: 139
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25. Type: Conference Papers and Presentations Status: Published Year Published: 2013 Citation: Wallis, C. M., Rashed, A., Wallingford, A. K., and Rush, C. M. 2013. Relationship of potato biochemical responses to ?Candidatus Liberibacter solanacearum?, causal agent of zebra chip, to disease progression. Phytopathology 103(Supplement 2):154. (abstract)
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29. Type: Conference Papers and Presentations Status: Published Year Published: 2013 Citation: Hamm, P.B., Rondon, S.I., Eggers, J.E., Crosslin, J.M., and Munyaneza, J.E. 2013. Zebra chip, the Columbia Basin experience in Oregon and Washington in 2011. American Journal of Potato Research 90: 133. (abstract)
30. Type: Conference Papers and Presentations Status: Published Year Published: 2013 Citation: Swisher, K.D., Crosslin, J.M., and Munyaneza, J.E. 2013. Three biotypes of the potato psyllid, Bactericera cockerelli (Sulc), identified within the United States by High Resolution Melting Analysis. American Journal of Potato Research 90: 151. (abstract)

PROGRESS: 2011/09/01 TO 2012/08/31
OUTPUTS: Experiments were conducted to address specific research objectives within each of the Primary Focus Areas outlined in the Zebra Chip (ZC) SCRI work plan. The regional survey was continued to monitor psyllid density and movement and to determine the number that were positive for Liberibacter solanacearum (Lso). Real time PCR primers and probe were used to evaluate detection of Lso in potato psyllids. Trips were made to the Pacific Northwest (PNW) to help educate growers, consultants and industry personnel in aspects of Zebra Chip disease development and vector ecology and epidemiology. Intensive sampling and diagnostic testing for Lso was initiated in the Pacific Northwest. Potato psyllids collected as part of the on-going survey in TX, NE, KS, CO, and WY, and psyllids collected in the Pacific Northwest, were subjected to high resolution melt analysis (HRM) of a portion of the cytochrome oxidase gene in an attempt to detect genetic variability within psyllid populations. DNA was extracted from composite samples of Lso-infected (hot) and Lso-free psyllids (cold) in ratios of up to 29 cold psyllids plus one hot psyllid. These were then tested by conventional PCR with primers OA2/OI2c or with the real-time primers and probe designed from the outer membrane protein of Lso. Research studies were initiated in Texas to determine the impact of plant age and temperature on infection by bacteriliferous psyllids, time to symptom development, and impact on tuber yield and quality. The effect of late season psyllid infestations on Lso titer in infected tubers, before and after storage, was investigated. The impact of late season infections on tuber quality and subsequent germination also was evaluated. During 2011-2012, assessment of biotype for insects collected from 2007-2011 was completed and analysis of insects from 2012 was begun. In

addition to this, we determined presence of Lso and begun to determine if specific genetic populations of potato psyllids have higher percentages of positives. A series of experiments were conducted under laboratory conditions at USDA-ARS Wapato, WA to determine time required for the potato psyllid to effectively acquire and transmit Lso to potato. A new study was initiated in 2011-2012 at the USDA-ARS Wapato, WA to evaluate effects of temperature on the feeding behavior and Lso transmission by the potato psyllid, using electrical penetration graph (EPG) technology. Studies to evaluate various sources of resistance to Lso and the potato psyllid were continued. Research was conducted to evaluate alternatives to traditional insecticide applications for vector management and new studies were initiated to investigate potential breakdown in certain insecticides, frequently used as at planting psyllid control. A large number of undergraduate, graduate and post-doctoral students were trained in traditional and molecular approaches to study zebra chip. PARTICIPANTS: In 2011, the USDA-ARS laboratory in Weslaco, TX permanently closed. Dr. John Goolsby, who had been in charge of the ZC SCRI psyllid survey since the beginning of the program was reassigned and unable to continue in the project. This program is exceptionally popular and highly valued by growers so Dr. Don Henne, AgriLife Research entomologist at Weslaco assumed responsibility for the program. Other significant changes that have occurred with regard to personnel include: Don Henne moved from Research Scientist in Amarillo to Assistant Professor with AgriLife Research in Weslaco; Christian Nansen, AgriLife Research entomologist, Lubbock moved to Australia and his responsibilities in the SCRI program were assumed by Jerry Michels, AgriLife Research entomologist, Amarillo; Dave Appel, AgriLife Extension plant pathologist left the program and his extension leadership responsibilities were assumed by Bob Harveson, Plant Pathology Extension Specialist, Univ. Nebraska, Scottsbluff; Arash Rashed, AgriLife Research entomologist, Amarillo, Chris Wallis, USDA-ARS Plant Pathologist, Parlier, CA, Cecilia Tamborindeguy, AgriLife Research entomologist, TAMU, Betsy Pierson, AgriLife Research, plant pathologist, TAMU, Silvia Rondon, Extension Entomology Specialist, OSU, Hermiston, OR, and Jeff Bradshaw, Extension Entomology Specialist, Univ. Nebraska, Scottsbluff joined the ZC SCRI research team either as co-PIs or collaborators funded through the ZC SCRI Minigrant program. TARGET AUDIENCES: As ZC is detected in countries outside of the USA, the ZC SCRI program,and particularly the Annual Reporting Session, has become the primary source of information and expertise concerning all aspects of the disease. Our target audience is becoming considerably more international than when the program began. PROJECT MODIFICATIONS: Nothing significant to report during this reporting period.

