2. Support breeding programs for developing rust resistant varieties; identify and develop new rust resistant germplasm; and map new resistance genes and develop molecular markers for stripe rust resistance genes.	**1) Stripe rust reaction data of various wheat and barley nurseries.** In each of the three years (2013-2015), we tested more than 30,000 wheat and more than 2,000 barley entries for resistance to stripe rust, and provided the data to breeding programs to eliminate susceptible lines, select rust resistant lines for developing new varieties and mapping resistance genes. **2) New rust resistant sources.** Through the germplasm screening, we identified new resistant sources and characterized the types of resistance. **3) New wheat varieties.** During the three years, we collaborated with breeders in registration of 15 wheat and 2 barley varieties, in addition to more than 10 varieties that have been released, and to be registered. The germplasm evaluation data were also used to update the Seed Buyer's Guides for growers to choose resistant varieties to grow. **4) Stripe rust resistance genes mapped and molecular markers developed.** During the three years, we mapped more than 30 stripe rust resistance genes to wheat chromosomes with molecular markers, permanently named 6 genes, and published 13 papers on molecular mapping and identification of stripe rust resistance genes. **5) Supplied seeds of germplasm to breeding programs.** We provided seeds of our recently developed new wheat germplasm lines to more than 30 breeding and research programs in the US and other countries for developing stripe rust resistant varieties.	In each of the three years, we completed evaluation of more than 30,000 wheat and more than 2,000 barley entries for resistance to stripe rust. The entries included germplasm, breeding lines, rust monitoring nurseries, and genetic populations from various breeding and extension programs. All nurseries were planted and evaluated at both Pullman and Mt. Vernon locations under natural stripe rust infection. Some of the nurseries were also tested in Walla Walla and Lind, WA . Germplasm and breeding lines in the variety trial and regional nurseries also were tested in the greenhouse with selected races of stripe rust for further characterization of resistance. Disease data of regional nurseries were provided to all breeding and extension programs, while data of individual breeders' nurseries were provided to the individual breeders. Through these tests, susceptible breeding lines can be eliminated, which should prevent risk of releasing susceptible cultivars and assisted breeding programs to release new cultivars of high yield and quality, good adaptation, and effective disease resistance. Through the germplasm screening, we have established a collection of wheat germplasm with stripe rust resistance, which are valuable sources of stripe rust resistance for further characterization of resistance, identified new effective resistance genes, and for development of wheat varieties with effective resistance. Varieties with durable resistance to stripe rust have been developed. We collaborated with breeders in registration of 15 wheat and 2 barley varieties, in addition to more than 10 varieties that have been released, but to be registered. Varieties developed by private breeding programs were also resulted from our germplasm screening program. During the three years, we mapped more than 30 stripe rust resistance genes to wheat chromosomes with molecular markers, permanently named 6 genes, and published 13 papers on molecular mapping and identification of stripe rust resistance genes. We also made numerous crosses and developed new mapping populations for identify new resistance genes.	All germplasm tests were completed and the data were provided to collaborators on time in each year. The 2015-16 winter wheat nurseries were planted in fields in September and October 2015. The 2015 spring crop nurseries will be planted in March-April, 2016. The greenhouse tests of the 2015 spring nurseries and the 2015-16 winter wheat nurseries have been conducting in the greenhouse during the winter, and will be completed by May, 2016	The data of variety trials and regional nurseries were sent to growers and collaborators through e-mails and websites. Summary information of varieties were sent to growers and collaborators through rust updates and recommendations through e-mails, website, Seed Buyer's Guide, variety release documents. Test data of individual breeding programs were sent to the individual breeders. New genes and molecular markers were published in scientific journals (see the publication and presentation lists in the report main file).

3. Determine effectiveness of fungicides for rust control and develop more effective strategies for integrated rust management.	**1) New fungicides and information on appropriate use of fungicides.** In each of the three years (2013-2015), we tested 19-30 fungicide treatments for control of stripe rust in both winter and spring wheat, and provided the data to collaborators. Chemical companies will use the data for registeration of new fungicides. **2) Yield loss by stripe rust and yield increase by fungicide application of major grown varieties.** The potential yield loss due to stripe rust and increase from fungicide application for 23 winter wheat and 15 spring wheat varieties commonly grown in the PNW, plus susceptible checks, were studied in each year. The data, together with such studies in the past, are used to guide stripe rust management on the individual variety basis. **3) Integrated control strategies.** From the fungicide and variety studies, together with race information, we developed an integrated control strategy consisting of primarily growing resistant varieties and secondarily using fungicides.	In each of the three years (2013-2015), we evaluated 19-30 fungicide treatments for control of stripe rust in experimental fields near Pullman, WA. Susceptible winter wheat varieties 'PS 279' and spring wheat 'Lemhi' were used in the studies. The tests were conducted as a randomized complete block design with four replications in each experiment. Fungicides were applied at different rates and different stages of crop growth. Stripe rust severities were recorded five times in both winter wheat and spring wheat during the rust season. Grains were harvested and weighted for each plot. Rusts and yield data were analyzed to determine the efficacy for each fungicide treatment. The data were used by chemical companies to register new fungicides and also used by us for guiding control of stripe rust with fungicides. In each year, we also tested 23 winter wheat and 15 spring wheat varieties commonly grown in the PNW, plus highly susceptible checks. The experiments were in a randomized complete split-blot design with four replications. For each blot, a half was sprayed with a fungicide to control stripe rust and the other half was not sprayed to allow stripe rust to develop. Stripe rust data were recorded four times during the growing season. Grain yield and test weight were recorded at harvest. The data were used to determine stripe rust resistance level, yield loss caused by stripe rust, and yield increase by fungicide application for each variety. The results were used to estimate damage by stripe rust and also used to guide growers for selecting cultivars to grow and determine whether fungicide application is needed based on individual varieties.	For this objective, all tests scheduled for each year were successfully completed. For the 2015-16 growing season, the winter wheat plots of the fungicide and variety studies were planted in October, 2015 and the spring plots will be planted in April, 2016. The tests will be completed in August (for winter wheat) and September (for spring wheat), 2016	The results were communicated to growers and collaborators through e-mails, presentations in growers meetings, field days, plot tours, project reports and reviews, and published in scientific journals (see the publication and presentation lists in the report main file).

