CONSIDERATIONS FOR MANAGING ALFALFA HAY IN THE FACE OF INSECTICIDE RESISTANCE: Demonstration and Discussion

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Alfalfa (*Medicago sativa* L.) is a valuable forage crop grown throughout the United States. Whether baled, chopped for silage, cubed, or pelleted, alfalfa provides high-quality feed for cattle (beef and dairy) and other livestock. Alfalfa market value is directly tied to feed quality, ranging in suitability as utility feed to premium forage for dairy applications. Factors affecting quality include plant maturity, weather, and pests.

A rising concern in alfalfa management is the development of alfalfa weevil (*Hypera postica*) resistance to pyrethroid insecticides. Alfalfa weevil is the most problematic insect pest of alfalfa hay across the western United States. Weevil larvae reduce hay quality and yield through leaf defoliation, leaving plants completely skeletonized. Resistance to pyrethroid-type insecticides (Mode of Action 3A) and the recent discontinuation of chlorpyrifos-based insecticides requires a thorough examination of remaining control options.

Consideration of how each management approach affects alfalfa yield, quality, and financial returns will be critical if producers are to maintain productive stands and avoid accelerating insecticide resistance to currently registered products. The demonstration trial outlined below serves as a guide for decision-making in areas of known alfalfa weevil insecticide resistance.

WEEVIL CONTROL

Pyrethroid-based insecticides (Mode of Action 3A) have been the go-to option for weevil control for some time. Many pyrethroid-based products have provided effective weevil control at a low cost to producers. However, with the identification of weevil populations resistant to many pyrethroid chemistries, few effective alternatives remain and each has its own set of benefits and constraints.

Early Harvest

First cutting alfalfa is harvested between bud break and one-tenth bloom. Weevil mortality occurs when alfalfa, the weevil's food source, is removed from the field. The decision to harvest alfalfa is often a compromise between quality and tonnage. While early harvest may result in yield reductions, it also has potential to increase harvested forage quality. If marketed appropriately, higher quality alfalfa may provide access to premium markets where profits could compensate for lost tonnage.

Table 1 demonstrates the relationship of three forage quality traits to plant growth stage. If multiple cuttings are expected, future cuttings could be managed to make up for lost yields. Early harvest may have the greatest negative impact on dryland alfalfa fields where only a single cutting is typically achieved. Reduction of weevil populations following early harvest is not guaranteed and pest mortality is reduced if cool and moist conditions occur after swathing.

Maturity	TDN (%)	CP (%)	ADF (%)
Pre-Bud	65	21.7	28
Bud	62	19.9	31
1/10 Bloom	58	17.2	34
1/2 Bloom	56	16	38
Full Bloom	54	15	40
Mature	52	13.6	42

Table 1. Relationship of Alfalfa Maturity to Forage Quality by Growth Stage. *Adapted from Lacefield (1988). Total percent digestible nutrients (TDN), crude protein (CP), and acid detergent fiber (ADF) are reported on a dry-matter basis.*

PYRETHROID (MoA3A) INSECTICIDES

Though resistance to pyrethroid insecticides has been identified in the Intermountain West, it is important to understand that not all pyrethroids contain the same active ingredients. Resistance in a weevil population to one active ingredient does not guarantee resistance to those with other active ingredients.

Test strip applications and pre- and post-treatment monitoring can help determine if resistance to a chemical is occurring in a field. The ability to include pyrethroids in an integrated pest management plan could provide significant savings and help prevent or delay future resistance to other modes of action.

Indoxacarb (MoA22A) Insecticide

Steward EC® is the only current offering for weevil control in pesticide group 22A. While several trials report high efficacy when applying Steward EC®, it is critical that producers avoid exclusive use of the product. Rotation with early harvest and other effective insecticides (where possible) will likely help delay weevil resistance to Steward EC®. Cost is an especially important consideration as Steward EC® applications can be 2–5 times more expensive than common pyrethroids like Mustang Max® (zeta-cypermethrin) or Baythroid XL® (beta-cyfluthrin). (See **Table 2**.)