IMPACT: 2011/09/01 TO 2012/08/31
As of June 2012, approximately 4,700 psyllids have been received at USDA in Prosser, WA and tested for Lso as part of the psyllid survey. Most samples have come from the McAllen, Pearsall, and Dalhart areas of TX. Additional samples are from KS, CO, NE, OR and WA as the season progresses. Total Lso infection rate in these psyllids has been less than 1%. The infection rate in samples collected from control plots in Weslaco and commercial fields near McAllen, TX, showed relatively high infection rates in Dec. 2011-Feb. 2012, but steadily declined since that time. In studies to evaluate the ability to detect Lso from bacteriliferous psyllids, after dilution with abacteriliferous psyllids, results show that composite samples can be used. Conventional and real-time PCR results were comparable. This ability enables the testing of large numbers of psyllids in an effort to determine the relative likelihood of developing zebra chip disease in the current season potato crop. Also, the ability to use primers designed from the outer membrane protein of Lso provides an alternative to the 16S rDNA that is commonly used in the molecular detection of prokaryotes. Results from the high resolution melt analysis Results indicated the presence of at least three haplotypes of the potato psyllid, corresponding to the "central" (TX, MX, CO region), "western" (CA, parts of OR and WA), and a newly described "northwestern" haplotype, only identified in psyllids from Prosser and Moxee, WA, and one insect collected near Boise, ID. These results

suggest there may be locally overwintering populations of the potato psyllid in portions of the Pacific Northwest. Additionally, since ZC was first reported in the Pacific Northwest in 2011, the presence of this third haplotype may relate to the epidemiology of ZC in this region. It was determined that potatoes are susceptible to infection by Lso regardless of plant age. Furthermore, high temperatures did not prevent infection of plants by bacteriliferous psyllids, although high temperatures clearly impact psyllid fecundity. The earlier in the season plants were infected, the lower tuber quality. At harvest time, Lso could be detected in tubers from plants infected two weeks before harvest but not from plant infected one week before harvest. However, after storage, Lso could be detected in those infected one week before harvest and germination of these tubers was significantly reduced compared to healthy controls. In studies to determine if specific genetic populations of potato psyllids have higher percentages of positives, our initial assessment is yes, clade 7 within the central biotype and the Western populations of psyllids have a significantly higher rate of pathogen occurrence. In Lso acquisition studies, we found that Lso latent period in the psyllid is about two weeks, after an acquisition period of 8-24 hours on Lso-infected plants. Using electrical penetration graph (EPG) technology, it was determined that adult potato psyllids tend to feed in the xylem at temperatures above 32 C, thereby limiting transmission of this phloem-limited bacterium and significantly reducing zebra chip development.

