Pheromones as Tools for Monitoring the Insect Pests in the Northern Plains - Instructive Tools for Agricultural Professionals

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Western Triangle Agricultural Research Center
Montana State University-Bozeman
9546 Old Shelby Rd
Conrad, MT 59425
(406) 278-7707

Contents

Major Participants

Dr. Gadi V.P. Reddy Principal Investigator	Professor (Entomology/Ecology), MSU Western Triangle Ag Research Center, Conrad, MT
Dr. Anamika Sharma Co-Principal Investigator	Postdoctoral Research Associate (Entomology/Ecology) MSU Western Triangle Ag Research Center, Conrad, MT
Mr. Daniel Picard Team member	WTARC Special Project Coordinator (Volunteer) MSU Western Triangle Ag Research Center, Conrad, MT
John H. Miller Team member	Research Scientist (Agronomy/Varietal Testing) MSU Western Triangle Ag Research Center, Conrad, MT
Ramadevi L. Gadi Team member	Research Associate (Entomology/Ecology) MSU Western Triangle Ag Research Center, Conrad, MT
Debra A. Miller Team member	Research Assistant (Entomology/Ecology) MSU Western Triangle Ag Research Center, Conrad, MT

Major Participants - MSU Extension County Agents

Jesse Fulbright	Liberty County Extension Agent
Tyler Lane	Chouteau County Extension Agent
Adriane Good	Pondera County Extension Agent
Rose Malisani	Cascade County Extension Agent
Kari Lewis	Glacier County Extension Agent
Kim Woodring	Toole County Extension Agent
Shylea Wingard	Hill County Extension Agent
Katie Hatlelid	Judith Basin County Extension Agent
Emily Standley	Fergus County Extension Agent
Juli Snedigar	Blaine County Extension Agent
Allison Kosto	Broadwater County Extension Agent
Jack Stivers	Lake County Extension Agent
Josh Bilbao	Gallatin County Extension Agent
Eric Miller	Garfield County Extension Agent
Shelley Mills	Valley County Extension Agent
Collen Buck	Sheridan County Extension Agent
Bobbie Roos	Daniels County Extension Agent
Elin Kittelman	Fallon/Carter County Extension Agent
Wendy Becker	Fort-Peck Reservation Extension Agent

Ken Nelson	McCone County Extension Agent
Marko Manoukian	Phillips County Extension Agent
Sharla Sackman	Prairie County Extension Agent
Tim Fine	Richland County Extension Agent
Jeffery Chilson	Roosevelt County Extension Agent
Molly Hammond	Big Horn County Extension Agent
Nikki Bailey	Carbon County Extension Agent
Mike Schuldt	Custer County Extension Agent
Mat Walter	Musselshell & Golden County Extension Agent
Lee Schmelzer	Stillwater County Extension Agent
Callie Cooley	Yellowstone County Extension Agent.

Major Participants - Stakeholders

Brad Birch, Crop Consultant, Dry Fork Ag, Ledger, MT 59456

Jeff Farkell, Crop Consultant, Centrol Crop Consulting, Brady, MT 59416

Joel Farkell, Certified Crop Adviser, Centrol Consulting, Brady, MT 59416

Kevin Johnson, Crop Consultant, Pinnacle Agriculture, Conrad, MT 59425

Jane Holzer, Program Director, Montana Salinity Control Association, Conrad, MT 59425

Stacy Denny Eneboe, District Conservationist, USDA-NRCS, (Conrad, Cut Bank and Browning), Conrad, MT 59425.

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Introduction

Pheromones are chemicals released by abdominal region of insects to communicate between members of a particular species. Pheromones acts as hormones outside the body of the secreting individual and affects the behavior of the receiving individuals. A pheromone trap is a type of insect trap in which pheromones are used to attract insects. The most commonly used are sex and aggregating pheromones. Pheromone traps are used for catching targeted insects for managing them and to study the population dynamics of an insect, detect presence of exotic pests, and monitoring of an insect. These traps can also be used for mating disruption to manage the insect populations. Pheromone traps help to attract male insects, trap them and hence prevent them from mating. By counting the number of males, a decision about release of beneficial insects can also be taken. Hence, pheromone traps are used for mating disruption, mass trapping, attract-and-kill, and push-pull as a direct pest control strategy.

Pheromone traps are active traps where pheromones are used as lures in an insect trap. In pheromone insect traps, a pheromone-impregnated lure is encased in a trap. Pheromone traps are usually simple to use and either only require peeling the protective paper from the glue area and using them or place the pheromone vial in the trap. Different types of traps can be used to put the pheromone lures in. Use of different types of traps increases the efficacy of pheromone lures in attracting insects and traps greater number of insects. Color and shape also plays a major role in selecting a trap for specific insect because both pest insects and non-target insects can be sensitive to certain colors.

Some of the commonly used insect pheromone traps are, wing trap; delta trap (white, yellow, transparent); funnel trap (unitrap) (yellow, green, transparent); rhyncho trap; fruit fly, wasp and fly trap (also known as Mc Phail trap); pit fall trap; ground trap; ramp trap; stink bug trap; and bucket trap.

Advantage of insect pheromone traps:

1. Can be used all around the season.
2. Easy to install and manage.
3. Very sensitive and even work at low insect densities.
4. Are affordable.

Disadvantage of insect pheromone traps:

1. Sensitivity to bad weather,
2. Limitation to attract only adults and their limitation to one sex.
3. Some traps are tiresome to manage.

4. Sometimes need a technical support in selecting and installing the traps.
5. Animals can ruin the traps.
6. Not available for all the insects yet.
7. Regular monitoring is must.

Some important factors to remember to avoid harmful impact of pheromone traps are (NPIC 2018):

1. Each pheromone is designed for a specific insect. No trap will be effective for all insects.
2. Some pheromones may be lower risk than conventional pesticides.
3. Lures need to be replaced often to better trap new insects.
4. Pheromone traps attract pests. Do not place them in high traffic areas near people or gardens, especially for wasps, hornets, or crop-damaging insects.
5. Traps can be affected by weather events, check them after storms to see if they need repair or replacement.
6. Keep traps out of reach of children and pets.
7. Wash your hands after using pheromones, as pests may follow you if you smell like one of their own.
8. Don't use outdoor products indoors. Always follow the label about how and where to use the product.