Treatment	$ oz^-1^	Rate	$ ac^-1^
Early Harvest	--	--	0
Steward EC®	2.24	11.3	25.31
Mustang Max®	1.44	4	5.76
Baythroid XL®	2.57	2.8	7.20
Check	--	--	0

Table 2. Treatment Cost ($ ac^{-1}). *Insecticides used in this demonstration were applied at maximum label rates. Due to variability in local retail costs of chemicals and application, prices were sourced from the* North Dakota Field Crop Insect Management Guide *to avoid bias toward specific retailers. Estimates include chemical and application expense. Growers should contact local suppliers for chemical prices and availability.*

Managing Resistance through MoA Rotation

Insecticides are categorized by modes of action (MoA numbered groups). All the insecticides in a group have a similar toxic mechanism by which they achieve pest control. Following the application of an insecticide, some less susceptible insects may remain. These individuals pass the genetic traits of resistance to the next generation. The proportion of the population containing the resistant gene continues to increase if the same MoA is applied.

Alternative modes of action target the pest using different toxic biochemical pathways or mechanisms. Inclusion of those alternatives into treatment rotations can target and remove individuals who expressed resistance to the previous MoA, likely preventing the resistant trait from being passed to the next generation of pests.

MONITORING

Avoiding pesticide applications when infestation levels do not warrant treatment is critical in resistance management. Monitoring is a key component of integrated pest management (IPM) strategies. Weevil monitoring is recommended when alfalfa reaches 10″ in height. Thereafter monitoring should be conducted pre- and post-treatment and again for second cutting regrowth.

In combination with monitoring, producers should also consider production costs, yield, quality, market trends, and pesticide efficacy and availability before treating.

Net-sweep and bucket methods are two monitoring approaches to consider when examining fields. Sweeps are recorded using a 15-inch-diameter insect net. The net is swept from one side of the body to the other across the top of alfalfa plants in a 180° arc. Ten consecutive sweeps should be recorded from multiple locations throughout a field. Average larvae per sweep is calculated by dividing the number of weevils by total sweeps.

Traditionally, 15–20 larvae per sweep was considered the threshold for treatment, but recent research suggests that samples of 1–3 large larvae per sweep can have significant negative yield impacts and may warrant treatment under the right combination of hay value and treatment costs (**Table 3**).

The bucket method is conducted by clipping 10 alfalfa stems (≥10″) from multiple locations throughout the field, inverting them into a 5-gallon bucket, and shaking the stems vigorously. The weevil total is divided by the number of stems to obtain average weevil per stem. Control is typically warranted when the average count exceeds 2–2.5.

$ Ton^{-1}	3 Large Larvae/Sweep							
320	Y	Y	Y	Y	Y	Y	Y	Y
310	Y	Y	Y	Y	Y	Y	Y	Y
300	Y	Y	Y	Y	Y	Y	Y	Y
290	Y	Y	Y	Y	Y	Y	Y	Y
280	Y	Y	Y	Y	Y	Y	Y	Y
270	Y	Y	Y	Y	Y	Y	Y	Y
260	Y	Y	Y	Y	Y	Y	Y	Y
250	Y	Y	Y	Y	Y	Y	Y	Y
240	Y	Y	Y	Y	Y	Y	Y	Y
230	Y	Y	Y	Y	Y	Y	Y	Y
220	Y	Y	Y	Y	Y	Y	Y	N
210	Y	Y	Y	Y	Y	Y	Y	N
200	Y	Y	Y	Y	Y	Y	Y	N
190	Y	Y	Y	Y	Y	Y	N	N
180	Y	Y	Y	Y	Y	Y	N	N
170	Y	Y	Y	Y	Y	Y	N	N
160	Y	Y	Y	Y	Y	N	N	N
150	Y	Y	Y	Y	Y	N	N	N
	5	10	15	20	25	30	35	40
	Treatment Cost $ acre^{-1}							

Table 3. Decision Table for Weevil Treatment with Density of 3 Large Weevil Larvae per Sweep. Adapted from Harrington, Carrière, & Mostafa (2021). Y-axis *represents alfalfa hay value ($ ton^{-1}). X-axis describes insecticide treatment cost ($ acre^{-1}). Green indicates justified treatment, yellow describes cost of treatment equivalent to economic impact level, and red signifies an unjustified treatment.*

DEMONSTRATION

To illustrate the many considerations associated with resistant alfalfa weevil, a demonstration trial was implemented at dryland and irrigated locations in Sheridan, Wyoming. The goal in implementing any pest treatment plan is fourfold: 1) reduce or eliminate the targeted pest; 2) preserve beneficial insects; 3) preserve crop productivity; and 4) preserve crop quality. This demonstration does not address impacts to beneficial insects; however, we evaluated monitoring methods, weevil control, and crop productivity and quality on four treatments and a control plot at each location. Plots were 0.55 acres and treatments were applied using a John Deere 400 series sprayer with an 80-foot spray boom. This application method was chosen with the intent to reflect the variability that often occurs when applying pesticides at commercial scales. The following control options were tested at each location.