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Washington Grain Commission
Wheat and Barley Research Annual Progress Reports and Final Reports

Project #: 3043-3697

Progress Report Year: 2 of 2

Title: Wireworm Control in Wheat-Based Cropping Systems

Cooperators: David Crowder (WSU Entomology); Aaron Esser (WSU Extension); Stephen Guy (WSU Crop Sciences); Kevin Murphy (WSU Crop Sciences); Ryan Higginbotham (WSU Crop Sciences)

Executive Summary: In FY 2016 our team made excellent progress on each objective related to improving wireworm management in cereal crops. Major accomplishments of our team include:

(1) Sampling 160 crop fields for wireworms, with over 3,200 wireworms collected and identified in total. We also collected data on factors influencing wireworms in each field. These data have provided a clear picture of how wireworms vary across the state both in terms of species present and their abundance. We have submitted two academic publications and published one extension bulletin detailing the results of these trials.
(2) Conducting trials for over 40 new insecticidal products for wireworm management at two locations in Washington State. Data from these trials will aid registration of new products, particularly novel chemistries that are not neonicotinoids. We have also aided chemical companies in trying to get an exemption to use Fipronil in wheat.
(3) Evaluation of the effectiveness of Gaucho in protecting wheat from wireworms at 16 variety testing locations. Data shows the extent of damage caused by three major wireworm species, and the economic returns provided by insecticides. Results will be published in 2016
(4) Large-scale experimental trials of the susceptibility of wheat, barley, and oats to wireworms. Preliminary results show that wheat is far more susceptible than barley and oats.
(5) Delivery of over 25 extension talks on wireworms

Impact: Based on previous work of our team, we estimate that wireworm management provides economic benefits exceeding $10 million/yr for the state for spring wheat crops alone. If we factor in other crops affected by wireworms (winter wheat, barley, etc) this estimate would be much higher. Our project will identify management strategies combining cultural and insecticidal controls for wireworms that can provide maximum economic benefit for growers depending on their location, the crops they produce, and the wireworm species present in their field(s). Our results have now provided a clear picture on how growers should modify their management strategies based on the wireworm species present in their field. Optimizing wireworm control could provide economic benefits in the millions annually for growers throughout Washington.

Our team also delivered over 10 extension talks in 2015 concerning wireworms, including the wheat academy. With a conservative estimate of 50 attendees per talk our team thus directly communicated results to approximately 500 growers and industry representatives in the past year. Our development of extension bulletins and content for the smallgrains.wsu.edu website is allowing us to communicate information broadly to growers throughout the state.

WGC project number: 3043-3697
WGC project title: Wireworm Control in Wheat-Based Cropping Systems
Project PI(s): David Crowder and Aaron Esser
Project initiation date: July 1, 2014
Project year: 2

Outputs and Outcomes:

Objective	Deliverable	Progress	Timeline	Communication
1 - Determine effects of climate, tillage, soil, and crop rotations on wireworms in cereal crops and develop a predictive model for wireworms	Data on wireworm distributions throughout Washington state; academic publications on predictive models for wireworms	We sampled over 160 fields in the past two years for wireworms (80 spring wheat, 40 winter wheat, 40 CRP). From these fields we collected wireworms from bait traps and identified all individuals to species (over 3,200 individuals were collected). We also collected data on 10 environmental and management factors associated with wireworms from each field. From these data we were able to discern the geographic delineations of the three major wireworm species in Washington (Limonius infuscatus, Limonius californicus, Selatosomus pruininus) and the factors that mediate their abundances. For L. infuscatus and S. pruininus we found that abundances were lowest in winter wheat, but the same was not true for L. californicus. This suggests this species is the only one of primary concern for growers in winter wheat, and growers may be able to move away from neonicotinoids in winter wheat for other species. We also found that soil moisture is strongly associated with wireworm and abundance. Growers in higher rainfall areas are likely to have more preferable conditions for wireworms. We have submitted two publications based on results from these studies.	The final year of sampling was completed in 2015. Two academic publications which contain these results were submitted for publication in scientific journals, and we hope to have them published in 2016 and post the results to the smallgrains.wsu.edu website.	We communicated the information gained in this objective with growers and scientific audiences at grower meetings, field days, the Wheat Academy, and academic conferences to communicate information from this objective. In spring 2015 we published an extension bulletin on the major wireworm species of economic significance in Washington. This bulletin also contains information on how to sample and identify wireworms, and describe the significance of each major species in reducing wheat and barley yields. Information on website will be uploaded as available on a page on wireworms at the WSU Small Grains Website, which contains information for growers about wireworm management (smallgrains.cahnrs.wsu.edu)
1 - Determine wireworm species of economic significance in Washington	Extension bulletin	We published an extension bulletin that provides details on the biology of the three most damaging wireworm species in Washington, along with a pictoral guide to identifying these species. The bulletin was reviewed and published and is available through WSU Extension or on the small grains website.	Completed in 2015	The bulletin is available on the small grains website. We have discussed the results in the bulletin at field days and the Wheat Academy to make growers aware of it.