PUBLICATIONS: 2011/09/01 TO 2012/08/31

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PROGRESS: 2010/09/01 TO 2011/08/31
OUTPUTS: Activities: Experiments were conducted to address specific research objectives within each of the Primary Focus Areas outlined in the Zebra Chip (ZC) SCRI work plan. A regional survey was continued to monitor psyllid movement and the number that were positive for Liberibacter solanacearum (Lso). Approximately 1,700 individual potato psyllids were tested. A ring test was conducted to compare traditional and qPCR methods of detecting Lso. New sampling strategies for psyllids were developed and presented to growers, state personnel, and research scientists. Deployment of weather stations was accomplished and climatic data collected. Studies to evaluate interactions and the impact of vector number, temperature, and plant age on time and severity of zebra chip were conducted. The Lso genome was sequenced and with the availability of sequence data, genome wide sequence analyses was conducted and simple sequence repeat (SSR) and multilocus sequence typing (MLST) molecular markers for Lso were designed and developed. Forty-four sets of SSR primers were screened, and eight sets of SSR primers were selected to study genetic variation of Lso. One set of the SSR primers was used to develop a PCR assay for laboratory routine ZC-Lso detection and genotyping. Efforts to sequence and assemble the potato psyllid genome were continued and methods for defining populations of potato psyllids were developed. A number of studies were conducted to evaluate various sources of resistance to Lso and the potato psyllid. Additional studies were conducted to evaluate alternatives to traditional insecticide applications for vector management. A large number of undergraduate, graduate and post-doctoral students were trained in traditional and molecular approaches to study zebra chip. Events: The annual Zebra Chip reporting session, November 6-9, 2011 in San Antonio, TX provided the most recent information on all aspects of ZC to over 100 participants from five countries. A potato

field day was held July 20 in Springlake, TX to provide growers, processors, and researchers an opportunity to view advanced germplasm lines and to share current research activities centered around genetic resistance to ZC. Services: Scientists associated with the ZC SCRI provided diagnostic services (for positive identification of Lso and the potato psyllid) for producers, industry personnel, consultants and other researchers. This included the introduction of the e-diagnostic feature on the ZC website http://zebrachipscri.tamu.edu. Dissemination: Information on ZC was provided to a large number of different groups in 2011. These included Joint meetings of the SPDN and GPDN Diagnostic Networks, Annual ZC Reporting Session, Annual Meetings of ESA and APS, Potato Expo, Annual Washington State and Oregon Potato Conference, Colorado Potato Conference, WSU and OSU Potato Field Days, Annual Meeting of Potato Association of America, and Columbia Basin Crop Consultants Association Meeting. In addition, several informal grower meetings were held in which Nebraska extension specialists discussed ZC and the importance of vector management with groups of approximately 40-45 farmers. PARTICIPANTS: Drs. John Goolsby, USDA-ARS Weslaco, TX, and Christian Nansen, Texas AgriLife Lubbock, were key scientists in the SCRI ZC Program and both left to take new positions. However, Dr. Goolsby's responsibilities will be assumed by Dr. Don Henne and those of Dr. Nansen by Dr. Jerry Michels. Dr. Henne and Michels both had previous experience with ZC and the potato psyllid and should be able to continue ongoing projects and responsibilities with minimal down time. Dr. Jeff Bradshaw, University of Nebraska, Scottsbluff recently has joined the SCRI ZC team. His focus will be on outreach and education and applied studies on the potato psyllid. The identification of ZC in the Pacific Northwest will expand the program and Drs. Phil Hamm and Silvia Rondon from Oregon, extension specialists in Plant Pathology and Entomology, respectively, and Dr. Phil Nolte from Idaho, extension specialist in Plant Pathology attended the ZC reporting session and are likely to become heavily involved in the program. The Washington, Oregon and Idaho potato commissions are likely to become more interested in ZC and members from all these groups attended the ZC Reporting Session in San Antonio. TARGET AUDIENCES: Growers in the PNW are now extremely interested in ZC and are attempting to learn as much as possible in the shortest time possible. Proceeding from the 2010 SCRI ZC Reporting Session were sent to the state commodity organizations and members were invited to attend the 2011 meeting, which many did. Potato farmers in the PNW primarily produce potatoes for french fries, fresh market and flaking instead of chipping, and service to this large group will require additional effort on all PIs currently involved in the SCRI ZC Program. PROJECT MODIFICATIONS: The detection of ZC in the PNW greatly expands the geographic area that must be covered in our program and the majority of potatoes are stored instead of immediately processed. However, from the outset of the SCRI ZC Program most PIs predicted the spread of ZC into the PNW and none of our primary research focus areas, objectives, methods or ultimate goal has changed. Indeed, the immediate attention and support that members of our team were able to provide to producers, industry personnel and researchers in the PNW demonstrates the success, value, and preparedness of our program.

