

# Demonstration of an Integrated Pest Management Program for Wheat in Tajikistan

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## Abstract

Wheat is an important food security crop in central Asia but frequently suffers severe damage and yield losses from insect pests, pathogens, and weeds. With funding from the United States Agency for International Development, a team of scientists from three U.S. land-grant universities in collaboration with the International Center for Agricultural Research in Dry Areas and local institutions implemented an integrated pest management (IPM) demonstration program in three regions of Tajikistan from 2011 to 2014. An IPM package was developed and demonstrated in farmer fields using a combination of crop and pest management techniques including cultural practices, host plant resistance, biological control, and chemical approaches. The results from four years of demonstration/research indicated that the IPM package plots almost universally had lower pest abundance and damage and higher yields and were more profitable than the farmer practice plots. Wheat stripe rust infestation ranged from 30% to over 80% in farmer practice plots, while generally remaining below 10% in the IPM package plots. Overall yield varied among sites and years but was always at least 30% to as much as 69% greater in IPM package plots. More than 1,500 local farmers—40% women—were trained through farmer field schools and field days held at the IPM demonstration sites. In addition, students from local agricultural universities participated in on-site data collection. The IPM information generated by the project was widely disseminated to stakeholders through peer-reviewed scientific publications, bulletins and pamphlets in local languages, and via Tajik national television.

**Key words:** wheat, integrated pest management, Wheat stripe rust, Sunn pest, cereal leaf beetle

Wheat (*Triticum* spp.) is a staple crop in Central Asia and the most important food security crop in Tajikistan. Following the collapse of the former Soviet Union in 1991, agricultural policy in Tajikistan shifted and farmers began to grow more wheat to satisfy local food grain demand and reduce reliance on imports. Implementation of these policies resulted in an unprecedented increase in wheat cultivation from 72,000 ha in the early 1990s to over 317,000 ha by 2013 (FAO 2013). While the area under cultivation has increased, average wheat yields have remained low. For example, dryland wheat in Tajikistan averages just 1.3–1.5 t/ha, and even with irrigation, yields seldom exceed 3 t/ha. As a result, while Tajikistan has produced 780,000 metric tons of wheat annually, this is insufficient to meet annual demand, which is in excess of 1.5 million metric tons (FAO 2013).

In most rural areas of Tajikistan, farming occurs at multiple spatial scales. To provide fresh vegetables and herbs, most households

maintain small kitchen gardens near the home. In addition, families also produce additional vegetable and wheat crops in small (typically 1–1.5 ha irrigated, or 2–3 ha nonirrigated) plots allocated to them at the village edge. Households also contribute labor to the village’s larger-scale collective production of cotton and wheat, which occurs in the surrounding fields. Mechanical tillage, planting, and harvesting are frequently utilized on these larger fields, but weed control is still typically done by hand. Gravity-fed flood irrigation is common in north and central Tajikistan, while in the south, wheat production is mostly rain-fed. Entire households contribute to farm labor, and increasingly, women farmers are becoming the norm, as many males leave for employment in Russia during much of the wheat-growing season (Fig. 1).

The current low productivity of wheat in Tajikistan stems from a variety of economic, technological, and cultural reasons. Improved



**Fig. 1.** (A) Women and children regularly contribute to wheat production in Tajikistan, (B) map showing locations of Wheat IPM Demonstrations in 1) the north (Spitamen), 2) central (Hissor), and 3) southern (Muminobad) districts. Base map courtesy of Wikimedia Commons [https://commons.wikimedia.org/wiki/File:Tajikistan\\_map\\_modern.png](https://commons.wikimedia.org/wiki/File:Tajikistan_map_modern.png).

