PROJECT NO: BJKT04, BJKT05, BJKT08 (plus a new collaborator)

TITLE: A survey of central and eastern Idaho wireworm species and evaluating ecological and chemical approaches to maximize cereal production

PERSONNEL: A. Rashed, X. Liang, C. W. Rogers, J. M. Marshall

ADDRESS: Arash Rashed, University of Idaho, Aberdeen R & E Center, 1063 S. 2700 W., Aberdeen, ID 83210; 208-397-7000 ext. 114; arashed@uidaho.edu

JUSTIFICATION: Wireworms continue to be one of the top concerns of wheat producers in Idaho, primarily due to the lack of an effective chemical control measure in cereals.

Since variations in the effectiveness of chemical options had been, in part, attributed to the among-species differences in susceptibility, an area-wide survey was initiated to identify key wireworm species and numbers, in approximately 120 fields across southern Idaho. Throughout the survey, relevant soil physical, chemical, and biological attributes were quantified to evaluate their impact on wireworm populations and to investigate species-specific habitat preferences. All findings were interpreted in relation to these soil health indicators as well as various cultural practices including tillage and crop rotation.

Throughout our studies, we have received unprecedented support from growers across Idaho. Currently, more than 34 growers are participating in our monitoring program; the largest ongoing survey in the Pacific Northwest region. We have not only co-organized an international team of researchers to identify shortfalls and explore new areas of research, but also developed close collaborations with IBEST on-campus, and colleagues in Washington (WSU and USDA-ARS), to understand genetic variations both within and among species, and to evaluate efficacy of biological control approaches in managing wireworms, respectively.

We have identified 10 predominant pest species of wireworms in cereal fields in southern Idaho. The majority of the species, identified in the past two years, was the sugar beet wireworm *Limonius californicus*. The other two species largely populating eastern counties were identified as *Hyponoidus bicolor* and the western field wireworm *L. infuscatus*. We have also shown that multiple species may be present within a field and that the time of activity of each species appears to be dependent upon environmental variables. We reported significant relationships between soil bulk density/soil texture and wireworm numbers, pointing to the importance of seed-bed preparation in minimizing losses due to wireworm damage.

Our preliminary evaluations of the endosymbionts, microbes associated with the sugar beet wireworms, revealed significant variations across eastern, central, and western Idaho; the presence and density of certain endosymbionts can affect insect susceptibility to insecticides. Moreover, our results indicated that the higher tillering barley is relatively more tolerant to wireworm damage than the lower tillering wheat. These findings have opened new avenues of research that we are proposing to explore in upcoming years. We also propose to continue our research on short-term management solutions by evaluating efficacy of different insecticides against wireworms, as well as cultivar tolerance to wireworm damage.

Our established collaborations with Idaho cereal growers and the continuous support from the Idaho Wheat Commission have been precursors to the development of this exemplary collaborative study, which also attracted support from competitive federal sources of funding.

We propose to continue this well-established interdisciplinary study by broadening its scope through addressing the following objectives.

Hypothesis: The degree of wireworm damage is species-dependent and a clear understanding of their interaction with the surrounding biotic and abiotic environment will assist with developing integrated management practices to minimize their negative impact. To evaluate this hypothesis we will address the following objectives:

I) Continue wireworm monitoring to share with growers and to collect sufficient number of samples for genetic analysis, and identify microbial communities associated with wireworm populations across southern Idaho,
II) Quantify wireworm susceptibility to neonicotinoids with respect to their associated microbe species and densities,
III) Study the impact of crop rotation options, and inter-cropping, on wireworm damage,
IV) Quantify among-cultivar differences in susceptibility to wireworms, in relation to tiller number and root structure,
V) Quantify variations in wireworm damage in response to heat/drought stress in relation to soil organic matter content.