In this manual we are presenting the data collected in Montana and results generated by implication of pheromone traps in past few years by Western Triangle Agricultural Research Center (WTARC) in Golden Triangle Region of Montana to monitor click beetles, wheat stem sawfly, wheat midge, wheat head armyworm and pea leaf weevil.

Click beetles/Wireworms (Coleoptera: Elateridae)

Background

Wireworms are the soil dwelling larval stage of click beetles (Coleoptera: Elateridae) and are a significant pest of a wide variety of crops grown around the world. In recent past years, wireworms have reemerged due to the absence of Lindane which was a primary chemical control agent and is no longer available due to toxicity concerns. In Montana its major host are wheat and barley. Major wireworms species in the Golden Triangle Area are *Limonius californicus* (Mannerheim), *Hypnoides bicolor* (Eschscholtz), and *Aeolus mellillus* (Say). Cultural and biological control of these species have been evaluated in Golden Triangle Area of Montana (Sharma et al., 2019a; Antwi et al., 2018; Adhikari and Reddy, 2017).

Pheromones are tested and used at the adult stage (click beetles) to elicit attraction between sexes in click beetles and can be used to monitor population occurrence and density in agricultural fields. For the click beetles of the Northern Great Plains, pheromone based monitoring has not been developed. Development of this technology is crucial to monitoring and control programs. This ongoing research looks at the development of pheromone based trapping systems for dominant wireworm species found in Montana. Although, no detailed work on the use of pheromone compounds has been done in the USA—other than some recent work—, there have been several reports available on related wireworms species found in Europe. Pheromone compounds appear to be similar in their related insect species. In this context, we attempted to lure in click beetles using chemical lures used to trap click beetles in Europe. In 2014, the work was built on trapping data from the previous flight season of 2013 and continued again in the spring of 2015. In 2013, sex pheromones from European *Agriotes* species of click beetle were tested for their ability to attract *Limonius* and *Hypnoidus* species in wheat fields around Conrad, MT. These studies showed that the local species exhibited no cross attraction with these sex pheromones. In 2014, we attempted plant volatile based attractants.

Pheromone Traps and Compounds

In 2014, we set out traps in a circular array and baited them with plant oil extracts shown to have attractive properties in *Agriotes* species. Cis-3-hexene-1-ol, (Z)-3-Hexenyl acetate, Methyl benzoate, and Methyl salicylate were tested alone and in combinations along with a control by filling 5 gram vials with a 0.5 Molar concentration of these plant oil extracts and capped them off with rubber septa. Odor release rates are highly dependent upon temperature and were not calculated, though a detectable smell was noticeable for each vial. Vials were wrapped in duct tape to keep UV light out and were individually wrapped in foil and placed in -20 ˚F freezer until needed (Figure 1A). There were three replicates of each volatile (*n*=30 trap total). Each trial consisted of the attractants randomly arranged on a circular array with the attractants hung from the exterior of the Yatlor trap (Figure 1C). Each trap was a minimum of 10m from the next trap. Each of the three arrays were a minimum of 25m from the next array. Traps were checked every two days for the presence of click beetles.

In addition to volatile traps, pitfall traps were placed in an array of 10 traps and placed 10 meters apart in a square grid pattern. Pitfall traps were deployed 30m from Yatlor traps in the same field and were checked every two days. Click beetles taken from pitfall traps (Figure 2A) were used to bait cages on Yatlor traps (Figure 2B). Beetles were held in captivity on a diet of honey water (1:10) soaked cotton balls (Figure 1B). Two types of pitfall traps were tested, bucket traps (solar traps; Figure 3) and funnel traps. The location of traps in one large wheat field was determined by spring scouting for wireworms and a historical presence in that field. The land was owned by the Devries family and plots were approximately located at GPS coordinates 48.182867, -111.805412. In 2017 and 2018, bucket traps (solar traps) were installed in the fields with wireworm infestation in Pondera and Teton counties.

Findings

Catch data was highly skewed by catch results. The only traps to catch any click beetles were the pitfall traps. These traps were not baited with any scents or plant material. Pitfall traps caught about 1000 *Hypnoidus* from May17th - June 23^{rd,} 2014. *Hypnoidus* beetles placed in cages did not attract more beetles, neither did the plant compounds. The effectiveness of the Yatlor traps is questionable. This trap proved to be effective in catching the click beetles in Europe. No statistics were performed on the data as the only trap to catch beetles was the pitfall trap. Solar traps on their own attracted click beetles installed in 2017–2018 with maximum number of click beetles collected in mid-June.

