December 2010

A Pyrethroid, β-Cyfluthrin (Baythroid® XL, BayerCrop Science) Applied at Reduced Rates for Control of Rangeland Grasshoppers in South Dakota, 2010.

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Abstract

The concentration of β-cyfluthrin (Baythroid XL) was reduced from the recommended rate of 2.6 fluid ounces (fl oz) per acre to 1.95 and 1.3 fl oz and applied using RAATs treatment spacing against rangeland grasshopper populations in southwestern South Dakota. There was no significant difference in dose response to the treatments at 7 days post treatment. Control, corrected for untreated check response, ranged from 88.38 to 87.01 for the high and low dose respectively. There was no statistically significant dose response difference in the relative abundance of the four most prevalent species; *Ageneotettix deorum*, 32.7%, average age (AA) 4.05; *Amphitornus coloradus*, 15.08 %, AA 4.74; *Cordilacris crenulata*, 22.33%, AA 5.09 and *Melanoplus sanguinipes*, 14.55%, AA 3.73 following treatment and compared with the untreated population before and after treatment. There was no statistically significant difference in the instar response to treatments compared with the untreated population. The cost of the insecticide alone was lowered from $4.02 to $2.01. The label for β-cyfluthrin is 2 gallons of water per acre over pasture and rangeland which is needed for complete coverage in order to be effective. A 600 gallon load will treat only 300 acres. In addition in the arid west, where most grasshopper treatments occur on a large scale, relatively large quantities of water will be required even if no additional adjuvants are required by the label.

Introduction

Grasshoppers are a leading insect competitor on western rangelands for forage with serious outbreaks occurring over large areas at irregular intervals. Outbreaks, composed of a few species reaching high densities, occur locally every season. These local outbreaks reduce a food supply of all that forage on the rangeland, including sage grouse and other upland game. Outbreaks can seriously strain the habitat, and in some cases, damage beyond recovery the native plants ecosystem thus allowing the introduction of invasive species, which result in restricted production and available habitat. Strategic applications of pesticides are used to control these local grasshopper populations and to protect federal, tribal and private rangeland itself as well as to protect nearby crops from grasshopper invasions produced on federal land. Cost of application, efficacy of control, and low impact on terrestrial vertebrates remains the guiding factors in selection of control agents. Malathion, (Fyfanon® ULV) has been one of the chemical mainstays of rangeland grasshopper control programs for many years and was originally used as a replacement for chlorinated hydrocarbons (Skoog et al., 1965). Today malathion faces the similar issues as the materials it replaced. As an organophosphate, it is considered 'old' and consequently faces deregistration by the EPA. In developing an alternative, trials with β-cyfluthrin (Baythroid® XL) were conducted near Edgemont, SD in 2009 (Jech et al. 2009) and continue in 2010. Initial results indicated that the β-cyfluthrin was equal to malathion in the first comparison. However, the cost for the material per acre is substantially higher than for malathion. In order to determine if the cost could be reduced, a trial was conducted to determine the effect of reducing the amount of material applied per acre coupled with reduced agent area treatment (RAATs). The label rate tested in 2009, 2.6 fl ounces per acre (189.9 ml / ha), was reduced to 1.95 fl. oz (113.9 ml / ha) and finally to 1.3 fl. oz. per acre (94.9 ml / ha) to determine its effect on grasshopper population control. The negative correlation with higher temperatures may detract from and curtail the use of pyrethroids (Ewen, et al.1984 and Hinks, 1985). However, Johnson, (1990) indicated this may not be so important and may be more of a sampling problem or the result of the different species, body sizes or ages at the time of treatment. Pyrethroids are considered to have a contact mode of action only, with little feeding activity. These attributes may affect overall population responses by species and instars.

Objectives:

1. Determine a low effective dose for β-cyfluthrin.
2. Determine if all grasshopper species are affected equally by the treatment.
3. Determine the cost of treatment for β-cyfluthrin at the reduced active ingredient applications.

Methods and Materials

Study Site

The study was conducted in Fall River County in southwestern South Dakota. The location was selected because of the good range conditions, density and diversity of grasshopper species, familiarity with the history of grasshopper species of the area and access to nearby ongoing

studies. The plots were north and west of Edgemont, SD on rangeland that can be characterized as silver sage-steppe. The area was composed of a mixed grass prairie on rolling hills with a good mixture of cool and warm season grasses (latitude 43.406 longitude -104.033) on the Mark Tubbs Ranch. The rangeland grasses were dominantly Needle-and-Thread (*Hesperostipa comate*), buffalo grass (*Bouteloua dactyloides*), and blue gramma, (*Bouteloua gracilis*). The previous fall temperature conditions had been normal with a slight deficit in rain fall for late autumn and winter. The area had received above normal spring rainfall and experienced very low air temperatures for extended periods of time during mid April through late May. Spring temperatures were slightly warmer for April, 0.8 °F above the average of 46.9°F daily average temperature. While the May average temperature was 51.2 °F which was 5.2 °F below the long term, 30 year average, daily high and low normal temperatures for the area. The average daily high (62.8 °F) for May was about 4 degrees cooler than expected with eleven days not reaching 60 degrees during the first 15 days of the month. Rainfall was slightly above normal for the season, with an excess in April of 0.41 in. and May had an excess of 0.61 in. These amounts are above the long term average of 2.52 in. and 3.30 for April and May respectively. June was wetter than the average (3.45 in) by almost an inch (0.94 in.). The daily high and low average temperature was 1.9 °F below the long term observed of 66.3 °F. It can be argued that the temperature for the late spring was cooler, by about 6.3 °F and the precipitation was almost 2 inches above normal.
This resulted in a good to excellent range forage conditions. Similar conditions had prevailed the previous season, but with less precipitation.

Treatments and Experimental Design

β-cyfluthrin (Baythroid XL®)was applied at three decreasing doses starting from the lowest recommended on the label, to determine the point at which grasshopper control was less than acceptable. Three treatments: the standard 2.6 fl oz/ac, 0.02 lb active ingredient (AI)/ac or 22.75 gm AI/ha; an intermediate rate of 1.95 fl oz per acre, 0.02 lb AI/ac or 17.02 gm AI/ ha; and the low rate, one half the standard rate or 1.3 fl oz per acre, 0.01 lb AI/ ac or 11.31 gm AI/ ha of β cyfluthrin were applied to four replicates of 40 acres (16 ha) each. A final treatment of four untreated control plots was included to allow correction for local population changes with time using the Connin, and Kuitert (1952) correction.

Treatments were applied using a Cessna Ag Truck owned by the USDA, APHIS, and equipped with winglets (DBA-Ag Tips: Clack Oberholtzer, Alberta, Canada). The aircraft was operated by a USDA-APHIS pilot and equipped with a standard commercial spray system and differentially corrected guidance and recording system. Prior to application, the aircraft was calibrated to deliver the target rate of 2 gallons per acre to within 1% of desired rate. This was accomplished by collecting and measuring the amount of material sprayed through the system in a predetermined period of time making adjustments in pressure until the desired output was achieved. The aircraft was calibrated for a 100 ft (30.5 m) swath, but flying a 125 ft (38 m) swath giving 80% coverage, flying altitude of 30 ft (9 m) with an airspeed of 120 mph (193 kph) and equipped with 27, 8020 flat fan tips operated at 40 psi (276 Kpa) see Table 1.

Following label directions for mixing the insecticide for grass/rangeland treatments, the B cyfluthrin was added to about one half the total volume in the aircraft hopper and was brought up to the final volume of water for each set of plots. Applications were completed with the aircraft

at label rates of water for the treatments. RAATs treatments were implemented on the 40 acre plots to simulate the malathion grasshopper control programs and reduced the total amount of material applied per acre by applying material to only 80% of the total area protected (Foster et al. 2000).

Grasshopper populations were evaluated by density and species composition following the method of Foster and Reuter, (1996) outlined as follows. To assess density, 40 0.1 m^2 rings were placed in a circle (100 m across) and 5 m apart and grasshoppers counted on approach by the observer. Finally, each ring arena was carefully examined to assure that no individuals were missed and the number of grasshoppers was recorded. To determine the species composition, 2 sets of sweep samples were collected using the circle as guide. The first fifty (50) 180°sweeps were taken low and slow inside the rings and a second set of fifty (50) were taken high and fast on the outside of the rings order to sample the grasshopper population. After identification the frequency of occurrence can be converted to number of grasshoppers by species for each plot and treatment.

Based on precount samples, plots were blocked on observed densities to assure that each treatment was applied to all population levels including the untreated check. This tested all density ranges and assured that one material was not assigned only low or high densities. Once blocked, the precount samples from all plots scheduled for treatment and corresponding untreated plots were sampled and served as the pre-count used in subsequent analyses. If treatments were delayed for 72 hours, fresh samples were collected from all untreated plots to serve as fresh pre-counts, including the untreated plots.

Density and sweep samples were collected at three and seven days post treatment, placed in paper bags, stapled shut, frozen and returned to Phoenix for species determination, enumeration and analysis using repeated measures randomized block design.

Connin and Kuitert's, (1952) procedure, was used to calculate percent mortality for the treated population based on changes in check plot population based on the formula: =100*(1-Ta*Cb/Tb*Ca). Where Tb equals total population of grasshoppers counted before the plot was treated, Ta equals the total counted after treatment, Cb equals the total counted for the check before treatment, and Ca equals the total counted for the check site after treatment. Further analyses were carried out using JMP 8.0 statistical software (JMP 8.0, 2008).

Results and Discussion

Onsite observers recorded prevailing conditions at time of application, including time of start, time of completion, ground and air temperature, wind speed and direction during treatments. Radio communication was maintained with the pilot throughout the application and conditions affecting the treatment were discussed. After each application, the air temperature observed by the pilot was also included as part of the record. GPS flight track are on file for these applications. Applications were started on the 2 July and completed on 5 July 2010; see Table 2 for the conditions recorded. Due to high wind speeds on 3 July no applications were made.

Daily high and low temperatures along with precipitation are presented in Figure 1. Ten days prior to starting the trial, 0.25 inches of rain fell which continued the cool wet spring trend. Rainfall occurred at the beginning and end of the trial, adding about 1 inch to the total received across the study site. Seasonal highs were near normal for the season but a cool period occurred from 3 July until 8 July. Low temperatures were below seasonal normal but not extraordinary for the region and season. Sweep and density samples collected were not adversely affected by changes in weather conditions.

Pretreatment densities ranged from a low of 5.50 (untreated plot) to the high of 23.75 (β-cyfluthrin plot) and averaged 14.8 grasshoppers/m^2 for all of the plots in the study. The average pretreatment density for the β-cyfluthrin 2.6 fl oz per acre, β-cyfluthrin 1.95 fl oz per acre and β-cyfluthrin 1.3 fl oz per acre was 11.94 per m^2, 14.56 per m^2 and 20.06 per m^2. The untreated plots ranged from 12.88 to 13.25 per m^2, respectively, for the pretreatment period Table 3.

At pretreatment, the population was composed of 12.47% third instars, 40.53% fourth instars, and 36.67% fifth instars. The population total mean age was 4.32 (slightly above 4th instar) see Table 4.

Following treatment, the untreated population means trended lower through the course of the experiment. The daily highs from the 4th through the 6th of July were cool and may have influenced the β-cyfluthrin activity which may be reduced by elevated temperatures and may appear to be more effective if applied during cooler weather, when high temperatures remain below 90 °F (Ewen 1984, Hinks 1985). Johnson et al. (1986) on the other hand makes a point that waiting before early morning samples are collected and making sure sampling conditions are as near the original sample conditions as possible are useful in ensuring good sampling.

One of the untreated plots dropped from 9.75 to 6.50, a drop of 33%. The other plots decreased, but not as much. On the average the most change occurred on the medium density plots, losing 3-4 grasshoppers per m^2 while the high and low density plots dropped only 1 grasshopper per m^2.

A series of Chi-square analyses were conducted for individual grasshopper species using before and after treatments to determine if there was any effect on either the age of the grasshopper or the species present. Using species with sufficient population densities, e. g., *Ageneotettix deorum*, *Aulocara elliotti*, *Cordillacris occipitalis* and *Melanoplus sanguinipes* no age or species differences were detected following treatments. However, it seems logical that treatment of a younger population is more likely to give better results than treating an older population, because of their size and reduced mobility. This was not the case in this study.