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In 2011 psyllid numbers were exceptionally low from Texas to Nebraska and the number of psyllids testing positive for Lso was less than 2%. Low psyllid numbers were possibly associated with a late freeze in south Texas and record drought and high temperature across the southern Great Plains later in the season. These factors resulted in a very low incidence of disease. However, temperatures in the Pacific Northwest (Idaho, Oregon, and Washington State) were unusually cool during the growing season, psyllid populations were higher and developed earlier than usual, and ZC was identified for the first time in this region. Results from the ring test indicated that there was relatively good agreement among diagnostic laboratories in their abilities to accurately detect Lso from infected plant materials. It was confirmed that qPCR is more sensitive than traditional and that tissue from

stem or tubers is preferred for Lso extraction and diagnostics and leaf tissue is unreliable. In a separate study, it was demonstrated that potato psyllids could be tested in bulk for Lso without any loss in accuracy. Field studies revealed that neither temperature nor plant age affected symptom development, and time from infestation to first symptom appearance was remarkably constant at 23-25 days. Tubers from plants infested with bacteriliferous psyllids three weeks before harvest exhibited a high percentage of symptomatic tubers which tested positive for Lso, while those infested two weeks before harvest had no symptoms of ZC but approximately 50% tested positive for Lso. Plants infested one week before harvest had no disease symptoms and all tested negative for Lso. The new sampling strategies for potato psyllids proved to be effective. Growers in California responded by changing psyllid assessment strategies from inaccurate trapping techniques to statistically-valid field sampling approaches. The effective use of insecticides and the management of psyllid resistance improved overall strategies for control by reducing the use of ineffective materials and rotating modes of action in a fashion recognized to slow or stop pesticide resistance development. Furthermore, it was determined that some biopesticides, including entomopathogenic fungi, mineral oils, and kaolin are effective in controlling the potato psyllid. These safer products could be useful in development of IPM programs for the potato psyllid and zebra chip. Sequencing projects for both Lso and the potato psyllid are proving to be very useful. Data from the psyllid sequencing project is being made available to the through the International Psyllid Genome Consortium hosted at UT Tyler (http://www.uttyler.edu/biology/faculty/bextine/psyllid consortium/po tato psyllids.php), and has been useful in developing methods for defining populations of potato psyllids. SSR and MLST molecular markers from the Lso sequencing study are useful tools for detection and genotyping of various isolates. SSR genotyping using 8 sets of SSR primer pairs revealed that there are two major lineages among North American and New Zealand populations.

PUBLICATIONS: 2010/09/01 TO 2011/08/31

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PROGRESS: 2009/09/01 TO 2014/08/31
Target Audience: The target audience was primarily potato farmers, processors and the agricultural scientists who were working on various aspectszebra chip and other related

diseases, such as citrus greening. Changes/Problems: During this reporting period, two of the lead PIs were diagnosed with cancer and had to undergo treatment and recover and this significantly impacted their programs. However, due to previous training of highly qualified personnel and team contributions, project objectives were still completed. In addition, one PI, Dr. Don Henne with Texas A&M AgriLife Research, Weslaco, Tx took another position and left the program in mid summer. Again however, due to highly trained personnel all research objectives were completed. What opportunities for training and professional development has the project provided? A significant number of undergraduate, graduate and post doctoralstudents, were exposed to and trained in the basic procedures of scientific research. This included specific training in insect identification, field plot design, simple data collection and statistical analysis, disease and insect management, IPM concepts, general laboratory skills, and basic training in molecular biology. A number of students were also taken to field dayts and grower meetings where they had the opportunity to see aspects of real production agriculture, visit with growers and make presentations concerning their activities in the ZC SCRI project. Students also had the opportunity to attend professional meeting, take part in development of research presentations and make oral and poster presentations. A number of students were given the opportunity to visit other research facilities and labs to meet peers and learn alternative ways of addressing research problems. How have the results been disseminated to communities of interest? Results of this program were disseminated through publication of a number of extension publications, conference proceedings, journal publications, presentations at field days and grower meetings and during the annual Zebra Chip Reporting Session. In order to facilitate reaching an expanded audience, the Annual Reporting Session was held in the Pacific Northwest (Portland, OR) this year instead of San Antonio, TX. What do you plan to do during the next reporting period to accomplish the goals? Nothing Reported