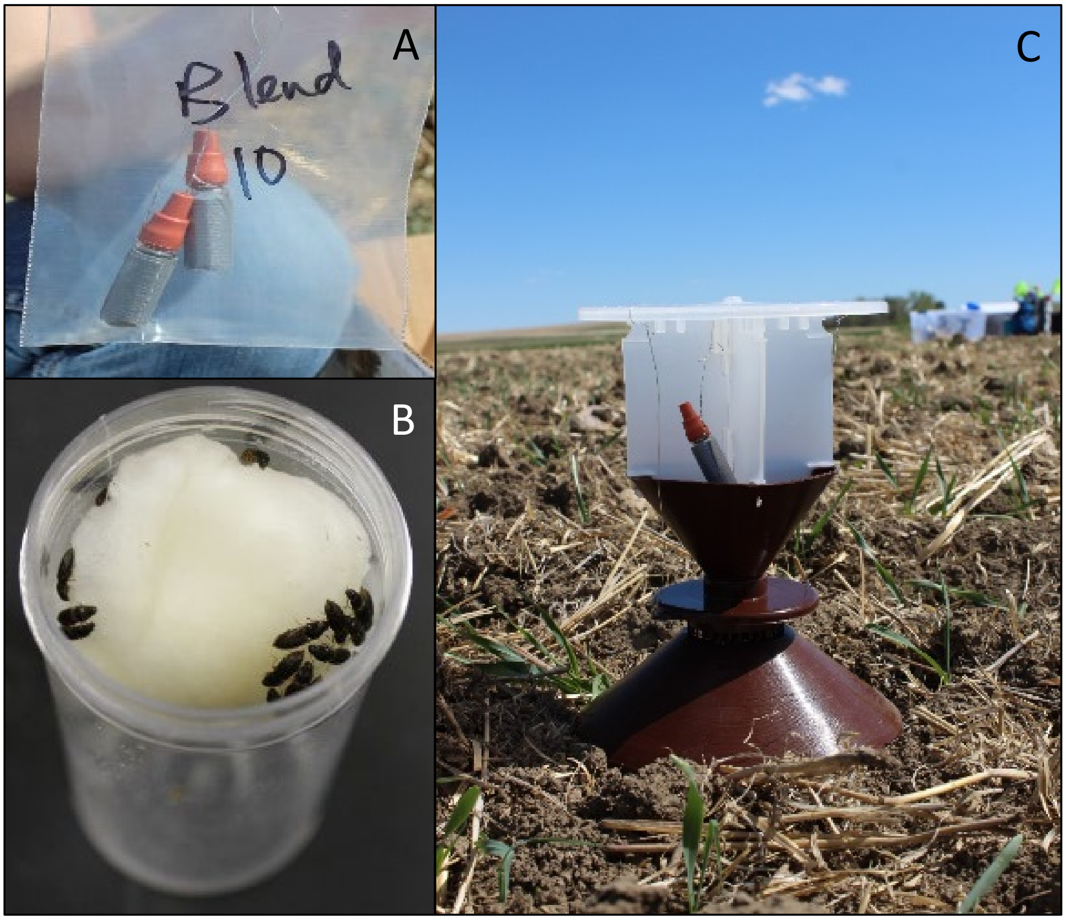

Figure 1. A) Plant volatile release vials B) Click beetles feeding on honey water (1:10) soaked cotton ball in storage vial C) Yatlor trap deployed in spring wheat field.

Figure 2. A) Pitfall trap B) Yatlor trap with cage affixed to top to hold live insects.

Figure 3. The Noronha Elaterid Light Trap, or "NELT", is made with three pieces — a small solar-powered spotlight, a plastic white cup and a piece of screening. The light is set close to the ground to attract the source of the wireworms, the female click beetles that emerge from the ground in May and June.

Wheat stem sawfly, *Cephus cinctus* Norton (Hymenoptera: Cephidae)

The wheat stem sawfly, *Cephus cinctus* Norton (Hymenoptera: Cephidae) is one of the principal pests of wheat in Montana and the northern Great Plains in general (Portman et al., 2018). Sawfly interfere with the seed filling and during pupation cut the wheat stem, due to this activity it causes damage to crops through yield reduction and yield loss. Cutting of wheat stems by sawfly results in wheat stem falling over (aka. lodging) where they may be missed by harvesting equipment. In areas where sawfly are persistent, many producers implement automatic procedures to reduce yield loss from lodging. Nevertheless, this is costly to the producers in terms of time and materials. In recent years, this pest has expanded its range to areas south of it traditional range. In these new geographic regions and in its traditional range, there is unpredictability in assessing the presence and magnitude of sawfly populations that hamper control measures.

Wheat stem sawfly distribution across the current geographic range is patchy. The density of populations varies from field to field and time to time. Uncertainty over where and when this pest occurs is expensive for land managers. Population controls, such as pesticides, rely on accurate information about when the pest is actively flying in the crop. The larvae of sawfly are not amenable to pesticide applications due to feeding internally, concealed within the wheat stem. Therefore, accurate prediction of when the sawfly is actively flying in the crop is the best way to control this pest. A pheromone lure has been developed for *C. cinctus* (Cossé et al., 2002), but optimal assessment of populations is not guaranteed with this lure alone.

The herbivore insects, such as sawfly uses chemical signals from plant to identify host plants for feeding or oviposition (Shrestha et al., 2018). In certain insects, attraction toward a source of nectar, signified by the flower color, leads to a preferred food source. Sawfly adults are not known to feed. However, adults may be preferentially attracted to particular colors due to innate characteristics of their biology. In this study, we tested sawfly preference to pheromone baited colored traps to evaluate potential improvement to sawfly trapping systems.

Pheromone Traps and Compounds

Sawfly traps consisted of a combination of commercially produced insect traps and handmade colored panel traps. The three commercial traps were the white L P delta trap (Scentry), green and yellow funnel trap (Scentry), and the Bite Free Stable Fly trap (Starbar) (Figure 1-4).The major compound was 9-Acetyloxynonanal. Additional compounds were 13-acetyloxytridecanal, aldehydes with 9–16 carbon chain lengths, acids with 8–10 carbon chain lengths, and phenylacetic acid. A gray rubber septum and membrane, each impregnated with 9-Acetyloxynonanal, were obtained from Chem Tica Internacional SA (Costa Rica).

Findings

Yellow sticky panel trap were found to be most effective in catching adult sawfly (Figure 5). Gray, purple and white color also attracted higher number of sawfly adults, however delta and stable traps were significantly less effective.

Figure 1. Traps were arranged in a random order in a straight line immediately adjacent to the crop of spring wheat but at a minimum of 10m inside the fallow field.