Figure 2 displays the changes in the treated and untreated population from pretreatment through the final samples. All β-cyfluthrin treatments immediately and dramatically reduced the grasshopper populations. Some recovery, usually minor has been reported for pyrethroid treatments (Johnson et al. 1986). In this study please note there was a slight population rebound with the lowest dose tested; however, this does not represent significant recovery. Examination of the untreated population in the figure shows there was a slight decline on the plots. Connin and Kuitert's, (1952) procedure, was used to calculate percent mortality for the treated population using changes in check plot population see Table 6. These percent mortalities were

then analyzed using repeated measure in time on the JMP 8.0 platform. The results were statistically not significant for either post-treatment sample dates, (two dates, F=0.26; df = 2, 5; P = 0.78). β-cyfluthrin 2.6 fl oz ac^{-1}, β-cyfluthrin 1.95 fl oz ac^{-1} and β-cyfluthrin 1.3 fl oz ac^{-1} were all equally efficacious, 88.4%, 87.0% and 87.0% respectively based on their resulting mortality in this experiment. This result indicates that the one half rate (1.3 fl oz/ac, 11.31 gm AI / ha) is as good for controlling grasshoppers as the label rate of β-cyfluthrin. As can be seen the β-cyfluthrin reduced the populations at the low dose applied even though due to chance alone the overall grasshopper density on the plot happened to higher than on the other low population density plots.

Our results are similar to those reported by Johnson et al. 1986. In their test the pyrethroid deltamethrin was initially effective, but the field population receiving a sub-lethal dose recovered. The recovery seen was unrelated to species and age structure of the population as others had reported.

The results are similar to 2009 findings; see Table 6 for combined results. The β-cyfluthrin dose can be lowered, by half with little loss of efficacy and thereby reducing the overall cost of the application. The cost is still high ($2.01 for β-cyfluthrin alone) and the requirement for two gallons of water per acre (18.70 l / ha) is still cost prohibitive. Since the pyrethroid must be ingested, full coverage applications with high water rates is understandable, but difficult to justify on large scale grasshopper control programs that may be conducted in dry rangeland conditions far from readily available water supplies. This will also present problems for ground applications, which may actually be increased by the demand for so much water in arid regions. At the current recommended rates, this treatment is non economical because the number of acres that can be treated with one spray tank of material is very limited when compared with the number of acres that can be treated with malathion.

Acknowledgements

The authors wish to thank Bruce Helbig for assisting with logistics associated with the study. We also wish to thank John W. Bell at Bayer CropScience and Brent Jacobson at Cheminova for their continued interest and support. To Randy Hedge, Edgemont, South Dakota, City/Airport Manager for providing logistical assistance at the airport. Special thanks to Mark Tubbs for providing the rangeland for the study and for his continued support and cooperation since 1989.

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Tables

Table 1. Summary of treatments and Calibration parameters

Treatment	AI/ac	Material fl oz/ac	Total fl oz/ac	Nozzle no.	Tip Size	Screen size	Pressure psi	Aircraft speed	Swath width	Percent Coverage
β-Cyfluthrin	0.203 lb	2.60	256	27	8020	50	40	120	125	80%
"	0.015 lb	1.95	256	27	8020	50	40	120	125	80%
"	0.010 lb	1.30	256	27	8020	50	40	120	125	80%

Table 2. Meteorological conditions recorded during aerial application of treatments in the grasshopper trial plots near Edgemont, South Dakota, 2010.

						Temperatures °F.						
	Plot	No.		Time (AM)		Ground		Air		Pilot	Wind (mph)	
Treatment	No.	Passes	Date	Start	End	Start	End	Start	End		Start	End
Baythroid 2.0	13	12	7/2	5:01	5:12	58	62	63	64	67	1-1.5 SE	1-1.5 E
	60	11	7/2	5:24	5:33	60	60	63	64	67	1.0 S	< 1 S
	66	11	7/2	6:08	6:20	65	66	67	71	70	1.5-2 SE	< 1 E
	105	11	7/2	6:34	6:45	65	69	69	72	71	< 1 SW	< 1 SW
Baythroid 1.5	30	11	7/4	5:05	5:16	59	57	60	59	56	1.5-2 NE	< 1 NE
	72	11	7/4	5:28	5:38	58	56	60	59	58	1-2 S	3-4 S
	84	11	7/4	7:35	7:45	67	64	66	64	62	1-1.5 SE	3.5-4 SE
	92	11	7/5	5:12	5:22	52	50	55	56	56	1.5-2 W	1-1.5 W
Baythroid 1.0	107	11	7/5	6:06	6:17	47	48	55	54	55	1.5-2 S	2.5-3.5 S
	50	11	7/5	6:32	6:42	53	54	56	61	56	1.5-2.5 E	1-2 E
	15	11	7/5	7:21	7:32	58	57	62	62	56	1-1.5 NE	1.5-2 N
	9	11	7/5	7:35	7:46	56	60	59	60	58	1-1.5 N	< 1 N

Table 3. Precounts from the plots taken immediately prior to the treatment application.

Treatment	Baythroid 2.06*	Baythroid 1.5	Baythroid 1.0	Untreated Checks by sample date		
Date of sample	2-Jul	4-Jul	5-Jul	1-Jul	2-Jul	4-Jul
High	13.75**	13.75	23.75	18.75	19.25	19.25
High Medium	18.50	21.50	18.25	17.50	14.25	19.50
Low Medium	8.25	11.75	18.25	9.75	9.25	8.50
Low	7.25	11.25	20.00	5. 50	6.50	5.75

* fl oz / ac

** grasshoppers / m²

(A value of 1-5 coincides with the first 5 instar stages and a value of 6 represents the adult stage **Table 2**.)

Table 4. Grasshopper species composition and age structure in the B cyfluthrin pretreatment plots from samples collected prior to treatment near Edgemont, South Dakota, 2010.

	Instar									
Grasshopper species	1	2	3	4	5	Adult	Total	%	Age	Hatch Group
Subfamily Gomphocerinae										
Acrolophitus hirtipes					1		1	0.05	5.00	3
Ageneotettix deorum		5	81	418	121	1	626	32.66	4.05	3
Amphitornus coloradus			1	29	21	1	52	2.71	4.42	3
Aulocara elliotti		1	5	86	172	25	289	15.08	4.74	3
Aulocara femoratum		2					2	0.10	2.00	4
Cordillacris crenulata				2	1		3	0.16	4.33	4
Cordillacris occipitalis			3	35	309	81	428	22.33	5.09	3
Opeia obscura			2				2	0.10	3.00	5
Phlibostroma quadrimaculatum	1	11	21	61	3		97	5.06	3.56	4
Psoloessa delicatula						1	1	0.05	6.00	2
Subfamily Melanoplinae										
Melanoplus confusus						22	22	1.15	6.00	1
Melanoplus gladstoni	2						2	0.10	1.00	4
Melanoplus infantilis		1	11	3			15	0.78	3.13	3
Melanoplus occidentalis					1	4	5	0.26	5.80	3
Melanoplus packardii		2	5	6	2		15	0.78	3.53	3
Melanoplus sanguinipes	1	25	88	99	66		279	14.55	3.73	3
Phoetaliotes nebrascensis	2	6	5	1			14	0.73	2.36	5
Subfamily Oedipodinae										
Encoptolophus costalis			1				1	0.05	3.00	5
Hadrotettix trifasciatus		3	9				12	0.63	2.75	4
Metator pardalinus				3	2		5	0.26	4.40	4
Pardalophora haldemani						1	1	0.05	6.00	2
Spharagemon collare			3	7	1		11	0.57	3.82	4
Trachyrhachys kiowa			4	27	3		34	1.77	3.97	4
Totals	6	56	239	777	703	136	1917		4.32	
%	0.31	2.92	12.47	40.53	36.67	7.09				

Hatch Group: 1. Very early hatching, 2. Early spring, large nymphs and adults, 3. Hatch in mid-spring, 4. Hatch in late spring, 5. Hatch in early summer

Table 5. Mean percentage reduction and control of rangeland grasshoppers aerially treated with selected doses of Baythroid near Edgemont, South Dakota, 2010.

	4 Days Post Treatment	7 Days Post Treatment
β-cyfluthrin 2.0	83.60	88.38
β-cyfluthrin 1.5	84.61	87.01
β-cyfluthrin 1.0	90.96	87.01

Table 6. Cost to treat with either Malathion or β-cyfluthrin using different swath spacing and application rates to determine the best cost benefit for an application.

Year	AI fl oz/ac	Material Spacing	Cost per gal	Ac per gal	Diluent per ac	Total Insecticide + Diluent	Cost of Material per ac protected	% Control
2009	7.72	Malathion	$35.00	16	none	8.0 fl oz	$2.19	96.3
2009	3.86	Malathion RAATS	$35.00	40	none	4.0 fl oz	$0.88	86.4
2009	0.328	β Cyfluthrin	$245.00	49	2 gal H_2O	98 gal	$5.00	76.2
2009 & 2010	0.262	β Cyfluthrin RAATS	$245.00	61	2 gal H_2O	122 gal	$4.02	72.5 & 88.4
2010	0.196	β Cyfluthrin RAATS	$245.00	61	2 gal H_2O	122 gal	$3.02	87.0
2010	0.131	β Cyfluthrin RAATS	$245.00	61	2 gal H_2O	122 gal	$2.01	87.0

Figures

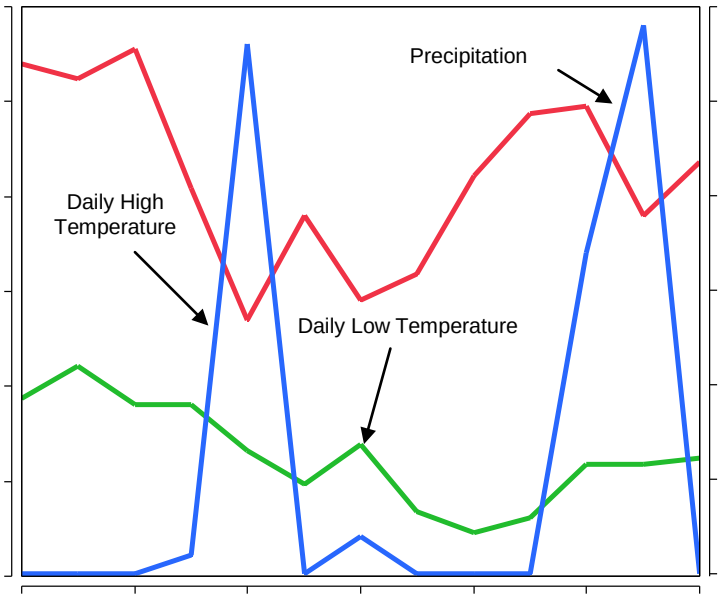

Figure 1. Temperature and precipitation during B cyfluthrin Study Interval Edgemont, SD, 2010.

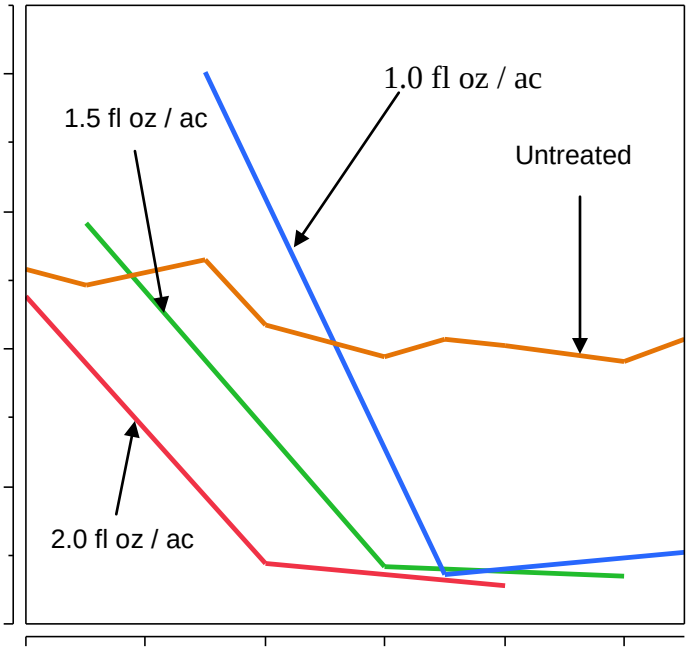

Figure 2. Population reduction following treatment with B cyfluthrin at 2.0, 1.5 and 1.0 fl oz / ac.

Comparison of registered and selected unregistered toxicant baits against *Camnula pellucida*, Phoenix, AZ, September 2010.

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Abstract

Three carriers, wheat bran, food byproducts (Tast-E-Bait) and apple pomace (Crumbles) were combined with carbaryl, permethrin, bifenthrin, Rynaxypyr®, Indoxacarb® and Metaflumazone® in varying concentrations, less than 5% by weight and exposed to *Camnula pellucida* to determine response (control) by the combination of carrier and toxicant. Wheat bran with carbaryl, 5%, gave the best results. Similar results were obtained with crumbles and Tast-E-Bait as carriers. The 2 and 4 % produced nearly identical result as the 0.22% indoxacarb. Coragen on wheat bran at the low dose, 0.025% was better than at the high dose, 0.5%. This may be due to feeding repellency since the wheat bran is known to acceptable to this species. Bifenthrin, 0.2%, on crumbles also has some promise as a bait. All of these materials will be further tested with other species.