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What was accomplished under these goals? The Zebra Chip SCRI has been an exceptionally successful program. Close to a thousand farmers and industry representatives have been educated about the disease and recommended management practices. These recommendations have been put to use at the farm level, with the result that no devastating epidemic of ZC has occurred in the last three years. Growers understand the nature of the disease, what causes it and how it spreads and the necessary steps to keep losses at a minimum. A large number of undergraduate, graduateand post doctoral studentshave been trained and a number have been placed in professional positions as university faculty and withthe potato agri-industry. DIspite changes in program personnel, individual projects continued,objectives were met and farmers currently rely on research and survey results to make disease and pest management decisions. Team members have nearly completed the sequence of three Lso haplotypes, which show considerable diversity in phage insertion sequences. This work has improved pathogen detection and differentiation andwill help to understand biological differences that exist among haplotypes. The team also discovered that over an eight year period, haplotype A has become the dominant type in the environment. Preliminary data suggest differences in temperature sensitivity and in acquisition and transmission success. Furthermore, it has been observed that haplotype A and B have differential effects on seed germination and in aggressiveness in tomato and that haplotype B is the more aggressive of thetwo. Surveys of non crop areas verified that psyllid haplotypes exhibit temporal shifts within a givenarea or region. In West Texas, the Southwestern haplotype was displaced during thesummer by the Western haplotype and this is highly significant because none ofthe southwesternhas tested positive for Lso, whereas the highest percentage of positive psyllids have been of the Western haplotype. Also, the recent discovery that potato psyllid successfully overwinters in the Pacific Northwest has led to studies which suggest that residency is a consequence of an apparently new adaptation by one psyllid haplotype (Northwestern) to a recently introduced

and invasive nightshade, Solanum dulcamara. Late-season access to this plant prompts a cold-hardening response by the Northwestern haplotype not observed for the other (non-resident) haplotypes. For example, psyllids of the Northwestern haplotype that were provided access to nightshade in October, and then exposed to a temperature of -12 oC, had very high rates of survival (>80%) compared to Northwestern psyllids collected from potato (53%), or compared to psyllids of the Central and Western haplotypes (which had mortality rates of 100% in several trials). Residency of the Northwestern haplotype also has been accompanied by a level of reproductive incompatibility between it and psyllids of the Central and Western haplotypes. Incompatibility is asymmetric, in that rates of egg hatch depend upon direction of the male:female cross. The cause of this asymmetry has now been traced to infection of some haplotypes with a bacterium (Wolbachia) that causes cytoplasmic incompatibility. An insecticide rotational program that allows growers to reliably produce potatoes in the presence of bacteriliferous potato psyllids was developed. While the rotation is not sustainable because of the limited number of materials, it cut pesticide use substantially, thereby allowing growers to produce an economically-viable crop with much less potential for pesticide residues and farm worker safety concerns. In a related study, baselines for psyllid resistance to key compounds were determined and it was documented that, at least in Texas populations, resistance has developed to a neonicotinoid. It also was demonstrated that field failures occur if pesticides such as organophosphates, pyrethroids and carbamates are used, and that these have an extremely detrimental impact on the primary parasite of the psyllid.Selected biorational insecticides were evaluated for the repellency or control of B. cockerelli. Results indicated >50% suppression of some psyllid stages, suggesting these materials may be useful in IPM programs. In a related study, the benefit of psyllid natural enemies was determined for the western haplotype of the psyllid in CA, and results will serve as a template for how to assess beneficial insects in other production regions. Breeding germplasm was screened for resistance to B. cockerelli and Lso. Compared to the susceptible control, several breeding clones exhibited reduced psyllid feeding and resting, suggesting resistance to the vector, and several clones displayed significantly reduced Lso infection. In a related study, 35 advanced breeding lines were screened by challenging with bacteriliferous psyllids. All lines developed typical foliar symptoms of ZC but nine lines had no, to only light, symptom development in tubers.