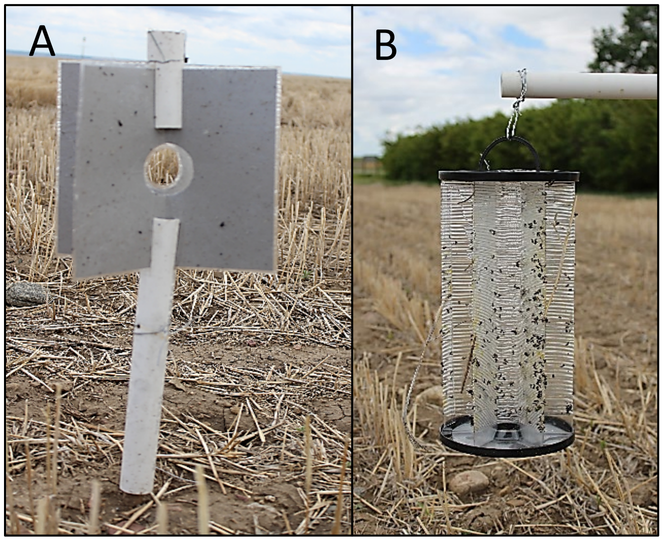

Figure 2. Trap designs for A) handmade sticky panel traps and B) commercial Stable Fly trap.

Figure 3. Yellow sticky panel trap was found to be superior in catching the wheat stem sawfly adults.

Figure 4. Insect catch on stable fly trap.

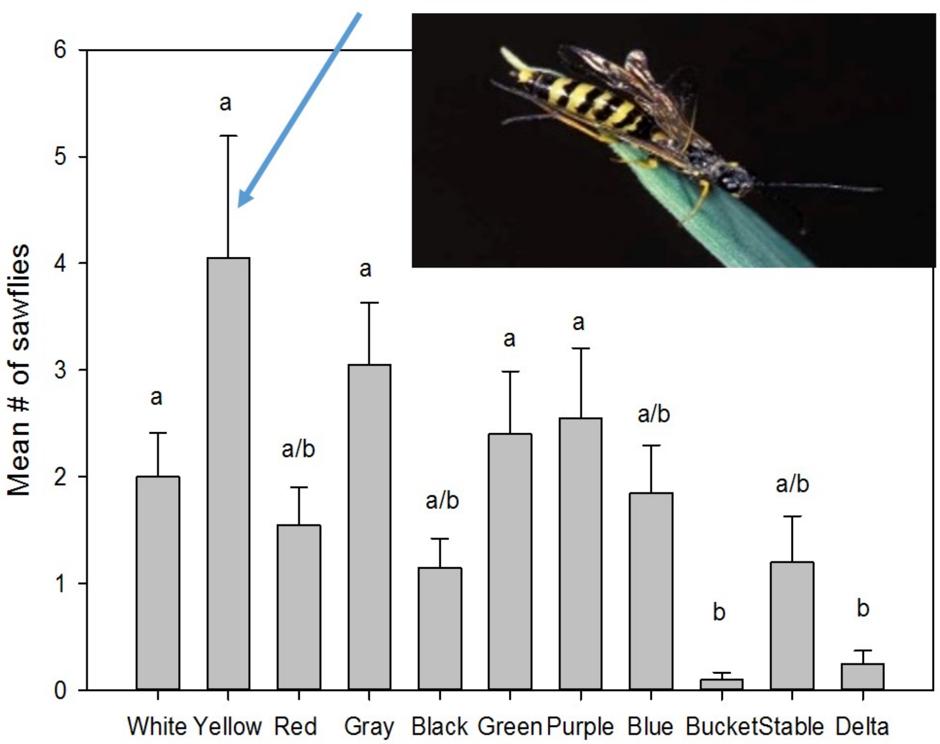

Figure 5. Mean ± SE Sawfly adult catch by each trap type.

Wheat midge, *Sitodiplosis mosellana* (Diptera: Cecidomyiidae)

Background

The wheat midge (orange wheat blossom midge), *Sitodiplosis mosellana* (Gehin) (Diptera: Cecidomyiidae), is a widespread pest of wheat of Palearctic origin that was introduced into North America in the early 1800s. This pest continues to expand to new areas of North America. The orange wheat blossom midge was first detected in northern and central Montana in 2000, near North Dakota where the midge had been detected earlier. Damage to the wheat crop in this region remained low, with only periodic minor outbreaks. Subsequently, an outbreak occurred in western Montana on spring wheat in the Flathead Valley. Initial estimates of wheat losses were over $1.5 million in Flathead County alone. Crop losses due to orange wheat blossom midge are often 30–80%, but can be100% if populations are extremely high. In North Dakota during the 1990s, wheat growers lost an estimated $30 million in gross revenue due to *S. mosellana*. According to the published literature, losses in Canada exceeded US$38.65 million in Manitoba and US$77.30 million in Saskatchewan in 1995. In contrast, in eastern Montana where the midge's parasitoid was found to be present along with the pest, significant losses were not reported.

In eastern Montana, adults of *S. mosellana* begin emerging from the soil between June and July (Thompson and Reddy, 2016). There is one generation per year and midges overwinter as mature larvae in the soil. Eggs are laid in developing wheat heads and larvae feed on the developing seeds, causing significant damage in spring wheat across North America. Larval feeding on the emerging kernel causes shriveling and reduces the value of the crop. Wheat is vulnerable to attack by *S. mosellana* from the boot stage until anthesis is complete. Yield loss and broken kernels resulting from midge feeding reduce the grade of the harvested grain, lowering its value. The concealed feeding niche of the larvae under the wheat glume and the short flight period of the adults make this pest difficult to control with insecticides.

In 2018, wheat midge populations were monitored in seven counties (Liberty, Toole, Teton, Choteau, Glacier, Cascade and Pondera) in the Golden Triangle, Montana.

Pheromone Traps and Compounds

The pheromone compound used was (2*S*,7*S*)-2,7-nonanediyl dibutyrate (Gries et al. 2000). A gray rubber septa with pheromone compound was installed in a delta trap each at every site (Figure 1). Number of sites varied in each county.