Introduction

Since before the 1900s wheat bran baits and other carriers with various toxicants have been used to efficiently control rangeland grasshoppers and Mormon cricket. When used widely there can be limited results if the entire grasshopper species complex does not feed on the bait. *Camnula pellucida*, a species that can reach high local densities, prefers moist habitats and is capable of long distance migration, is a severe pest on rangeland grasses small grains and alfalfa. High densities of eggs in restricted locations make this a pest that can be readily controlled on hatching beds if populations are located during nymphal surveys. It is readily controlled with available toxicant and bait combinations. As the current group of insecticides comes under additional scrutiny from the EPA, new active ingredients and toxicants must be screened to find effective, cost-competitive, and efficient materials. As new chemistries are discovered and brought forward for evaluation, they will be tested for their utility as tactical control agents for grasshopper and Mormon cricket control.

Baits offer an environmentally friendly approach for pest control near sensitive sites since they are rapidly consumed by the target, grasshoppers and Mormon crickets, and in general are not as toxic to vertebrates as some of the other materials used in the past. Since not all grasshoppers consume bait (Onsager et al. 1996), complete elimination from the area is not possible. The following trial with *C. pellucida* was conducted to evaluated the acceptability and toxicity for

some new materials not previously tested including rynaxypyr, indoxacarb, metaflumazone, bifenthrin, and Permethrin. These candidates were compared with carbaryl on currently available carriers used for grasshopper control Table 1. Rynaxypyr, formulated by DuPont as Coragen, is a novel anthranilic diamide which activates the insect ryanodine receptors, causing rapid muscle dysfunction and paralysis. The EPA has recognized chlorantraniliprole, or rynaxypyr, as a reduced-risk pesticide which is defined as: low-impact on human health, low toxicity to non-target organisms (birds, fish, and plants), low potential for groundwater contamination, lower use rates, low pest resistance potential, and compatibility with Integrated Pest Management (EPA, 1997, Davis, 2008). Other reduced risk agents previously tested include indoxacarb, and metaflumizone and will be included in future trials. Permethrin and bifenthrin which have shown some promise in previous trials are also included in these trials.

Methods and Materials

Adult grasshoppers were collected by Dewey Murray and Dustin Akina a few miles south of Mormon Lake, Arizona on open meadows (7366 ft elevation, latitude 34.807, and longitude 11.442) in early September 2010 and returned to the CPHST Phoenix Lab. The *C. pellucida* were held in cages and fed fresh romaine lettuce and cheerios. The test was started 9 September 2010 at the CPHST Phoenix lab range (1129 ft elevation, latitude 33.403, longitude -112.002) consisting of planted buffalo grass, *Buchloe dactyloides*, and blue gramma, *Bouteloua gracilis*. Ten (10) 2 gallon cages, 7.75 inches (19.6 cm) in diameter, per treatment, were placed over the forage. Sixteen (16) treatments, including three untreated carriers and one with no treatment, were applied at 10 pounds per acre per cage (0.040 gm). Each cage was stocked with five (5) *C. pellucida* adults and checked daily for mortality for seven (7) days. Survival analysis was used to separate treatments.

Results and Discussion

Daily maximum and minimum temperatures from the Phoenix Sky Harbor Airport and Mormon Lake, AZ for the period are shown in Fig. 1. It was much hotter in CPHST Phoenix. Day time average temps were 107.8 °F and overnight lows were 85.7 °F, compared with Mormon Lake, AZ, which had 80.1 °F and 50.1 °F respectively. The daily temperature differences are shown in Fig. 2. The average daily high in Phoenix was 27.7 °F higher than Mormon Lake, while the nighttime lows were even greater at 35.6 °F indicating that the Phoenix nights were much warmer than Mormon Lake. The higher temperatures may have placed additional stress on the grasshoppers in the test.

Analyses are Kaplan-Meier, which is used in research to study time to an event, such as mortality performed using JMP 8.0. This allows comparison of the survival curves among the treatments based on time to mortality. When the data from all treatments are presented together, (Fig. 3) it is apparent that there are at least three bait groups. One group appears to provide good results; a second group provides some mortality, and the third group provides little response to the baits. It is observed that the toxicant and carriers could be separated based on the time to death following treatment. Kaplan-Meier analysis confirms the observation (Log-Rank test = 10.1651; df = 2; Prob > ChiSq = 0.0062) based on the mortality of the C. *pellucida*. It is expected that any treatment will be better than no treatment; and indeed analysis of the untreated wheat bran,

untreated crumbles, untreated Tast-E-Bait and the no bait treatment are not significant (Log-Rank ChiSquare = 3.9850, df = 3, Prob > ChiSq = 0.2631) Therefore the following tests are based on comparing toxicants and doses of toxicants rather than carriers. This would be of interest if there was some observed difference of feeding by the *C. pellucida* on one of the carriers, none was noted.

When logical comparisons are made, such as the three carriers, wheat bran, crumbles and Tast-E-Bait, treated with carbaryl, no differences among the three are detectable (Fig. 4). Log-Rank ChiSquare = 1.9922, df = 2, Prob > ChiSq = 0.369). This indicates that the grasshopper was accepting the bait as had been seen in earlier studies (Jech et al., 1993, Foster et al. 1998).

In a comparison of the Tast-E-Bait with indoxacarb, 2%, (mfg. by DuPont), Tast-E-Bait with indoxacarb, 4%, (mfg. DuPont), and wheat bran, with carbaryl, 5.00% no difference was detectable among treatments (Log-Rank, ChiSquare = 5.2738, df = 2, Prob > ChiSq = 0.0716,) (see Fig. 5). This is a good indication that these would be suitable for replacing the carbaryl in the formulation.

Five newer materials at lower doses including crumbles with bifenthrin, at 0.20% concentration (mfg. by Wilbur-Ellis), crumbles with metaflumizone at 0.15% concentration (mfg. by Wilbur-Ellis), flaky wheat bran, with Coragen, at 0.025% concentration (mfg. by DuPont), flaky wheat bran, with Coragen, at 0.5% concentration (mfg. by DuPont), and small crumbles with indoxacarb, at 0.22% concentration (mfg. by DuPont) were compared against carbaryl with wheat bran, at 5.00% concentration (see Fig. 6.). Results of the analysis indicate strong differences among the treatments compared to the carbaryl 5% (Log-Rank, ChiSquare = 38.5650, df = 5, Prob > ChiSq <.0001). There are two materials that don't look as good as the wheat bran and carbaryl and they are flaky wheat bran, with Coragen, at 0.5% concentration and crumbles with metaflumizone at 0.15% concentration. We interpret the results to indicate the concentration of the metaflumizone (0.15%) is too low and the concentration of Coragen is possibly too high. The bifenthrin quickly produced mortality at the dose used in this experiment.

Analysis of the combination that did not provide acceptable mortality is presented in Fig. 7. The comparison of the crumbles with bifenthrin, at 0.20% concentration (mfg. by Wilbur-Ellis) and crumbles with metaflumizone at 0.15% concentration (mfg. by Wilbur-Ellis), flaky wheat bran, with Coragen, at 0.025% concentration (mfg. by DuPont), again were easily separated from the 5% carbaryl bait (Log-Rank, ChiSquare = 19.3649, df = 3,Prob > ChiSq <0.0002) as shown in Fig. 7. The toxicants used are possibly at sub-optimal concentrations to be effective. As noted earlier the higher dose of Coragen did not give as good of results as the lower dose, leading to the speculation that this material as well as the permethrin may be causing the bait to be rejected rather than ingested. It is also suspected that the metaflumizone concentration may be too low, but until a higher concentration is available, work will continue with current materials.

Figure 8 depicts the mortality curves for those toxicants that are suitable or have other characteristics that make them candidates for further investigation. Even though the materials are easily separated from the wheat bran with 5% carbaryl (Log-Rank, ChiSquare = 14.8635, df = 3, Prob > ChiSq <0.0019), the candidates will be tested in the upcoming season. If enough material is available, larger plots, 10 acres, may be set out for optimal scale testing.

The second best combination was the indoxacarb 4 % on the Tast-E-Bait. This combination was nearly as good as the carbaryl flaky wheat bran combination. Permethrin does not look like a toxicant for baits. Permethrin has a reputation as an antifeeding agent and is used as a 'flushing' agent in commercial pest control. Indoxacarb and possibly metaflumizone appears to have promise, especially if the concentrations of the toxicants are increased. The good news is that these materials are on the EPAs list of 'soft' chemistry and are likely to be available for a longer period of time.

Conclusions

Using the Kaplan-Meier Log Rank test statistic, from mortality following a toxic challenge, allows univariate analyses that are readily interpreted. Based on this analysis, carbaryl on wheat bran, or other carriers, continues to be the best overall combination for grasshopper control. There are three materials that continue to show promise and warrant further testing. These are bifenthrin, Coragen, and indoxacarb. The 2 and 4% indoxacarb produced the same mortality as the 0.22% rate. It is suspected that the rate of metaflumizone is slightly lower than what may be considered optimal. The Coragen at the lower, 0.025%, rate was superior to the higher rate, 0.5%, and may be evidence that the Coragen may have antifeeding properties at the higher dose. The rates of metaflumizone and Coragen, should be evaluated at additional doses to look for a balance of dose, cost and acceptance by the grasshoppers. The bifenthrin should be field tested in larger scale, ten acre replicated trials, against carbaryl in the field as soon as possible

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Table 1. List of toxicant and carriers tested at the concentration tested. Application rate was ten (10) pounds per acre

Toxicant	**Carrier**	**Percent**
UTC	Wheat Bran	Untreated
UTC	Crumbles	Untreated
UTC	Tast-E-Bait	Untreated
Carbaryl	Crumbles	5.00
Carbaryl	Tast-E-Bait	5.00
Carbaryl	Wheat Bran	5.00
Bifenthrin	Crumbles	0.20
Indoxicarb	Crumbles	0.22
Indoxacarb	Defatted Corn	0.22
Indoxacarb	Tast-E-Bait	2.00
Indoxacarb	Tast-E-Bait	4.00
Metaflumizone	Crumbles	0.15
Permethrin	Crumbles	0.60

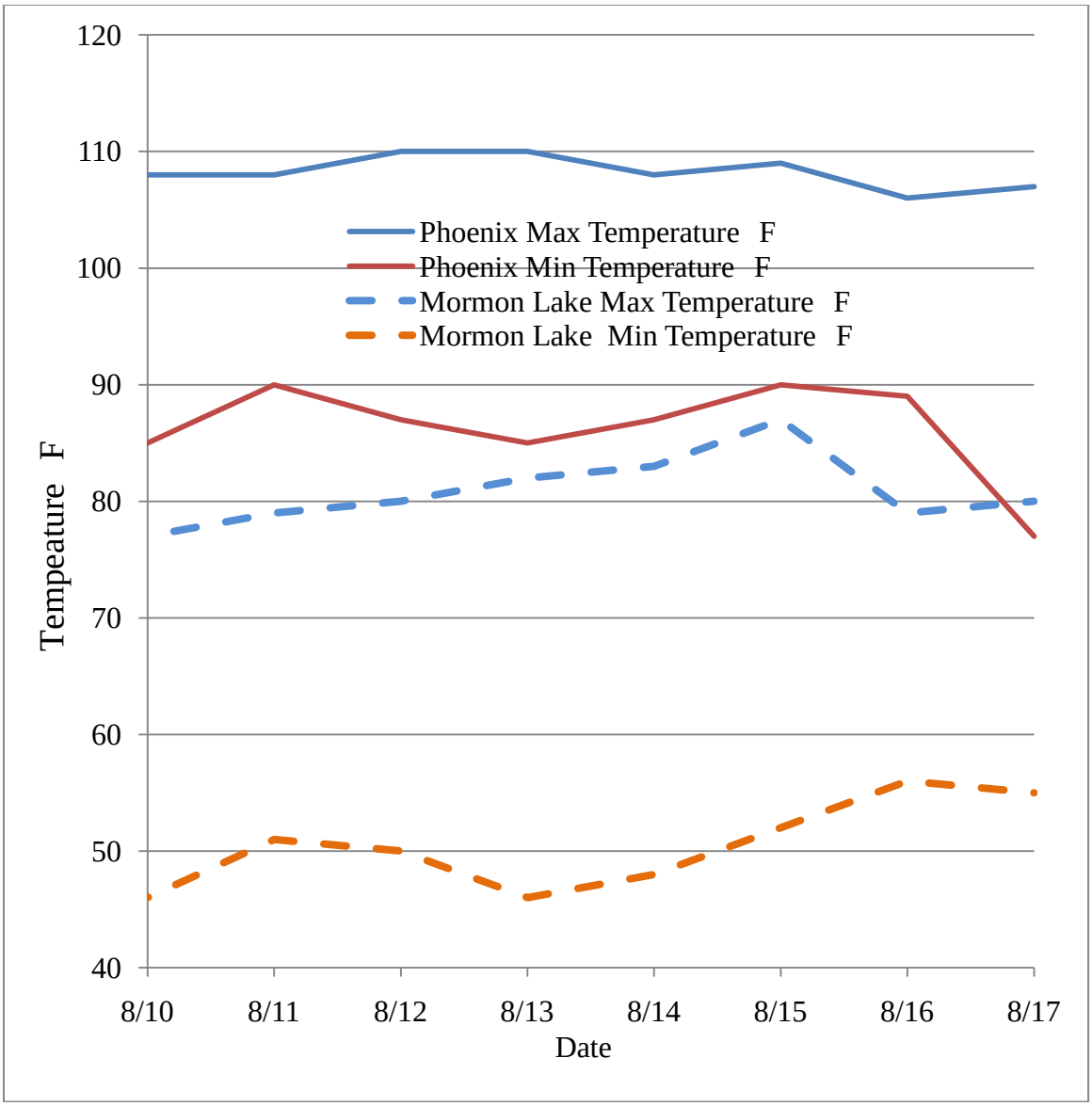

Figure 1. Daily Maximum and Miniumum temperatures from Phoenix Sky Harbor Airport and Mormon Lake, AZ.,