varieties of wheat that are higher-yielding and resistant to some pests are available in the region, but high-quality seed supplies at the village level are often limited or nonexistent. This results in farmers commonly saving and replanting seed of available and familiar varieties. Due to a lack of seed-cleaning equipment, harvested wheat seed often also contains weed seeds that are then re-sown with the subsequent planting. For example, common vetch (*Vicia sativa* L.) is a prevalent weed and readily twines up the tall-statured wheat varieties favored by many farmers. Indeed, fields of meter-tall wheat with emergent vetch plants are a common sight in many areas (Fig. 2). In inquiring about farmers' views on such infestations, they commented that because wheat yields are low and unreliable, they also highly value the forage these systems produce as a source of animal feed. This view of wheat as a dual-purpose crop is a practical bet-hedging strategy, but contributes to low yields, as tall-statured (i.e., better forage-producing) but lower-yielding varieties are frequently favored. While Tajik farmers understand the need for fertilizer use in wheat, fertilizers are expensive and farmers often lack the capital to purchase and apply them at optimal levels. Pesticides (herbicides, insecticides, and fungicides) are also considered expensive and farmer confidence in their use is not universal, as diluted or even counterfeit products are sometimes suspected. Pesticide application equipment is also limited and farmers frequently spray even large fields using backpack sprayers.

A variety of pests contribute to yield loss in wheat in Central Asia (Fig. 2). The major insect pests include Sunn pest, a complex of insects in the families Scutelleridae and Pentatomidae, with *Eurygaster integriceps* being the most economically important, cereal leaf beetle *Oulema melanopus*, and several aphid species, including *Schizaphis graminum*, *Diuraphis noxia*, and *Rhopalosiphum padi* (Pett et al. 2004, Rashidov 2001, Saidov et al. 2007a). In northern Tajikistan, Sunn pest is the single most damaging insect. Both nymphs and adults cause damage to plants and reduce yields by feeding on leaves, stems, and grains. In addition to the direct reduction in yield, the insects also inject digestive enzymes into the wheat grain while feeding, which greatly reduce the quality of flour produced. In general, when only 2–3% of the grain is affected, the entire lot is rendered both unpalatable and unacceptable for baking purposes, leading to 100% crop loss (Darkoh et al. 2010). In central and southern Tajikistan, cereal leaf beetle is the

key insect pest. Both adults and larvae feed on wheat leaves, and larvae feeding can damage the flag leaf, leading to 20% yield losses.

The most serious wheat diseases in Tajikistan are the wheat rusts: stripe rust, also called yellow rust, (*Puccinia striiformis*), leaf rust (*Puccinia triticina*), and stem rust (*Puccinia graminis* f.sp. *tritici*). In addition, Septoria (*Mycosphaerella graminicola*), tan spot (*Pyrenophora tritici-repentis*), powdery mildew (*Blumeria (Erysiphe) graminis*), loose smut (*Ustilago tritici*), and common bunt (*Tilletia caries* and *Tilletia foetida*) are common (Muminjanov et al. 2004, Pett et al. 2004, Sagitov 2007). Due to a lack of diagnostic capabilities, viral diseases of wheat have been less well studied in Central Asia; however, wheat barley yellow dwarf virus, wheat streak mosaic virus, barley yellow streak mosaic virus, and wheat dwarf virus are all known to occur in the region (Kadirova 2007). Commonly occurring weeds in wheat production include common vetch, oat grass (*Avena fatua*), winter cress (*Barbarea vulgaris*), shepherd's purse (*Capsella bursa-pastoris*), pigweed or lambsquarters (*Chenopodium album*), and bermuda grass (*Cynodon dactylon*). Finally, several nematode pests of wheat are found in Tajikistan: *Anguina tritici*, *Heterodera avenae*, and *Ditylenchus dispanci*; however, there are little data regarding their economic importance (Ivanova et al. 1985).

## Pest Management Practices

Current pest management practices in wheat vary throughout Tajikistan and are influenced by farm size and landscape context, as well as farmer access to information and inputs. While improved varieties and some integrated pest management (IPM) practices have been developed for some of the key pests, implementation remains uneven, in large part due to a lack of farmer capital and advisory services. For example, many of the key wheat diseases can be controlled by use of resistant varieties or pesticide applications; however, the degree to which this is actually accomplished varies widely (Pett et al. 2004, Rashidov 2001, Saidov et al. 2007a). A number of IPM options for the management of Sunn pest have been developed, including the deployment of genetic resistance (El Bouhssini et al. 2013), entomopathogenic fungi (Edgington et al. 2007, Parker et al. 2003, Trissi et al. 2012), and egg parasitoids (Trissi et al. 2006). In addition, the use of early maturing varieties coupled with early



**Fig. 2.** Wheat production systems and key pests in Tajikistan. (A) field day participant's examine weed control in farmer practice fields, (B) typical field wheat in Muminobad District, (C) Sunn pest nymph on wheat head, (D) cereal leaf beetle larvae and damage on flag leaf, (E) severe yellow rust infestation near Hissor.

harvest can reduce Sunn pest damage. Some pesticides are also available, with current use recommendations based on localized ground sprays based on sampling and economic thresholds. On larger mechanized farms, weed control in wheat is typically accomplished by a combination of tillage, herbicides, and fallow techniques. Farmers also use crop rotation practices with a leguminous crop as a means of breaking weed cycles. On small holdings, weed control is almost exclusively accomplished via manual weeding.