Findings

Portions of the wheat midge count data was extracted from Pestweb Montana. Total number of wheat midge pheromone traps installed in wheat fields were 39 in 2018. Among the seven counties, the highest wheat midge population level per trap was observed in Liberty County in comparison to no presence of wheat midge in Cascade and Glacier County (Figure 2). The second highest wheat midge populations were noticed at Pondera County followed by Toole and Teton Counties (Figure 2). Compared to the last year, wheat midge population was low in Toole County but higher in Pondera and Liberty Counties.

Figure 1. *Sitodiplosis mosellana* populations as predicted by pheromone baited trap and by counts of larvae in wheat heads (Larvae) were marginally significantly different by t-test.

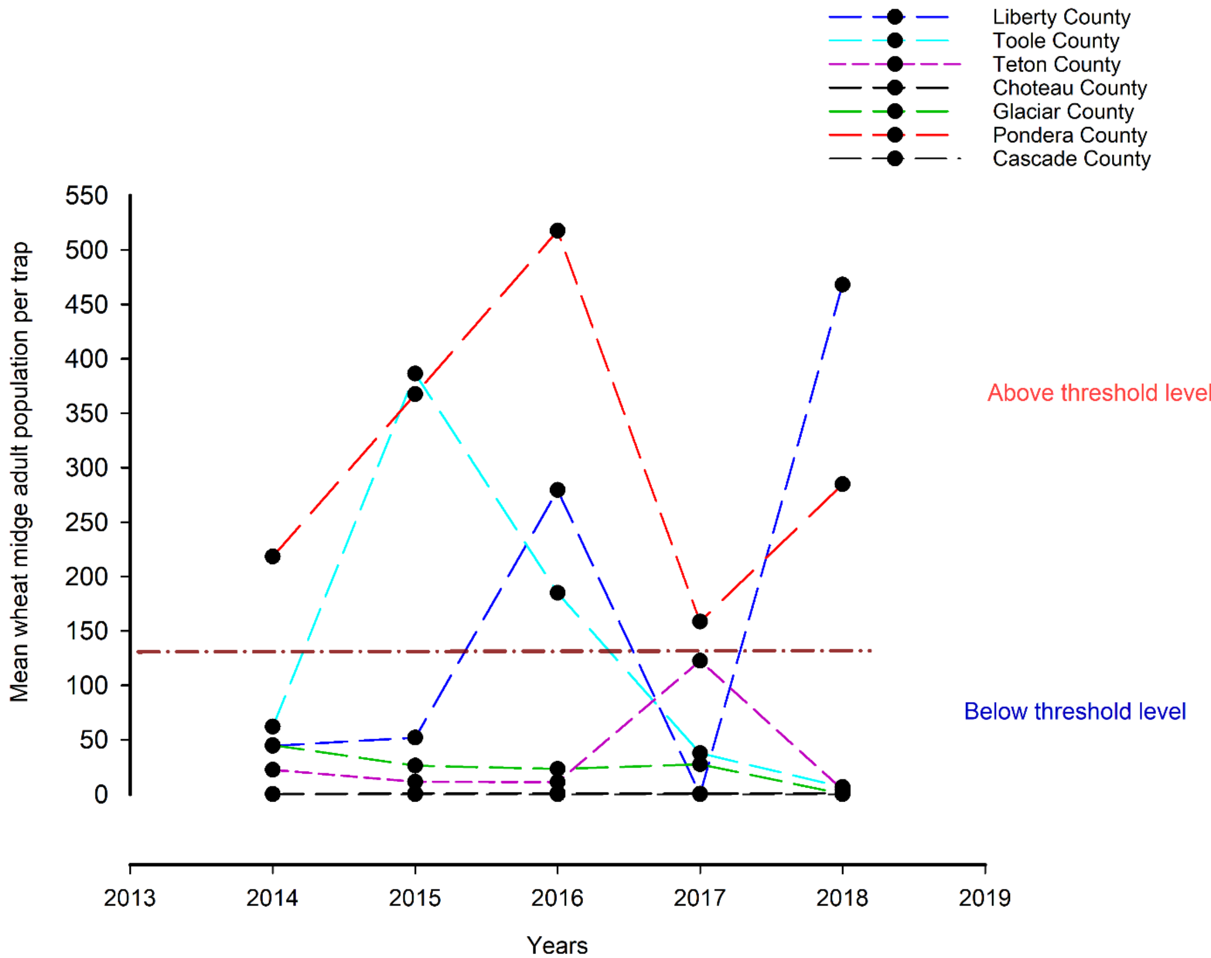

Figure 2. Wheat midge population levels in the Golden Triangle, Montana from 2014–2018.

Wheat head armyworm, *Dargida diffusa* (Walker) (Lepidoptera: Noctuidae)

Background

Dargida diffusa (Walker) and *Dargida terrapictalis* (Buckett) (Lepidoptera: Noctuidae) are two members of the wheat head armyworm complex. *Dargida terrapictalis* is native to the temperate western North America and origin of *Dargida diffusa* is unknown (Roberts et al. 2017). Both the species are found throughout the United States and are closely related to each other. *Dargida diffusa* is considered to be a minor pest with sporadic outbreak and causes occasional significant crop injury, such as a 35% yield loss in spring wheat in Washington State; whereas *D. terrapictalis* does not hold a pest status. The adult moths of both species have apparent differences, but differentiating between the larvae is not possible, which makes the accurate damage assessment by any of the species ambiguous (Roberts et al., 2017; Sharma et al., 2019b). The adult moth of *D. diffusa* is yellowish brown with a prominent chocolate-colored stripe along the length of each forewing. The color of larvae depends on the maturity of the consumed grain and varies from greenish to cream with a line down each side of the body.