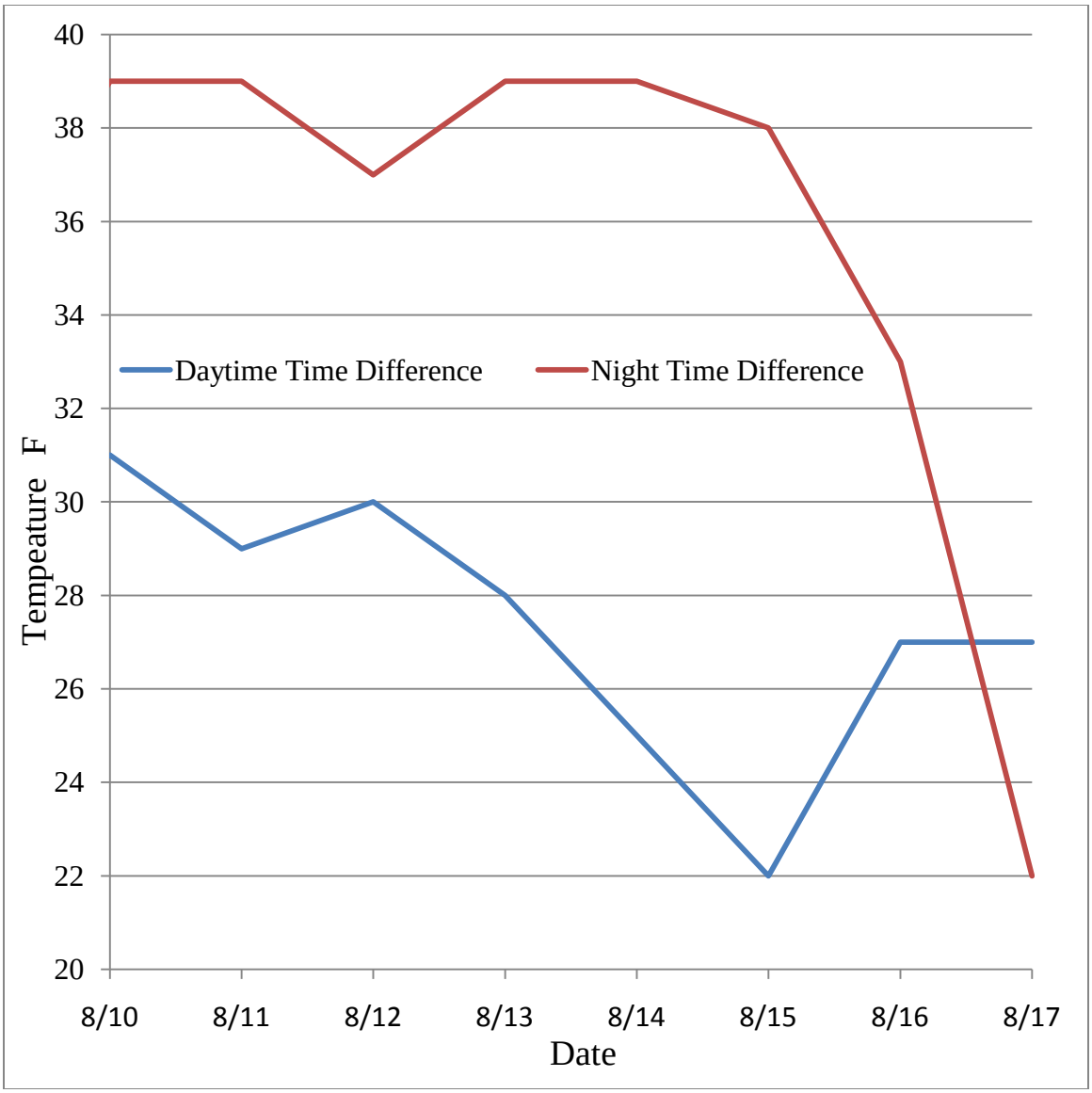

Figure 2. The daily difference in temperatures from from Phoenix Sky Harbor Airport and Mormon Lake, AZ , for the outdoor cage test period at CPHST Phoenix.

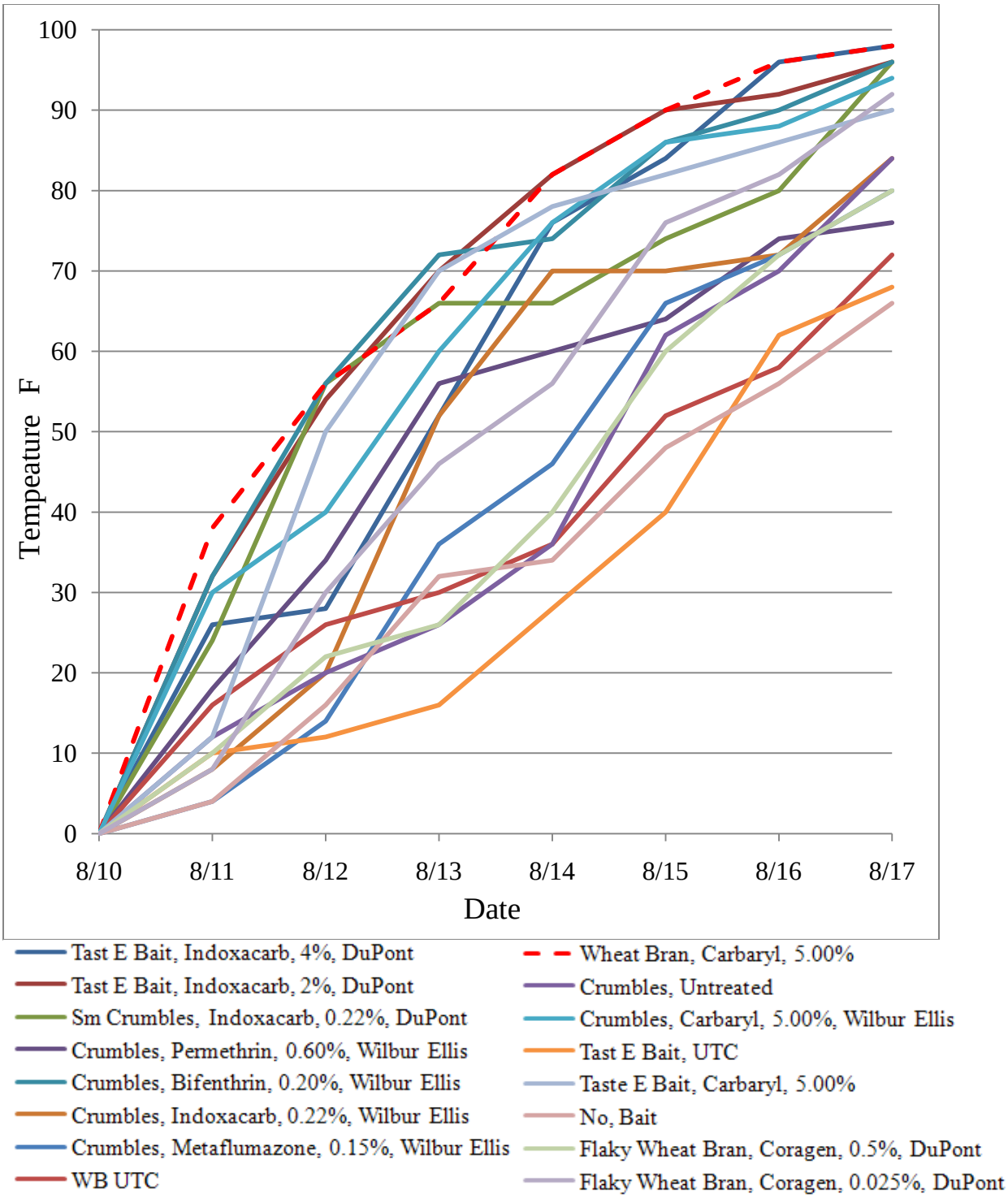

Figure 3. All treatments applied to Camnula pellucida, August 2011. Note that there are three low mortality, four intermediate mortality and eight with higher mortality.

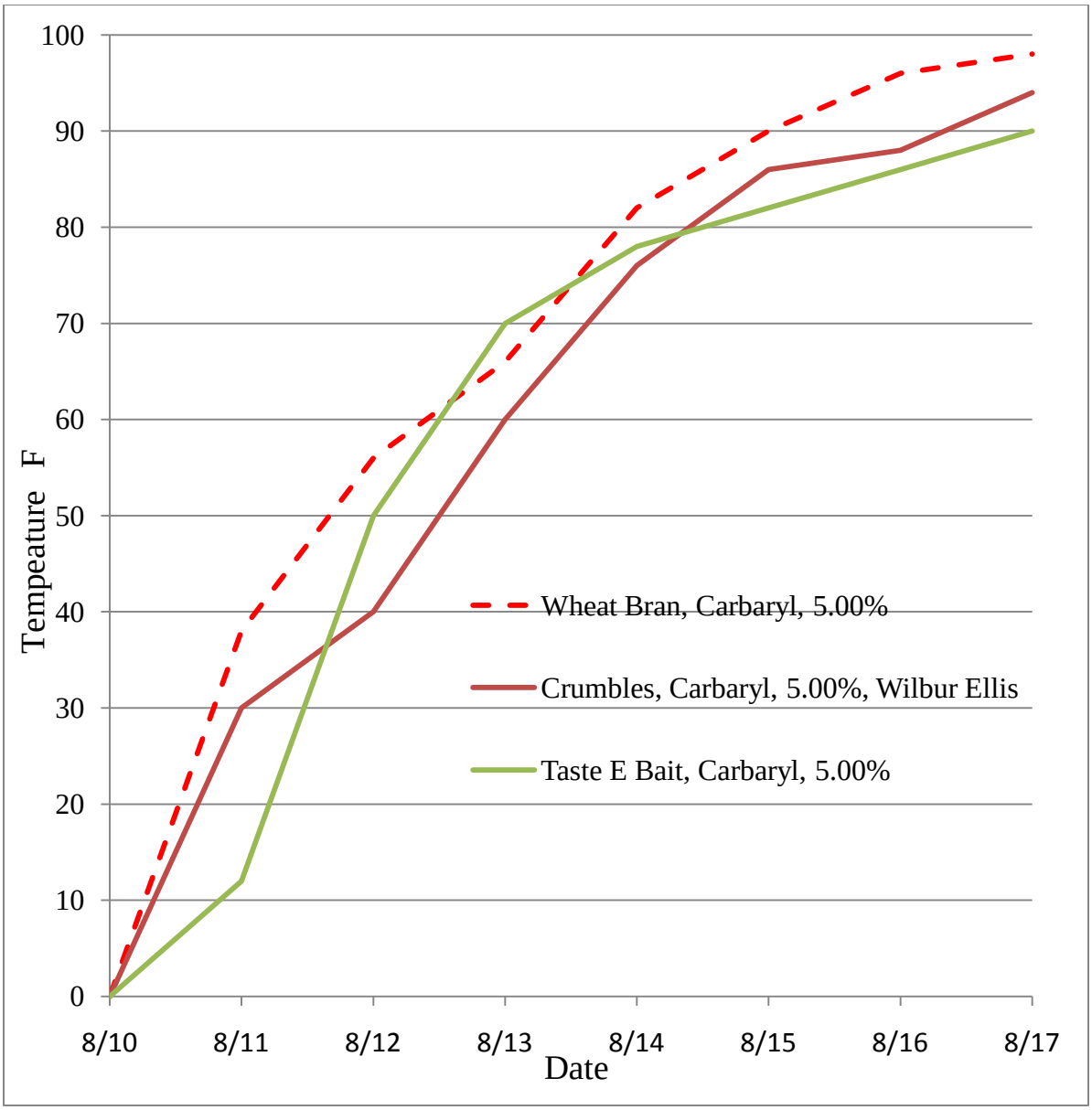

Figure 4. The carbaryl treatments compared with each other are inseparable.