PUBLICATIONS: 2009/09/01 TO 2014/08/31

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37. Type: Conference Papers and Presentations Status: Awaiting Publication Year Published: 2014 Citation: Trumble, J. and Prager, S. 2014.Resistance evaluation and insecticide rotation programs for control of potato psyllids. 14th Annual SCRI ZC Reporting Session. Portland, OR. Nov. 9, 2014.
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PROGRESS: 2009/09/01 TO 2010/08/31
OUTPUTS: Administrative complications delayed distribution of Zebra Chip (ZC) SCRI funding until April 2010. Despite this delay, all principal investigators initiated projects and developed collaborations, which resulted in significant progress the first year of the program. ZC SCRI principal investigators participated in a joint meeting with scientists studying Citrus Greening. The meeting was held in McAllen, TX and attended by 229 researchers, industry personnel, and potato and citrus producers. Researchers presented project plans and data from preliminary studies. The ZC SCRI Advisory Board met for the first time during this meeting and agreed on management format, protocol for allocation of

matching funds and reaffirmed key programmatic goals and objectives. In July, Dr. Creighton Miller conducted a potato field day that focused on ZC. Approximately 75 growers, researchers and agri-industry personnel participated. Brief presentations were made by researchers, outlining their plans for ZC projects. A regional sampling program of potato psyllid populations and its associated pathogen, Liberibacter solanacearum (Lso) was conducted in McAllen, Pearsall, Olton and Dalhart, TX; Garden City, KS; Minden, Imperial, Alliance and Scottsbluff, NE. Each week, leaf samples and yellow sticky traps were collected from test fields to assess the efficacy of the grower's IPM program and the incidence of adults that were positive for Liberibacter. To determine the percentage of hot adult psyllids, psyllids were removed from the traps and assayed using molecular diagnostics. The information from the field and laboratory testing was reported weekly from Dec, 2009 to Oct. 2010 to more than 200 growers, consultants, researchers, and potato processors. An aerial sampling device was designed, constructed, and installed at four locations in the western panhandle of Nebraska. The purpose of the sampling device was to develop a way to sample aerial biota at multiple elevations. The basic trap design is modular for ease of transport and the trap clamp construction is flexible enough to accept a diversity of trapping systems. A series of epidemiological studies were initiated. Automated weather stations were deployed from the lower Rio Grande Valley to NE to collect meteorological data. Ten potato fields across the region were assessed for ZC incidence. Plots were established around the edges and in the center of fields. Symptomatic plants in each plot were dug up for verification of ZC, and subsamples were taken to the laboratory and tested for Lso by PCR. To further understand the dynamics of ZC incidence and psyllid abundance over time and space, an additional ring of plots was established, giving rise to 3 rings (edge, 100 m, and 200 m from the edge) of 16 plots each (n=48) around the center pivot. Yellow sticky traps were deployed for monitoring psyllid abundance. ZC incidence in each plot was assessed weekly and traps were removed for psyllid counts and replaced weekly. PARTICIPANTS: A ZC research and extension team composed of twenty scientists, representing a variety of disciplines, areas of expertise, and institutions was assembled for this program. Each was selected to participate in this project because of their specific research/extension expertise, and all are unified in commitment to our common goal: Reducing losses from ZC to economically sustainable levels by development of a comprehensive, environmentally responsible disease management program. Team members represent potato production from TX, CA, ID, WA, ND and NE. Each scientist will be involved with specific research/extension objectives within one or more of the seven priority focus areas. One scientist will be designated as lead for each specific objective. Lead scientists will have responsibility for coordinating efforts of other scientists who are collaborating in that objective, and for compiling and reporting research results for that objective. Project Leaders also have been identified for each PFA: PFA 1- Pathogen Detection, Vector/Pathogen Diversity and Disease Etiology, Neil Gudmestad, PFA 2 - Epidemiology, Don Henne, PFA 3 - Pest Management, Christian Nansen, PFA 4 - Breeding, Creighton Miller, PFA 5 - Economics, Joe Guenthner, PFA 6 - Risk Assessment/Disease Forecasting, Fekede Workneh, and PFA 7 - Technology Transfer and Outreach, Dave Appel. The lead scientist for each objective within a PFA will report to the Project Leader for that PFA. Project Leaders for each of the seven PFAs, and the Project Director (PD), Charlie Rush, and co-PDs, Neil Gudmestad and John Trumble, will meet at least quarterly by conference call to discuss progress or problems within their respective areas of responsibility. Frito Lay has been the driving force behind ZC research since it was first identified in Texas in 2000. Because of their past experience with ZC, their current support of ZC research, and their interest in expanding the program into a national effort that is strongly supported by the entire US potato industry , Gerhard Bester, Director of Ag Research with Frito, was selected to chair, and help recruit, an Advisory Board for this project. The ZC Advisory Board (AB) was assembled by recruiting potato growers, processors, scientists, and representatives from ag industry, state and Federal government, and commodity organizations, who have a vested