- Early Harvest
- Steward EC® (indoxacarb): 11.3 oz ac^{-1}
- Mustang Max® (zeta-cypermethrin): 4 oz ac^{-1}
- Baythroid XL® (beta-cyfluthrin): 2.8 oz ac^{-1}
- Check: No treatment, standard harvest timing

Weevils were monitored using net-sweep and bucket methods when alfalfa reached 10″ in height. Treatments were implemented when alfalfa weevil counts reached the traditional targeted thresholds for each monitoring method. Weevil counts pre- and post-treatment and prior to harvest were reported.

The nature of a demonstration trial prohibits statistical declarations of treatment similarity or difference. Data presented here are purely observational and can be used as a model for reviewing treatment options.

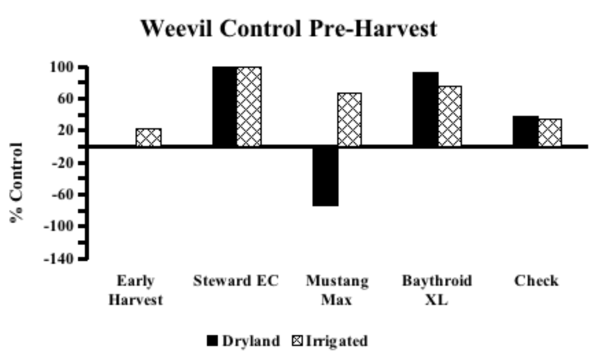

Figure 1. Weevil Control (%) 7 Days Post Treatment. *Negative control describes population growth and positive control describes population decrease since the original sampling event. While there is no treatment in check plots and harvest is the treatment for early harvest plots, these samplings were included in the post-treatment figure because sampling dates coincided with chemical treatments. Data are not replicated and are observational only.*

RESULTS

Weevil Control

Most treatments were consistent in their effect on weevil larvae. Check (no control methods implemented) plots saw rapid increases in larvae seven days after initial sampling followed by a natural population decline prior to harvest **(Figures 1 & 2)**. Steward EC® at the maximum labeled application rate (11.3 oz.) resulted in a near complete removal of weevil larvae.

The difference in Mustang Max® (zeta-cypermethrin) and Baythroid XL® (beta-cyfluthrin) treatments was notable. Both are group 3A, Type II pyrethroids, yet they delivered much different levels of efficacy. Evidence of resistance to Mustang Max® was apparent at both sites. Approximately 40% control was observed under irrigation, but weevil populations increased by nearly 150% in the dryland field seven days after treatment. Baythroid XL® offered ≥75% control at both locations post treatment.

These results reinforce the need to explore alternative pyrethroid chemistries at local levels, as they may be valuable IPM tools in resistant weevil populations. As in the check plot, early harvest allowed weevil numbers to increase initially. When irrigated, a natural decline similar to check populations was observed. Dryland conditions necessitated an earlier harvest and only one weevil collection was performed following the initial sampling interval.

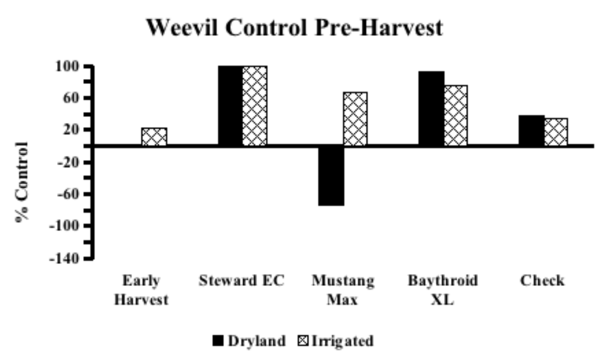

Figure 2. Weevil Control (%) the Day Prior to Harvest. *Negative control describes population growth and positive control describes population decrease since the original sampling event. No sample is reported for dryland early harvest as this plot was harvested the day following the post-treatment sample. Data are not replicated and are observational only.*

Dryland Alfalfa

The untreated check yielded the lowest tonnage. All other treatments appear to have preserved yields, even if only marginally. Early harvest was the highest yielding treatment.