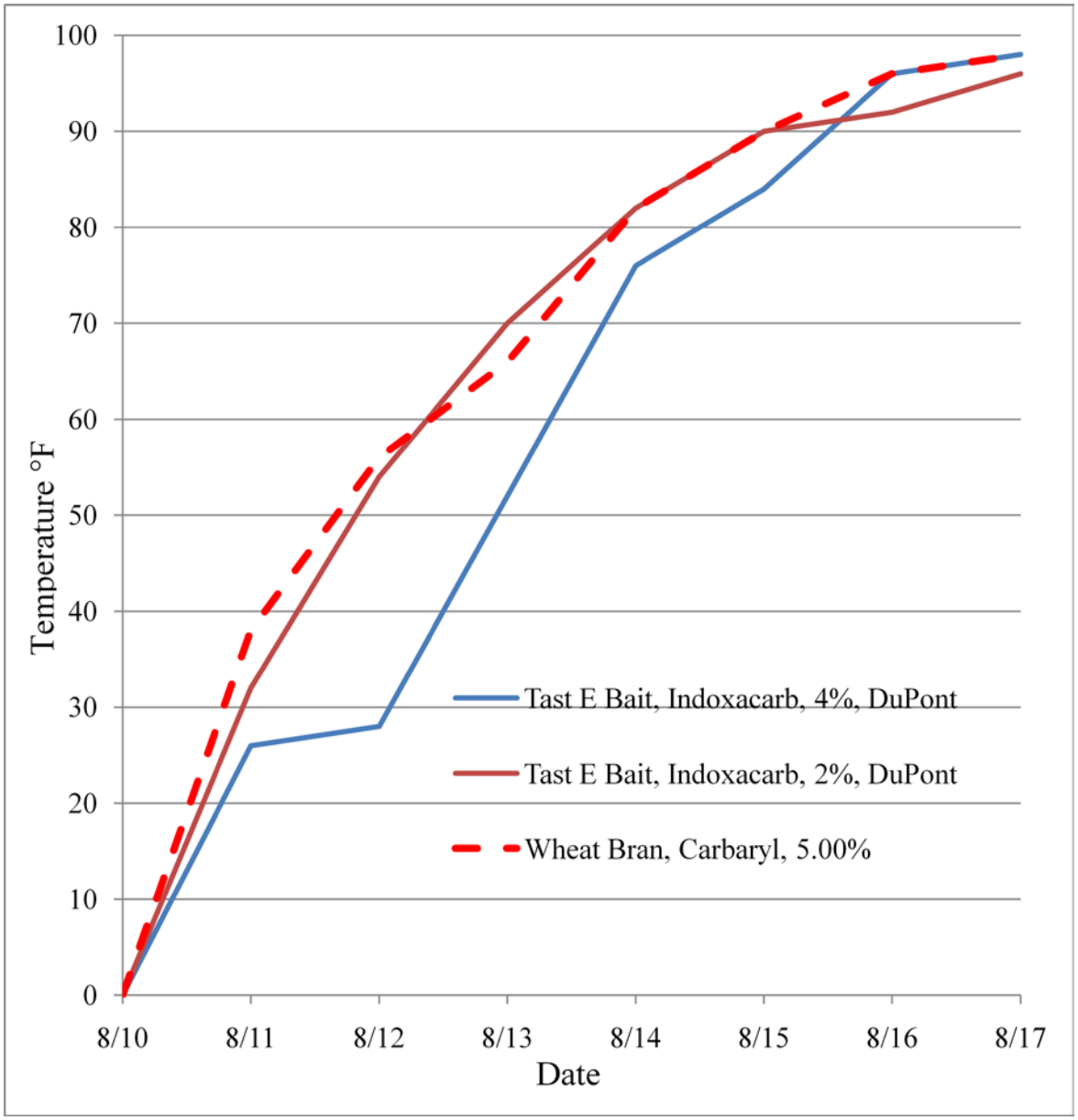

Figure 5. The two high doses of Indoxacarb on Tast-E-Bait compared with carbaryl on wheat bran.

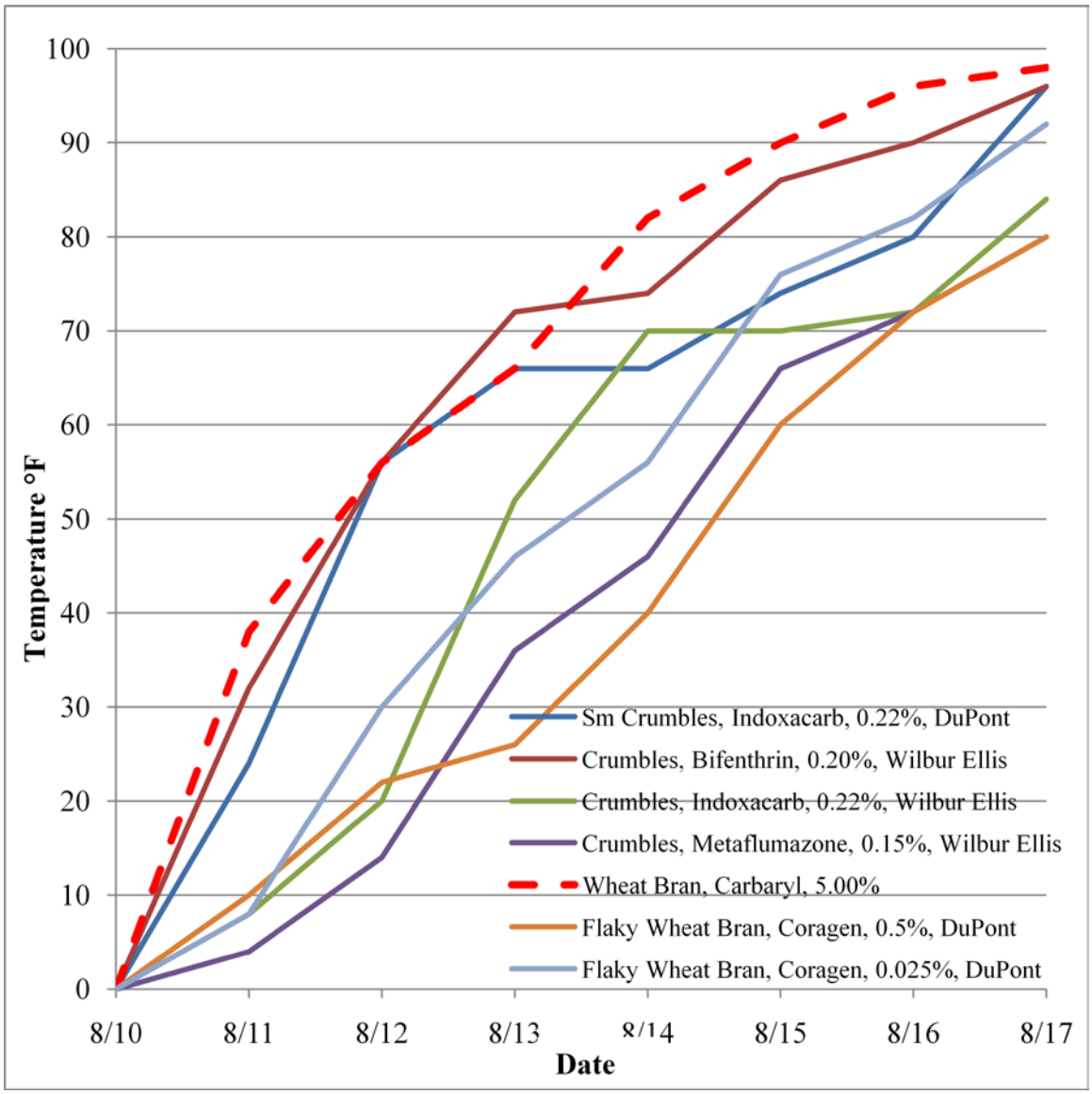

Figure 6. Comparison of the new materials that show some promise as active ingredients for grasshopper control.

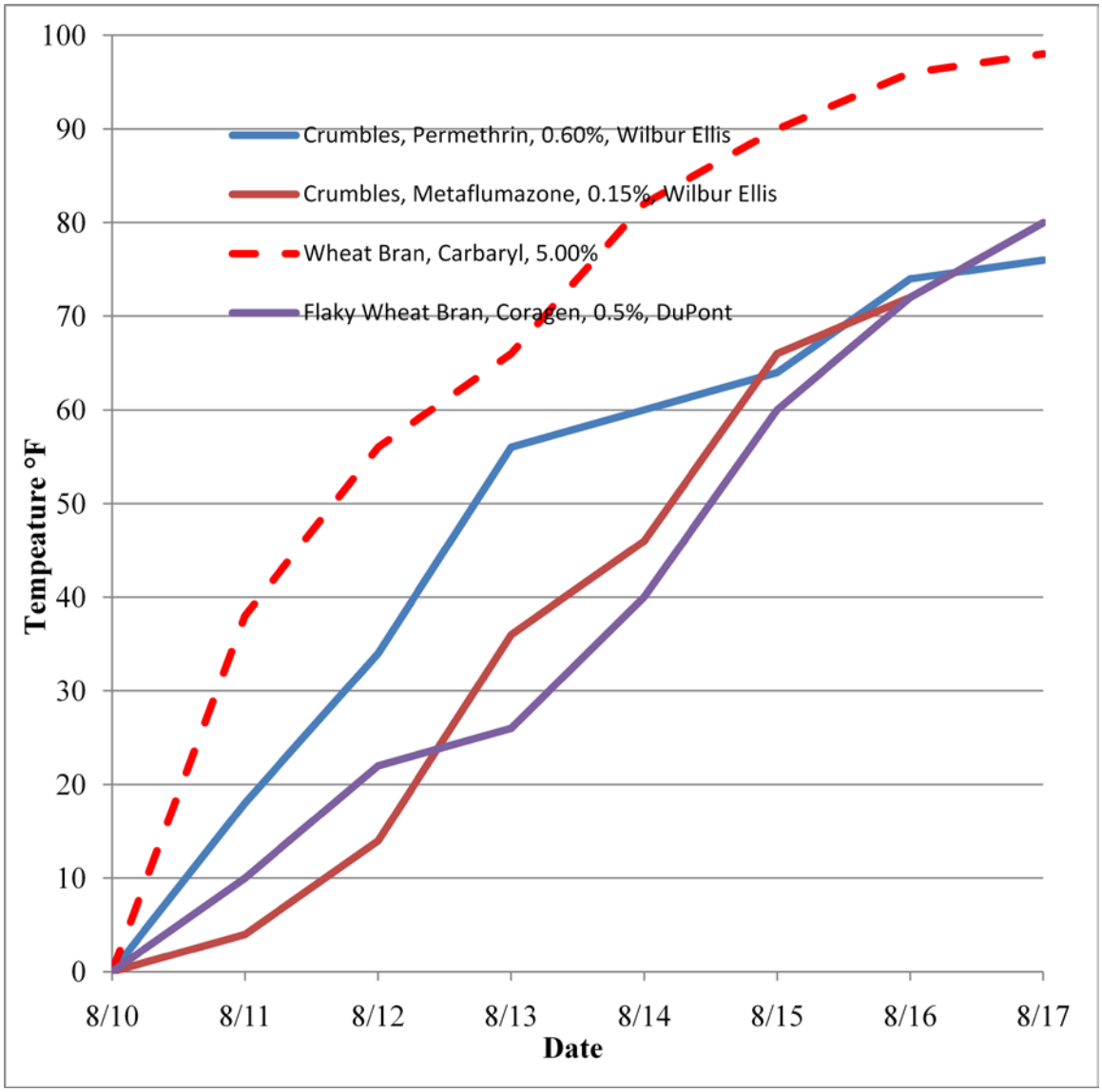

Figure 7. Toxicants that appear to be unsuitable for baits at this time.