### Project History

From 2005 to 2009, a team of scientists from Michigan State University, the University of California-Davis, and the International Center for Agricultural Research in the Dry Areas (ICARDA) collaborated on a United States Agency for International Development (USAID)-funded Integrated Pest Management Collaborative Research Support Program (IPM CRSP) in Central Asia (Maredia et al. 2015). During that time (Phase I), the project was focused on collaborative research to address key constraints to IPM implementation in the region and the initial development of IPM packages for wheat, potato, and tomato in Tajikistan, Kyrgyzstan, and Uzbekistan. From 2010 to 2014, Phase II of the project was continued in Tajikistan with a focus on wheat IPM with funding from the USAID Feed the Future

Innovation Lab for Integrated Pest Management (Maredia et al. 2015). In Phase II, the “wheat team” consisted of a Tajik project coordinator (an entomologist) and Tajik plant pathologist, advised by the international team that included members with expertise in IPM project facilitation, entomology, plant breeding, and plant pathology. Here we report on Phase II activities, which focused on capacity-building to further IPM adoption by demonstrating a package of best IPM practices for wheat, and using them as a platform for training farmers, crop advisors, and students in their implementation.

### Basis of IPM Program

Given our understanding of the key pests and cropping system constraints from Phase I, our approach in Phase II was to demonstrate a comprehensive package of agronomic best practices for stand establishment and fertility combined with IPM practices that addressed each of these key pests using one or more tactics. Termed the “Wheat IPM Package,” we established field sites in three major wheat-growing regions of Tajikistan to demonstrate the yield effects of the following combined components: locally tuned best cultural practices including optimal planting dates, fertilizer use, seed treatment, use of stripe rust-resistant wheat varieties, and weed management via herbicides and cultural practices. In all cases, regular field scouting was

**Table 1.** Fertilizer and pesticide inputs in farmer practice Wheat IPM Package and demonstration plots, 2011–2014

Treatment	Seed Treatment <sup>a</sup>	Herbicide <sup>b</sup>	Fertilizer <sup>c</sup>	Insecticide <sup>d</sup>
Farmer Practice	None	None	#1 Urea (46.2 kg N/ha) #2 Ammonium nitrate (51 kg N/ha)	Karate Zeon (0.01 kg AI/ha)
Wheat IPM Package	Vitavaks 200 FF (2g AI/kg of seed)	Granstar 75 DF (2.25 kg AI/ha)	#1 Urea (46.2 kg N/ha), plus Ammophos (11 kg N, 51 kg P/ha) #2 Ammonium nitrate (34 kg N/ha), plus Ammophos (11 kg N, 51 kg P/ha) #3 Ammonium nitrate (17 kg N/ha), plus Ammophos (11 kg N, 51 kg P/ha)	Neem leaf extract (0.125 g AI/ha)

<sup>a</sup>Vitavaks active ingredients 200 g/L Carboxin, 200 g/L Thiram.

<sup>b</sup>Granstar active ingredient 750 g/kg Tribenuron methyl (sulfonylurea).

<sup>c</sup>Fertilizer applied in split applications at Feeke's Stage 2 and 10.5 in farmer practice, and at Feeke's Stage 2, 8, and 10.1 in IPM package plots. Urea = 46.2% N, ammonium nitrate 34% N, Ammophos 11% N, 51% P.