PROCEDURES: To address **Objective I**, we will continue to monitor wireworm populations in ~60 fields, previously known to be infested, in southern Idaho. Baits will be placed at 6 inches deep (minimum of three traps in each field), throughout the growing season, in every field starting 3 weeks before planting until after harvest in October. Traps will be replaced every 3-4 weeks. The DNA of the trapped wireworms will be extracted. Subsamples will be provided to IBEST for genetic variability analysis. Another subset will be analyzed for the presence of endosymbiont DNAs, using available primers. As a part of **Objective II**, sugar beet wireworms hosting different endosymbiotic communities will be evaluated for their susceptibility to the commonly used seed treatments. A wireworm-infested field located at the University of Idaho, Kimberly R&E Center will be used to setup study plots to compare the impact of recommended rotation crops for dryland and irrigated cropping systems (i.e. peas, quinoa, mustard, radish) on wireworm pressure (**Objective III**). Since anecdotal observations suggested a greater wireworm damage following beans, we also propose to evaluate the effectiveness of its use as an inter-crop to divert potential damage away from the seeded wheat at the initial stages of its growth. To address **Objective IV**, a selection of high- and low-tiller varieties will be obtained from the USDA seed bank in Aberdeen, ID. This objective is to evaluate whether losses to wireworms could be reduced by using varieties with relatively more robust tiller production and rooting system. In the face of our ever-changing climate and continuous shortage of water, **Objective IV** is set to quantify losses to the sugar beet wireworm in drought/heat stressed plants, a key step towards providing an objective measure to predict the extend of yield loss. This assessment will be conducted in relation to soil organic matter content; organic matter may not only reduce wireworm damage, it may also assist with increasing water-holding capacity of the soil.

DURATION: Spring 2017 through Spring 2020.

COOPERATION: This is a cooperative project between Drs. Rashed, Liang, Rogers and Marshall at the Aberdeen R & E Center. In an established collaboration with U of I, IBEST, we will continue to provide DNA of the collected wireworm species for genetic assessments. An international effort has been coordinated to expand our genetic analysis of wireworm species

beyond the US. Our work and success would not have been possible without strong support and active collaboration from Idaho cereal producer community.

ANTICIPATED BENEFITS/EXPECTED OUTCOMES/INFORMATION TRANSFER:
This proposal is built upon our most recent findings of wireworm ecology and species composition, based on our 2014-2017 efforts, and is now expanded to address objectives that are directly relevant to efficacy of the currently available seed treatments, and developing cultural practices that may limit wireworm damage. Our collaborative efforts have resulted in the first time publication of the full mitochondrial sequence of the sugar beet wireworm, the first published comparison of wireworm damage in wheat and barley in relation to seeding depth and soil texture, and a comprehensive visual key to wireworms and management options in Idaho. Several manuscripts and talks are currently in preparation for presentations in upcoming months.

LITERATURE REVIEW:
Historically, wireworms were controlled by using environmentally persistent chemistries that are now banned due to environmental and health concerns (Vernon et al 2009). Although substitute chemistries provided some level of protection, wireworm susceptibility to the new generation of chemicals varied depending on the species (Van Herk et al. 2007) and the insect pressure. Moreover, anecdotal observations suggest potential among-population variability in response to neonicotinoid seed treatments within species.

Recently, more emphasis has been placed on alternative control measures to achieve more successful and sustainable damage control in conjunction with seed treatments. The effectiveness of any IPM program in controlling wireworms depends on a clear knowledge of the present species and their ecology (Furlan 2005). The sugar beet wireworm *Limonius californicus* is known to be the most damaging species to cereals in Idaho and is believed to show inconsistent degrees of susceptibility to neonicotinoid seed treatments (Rashed et al. 2015). Relatively recent studies have indicated that the susceptibility to imidacloprid and other insecticides can be affected by pest association with its microbial communities (Ghanim and Kontsedalov 2009).

Unfortunately, knowledge of wireworm ecology and control is generic without taking among-species variations into account. For instance, wireworm species may vary in the range of plant species they utilize (Pazmand and Traugott 2005) and the soil characteristics (such as pH, texture, organic matter, and moisture) with which they are associated (Barsics et al 2013). It has been also shown that soil type (Rashed et al. 2016), CO_2 (Barsics et al 2013; Gfeller et al 2013), and volatile organic compounds released from roots (Gfeller et al. 2013) can affect wireworm movement and survival. Such ecological traits can be used in trap cropping and baiting various wireworm species as a part of a sustainable IPM program.