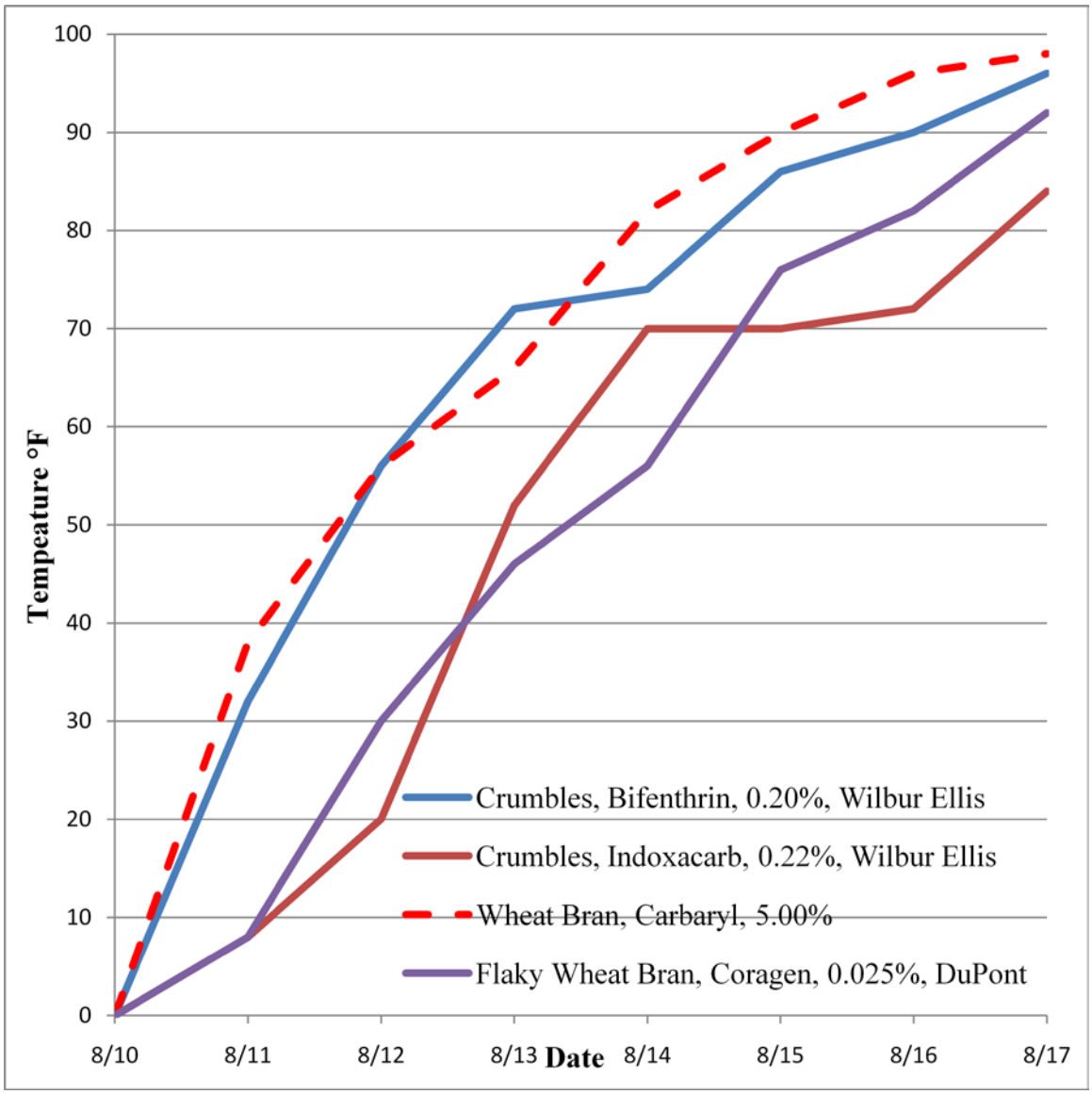

Figure 8. Baits and Carriers selected for further evaluation in2011 season.

July-October 2010

Preliminary field evaluation of aerially applied Coragen for control of grasshoppers on South Dakota rangeland

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Organizations

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Cooperators

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Mark Tubbs, rancher, Edgemont, SD

Abstract

Malathion, carbaryl and diflubenzuron in spray formulations and carbaryl in bait formulations are currently the only treatment options available for use in USDA sponsored control efforts against grasshoppers on rangeland. In anticipation of limited future choices, the Coragen formulation of chlorantraniliperole was evaluated as an alternative. When applied at 1 fluid oz (containing 5.9 g AI) plus 63 oz of water per acre it produced 58%, 56% and 77% control at 3, 7 and 14 days after treatment, respectively. This dose was fast acting but was insufficient to yield mortalities that could compete with existing treatments used on rangeland grasshoppers in USDA sponsored programs. Slightly higher doses could provide the needed level of control and should be evaluated under replicated field plot studies and operational scale studies as soon as possible.

Introduction

The current treatment options for USDA-APHIS sponsored grasshopper suppression efforts on rangeland are carbaryl (Sevin XLR Plus), diflubenzuron (Dimilin 2L) and malathion (Fyfanon ULV) sprays and carbaryl baits. Both malathion and carbaryl have been used for almost 50 years and diflubenzuron since ca. 2000. There are other treatments registered for grasshoppers on rangeland. However, certain label restrictions (high volume per acre requirements) and cost make them unattractive. The broad conditions under which grasshopper control is implemented require several tools that function differently. For an effective grasshopper suppression program to continue, choices must be available that provide control on both immature and adult grasshoppers, under both hot and cool conditions and that have either short or longer residual activity, and that can be applied by air and ground as baits or sprays.

A new class of insecticides may offer some alternative solutions for rangeland grasshopper control. Coragen is a member of the anthranilic diamide class of insecticides that provides control through a novel target, the ryanodine receptor. Anthranilic diamides activate this receptor, releasing stored calcium from the sarcoendoplasmic reticulum causing impaired regulation of muscle contraction. This insecticide has been shown to exhibit a > 500-fold differential selectivity toward insect, over mammalian receptors (Cordova et al. 2006). Although Coragen has some contact activity, it is most effective through ingestion of treated material, as are all of our current treatments (Pfadt et al. 1970, Lloyd et al. 1974, Foster et al. 2008). After exposure to Coragen, affected insects exhibit rapid cessation of feeding, lethargy, regurgitation, muscle paralysis and typically die within 1-3 days. (DuPont, Coragen Technical Bulletin).

Because of the uncertainty in future availability and the continued need for multiple treatment options, evaluations of new alternatives are required. The following study was conducted to help develop new treatment alternatives for suppression and control of grasshoppers on rangeland.

Objectives:

1. Evaluate the currently lowest suggested testing rate (one fl oz/acre) of Coragen for activity against grasshoppers on rangeland
2. Compare the field activity of Coragen at one fluid oz/acre with the most often used treatment (Dimilin 2L) for grasshoppers on rangeland
3. Generate bridging data for comparison with other proposed studies with Coragen (1, 3 and 5 fluid oz /acre) for rangeland grasshoppers
4. Evaluate an aqueous formulation of Coragen for ease in mixing, calibrating and aerial application.

Materials and Methods

Study Site

The study was conducted in Fall River County of southwestern South Dakota ca. 6 miles north and 7 miles west of the town of Edgemont on the Mark Tubbs ranch during the period of July 5 – July 20, 2010. The location was selected because of the diversity in grasshopper species and grasses, density of grasshoppers, history of grasshoppers in the area, better than average range condition, contiguous rangeland suitable for aerially applied plot studies and proximity to several other ongoing studies.

Treatments and Experimental Design

The Coragen (DuPont) formulation of chlorantraniliperole was aerially applied to a single 10 acre plot of grasshopper infested rangeland. The specific treatment was one fluid oz of Coragen (5.9 g AI) plus 63 fluid oz of water for a total volume of 64 fluid oz per acre. This total volume was used because we only had 32 fluid oz of Coragen and the spray system requires 10 gallons of final spray mix at a minimum. Therefore, the 10 gallons was equivalent to 20 acres at one half gallon total volume per acre. That and the 10 acre plot required 30 of the 32 fluid oz of Coragen we had available.

The treatment was aerially applied at 100% coverage on July 6, 2010 to a square 10 acre grasshopper infested rangeland plot. One untreated plot from an ongoing adjacent study was included in the experimental design for comparison. The treatment was applied with a Cessna Ag Truck owned by the USDA, Animal and Plant Health Inspection Service (APHIS) and equipped with winglets (DBA- Ag Tips: Clack Oberholtzer, Alberta, Canada). Winglets are added to spray aircraft to reduce the production of fine droplets and to improve handling characteristics. The aircraft was operated by a USDA – APHIS pilot**.** The aircraft was equipped with a standard commercial spraying system and differentially corrected guidance and recording system. Ground personnel also provided guidance and ensured acceptable operating parameters during application. Prior to application the aircraft spray system was calibrated to operate under parameters which resulted in delivery of spray within 1% of the desired rate per acre. Calibration was accomplished by collecting and measuring the amount of material sprayed through each nozzle for a predetermined amount of time, and making adjustments in pressure until the desired output was achieved **(Figure 1)**. The aircraft was equipped with 23, 8004 stainless steel flat fan spray tips operating at 30 psi. The aircraft was calibrated for a 75 feet wide swath and operated at 120 mph at an altitude of 30 feet during treatment **(Figure 2)**.

Winds during application ranged from 1 to 3 mph and averaged 2 mph. Ground temperatures did not exceed air temperatures (taken by ground personnel) at any time during applications. Other meteorological conditions recorded during application are summarized in **Table 1.** The precipitation and daily minimum and maximum temperatures recorded by a temporary weather station established in the treated area for the duration of the study are shown in **Figure 3.**

Sampling Methods

Generally, grasshopper density and species composition sampling followed protocols established by Foster and Reuter, 1996. Grasshopper populations in treated and untreated plots were counted and sampled 1 to 3 days before treatment and at 3, 7 and 14 days after treatment. Untreated

control plots were also counted and sampled on any day a treated plot was monitored. Grasshopper densities were determined by counting grasshoppers in (40) 0.1 m^2 rings **(Figure 4)** arranged in an approximate 100 yard diameter circle near the center of each plot. Rings were separated from adjacent rings by ca 5 yards.

The abundance of each species was determined from uniform sweep samples taken at each site (Foster and Reuter, 1996). Each sample consisted of 50 high and fast sweeps and 50 low and slow sweeps. Low and slow sweeps performed at ground level insured capture of very young instars and less active grasshopper species while high and fast sweeps performed at the canopy of the vegetation insured capture of older instars and the more active species. Sweep samples were always collected immediately after grasshopper densities had been determined at each site on each visitation. Densities of individual species can be determined by multiplying the frequency of occurrence times the total density of grasshoppers at the same site. After collection, samples were cold stored until they could be sorted and identified in the lab.

Analysis

For the general population, data were expressed as percent mortality based on pretreatment counts in the same plot and were analyzed as such. Additionally, data was adjusted for the natural population change by the method of Connin and Kuitert (1952) by using the mean values of the untreated plots on the appropriate day. This allowed for converting data from percentage mortality to percentage control and accommodated the natural population change to insure against natural mortality and other environmental factors that affect grasshopper counts, which can confound real differences between treatments.

The adjusted percentage control of the treatment (which takes into account natural changes in the untreated population) was calculated by the formula 100 x (1 – Ta x Cb/Tb x Ca), where Tb equals the total population of grasshoppers counted before the plot was treated, Ta equals the total counted after treatment, Cb equals the total counted for the check sites before treatment, and Ca equals the total counted for the check sites after treatment.

A Kruskal-Wallis one-way nonparametric analysis of variance was performed for each post-treatment interval. All analyses were performed using Statistix® 8 Analytical Software.

Results and Discussion

Pretreatment densities ranged from 10.8 (Coragen plot) to 18.8 (untreated plot) and averaged 14.8 grasshoppers/m^2 for all of the plots in the study. At the time of treatment, the population was composed of 11.1 % third instars, 50.0 % fourth instars, and 38.9 % fifth instars. The population maturity index was 0.713 and the total mean age was 4.3 (slightly above 4th instar). A value of 1-5 coincides with the first 5 instar stages and a value of 6 represents the adult stage **Table 2**. The six most abundant species were *Spharagemon collare* 33.3%, *Melanoplus sanguinipes* 16.7%, *Ageneotettix deorum* 11.1%, *Aulocara elliotti* 11.1%, *Melanoplus packardi* 11.1% and *Trachyrhachys kiowa* 11.1%.

The grasshopper populations treated with Coragen demonstrated a substantial and significant decline at all of the time intervals evaluated when compared to untreated populations **(Table 3).** Coragen reduced the combined grasshopper population by 60%.(P=0.0274), 58% (P=0.0047) and 72% (P=0.0047) at 3, 7 and 14 days after treatment, respectively. Untreated populations declined by 6.6% and 5.3% at 3 and 7 days after treatment, respectively but increased by 21.3% at 21 days after treatment. When the data from the treated plot was adjusted to reflect the changes in the untreated population the percentage control was 57.6%, 55.8% and 77.0% at 3, 7 and 14 days after treatment respectively. A cursory examination of species composition data generated from post treatment sweep samples suggests the possibility of unequal susceptibility in the species evaluated during this study. *M. sanguinipes* was second in prominence before treatment, but was 7 – 10 times more prevalent than any other species in post treatment samples. Only additional studies will provide a clearer understanding of this possible difference in susceptibility.