<sup>d</sup>Karate Zeon active ingredients 100 g/l lambda-cyhalothrin and 1,2-benzisothiazolin-3-one. Neem 5% extract of *Azadirachta indica*.

used to determine pest thresholds and trigger any necessary pesticide treatments. The Wheat IPM Package also included habitat management to foster natural enemies. Previous studies have shown that egg parasitoids can play a major role in suppressing Sunn pest populations in wheat fields (Trissi et al. 2006); however, conserving these natural enemies in wheat is a challenge. Building on Phase I research results (Saidov et al. 2007b, Saidov et al. 2008, Saidov et al. 2011), we incorporated the use of nectar plants within the Wheat IPM Package to provide nectar and pollen resources to support natural enemies as a form of habitat management (Landis et al. 2000), and utilized insecticides (neem leaf extract) known to be less harmful to natural enemies (El Bouhssini et al. 2008).

### Capacity-Building

To build local capacity, the in-country members of the wheat team recruited approximately 20 local farmers at each site to plan farmer practice treatments, plant, sample, and harvest the demonstration plots. The landowners and local farmers also participated in regular farmer field schools and annual field days associated with each site. The contribution of women to labor and decision-making is often underestimated in rural societies, and the success of extension efforts depends on reaching women as well as men (Hallett 2000). As such, a key consideration in our program was ensuring participation by women. We specifically recruited women farmers, and the gender of participants was recorded at all project events. At one site, we engaged 20 Tajik students from local universities to gain practical experience in IPM practices. Finally, to enhance the long-term impact of our training efforts, we recruited a promising female Tajik student to attend graduate school at Michigan State University.

## Methods and Approach

### Locations

IPM demonstrations were conducted in each of the three major wheat-growing regions in Tajikistan for 2–4 years, depending on location. Hereafter, the demonstration year listed is the year of wheat harvest, with fields established the prior fall. In the north, demonstrations were located in the districts of Spitamen (2011–2013) and Bobojon Ghafurov (2014) in the Sughd Region. In central Tajikistan, demonstrations occurred in Hissor within the District of Republican Subordination (2011–2014), while in the south, demonstrations were located in the Muminobod District in the Khatlon Province (2011–2012; Fig. 1). There was one demonstration site per region each year (total of 10), and all were embedded within existing wheat fields.