The check and both pyrethroid treatments received utility quality designations based on forage quality analysis. This is the poorest of alfalfa quality

									Returns ($ ac^{-1})	
		Tons ac^{-1}	ADF%	NDF%	TDN%	CP%	RFV	Hay Class	Gross	Net
Dryland	Early Harvest	1.20	31	46	67	19	132	Fair	155	155
	Steward EC®	0.95	32	45	67	17	132	Fair	123	98
	Mustang Max®	092	32	46	66	17	129	Utility	101	95
	Baythroid XL®	1.00	31	46	64	16	126	Utility	110	103
	Check	0.85	33	47	65	17	125	Utility	93	93
		Tons ac^{-1}	ADF%	NDF%	TDN%	CP%	RFV	Hay Class	Gross	Net
Irrigated	Early Harvest	2.27	30	46	68	21	134	Fair	295	295
	Steward EC®	2.08	32	46	66	20	130	Fair	270	244
	Mustang Max®	2.50	33	49	65	19	120	Utility	275	270
	Baythroid XL®	2.76	33	47	65	20	126	Utility	304	296
	Check	2.80	33	48	65	20	122	Utility	308	308

Table 4. Alfalfa Productivity, Quality, and Returns ($ ac^{-1}) on Weevil Treatment. *Acid detergent fiber (ADF), neutral detergent fiber (NDF), total digestible nutrients (TDN), and crude protein (CP) are reported on a dry-matter basis. Tonnage is reported as 12% moisture hay. Hay class is determined by relative feed value (RFV) in accordance with USDA Hay Quality Designation Guidelines. Gross returns per acre are calculated by multiplying the 10-year average price received for each quality class by treatment tonnage yielded. Cost of treatment was subtracted to obtain net return per acre. Other costs of production are assumed to be equivalent and are not reported here.*

designations based on relative feed value (RFV) and USDA hay quality designation guidelines. Steward EC® and early harvest treatments were considered fair quality (**Table 4**).

Steward EC® delivered exceptional control and preserved forage quality, but at an expense of $25.31 ac,$^{-1}$ even ineffective applications of Mustang Max® resulted in similar net returns.

Irrigated Alfalfa

Weevil counts obtained in monitoring greatly exceeded thresholds that typically warrant treatment. However, weevil presence seemed to have a minimal impact on alfalfa yield. First and second cutting patterns were consistent for each plot, suggesting that field position was primarily responsible for vegetative production and perhaps the cumulative effect weevils had on alfalfa in each plot (**Table 5**). The check treatment provided the highest first cutting yields and, at no treatment cost, provided the greatest net return.

While these results likely would not remain consistent in a replicated study, they demonstrate that visual assessments are an important component of monitoring. Generally, it is said that if you can see weevil impact, the damage is already done. Our sweeps gathered more than enough weevils to suggest we would reach the economic threshold for treatment; however, it was difficult to identify weevil damage on individual plants.

Any decision in this situation involves risk. The choice to forego treatment may result in significant losses to alfalfa quality and tonnage, while the choice to treat involves accepting the financial risk of application without realizing quality or tonnage improvements to offset application costs.

Table 4. Irrigated First Cutting, Second Cutting, and Total Alfalfa Yield (Tons ac^{-1}) by Weevil Treatment.
Tonnage is reported at 12% moisture content.

	Tons acre^{-1}		
	1st	2nd	Total
Early Harvest	2.27	2.02	4.29
Steward EC®	2.08	1.43	3.51
Mustang Max®	2.50	1.87	4.38
Baythroid XL®	2.76	2.35	5.11
Check	2.80	2.29	5.09

The second highest yields were achieved when using Baythroid XL®. When the cost of treatment is factored in, net returns were nearly equivalent to early harvest. In this instance, preference should be given to early harvest for three reasons. First, quality was higher with this treatment. Second, elimination of the Baythroid XL® application would reduce equipment trips through the field, whether by the producer or an outsourced applicator. Finally, without insect exposure to pesticide, the development of resistance is delayed.