While the dose studied produced significant mortality, it was not at a level sufficient to compete with existing USDA sponsored treatments used against grasshoppers on rangeland. Full coverage large scale traditional treatments of malathion produce mortality ranging from 90-95%; carbaryl produces 95% mortality or better; and diflubenzuron produces 98% to 99% mortality. Reduced Agent Area Treatments (RAATs) of these same chemicals produce mortality in the range of 80% (malathion), 80 to 85% (carbaryl) and 98% (diflubenzuron). RAATs treatments are applied at one-half to one-third the standard dose and are applied to 50-80% of the infested area in alternating treated and untreated strips. (Foster et al. 2000).

No problems were detected during the mixing, calibration and clean-up phase of the study. This is very important to the utility of this product.

The dose of Coregon evaluated in this study was fast acting but was insufficient to yield mortalities that could compete with existing treatments used on rangeland grasshoppers in USDA sponsored programs. However, slightly higher doses could provide the needed level of control and should be evaluated along with lower total volumes per acre under replicated field plot studies and operation scale studies as soon as possible.

Acknowledgements

The authors wish to thank John D. Cantlon, DuPont Company for supplying the material used in the test. Thanks are also extended to Randy Hedge, Edgemont, South Dakota, City/Airport Manager, for providing logistical assistance at the airport. Special thanks are extended to rancher Mark Tubbs for providing the rangeland for the study and for his continued support and cooperation since 1989.

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Figure 1. Aircraft calibration of the Coragen formulation prior to field application.

Figure 2. Aerial application of a rangeland grasshopper treatment near Edgemont, South Dakota.

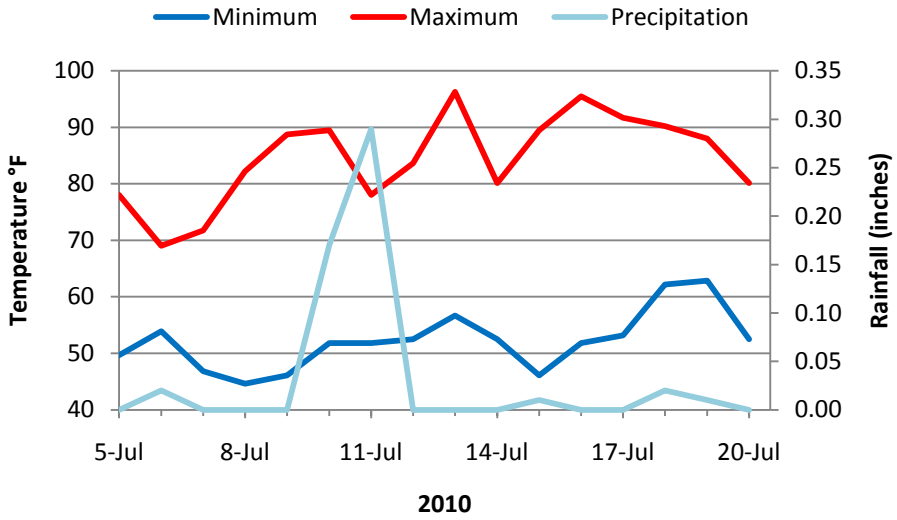

Figure 3. Minimum and maximum temperatures and precipitation recorded at the study area near Edgemont, South Dakota, 2010.

Figure 4. Grasshopper density estimates determined by counting grasshoppers in forty 0.1 m^2 rings in the study plot.

Table 1. Meteorological conditions recorded during aerial application of the ten-acre Coragen plot near Edgemont, South Dakota, 2010.

						Temperatures ºF.						
	Plot	No.		Time (AM)		Ground		Air		Pilot	Wind (mph)	
Treatment	No.	Passes	Date	Start	End	Start	End	Start	End		Start	End
Coragen	106	9	7/6	5:08	5:14	60	58	62	62	62	1-2 E	2-3 E

Table 2. Grasshopper species composition and age structure in the Coragen treated plot prior to treatment near Edgemont, South Dakota, 2010.

	Instar							
Species	1	2	3	4	5	Adult	Total	%
Gomphocerinae								
Ageneotettix deorum	0	0	0	2	2	0	4	11.11
Amphitornus coloradus					2	0	2	5.56
Aulocara elliotti					4	0	4	11.11
Melanoplinae								
Melanoplus packardii	0	0	0	2	2	0	4	11.11
Melanoplus sanguinipes	0	0	2	4		0	6	16.67
Oedipodinae								
Spharagemon collare	0	0	2	10	0	0	12	33.33
Trachyrhachys kiowa	0	0	0	0	4	0	4	11.11
Total	0	0	4	18	14	0	36	
%	0	0	11.11	50.00	38.89	0		

Table 3. Mean percentage reduction and control of rangeland grasshoppers aerially treated with a selected dose of Coragen near Edgemont, South Dakota, 2010.

	3d post-treatment			7d post-treatment			14d post-treatment		
Treatment[1]	% reduction	% control	P	% reduction	% control	P	% reduction	% control	P
Coragen	60.47	57.64	0.0274	58.14	55.78	0.0047	72.09	76.99	0.0047
Untreated	6.67			5.33			-21.33		

[1] The data were analyzed with the Kruskal-Wallis one-way nonparametric analysis of variance. Percentage control was determined by adjusting percentage reductions according to changes in the untreated population.

October 2010

Evaluating the adjuvant EDT Concentrate as a replacement for oil diluents in Dimilin spray mixes to control rangeland grasshoppers

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Abstract

Diflubenzuron mixes relying on low total volume aerial application rates (12 and 13 fl oz/acre) performed as well as higher volume (31 fl oz /acre) traditional rates. RAATs treatments performed as well as the full coverage treatment. The use of a touted canola oil attractant showed no advantage over other treatments studied. Replacing the deposition and drift management agent, In-Place, in previous experimental treatment mixes with the deposition aid EDT resulted in the numerically highest mortality observed in this study and eliminated mixing, settling and clean up problems experienced in the past. Simpler ultra low volume diflubenzuron treatment mixes containing EDT rather than paraffinic oil and canola oil mixes produced mortalities that were highly efficacious. This treatment is easy to standardize as both EDT and diflubenzuron (Dimilin 2L) can be purchased directly from suppliers and no additional oils or emulsifiers are required, only water.

Introduction

The broad/varying conditions under which grasshopper control is implemented require several tools that function differently. An effective grasshopper suppression program requires choices that provide control on both immature and adult grasshoppers, under both hot and cool conditions and that have either short or long residual activity, and that can be applied by air and ground as baits or sprays. The current treatment options for USDA-APHIS sponsored grasshopper suppression efforts on rangeland are carbaryl (Sevin XLR Plus), diflubenzuron (Dimilin 2L) and malathion (Fyfanon ULV) sprays and carbaryl baits. While all of these treatment options are highly effective in controlling grasshoppers, the economics of each tool is of continuous concern.

Diflubenzuron, in the Dimilin 2L formulation, has been an ULV option for the USDA APHIS sponsored grasshopper management program since 2000 (Foster et al. 2000; USDA 2002). It was originally applied at 31 total fluid oz (one fl oz Dimilin 2L plus 10 fl oz oil and 20 fl oz water) per treated acre in traditional and RAATS applications for rangeland grasshoppers (Foster et al. 2001) and Mormon crickets (Foster et al. 2002). Since the original registration, mixes of this formulation have evolved to include vegetable oil, paraffinic oil or combinations of both in various ratios. While this flexibility has facilitated greater use, the accompanying inherent complications should be considered. Depending on the brand and/or oil type, different diluents or diluent mixes can exhibit different specific gravities, and flow characteristics that affect equipment calibration. The type of emulsifier used in the preparations can also affect specific gravity, flow characteristics and calibration.

The current label has been modified to allow for lower total volume per acre applications. In ULV applications, the label now allows total volumes of at least 12 – 32 fl. oz per acre but requires at least 4 fl oz of emulsified vegetable or paraffinic crop oil per acre, with at least two parts of water for each part of oil. Obviously, the wide range in total per acre diluent use can impact the economics of the treatment. The higher total volume occupies more space in an aircraft hopper (less acres treated per load compared to lower volume treatments) and requires more mixing time. Additionally, more oil increases the diluent cost and mixes of oils can complicate calibration of equipment because various oils and emulsifying agents may require different application parameters.

Initial studies conducted with two selected mixes of Dimilin 2l, water and In-Place (a deposition and drift management agent envisioned to replace the oil requirement and purported to encapsulate the active ingredient to reduce evaporation and thus increases deposition) and water resulted in very good field efficacy (Foster et al. 2008). However, precipitation in the aircraft tank and some difficulty in post application clean up was of substantial magnitude to cause concerns. In an attempt to alleviate these problems further field studies were conducted using lower ratios of In-Place to Dimilin 2L (Foster et al. 2009). In those studies acceptable field mortality was again achieved and clean-up was not a problem. However, substantial precipitation again remained in the aircraft hopper after the draining phase of the study. In another attempt to solve the problem, R 11, a spreader activator nonionic surfactant recommended by Wilbur-Ellis as a possible solution, was added to the mix and apparent success was achieved (Foster and Jech, 2009). Unfortunately, it was discovered that this product was determined to be unacceptable for

use on BLM managed land. Further testing with Tri-Fol, an acidifier and buffering agent recommended by Wilbur-Ellis as a possible alternative solution to the R11 additive, yielded very inconsistent results. At this point, Wilbur-Ellis recommended that we replace the In-Place additive in the Dimilin mix with EDT Concentrate, another deposition aid.

As a result, the following field study relying on an EDT Concentrate mix component, was conducted to simplify and standardize the pre-spray mixing and calibration of diflubenzuron spray treatments while improving the economics of diluting materials used in ultra-low volume applications for control of rangeland grasshoppers.

Objectives

1. Improve the economics of the diluting materials used in diflubenzuron spray mixes.
2. Simplify pre-spray mixing by replacing several types and volumes of diluents currently used with a consistent standard.
3. Simplify calibration by replacing different types and brands of oil diluents (vegetable and paraffinic) and emulsifying agents with a consistent standard.
4. Specifically compare experimental, EDT Concentrate and water diluent Dimilin mixes applied as RAATs coverage with the traditional 31 fl oz total volume/acre full coverage and RAATs coverage Dimilin 2L treatment mix for field efficacy.
5. Specifically evaluate EDT Concentrate and water diluent Dimilin mixes and traditional standard and RAATS Dimilin mixes against the low volume Dimilin, paraffinc oil, canola oil and water mix used by several weed and pest districts in Wyoming.

Materials and Methods

Study Site

The study was conducted in Fall River County of southwestern South Dakota ca. 8 miles north and 9 miles west of the town of Edgemont on the Mark Tubbs ranch during the period of June 22- July 18, 2010 **(Figure 1)**. The location was selected because of the diversity in grasshopper species and grasses, density of grasshoppers, history of grasshoppers in the area, better than average range condition, contiguous rangeland suitable for aerially applied replicated plot studies and proximity to other proposed studies.

Treatments and Experimental Design

The Dimilin 2L formulation of diflubenzuron (Chemtura Corp) was used in all spray treatments studied. The specific treatments were: (1) one fl oz of Dimilin 2L plus 10 fl oz of Ferti-Oil (an emulsified vegetable oil, Compton Ag Services LLC) plus 20 fl of water equaling a total volume of 31 fl oz/acre applied at 100% coverage and termed **Dim 1, 100%** (the standard Dimilin treatment originally used in APHIS sponsored grasshopper programs) (2) the same treatment mix applied at reduced agent and area treatment (RAATs) 50% coverage and termed **Dim 1, 50%** (3) one fl oz of Dimilin 2L plus 0.4 fl oz Ferti-Oil plus 3.6 fl oz canola oil plus 8 fl oz of water equaling a total volume of 13 fl oz/acre applied at RAATs 50% coverage (a popular mix used by several Weed and Pest Districts in Wyoming) and termed **Dim 1,WP, 50%** (4) one fl oz Dimilin

2L plus 0.09 fl oz EDT Concentrate (Deposition Aid, Wilbur-Ellis) plus 10.9 fl oz water equaling a total volume of 12 fl oz/acre applied at RAATs 50% coverage and termed **Dim 1, EDT, 50%** and (5) three-fourth fluid oz Dimilin 2L plus 0.09 fl oz EDT Concentrate plus 11.15 fl oz water equaling a total volume of 12 fl oz/acre applied at RAATs 50% coverage and termed **Dim ¾, EDT, 50%.** All RAATs 50% coverage treatments were achieved by calibrating the aircraft for a 75 feet wide swath and spacing the aircraft during application at 150 feet. The standard Dim, 1, 100% treatment was applied with a swath width and spacing of 75 feet.