interest in solving the ZC problem. The AB will provide administrative leadership and overall programmatic guidance to the team of researchers and extension specialists. Members of the AB will be regularly briefed by individual lead scientists, project leaders and the project directors, concerning general progress of the program and specific topics of interest to individual members of the AB. The AB will provide primary administrative governance and fiscal direction to the program. By identifying Priority Focus Areas each year, the AB also will be providing research direction that is strongly influenced by the grower's perspective. TARGET AUDIENCES: The primary target audience for this research/extension effort is US potato producers and processors. However, results from this program will be applicable to potato producers worldwide. Information should also be relevant to tomato producers and all scientists investigating diseases vectored by psyllids. PROJECT MODIFICATIONS: Nothing significant to report during this reporting period.

IMPACT: 2009/09/01 TO 2010/08/31
In field trials,441 selections/ varieties were evaluated for ZC using fresh cut and chip evaluations. Of these, 18 entries which did not exhibit ZC expression were further evaluated under controlled cage conditions in a 2009/10 winter trial in Weslaco, TX. While resistance was not observed in these trials, there did appear to be differential preference (tolerance) by the psyllid among the entries which could be attributed to volatiles or differences in leaf characteristics. Psyllid pressure in Texas was similar to previous years; however the percentage of adults with Liberibacter was much lower, which resulted in a low incidence of zebra chip. In Kansas and Nebraska, potato psyllid populations were high, but with a very low incidence of adults with Liberibacter. The high population levels, especially in Imperial and Alliance, NE, were associated with direct feeding damage to potatoes called psyllid yellows. Simple sequence repeat (SSR) primers based on the sequences of Lso were validated in PCR experiments using 68 Lso strains collected from different geographical locations. Four primer pairs differentiated these Lso strains and divided them into two major groups, which are in agreement with the two groups based on 16S rRNA gene sequences revealed previously. Lso strains associated with ZC, psyllid-yellows, haywire and seedborne ZC were highly differentiated using the four primer pairs. In epidemiological studies, average ZC incidence per plot declined significantly with increasing distance from south to north. ZC incidences in the Rio Grande Valley varied substantially among the three fields, the earlier planted field having much lower ZC incidence than the other two, which were planted 2 to 3 weeks later. The later plantings were bordered by thick bushes which may have served as psyllid source leading to greater infection. In addition, winter temperatures in 2010 in the Valley were colder than normal, which may have affected the activities of both the psyllid and the pathogen early in the season resulting in low ZC incidence in the early planted field. In a spatio-temporal study, ZC-symptomatic plants were observed for the first time on June 16 in the two outer plot rings (the edge and the 100 m), but were not observed until the third week in the innermost plot ring (200 m). The incidence of new symptomatic plants was at its maximum on the edges on the third week in which there were twice as many ZC-symptomatic plants as in the inner plots. The number of psyllids per trap was significantly greater on the edges than in the infields in the first two weeks of observations. However, psyllid numbers on the edges declined after the second week while those in the infields continued to increase until the fourth week. The reason for this was not clear. The fact that field edges had greater psyllid densities early in the season suggests that psyllids land on the edge, establish and multiply, and then move inward. The progress of ZC incidence over the 6-week-observation period in each ring was near perfectly described by a logistic growth model.

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