In the spring season, March–May, adults emerge and lay eggs on a wide variety of members of Poaceae. Larvae go through five instars and feed from May to July. The maximum populations are found to occur around mid-June. As pupae, they pass winter in the soil. The life cycle of *D. diffusa* includes two or three generations per year. The first generation of larvae feeds on maturing heads and causes direct damage to kernels, whereas second generation moths emerge and lay eggs in summer, June–August. Adults flying in autumn, October, are considered either a third generation or a late-developing second generation (Michaud et al., 2007; Sharma et al., 2019b). Primarily at night when an ambient temperature is cooler, larvae feed on wheat heads. During daytime when temperature increases, the larvae migrate towards the base of the plant. Hence, larvae cause feeding damage to wheat heads during the night and during daytime. They rest at the base of the plant. Feeding damage by these insects resemble the feeding damage caused by stored grain pests and the sporadic damage caused by this insect makes the damage assessment tough. The damage usually occurs along field margins. With their chewing and biting mouthparts, larvae bore a small hole into the base of the floret and feed on developing grain, hence, when the grain is stored the damage looks similar to damage caused by stored weevil pests. The damage caused by *D. diffusa* and *D. terrapictalis* is commonly known as 'insect-damaged kernels (IDK)' (Figure 1A) and is reported from Washington, Idaho and Oregon in USA (Rondon et al., 2011; Roberts et al., 2017).

Due to the scarcity of information about *D. diffusa* and *D. terrapictalis* and management strategies to control them, a thorough monitoring of this pest is very necessary. For monitoring purposes, (Underhill et al., 1977)it was reported that *D. diffusa* were attracted to the lures which were baited with a combination of the sex attractant compounds Z11-16Ac and Z11-16Ald. Further, a study showed that the combination of these two compounds also attracted *D. terrapictalis* in wheat fields of Oregon and Washington states of USA (Landolt et al., 2011). Later on, pheromone traps installed in Washington and Oregon states captured both *D. diffusa* and *D. terrapictalis.* The difference in the population of trapped insects depends on seasonal variation in population of both insects. The pheromone traps are recommended to be put out when winter wheat enters the boot stage (April–May). The monitoring should be done weekly and in nearby fields of infested field should also be monitored (Roberts et al., 2017). In Pondera and Chouteau counties, pheromone traps were installed to monitor the population of this insect.

Pheromone Traps and Compounds

Rubber septa impregnated with 1 mg, 3 mg, and 10 mg of pheromone (Z)-11-hexadecenyl acetate (Z11-16Ac) and (Z)-11-hexadecenal (Z11-16Ald) in 9:1 ratio with Hercon Vaportape was installed in unitraps. [PHEROCON® unitraps (or funnel traps); (Trécé, Oklahoma, USA)] (Figure 1B).

Findings

Lure dose response was assessed by using 1 mg, 3 mg, and 10 mg doses. The higher number of adults were captured at Chouteau county compared to Pondera county in 2015, 2016 and 2017 (Figure 2, 3 and 4). Sweep netting was also used to the survey the population of *D. diffusa*. In dose response study, although, the higher dose (10 mg) attracted a numerically greater number of adults (Figure 1A, B). No significant difference was found among the treatments (Figure 3A, B; 4A, B). Results indicated that the pheromone attracted the males of *D. diffusa* at all the study sites indicating the presence of this pest in Montana. Efficacy of these lures at lower dose (1 mg) were compared to the control and higher doses.

Figure 1. A) Wheat head armyworm larvae and damaged wheat seeds. B) PHEROCON Unitrap in winter wheat fields at Western Triangle Agricultural Research Center.

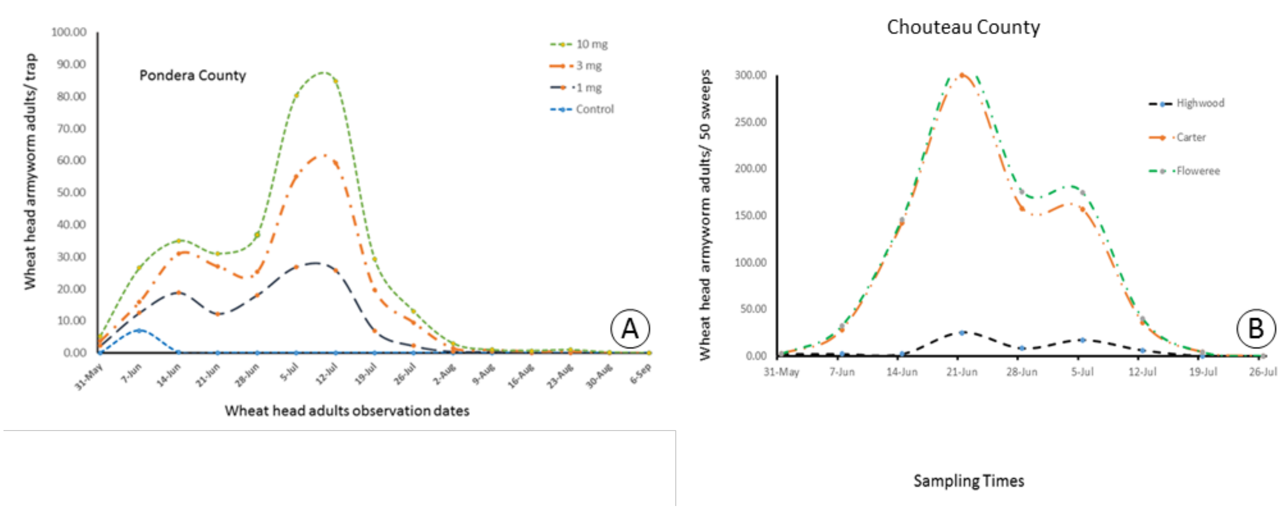

Figure 2. Population pattern in two counties. A) Wheat head armyworms population pattern at Pondera County, 2016. All data from 4 field sites were pooled for this graph. B) Wheat head armyworms population pattern at Chouteau County, 2015.