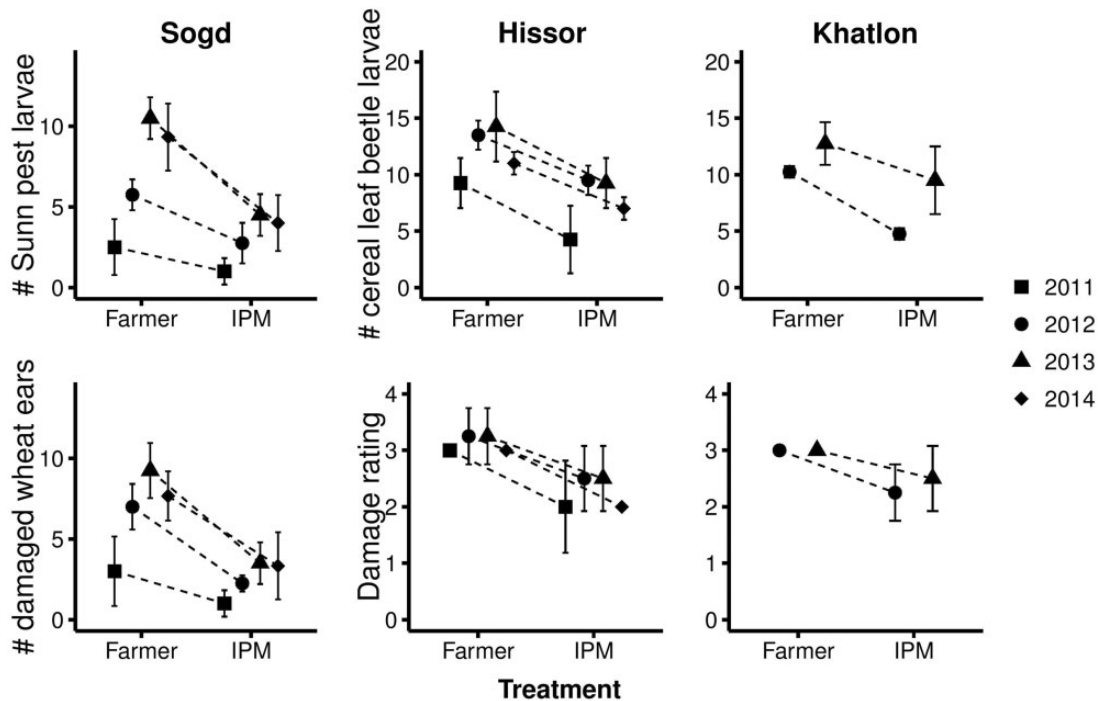
### Demonstration Design

Farmer practices and the IPM package were contrasted at each site in a replicated but nonrandomized design. At the outset of the project, the in-country project team met with local farmers in each region to learn about typical farmer practices (varieties, fertilization, pest management, etc.) to be contrasted to the IPM package. To reduce sources of variation, the final set of farmer practices and IPM package components were largely held constant across all sites and years; however, sites did vary in the varieties planted and timing of pest management operations. In 2011–2013, four 10 by 10-m farmer practice plots were arranged in a 2 × 2 grid with 1-m alleys between plots and separated from a similar set of IPM package plots 100 m away within the same field. IPM package plots were each bordered on one side by a 2-m-wide strip containing five species of flowering plants to support natural enemies. The borders consisted of alternating patches of coriander (*Coriandrum sativum* L.), dill (*Anethum graveolens* L.), sweet basil (*Ocimum basilicum* L.), ziziphora (*Ziziphora interupta* Juz.), marigold (*Calendula officinalis* L.), and winter cress (*Barbarea vulgaris* W.T. Aiton). In 2014, a similar overall design was used but individual plots were scaled-up to 0.25 ha and the number of replications was reduced from 4 to 3.

IPM plots were planted with the disease-resistant Ormon wheat variety across all years and sites, while farmer variety selection varied. In the north, the farmers selected the variety Starshina in 2011, Ulugbek in 2012–2013, and Krasnodarski 99 in 2014. At the Hissor (central) site, they selected Norman in 2011–2012, Irishka in 2013, and Jagger in 2014. In the south, farmers selected Norman in both 2012 and 2013. Farmer practice plots received fertilizer applications twice per growing season, and insecticides were applied when Sunn pest and cereal leaf beetle were observed (Table 1). IPM plots received a protective seed treatment at planting, fertilizer applications split over three times during growing season, application of a post-emergent herbicide, and insecticides as determined by scouting and thresholds. Insecticides were applied against Sunn pest when populations exceed 2–3 adults/m<sup>2</sup> during initial migration to fields, or 7–10 nymphs/m<sup>2</sup>. Cereal leaf beetles were treated when populations exceeded 10 larvae/m<sup>2</sup>.

### On-Site Assessments

Sites were planted in the fall and visited by a member of the wheat team every 2 to 3 wk during the growing season. The local farmers participated in most of these visits and were trained in recommended techniques for sampling pest abundance and application of fertilizers herbicides and insecticides. Each plot was sampled multiple times during the season to assess levels of insect pests and disease



**Fig. 3.** Mean ( $\pm$  SD) abundance of Sunn pest and cereal leaf beetle in wheat (top) and damage ratings (bottom) in farmer practice and IPM package demonstration plots in three regions of Tajikistan, 2011–2014. Damage by Sunn pest was assessed as number of damaged wheat heads per square meter. Cereal leaf beetle damage was assessed using a six-point rating system based on total leaf area damaged (see text).

incidence. Pests were sampled using a 1-m<sup>2</sup> sampling quadrat placed within the plot. At the north site, Sunn pest adults and nymphs were counted within the quadrat and Sunn pest damage was assessed by counting the number of wheat heads with damage in that same area. In the central and southern sites, where Sunn pest is rare, cereal leaf beetle larvae and adults were counted using the quadrat method and flag leaves were evaluated for damage associated with the feeding of cereal leaf beetle larva. Damage was reported in percent leaf damage based on a 1–6 rating scale: 1 = no damage, 2 = 10% or less, 3 = 25% or less, 4 = 50% or less, 5 = 75% or less, and 6 = more than 75% including flag leaf. The severity of stem and stripe rust infections was evaluated 2 to 3 times during the weeks of peak disease development prior to wheat senescence. The percentage of leaf surface showing disease symptoms was recorded in each plot using 5% intervals for leaves with  $\geq 5\%$  of their area affected, and 1% intervals when disease symptoms affected  $< 5\%$  of leaf tissue. At harvest, the wheat was evaluated to determine seed size (1,000 kernel weight in g) and overall yield in metric tons per hectare.