REFERENCES
Barsics F., Haubruge E., Verheggen F.J. 2013. Wireworms' management: An overview of the existing methods, with particular regards to *Agriotes* spp. (Coleoptera: Elateridae). Insects, 4: 117-152.

Furlan L. 2005. An IPM approach targeted against wireworms: what has been done and what has to be done. In: Insect Pathogens and Insect Nematodes: Melontha IOBC/wprs Bulletin. 28: 91-100.

Ghanim M., Kontsedalov S. 2009. Susceptibility to insecticides in the Qbiotype of *Bemisia tabaci* is correlated with bacterial symbiont densities. Pest Management Science, 65: 939-942.

Gfeller A., Laloux M., Barsics F., et al. 2013. Characterization of volatile organic compounds emitted by barley (*Hordeum vulgare* L.) roots and their attractiveness to wireworms. *Journal of Chemical Ecology*, 39: 1129-1139.

Pazmand C., Traugott M. 2005. A stable isotope analysis of wireworms puts new light on their dietary choices in arable land. In: Insect Pathogens and Insect Nematodes: Melontha IOBC/wprs Bulletin. 28: 127-132.

Rashed A., Rogers C.M., Rashidi M., Marshall J.M. 2016. Sugar beet wireworm *Limonius californicus* damage to wheat and barley: Evaluations of plant damage with respect to soil media, seeding depth, and diatomaceous earth. *Arthropod-Plant Interactions, in press.*

Rashed A., Etzler F., Rogers C.W., Marshall J.M. 2015. Wireworms in Idaho cereals: A guide to monitor numbers and identify predominant species in the intermountain region. University of Idaho Extension Bulletin 898.

Toba H.H., O'Keeffe L.E., Pike K.S., et al. 1985. Lindaine seed treatment for control of wireworms (Coleoptera: Elateridae) on wheat in Pacific Northwest. *Crop Protection*, 4: 372-380.

Vernon R.S., Van Herk W.G., Clodius M., Harding C. 2009. Wireworm management I: Stand protection versus wireworm mortality with wheat seed treatments. *Journal of Economic Entomology*, 102:2126-2136.

IDAHO WHEAT COMMISSION - BUDGET FORM

Allocated by	Idaho Wheat Commission	during FY 2016	$	34,105
Allocated by	Idaho Wheat Commission	during FY 2017	$	35,943

REQUESTED FY2018 SUPPORT:

	Salary	Temporary Help	Fringe	Travel	OE	Graduate Tuition/Fees	TOTALS
Idaho Wheat Commission	$ -	$ 22,600	$ 9,243	$ 2,900	$ 1,200	$ -	$ 35,943

TOTAL BUDGET REQUEST FOR FY 2018: $ 35,943

BREAKDOWN FOR MULTIPLE SUB-BUDGETS:

	Rashed	*Liang*	*Rogers*	*Marshall*
Salary	$ -		$ -	$ -
Temporary Help	$ 17,900	$ 3,500	$ 1,200	$ -
Fringe Benefits	$ 7,321	$ 1,432	$ 491	$ -
Travel	$ 2,400	$ -	$ -	$ 500
Operating Expenses	$ 300	$ -	$ 400	$ 500
Graduate Student Tuition/Fees	$ -	$ -	$ -	$ -
TOTALS	$ 27,921	$ 4,932	$ 2,091	$ 1,000

Total Sub-budgets $ 35,943

Explanatory Comments: (see FY2018 Guidelines for definition)

11.21.2016 - Version

ANNUAL REPORT

PROJECT NO: BJKT04, BJKT05, BJKT08
TITLE: A survey of central and eastern Idaho wireworm species and evaluating ecological and chemical approaches to maximize cereal production
PERSONNEL: Arash Rashed, Entomologist, Aberdeen
Juliet Marshall, Smalls Grains Specialist, Aberdeen
Christopher Rogers, Soils/Agronomist, Aberdeen
ADDRESS: Arash Rashed, University of Idaho, Aberdeen R & E Center, 1063 S. 2700 W., Aberdeen, ID 83210; 208-397-7000 ext. 114; arashed@uidaho.edu