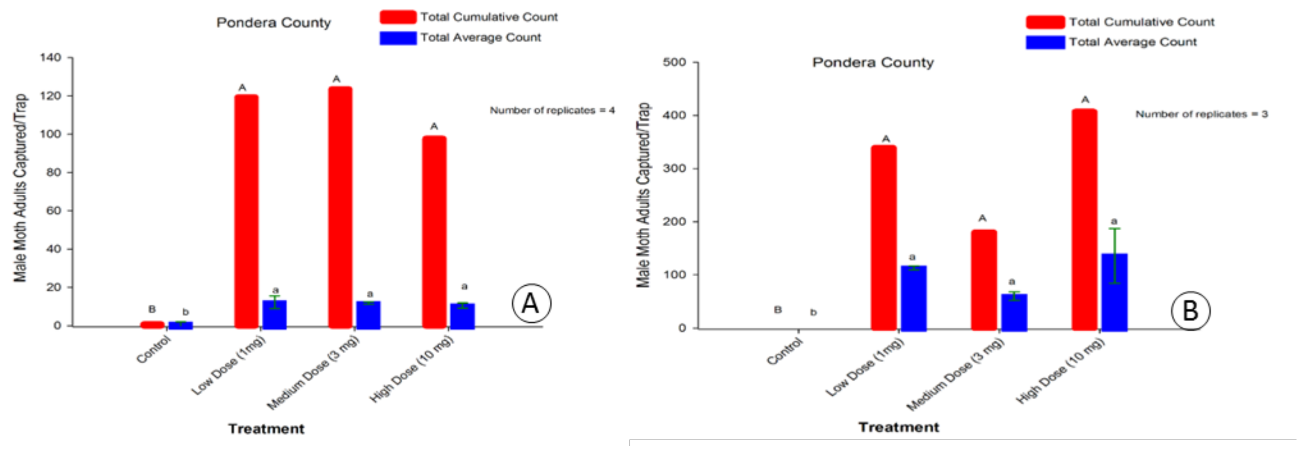

Figure 3: Lure dose response study at Pondera County (Ledger, Conrad and Lothair). A) Lure dose response study for 2016. B) Lure dose response study for 2017. For both figures, bars bearing the same uppercase or lowercase letters are not significantly different (Tukey test, P > 0.05).

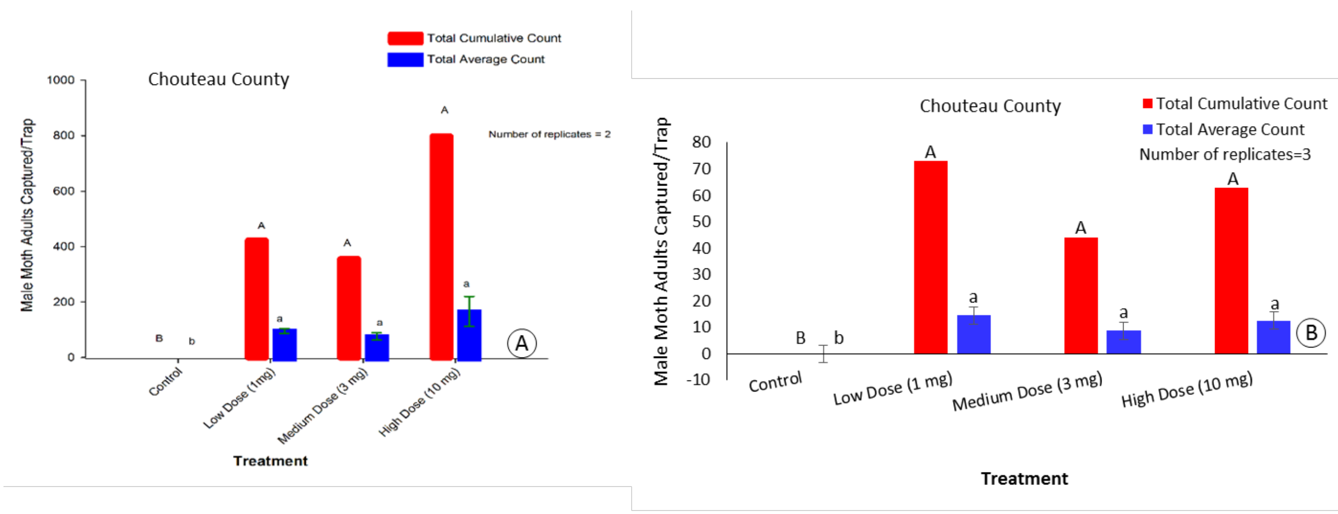

Figure 4. Lure dose response study at Chouteau County (Carter location). A) Lure dose response study data combined for 2016 and 2017. B) Lure dose response study for 2018. For both figures, bars bearing the same uppercase or lowercase letters are not significantly different (Tukey test, P > 0.05).

Pea leaf weevil, *Sitona lineatus* (L.) (Coleoptera: Curculionidae)

Background

The pea leaf weevil, *Sitona lineatus* (L.) (Coleoptera: Curculionidae), is a major pest of field peas and faba beans, *Vicia faba* (L.) (Fabales: Fabaceae), worldwide. This weevil is believed to be of European origin, but has spread to most field pea regions of the world, including Asia, Africa and North America, over the last 50 years (Nielsen, 1990). In North America, this pest was first reported in 1936 by Downes (Downes, 1938). In Montana, *S. lineatus* has been a serious economic pest of field pea in most of the state's pulse growing region since 2010 (Wanner, 2016).

Sitona lineatus is typically univoltine and in the fall, adults migrate to field shelterbelts, alfalfa fields, and roadside areas where they feed on secondary leguminous hosts before overwintering in soil. In spring, when temperatures reach 12.5 °C, overwintered adults emerge and move into new plantings of field peas. Oviposition, larval development, and pupation all occur in the soil. New adults emerge in late summer and migrate to secondary hosts to overwinter. Adult feeding on pea seedlings leaves characteristic "U"-shaped notches along the leaf margins. Both larvae and adult feeding reduce photosynthesis, pod production, and formation of root nodules. Larvae feed on the rootlets and on Rhizobium root nodules, causing weak root growth and decreasing nitrogen fixation. In addition, larval feeding reduces seed protein content, particularly in nutrient-poor soils, as well as the amount of nitrogen returned to the soil. It is believed that adults have less effect on yield than larvae, but this remains to be quantified. El-Dessouki (1971) reported that infestation of pea plants with 100 *S. lineatus* eggs per plant reduced yield by 27%.