### Economic Evaluation

A post-hoc economic evaluation was conducted for the 2011–2013 demonstrations. Using the methods of Beskorovajnaja (2011), farmers were interviewed to collect data on the field operations, equipment, and inputs utilized from planting through harvest. This method was also used to account for the value of wheat straw and grain sold off-farm, as well as that retained for use as animal forage, household consumption, and seed for the following year.

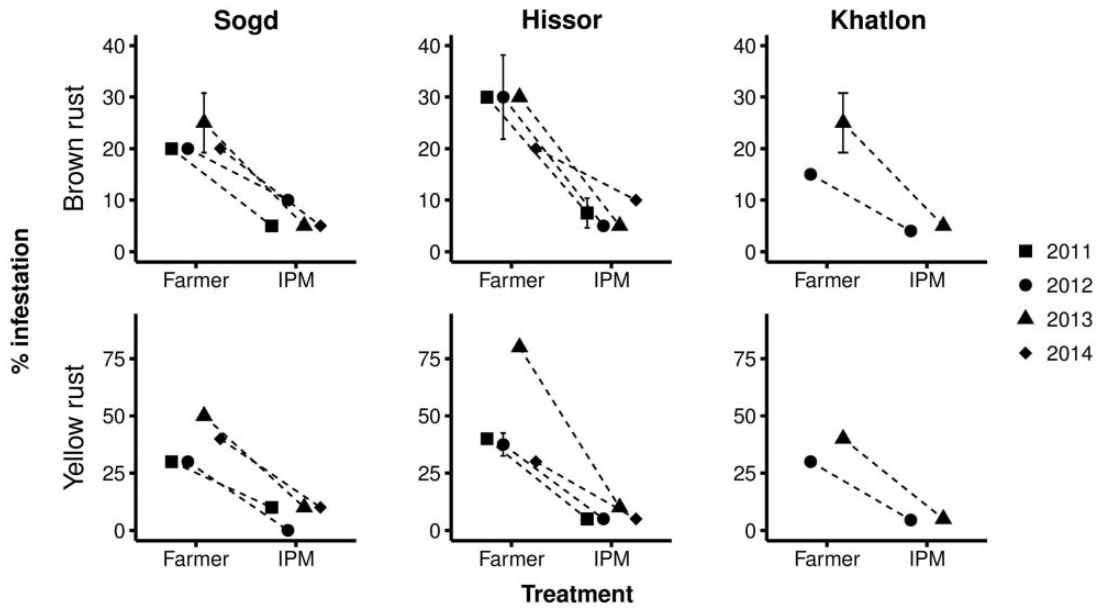
### Major Findings

Farmer practice plots almost universally had higher pest abundance and damage, and lower yields than the IPM package plots. Over the four years of the study, Sunn pest nymph abundance in the north