ACCOMPLISHMENTS:

The wireworm monitoring program in Idaho has expanded from 65 fields in 2015-2016 to nearly 120 irrigated and dryland fields in the 2016-2017 season. Fields are located in 14 counties across southern Idaho. All fields have been monitored continuously throughout the year (with the exception of December and January). Traps were replaced on a 3 to 4-week schedule, and remained in the soil for approximately two weeks, starting 3 weeks before planting. 34 cereal growers in southern Idaho participated in our 2015-2016 monitoring program. Overall, 10 species of wireworms have been identified throughout our monitoring program (two previously unobserved species were added in this reporting period). At each sampling date, soil moisture and temperature data were recorded at different depths (0-6, 6-12, and 12-24 inches below the soil surface). Soil bulk density, texture (i.e., sand, silt, clay), inorganic carbon (i.e., carbonates) and total nitrogen and carbon contents were characterized on a single sample per field, as these factors are relatively fixed within a growing season. Findings were presented in conferences, meetings and cereal schools. A scientific paper was published in a recognized international journal in 2016, comparing plant susceptibility to the sugar beet wireworm between wheat and barley, and evaluating diatomaceous earth efficacy against wireworms. We also continued our collaborations with the IBEST, by providing DNA samples from species collected throughout the season.
We are currently combining our two-year datasets. Final results will be presented in cereal schools, research review and field days. Here we present a summary of our 2015-2016 activities.

Species identification

We have now identified a total of 10 wireworm species in Idaho:

1- *Limonius californicus* (sugar beet wireworm)
2- *Aeolus mellillus* (Say)
3- *Hypnoidus bicolor* (Eschscholtz)
4- *Limonius canus* LeConte
5- *Limonius infuscatus* Motschulsky (known as western field wireworm)
6- *Selatosomus aeripennis* (Kirby)
7- *Selatosomus pruininus* (Horn) (known as Great Basin wireworm)
8- *Hadromorphus glaucus* (Germar)
9- *Agriotes lemosus* group- *currently unknown species* **(2016 reporting)**
10- *Hemicrepidius* sp. **(2016 reporting)**

More than 900 wireworm samples have been collected in 2016-2017, of which 582 have been identified: *H. bicolor* (40.7%), *L. californicus* (33%), *L. infuscatus* (10%), *S. aeripennis* (7%), *H. glaucus* (3.8%), *A. mellillus* (1.5%), *S. pruininus* (0.8%) and *L. canus* (0.03%). Although the highest percentage of the collected species was identified as *H. bicolor*, this was primarily due to a heavy infestation in one particular barley field in southeast Idaho.

Wireworm activity in relation to environmental factors

We have continued our data collection, on environmental and cultural variables, to identify factors affecting wireworm presence and pressure. Currently, we are in the process of compiling a large dataset for analysis and results will be presented at the research review. In central Idaho, wireworm activity was observed beginning in early March, a pattern similar to previous years. Wireworm activity in Blaine and Butte counties began as late as May. In all other locations, wireworms were detected in April (see Figure 1). Variability in the time of wireworm appearance was also reflected in a significant effect of location, detected using a generalized linear regression model ($F_{13, 261}$= 3.06, $P < 0.001$). Wireworm presence was also affected by time of sampling ($F_{13, 261}$= 2.96; P = 0.013), temperature ($F_{1, 261}$= 7.20; P = 0.008), and irrigation ($F_{1, 261}$= 7.27; P = 0.007). The majority of collected wireworms were associated with fields under cereal production in southeastern Idaho; there was an increase in the population of *H. bicolor,* a species associated with heavy soil types. Wireworm presence was not statistically different among the three depths. Please note that some traps are being counted at the time of this report and results are subject to change due to updates. Wireworm appearance was associated with temperatures ranging between 40 and 80 F. 2015-2016 soil samples have been analyzed and moisture, pH, C, N and bulk density data are being organized for statistical analyses.