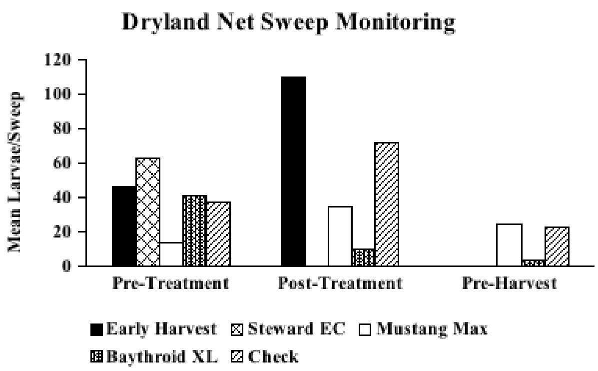

Figure 3. Dryland Mean Weevil Larvae per Sweep. *Baythroid XL, Mustang Max, and Steward EC are registered trademarks. Conventionally, treatment is warranted when 15–20 mean weevil larvae per sweep is exceeded. Early harvest plots were harvested the day following post-treatment sampling; therefore, no pre-harvest sample is reported.*

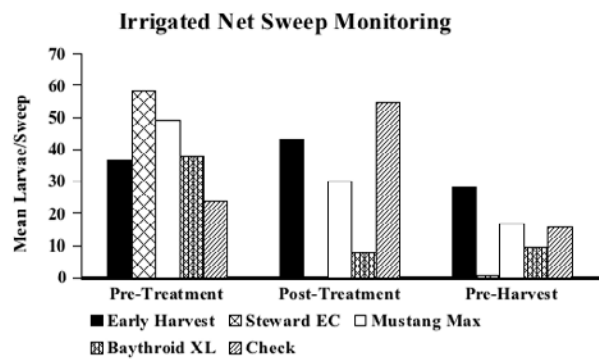

Figure 5. Irrigated Mean Weevil Larvae per Sweep. *Baythroid XL, Mustang Max, and Steward EC are registered trademarks. Conventionally, treatment is warranted when 15–20 mean weevil larvae per sweep is exceeded.*

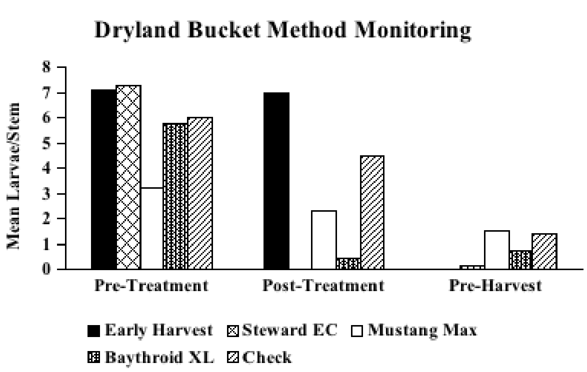

Figure 4. Dryland Mean Weevil Larvae per Stem. *Baythroid XL, Mustang Max, and Steward EC are registered trademarks. Fields exceeding 2–2.5 larvae per stem should be considered for treatment. Early harvest plots were harvested the day following post-treatment sampling; therefore, no pre-harvest sample is reported.*

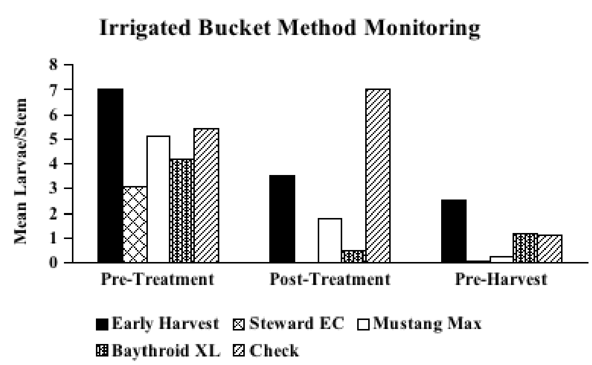

Figure 6. Irrigated Mean Weevil Larvae per Stem. *Baythroid XL, Mustang Max, and Steward EC are registered trademarks. Fields exceeding 2–2.5 larvae per stem should be considered for treatment.*

Monitoring

Results from this demonstration trial clearly point to the need for thorough monitoring to make timely and effective treatment decisions. Growers may wonder which monitoring method will provide them with the most consistent results. Is there a need to acquire insect nets, or can effective decisions be made using one of the many 5-gallon buckets found on the farm?

Both methods were used at each stage of the demonstration project. **Figures 3–6** depict dryland larvae counts for weevil treatments using net-sweep and bucket methods. Both were consistent in reporting infestations sufficient for treatment and reported a similar magnitude of change between post-treatment and pre-harvest. Methods varied in reporting an initial population increase or decrease between pre- and post-treatment events.

When using net sweeps, population growth post treatment was observed for dryland early harvest, Mustang Max®, and check plots, and recorded decreases for Steward EC® and Baythroid XL® treatments. When the bucket method was employed on the same plots, all plots except early harvest demonstrated population decrease over the same time frame **(Figure 3)**.