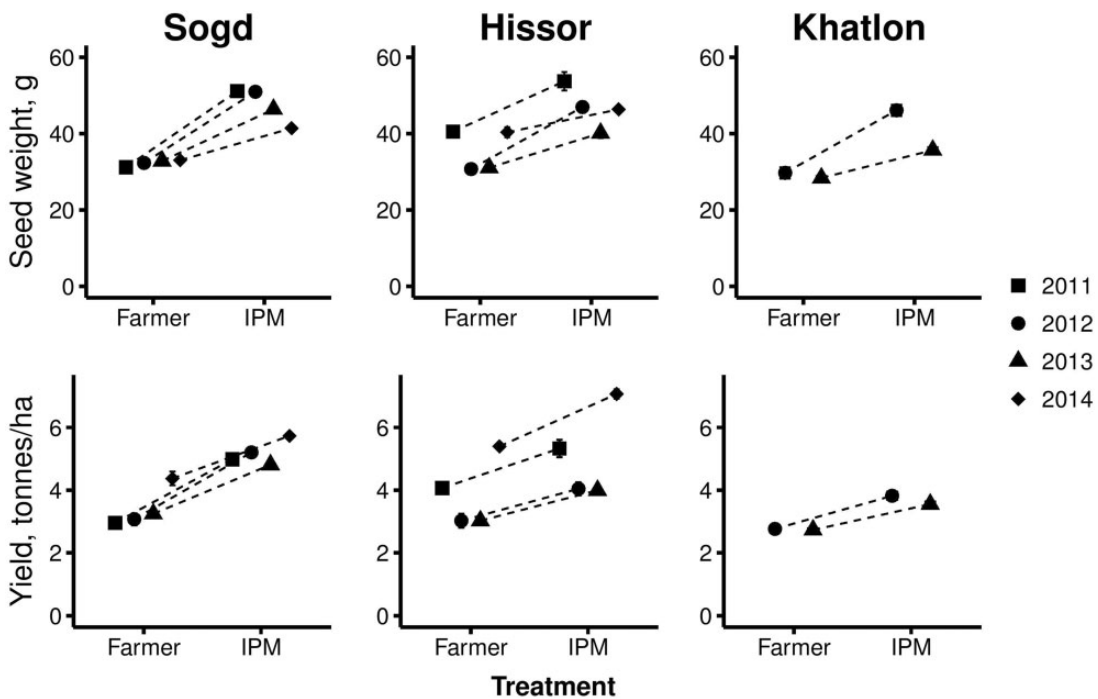
peaked between 2.5 to over 10/m<sup>2</sup> and within each year, almost twice as many nymphs and three times the number of damaged wheat heads were observed in farmer practice plots compared with IPM package plots (Fig. 3). Similarly, in central and southern sites, cereal leaf beetle larval abundance and damage rating were higher in farmer practice than IPM plots (Fig. 3). In these regions, we observed a 25–54% reduction in pest numbers and a 17–33% reduction in cereal leaf beetle damage in IPM plots compared with farmer practice. Levels of both rust diseases were also higher in farmer versus IPM plots. Leaf rust severity ranged from 15 to 40% in farmer practice plots and less than 10% in the IPM plots. Similarly, stripe rust severity ranged from 30% to over 80% in farmer practice plots, while generally remaining below 10% in the IPM package plots (Fig. 4).

Wheat yields also responded to the combination of agronomic and pest management practices contrasted in this demonstration. Seed weight per thousand seeds ranged from 28 to 42 g in farmer plots and 35 to 56 g in IPM plots, representing a gain of 15–64% over farmer practice across all sites and years (Fig. 5). Overall yield varied among sites and years but was always at least 30% to as much as 69% greater in the IPM package versus farmer practice plots. Yields in the farmer practice plots varied dramatically by region and year from 2.7 to 5.4 t/ha, although the majority hovered around 2.8 to 3 t/ha, with the lowest yields occurring in the rain-fed southern region. The IPM plots were similarly variable, with yields ranging from a low of 3.8 to as high as 6.4 t/ha. Despite the variability between sites and years, yields were significantly higher in IPM package plots than the comparison farmer practice plots. In the north, yield increases under the IPM package ranged from 31–69% ( $\bar{X} = 54.3$ ,  $n = 4$ ), while in the central and southern regions, yield increases were smaller and more consistent ranging from 31–33% ( $\bar{X} = 31.9$ ,  $n = 4$ ), and 30–38% ( $\bar{X} = 34.2$ ,  $n = 2$ ), respectively.

The economic analysis revealed that while costs were higher for the IPM package, the large increase in yield and saleable products



**Fig. 4.** Mean % infection (+ SD) of leaf rust (brown rust; top) and stripe rust (yellow rust; bottom) on wheat leaves in farmer practice and IPM package demonstration plots in three regions of Tajikistan, 2011–2014.



**Fig. 5.** Mean (+ SD) of wheat seed weight/1000 seeds and total yield (metric tons per hectare) in farmer practice and IPM package demonstration plots in three regions of Tajikistan, 2011–2014.

consistently resulted in increased profitability of the IPM system. Input costs (seed, fertilizer, pesticides) averaged 225 USD/ha for the farmer practice treatment and 515 USD/ha for IPM package, largely as a result of increased fertilizer rates, and use of herbicide and seed treatment in the IPM package. There were also slightly higher labor costs resulting from the extra applications in the IPM plots. However, the extra costs were more than offset by the increased yields, with average profitability a negative 12 USD/ha in farmer practice (range –21 to 4 USD/ha) and positive 35 USD/ha in IPM plots (range 12 to 51 USD/ha).