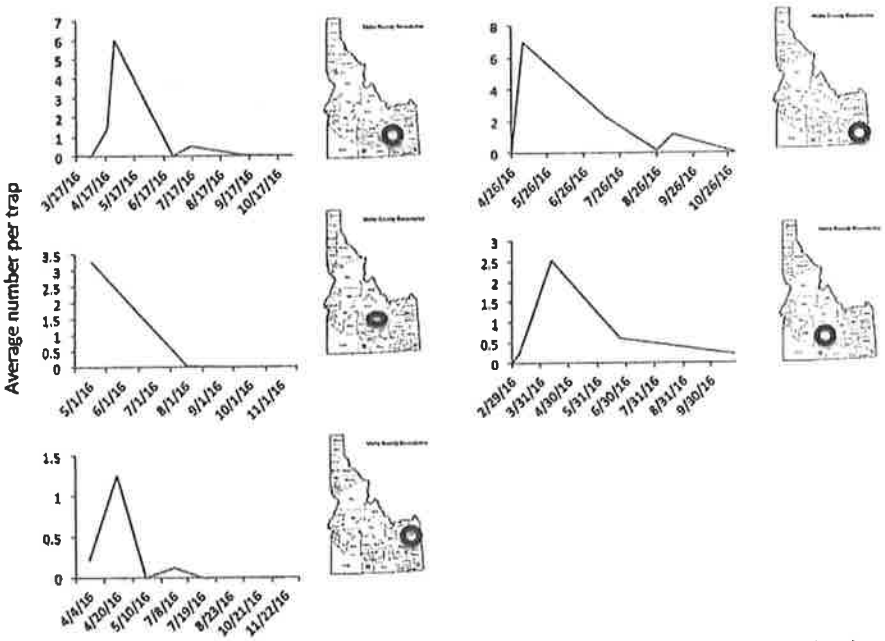

Figure 1: Representations of average wireworm numbers per trap in different monitoring sites.

Greenhouse studies

Results of a greenhouse study were finalized and published in an international scientific journal. The study was included in the previous report; however, as previously reported data was preliminary the summary of our results presented has been updated after completion of statistical analyses. The study evaluated wheat (Klasic) and barley (IdaGold) susceptibility to sugar beet wireworm damage at different planting depths (1 inch and 3 inches) and soil media (sand, peatmoss, and a mix of 1:1 sand/peatmoss mixture). Overall, a relatively greater susceptibility to wireworm damage was observed in wheat than in barley. This was reflected in greater reductions in emergence success and foliar biomass in wheat when compared to barley (Figure 2A). Although the rate of post-emergence feeding damage was not statistically different between wheat and barley, a significantly higher rate of damage was associated with the sand-dominated medium (Figure 2B). The greatest loss of foliar biomass was observed in wheat seedlings planted in the peatmoss-dominated medium. Please note that figure 2 included updates from previously reported preliminary data and some corrections.