There is substantial worldwide interest in the development of a pheromone-trap monitoring system (Reddy and Guerrero, 2004, Reddy et al. 2018) and management program for *S. lineatus*. Blight et al. (1984) were the first to run bioassays on an adult male-produced aggregation pheromone of this weevil that was found to attract both males and females. The same researchers later isolated, identified, synthesized and assessed the attractiveness of the active component of this pheromone, 4-methyl-3,5-heptanedione. Field studies conducted worldwide have shown that this pheromone attracts both males and females in both spring and fall. In addition, Landon et al. (1997) showed that adults are also attracted to host plant volatiles in both spring and fall. The use of pheromone-baited traps offers a convenient and potentially potent tool for monitoring *S. lineatus* adult populations.

Work on pheromone traps for *S. lineatus* has been conducted since the pheromone compounds were first identified and being used for monitoring. This trap allows early detection of the pest and allows differences with-in field pest infestations to be measured. The use of pheromone traps for this pest can improve decision making in pea leaf weevil management.

Pheromone Traps and Compounds

In 2016 and 2017, pitfall, ground, delta, and ramp traps were used to catch the insect (Figure 1). Delta traps were obtained from Great Lakes IPM Inc. (Vestaburg, MI, USA) and ramp traps from ChemTica Internacional SA (Costa Rica). Ground traps were constructed in our laboratory based on a design from previous studies. A red solo cup (diameter 6.5 cm; height 12.5 cm) served as a pitfall trap. Among all these traps, pitfall traps were found to be the most effective in catching the adults. Two types of pheromone lures were used, a gray rubber septum and membrane, each impregnated with 4-methyl-3,5-heptanedione. Lures were obtained from ChemTica Internacional SA (Costa Rica). Each type of lure contained 10 mg of pheromone, emitting the active ingredient at 0.1 mg/day. Septa were prepared by depositing 100 µL of a 0.1 mg/µL hexane solution into the cup of each septum and the hexane was allowed to evaporate at room temperature over 4 h. The membrane release devices were prepared by heat sealing the required amount of pheromone in a circular plastic pouch (1 cm internal diameter) using a custom sealing device. The pheromone slowly evaporated through the proprietary plastic. Pitfall traps have to be placed in the ground.

Findings

Traps with pheromones attracted greater number of adults. Among septa and membrane, gray rubber septa was more effective than membrane. Among the traps tested, pitfall trap collected significantly greater number of adults followed by ramp traps. Both delta and ground traps were found to be equally efficient.

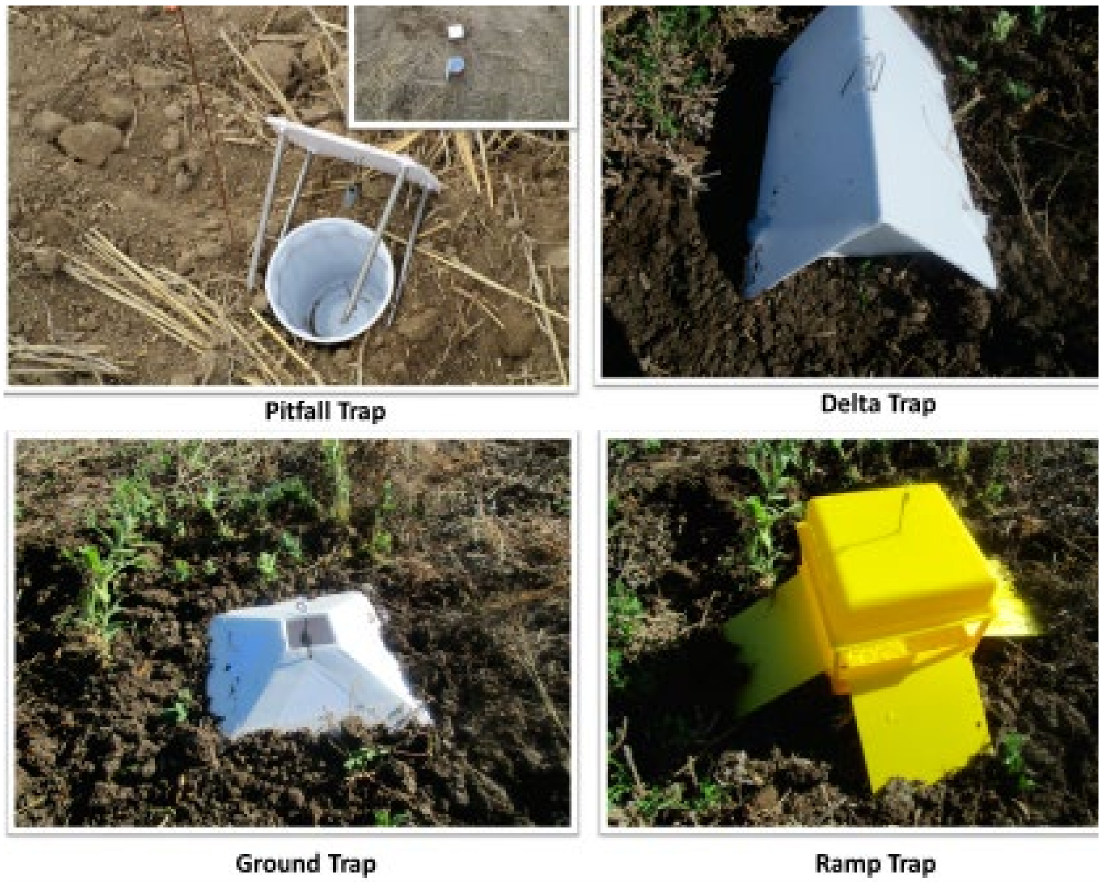

Figure 1. Different types of pheromone insect traps were used in 2016 and 2017 to catch pea leaf weevil.

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