Training, outreach, and capacity-building were an integral part of the Phase II activities and during the course of four years, a number of programs were implemented in collaboration with local farmers and other stakeholders (Fig. 6). Given that a government-supported farmer advisory and extension system is not well developed, the project designed and implemented a farmer field school program to train local farmers and empower them with information, skills, and knowledge on various aspects of IPM. Through the farmer field schools, more than 1,500 farmers (40% women) were trained at IPM demonstration sites. The university students



**Fig. 6.** Outreach and capacity-building on wheat IPM in Tajikistan. (A) Farmer field day participants examine flowering plant strips for natural enemy support in IPM Package plots, (B) project bulletin entitled "Pests and Diseases of Wheat and Methods of Control (in Tajik), (C) students from Tajik National University present posters during an IPM field tour, (D) field day participant.

participated in data collection and developed posters on IPM topics (e.g., identification of biological control agents) that they shared with other field day participants. The project also provided a long-term training opportunity for one female Tajik student. The student successfully completed her master's degree program in entomology at Michigan State University, where she conducted research on biological control in wheat (Safarzoda et al. 2014). She has since returned to Tajikistan, where she is currently working in agricultural development with an international nongovernmental organization (NGO).

Using the information and experiences generated from both project phases, the project team members developed the Central Asia IPM Web site as repository for project outputs (Central Asia IPM 2016). Specifically, the site provides descriptions of the overall program, annual reports, publications, and outreach efforts. More than 15 publications specifically focused on various aspects of wheat IPM, including an overall description of the Wheat IPM Package, the supporting scientific publications, pest identification bulletins, and poster presentations in national and international meetings. All of the farmer outreach publications were translated into the Tajik language, and many were also translated into Russian for regional use. The project organized a wrap-up regional IPM workshop

in Dushanbe, Tajikistan, in August 2014 entitled: Building Ecologically-based IPM Program in Central Asia for Food Security. The workshop attracted 45 participants from Tajikistan, Uzbekistan, and Kyrgyzstan. Participants included government officials, representatives of the Tajik Academy of Agricultural Sciences, university and government-based scientists, and regionally active NGOs. The finding and results of the project were presented by our project coordinator at various regional, national, and international conferences, including ones held in the Philippines, Egypt, and the United States. In addition, the project coordinator was invited to share the experiences and achievements of the project on Tajik national television, which reaches out to the more than 2 million citizens of Tajikistan.

## Recommendations

Creating and implementing an IPM package for wheat in Tajikistan was a challenging and rewarding activity. Key to our success was effective partnering with established local and international entities, including ICARDA, the Tajik Academy of Agricultural Sciences, Tajik National University, local NGOs, and the USAID Mission in Dushanbe. Equally important to success was the participation of

highly professional and dedicated in-country collaborators. Their intimate knowledge of local practices and organizations facilitated our ability to develop and demonstrate the Wheat IPM Package in an effective fashion. These relationships opened many doors, not only improving the outcomes of our current work but also ensuring ongoing integration. For example, the ICARDA Biodiversity and Integrated Gene Management Program in collaboration with Central Asia national programs have conducted surveys and established trap nurseries to monitor physiological races of stripe rust and map the distribution of new races and effective resistance genes (Hovmöller and Rodrigues-Algaba, 2015). The networks we developed in our project are aiding in wider dissemination of this information enhancing improved management of this disease.

The IPM package for wheat was demonstrated to be effective in reducing pest damage and increasing yields and profitability; however, additional research is needed to identify the relative contribution of different package components. We suspect that effective fertilization, weed control, and use of disease-resistant varieties were key contributors to yield increases. Identifying which package components provide the most economically efficient yield increase is important to resource-limited farmers, and barriers to wider adoption remain. Fertilizer and chemical inputs remain expensive for Tajik wheat producers and modern field-scale pesticide application equipment remains in short supply. IPM programs will increasingly need to address the economic and social drivers that limit adoption if they are to be successful. Participatory approaches such as those used here are critical to engage various stakeholders in addressing their IPM needs, and capacity-building should remain a priority not only for Tajikistan but for the whole Central Asia.

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