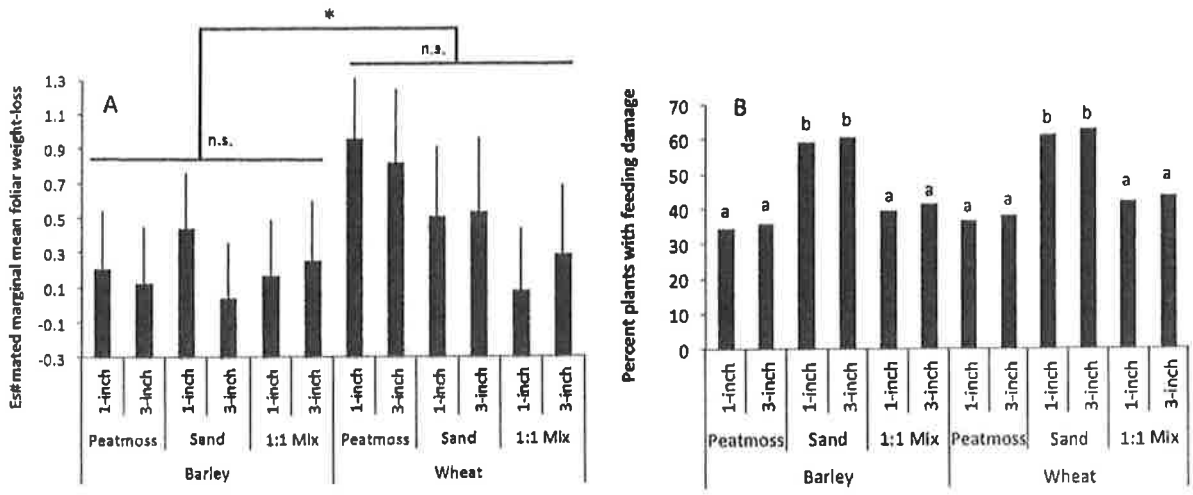

Figure 2: Illustration of the losses in foliar biomass (A) and post-emergence feeding damage (B) in wheat (var. Klasic) and barley (var. Ida Gold) planted in different soil media in different depths.

Efficacy of diatomaceous earth (DE) against wireworms was evaluated in 2015-2016. No significant effect was detected between the DE-treated and non-treated treatments (Binary logistic regression: Wald $X^2_1=1.25$, P = 0.262).

In summary, we considerably increased our field sites and co-operations with cereal growers in Idaho. We completed multiple greenhouse studies to confirm the impact of different ecological variables and chemical compounds on different species of wireworms (results not presented here). We have assembled a large dataset, which would allow us to develop hotspot maps and to identify factor and cultural practices that impact different species of wireworms. With support from Idaho Wheat and Barley Commissions, and our cereal growers, we have completed another successful year for one of the most thorough regional studies focused on understanding wireworm behavior to develop management strategies. We have used these two-year data to justify much needed additional funding from federal sources. During cereal schools, we recommended management options, including crop rotation, seed treatment and proper seedbed preparation, based on our last-year survey results. We have also used these two-year data to justify much needed additional funding from federal sources.

Next Steps

We will continue our sampling program to collect samples for experiments (wireworms cannot be reared in the laboratory) and for our extensive ongoing phylogenetic studies in collaboration with the IBEST institute on campus. The role of genetic variations among populations in susceptibility to seed treatments will be evaluated through this collaborative research. We will continue our research on developing more effective and sustainable cultural control measures that are tailor-made to dryland and irrigated cropping systems. New objectives have been developed, as a result of our findings during the past three years. In an original approach in wireworm system, we have started to identify endosymbionts (microbes) associated with wireworms, in collaboration with colleagues at the USDA-ARS in Wapato (WA). Variations in endosymbiotic microbes have been observed in samples collected across southern Idaho. As some endosymbionts are known to influence insect susceptibility to pesticides this would be an essential topic to pursue, as a part of

our efforts towards understanding underlying mechanisms for variations in seed treatment efficacy against wireworms.

PROJECTIONS:

Conducting studies on the damaging location-specific species provide information that is essential in developing effective management practices. Variations in microbial communities have never been investigated in wireworm populations, and this information will be essential in predicting pesticide efficacy. Results of this research are set to provide information on integrated and sustainable control measures that are species specific. Two additional refereed publications are expected by the fall of 2017.

PUBLICATIONS

- Rashed, A., C.W. Rogers, M. Rashidi, & J.M. Marshall. 2016. Sugar beet wireworm *Limonius californicus* damage to wheat and barley: Evaluations of plant damage with respect to soil media, seeding depth, and diatomaceous earth. *Arthropod-Plant Interactions, in press.*
- Rashed, A., Etzler, F., Rogers, C.W, Marshall, J.M. 2015. Wireworms in Idaho cereals: monitoring and identification. University of Idaho Extension Bulletin: 898.
- Gerritsen, A.T., Robison, B.D., New, D.D., Rashed, A. and Settles, M.L. 2015. *Limonius californicus* mitochondrion, complete genome. GenBank, KT852377.1
- Gerritsen, A.T., Robison, B.D., New, D.D., Hohenlohe, P. Rashed, A. Forney, L., Rashidi, M. Wilson, C., and Settles, M.L. 2015. Full Mitochondrial Genome Sequence of the Sugarbeet Wireworm Limonius californicus (Coleoptera: Elateridae), a Common Agricultural Pest. *Genome Announcement*, accepted.