Comparison of irrigated approaches varied slightly from the aforementioned trend. Two explanations could plausibly account for these differences. First, sweep nets gather a larger quantity of insects per unit and can correct for plant-to-plant variability. The larger sample size may more accurately capture field conditions. Second, weevils may have been dislodged from stems during the process of clipping and transferring to the bucket.

SUMMARY

Overcoming the effects of alfalfa weevil predation requires an effective integrated pest management approach. Successful IPM begins and ends with monitoring, and is carried out using methods that are both effective and economically necessary. IPM principles increase in importance when treatments are limited by legality, pest resistance, or other factors. Demonstration trial results presented in this bulletin are purely observational. Treatment costs, efficacy, and availability will vary locally; however, the following observations may have applicability in a wide array of alfalfa hay production systems.

Visual assessments may be a necessary component of an effective monitoring program. Weevil populations in both fields selected for the demonstration trial reached thresholds often considered sufficient for treatment. Still, minimal weevil feeding impact and the affordability of early harvest and no-control approaches under irrigation combined to positively influence financial returns. When pairing monitoring results with visual observations of alfalfa damage to make treatment decisions, producers should consider what risks they are willing (and financially able) to accept. If both observations suggest a need for treatment, producers should then consider the cost and availability of weevil control.

Tonnage and quality are of equal importance. It is widely understood that treating weevils can preserve alfalfa yields. This is easily tracked given that hay sales are based on tonnage. Consideration of treatment effects on hay quality may be overlooked because operations do not always track these parameters. Using forage quality to market hay can provide growers access to higher-earning markets. Higher crop value may be necessary to offset the cost of insecticides or reduced crop yields. Producers will obtain the most benefit by implementing treatments that maximize yield and quality. Any realization of benefits will require that producers track forage quality and market their hay accordingly.

In this demonstration, dryland early harvest secured the highest yield and quality without added chemical or application expenses. Irrigated hay quality was improved with early harvest to the detriment of yields. Dryland and irrigated Steward EC® treatments provided a similar improvement in quality, but failed to secure higher yields and were more expensive to implement.

Management of alfalfa weevil may require different approaches in irrigated and dryland hayfields. In terms of alfalfa weevil management, the primary difference between dryland and irrigated hayfields is yield potential. Dryland environments are water limited and typically achieve only one cutting each growing season. This places strong limitations on the efficacy of early harvest as a weevil control alternative since tonnage lost to the approach may not be regained by future cuttings.

Early harvest was cost effective and consistent in improving forage quality at both demonstration locations. The approach generated the second lowest yields when irrigated but, surprisingly, was the highest yielding treatment in dryland conditions. While early harvest may be risky for dryland hay production, an exception arises in conditions where alfalfa growth fails to continue post treatment.

Prior to treatment, alfalfa growth and weevil presence will be somewhat uniform across a field. If growth then ceases, early harvest would be the most advantageous option because it incurs no treatment costs and may improve quality. This is likely what occurred at our dryland site, the difference being that alfalfa growth was not uniform across the field prior to treatment and favored the location of the early harvest plot.

The primary disadvantage of early harvest under irrigation was yield loss. Some have suggested that by harvesting early, producers could extend the growing window of future cuttings to make up for lost volume. While we recorded second cutting yields in this demonstration, plot orientation prevented irrigation of the early harvest treatment alone, meaning that we were not able to irrigate this plot until each of the other treatments had been harvested. This concept should be evaluated in future research.

Demonstration data suggest that insecticide applications may offer similar performance in dryland and irrigated locations. Steward EC® and Baythroid XL® provided similar levels of control at both locations. Only Mustang Max® showed highly variable levels of efficacy, possibly alluding to different levels of weevil resistance at the two locations.

Populations can be resistant to one active ingredient and not others within the same chemical grouping. Mustang Max® has been the chemical of choice in Sheridan County, Wyoming, for years while other Type II pyrethroids have largely been avoided. While weevil control was poor with Mustang Max® (zeta-cypermethrin), Baythroid XL® (beta-cyfluthrin, also Type II) provided greater than 75% control at both locations. When considering alternative chemistries, local application records and retailer knowledge can help to determine chemicals that have not been recently applied.

Consider sweeping!

Stem counts and net sweeps can produce variable results in tracking weevil populations. Both options can be conducted in a relatively similar amount of time. If the difference in methods boils down to the cost of a net, the expense may be justified by the increased clarity sweeping provides.

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