All treatments were aerially applied at 100% or RAATS 50% coverage to square 40 acre grasshopper infested rangeland plots and were replicated four times. Four untreated plots were included in the experimental design for comparison. The replicated study consisted of 24 forty acre plots. To insure that any one treatment was not assigned exclusively to plots with high or low grasshopper densities and that all treatments were tested against similar population densities, pretreatment counts were arranged in descending order and divided into groups of four. Subsequently, each of the 6 treatments, including the untreated control, was randomly assigned to one of the four plots within each group (Foster and Reuter, 1996).

The standard Dim 1, 100% was applied on June 24. The RAATs application of the same mix was applied over a three day period (June 24-26) due to excessive winds. The Dim 1, WP 50% mix was applied on June 26. Both Dim 1, EDT, 50% and Dim ¾, EDT, 50% were applied on June 27. All treatments were applied with a Cessna Ag Truck owned by the USDA, Animal and Plant Health Inspection Service (APHIS) and equipped with winglets (DBA- Ag Tips: Clack Oberholtzer, Alberta, Canada). Winglets are added to spray aircraft to reduce the production of fine droplets and to improve handling characteristics. The aircraft was operated by a USDA – APHIS pilot **(Figure 2).** The aircraft was equipped with a standard commercial spraying system and differentially corrected guidance and recording system (Figure 1). Ground personnel also provided guidance and ensured acceptable operating parameters during application. All applications occurred from an altitude of 30 to 40 feet. Prior to application the aircraft spray system was calibrated to operate under parameters which resulted in delivery of spray within 1% of the desired rate per acre. Calibration was accomplished by collecting and measuring the amount of material sprayed through each nozzle for a predetermined amount of time, and making adjustments in pressure until the desired output was achieved **(Figure 3).** The aircraft was calibrated for a 75 feet wide swath and operated at 120 mph for all treatments.

The specific mix, total volume applied per acre, number of nozzles, nozzle screen size, nozzle tip size, boom pressure, aircraft speed, and swath width used for each of the 5 different treatments is summarized in **Table 1**. Winds during application ranged from <1 to 4 mph and averaged 2.0 mph. With one exception, ground temperatures did not exceed air temperatures (taken by ground personnel) at any time during applications. Meteorological conditions recorded during application are summarized in **Table 2**. The precipitation and daily minimum and maximum temperatures recorded by a temporary weather station established in the treated area for the duration of the study are shown in **Figure 4.**

Sampling Methods

Generally, grasshopper density and species composition sampling followed protocols established by Foster and Reuter, 1996. Grasshopper populations in treated and untreated plots were counted and sampled 1 to 3 days before treatment and at 7, 14 and 21 days after treatment. Untreated control plots were also counted and sampled on any day a treated plot was monitored. Grasshopper densities were determined by counting grasshoppers in (40) 0.1 m^2 rings **(Figure 5)** arranged in an approximate 100 yard diameter circle near the center of each 40 acre plot. Rings were separated from adjacent rings by ca, 5 yards.

The abundance of each species was determined from uniform sweep samples taken at each site (Foster and Reuter, 1996). Each sample consisted of 50 high and fast sweeps and 50 low and slow sweeps. Low and slow sweeps performed at ground level insured capture of very young instars and less active grasshopper species while high and fast sweeps performed at the canopy of the vegetation insured capture of older instars and the more active species. Sweep samples were always collected immediately after grasshopper densities had been determined at each site on each visitation. Densities of individual species can be determined by multiplying the frequency of occurrence times the total density of grasshoppers at the same site. After collection, samples were cold stored until they could be sorted and identified in the lab.

Analysis

For the general population, data were expressed as percent mortality based on pretreatment counts in the same plot and were analyzed as such. Additionally, prior to analysis, data was adjusted for the natural population change by the method of Connin and Kuitert (1952) by using the mean values of the untreated plots on the appropriate day. This allowed for converting data from percentage mortality to percentage control and accommodated the natural population change to insure against natural mortality and other environmental factors that affect grasshopper counts, which can confound real differences between treatments.

The adjusted percentage control of the treatment (which takes into account natural changes in the untreated population) was calculated by the formula 100 (1 – Ta x Cb/Tb x Ca), where Tb equals the total population of grasshoppers counted before the plot was treated, Ta equals the total counted after treatment, Cb equals the total counted for the check sites before treatment, and Ca equals the total counted for the check sites after treatment.

An analysis of variance was performed with the Tukey's HSD multiple comparison test used to separate means. All analyses were performed with Systat 6.1 For Windows.

Results and Discussion

Pretreatment densities from individual sites ranged from 11.4 to 14.9 and averaged 13.3 grasshoppers/m^2 in the treated plots and from 12.6 to 15.1 and averaged 13.6 grasshoppers/m^2 in the untreated plots. At the time of treatment the population was composed of 1st instars (3.6 %), 2th instars (22.2 %), 3th instars (33.6 %), 4th instars (33.8 %), 5th instars (5.6 %), and adults (1.3 %). The total average instar age or population maturity index was 3.194 between third and fourth instar. The age mixture is considered to be very realistic of an ideally timed program

treatment. The seven most dominant species were *Cordillacris occipitalis* (25.5 %), *Ageneotettix deorum* (23.6 %), *Aulocara elliotti* (17.9 %), *Melanoplus sanguinipes* (12.9 %), *Amphitornus coloradus* (8.6 %), *Phlibostroma quadrimaculatum* (2.9 %) and *Trachyrhachys kiowa* (2.3 %). The relative abundance of all species in pretreatment samples is shown in **Table 3**.

All treatments produced mortality significantly greater than occurred in the untreated population. These reductions were statistically equivalent among treatments regardless of the post treatment interval **(Table 4)**. At 7 days after treatments (DAT) all treatments had reduced populations similarly by 79- to 87%. At 14 DAT, reductions in treated populations increased, ranging from 94-96%, but were statistically similar for all treatments. At 21 DAT, reductions remained near the 14 DAT levels and were again statistically equivalent. Mortality in untreated populations increased during this study by 13, 29 and 26% at 7, 14 and 21 DAT, respectively. Additional analysis with data adjusted for mortality that occurred in untreated populations showed similar results **(Table 4)**. The higher 31 fluid oz total volume per acre treatments showed no advantage compared to the 12 and 13 fluid oz total volume per acre treatments. No advantage was seen in the full coverage treatment compared to the RAATs treatments. Additionally, no advantage was seen with the WP treatment compared to the new treatments containing EDT or the traditional high volume treatments.

The levels of control attained in this study were somewhat similar, although tending slightly higher than those seen in 2009 (Foster et al. 2009). The 2010 mortalities, especially those associated with the one fl oz EDT (highest numerical mortality), were more in line with what was expected of diflubenzuron treatments based on early operational scale evaluations (Foster et al. 2000).

In 2010 the untreated populations demonstrated natural mortalities increasing slightly faster than expected (Foster et al.2008; Foster et al.2009). It is interesting to note that pathogen exploration of cadavers from this study showed a surprisingly high level of the grasshopper fungal pathogen *Entomophaga grylli*. This pathogen had not been observed in the characteristic “summit disease” death pose in this area in the past. This year was also very wet compared to most years in this area. These occurrences together could help explain greater and/or faster UTC mortalities compared to the last two years. (Foster et al. 2008: Foster at al. 2009).

In comparison to the last two years where significant settling and clean up problems were encountered when In-Place was used in the mix (Foster et al 2008, Foster et al 2009), no problems in mixing or clean-up were encountered with the replacement, EDT. The addition of EDT simplified the mixing, calibration and clean-up stages.

The results of this study indicate that when compared to some of the previous treatments that relied on various types of oils (paraffinic and vegetable) and emulsifiers and a touted attractant (canola oil), simpler and more standardized diflubenzuron treatments that produce excellent control may be attained. When applied correctly, lower total volumes and less complicated mixes than previously used may achieve results statistically equivalent to higher total volume treatments and treatments with touted attractants (treatments containing canola oil). Oils either parafinnic, vegetable or a mixture of both and their various emulsifying agents apparently are not needed. Simply using lower total volumes of Dimilin and water mixes with a small amount of a

deposition aid appear highly efficacious. Further testing on larger operational scale plots should be conducted to corroborate these findings.

Acknowledgements

The authors thank Bruce Helbig for assisting with some of the logistics associated with the study. Thanks are extended to Dan Largent and Todd Edgington, Chemtura Cooperation, for providing the diflubenzuron used in the study and to Bob Eccles and Bill Bagley, Wilbur-Ellis, for providing the EDT Concentrate used in the study. Thanks are also extended to Randy Hedge, Edgemont, South Dakota, City/Airport Manager**,** for providing logistical assistance at the airport. Special thanks are extended to rancher Mark Tubbs for providing the rangeland for the study and for his continued support and cooperation since 1989.

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Table 1. Summary of treatments and calibration parameters

Treatments AI/acre protected	Coverage	Amounts per treated acre: Dimilin 2L fl oz/acre	Diluent fl oz/acre	Diluent fl oz/acre	Total fl oz/acre	Nozzle no.	Tip size	Screen size	Pressure psi	Aircraft speed	Swath width ft	Swath spacing
Dim 1, 100 0.016 lbs 7.09 g	100%	1.0	10.0 Ferti-Oil	20.0 water	31	15	8003	50	28	120 mph	75	75
Dim 1, 50 0.008 lbs 3.54 g	50%	1.0	10.0 Ferti-Oil	20.0 water	31	15	8003	50	28	120 mph	75	150
Dim 1,WP, 50 0.008 lbs 3.54 g	50%	1.0	0.4 Ferti-Oil 3.6 Canola	8.0 water	13	6	8003	50	30	120 mph	75	150
Dim 1, EDT, 50 0.008 lbs 3.54 g	50%	1.0	0.09 EDT	10.9 water	12	6	8003	50	27	120 mph	75	150
Dim 3/4, EDT, 50 0.006 lbs 2.66 g	50%	0.75	0.09 EDT	11.15 water	12	6	8003	50	27	120 mph	75	150

Table 2. Meteorological conditions recorded during aerial application of Dimilin treatments in the grasshopper study plots near Edgemont, South Dakota, 2010.

						Temperatures °F.						
	Plot	No.		Time (AM)		Ground		Air		Pilot	Wind (mph)	
Treatment	No.	Passes	Date	Start	End	Start	End	Start	End		Start	End
Dimilin 1oz	71+84	18	6/24	5:05	5:23	50	52	56	56	60	1-3 SE	2-3 SE
100	40	18	6/24	5:38	5:52	50	52	56	59	60	1.5-2 S	1-1.5 SE
full coverage	48	17	6/24	5:53	6:10	52	58	59	62	60	1-1.5 SE	< 1 SE
Dimilin 1oz	85	9	6/24	6:37	6:45	60	63	65	65	63	3.5-4 SE	4 SE
50	82	10	6/24	7:04	7:15	64	68	64	70	64	1-1.5 E	2.5-4 E
RAATs	7	9	6/25	5:00	5:07	61	58	62	63	68	1.5-2 W	2.5-3 W
	28	10	6/26	5:15	5:22	65	66	67	67	71	1-2 S	4 N
Dimilin 1oz	16	10	6/26	6:08	6:17	66	68	68	69	67	2 SE	< 1 SE
WP, 50	38+39	9	6/26	6:21	6:35	68	69	69	69	71	1-2 S	2-3 S
	83	9	6/26	6:53	7:02	70	71	69	69	71	2-3 S	2-3 S
Dimilin 1oz	37	9	6/27	5:04	5:13	50	49	53	53	54	< 1 N	< 1 N
EDT, 50	5	9	6/27	5:23	5:32	46	47	54	52	54	2.5-3 W	< 1 W
	49	9	6/27	5:43	5:51	52	52	53	53	54	1-2 N	1-2 N
	63	9	6/27	5:52	6:01	54	54	54	54	54	1-2 N	2-2.5 N
Dimilin 3/4 oz	41	9	6/27	6:33	6:41	54	58	56	60	56	1.5-2 NW	1.5-2 NW
EDT, 50	62	9	6/27	6:44	6:52	55	60	57	62	56	2-3 N	< 1 N
	59	9	6/27	7:00	7:10	60	61	62	62	57	1-2 N	1-2 N
	73	9	6/27	7:10	7:20	62	62	63	62	58	1.5-2 NW	2.5-3.5 W

Table 3. Grasshopper species composition and age structure in the Dimilin EDT study area prior to treatment (June,22-24) near Edgemont, South Dakota, 2010.

	Instar							
Grasshopper species	1	2	3	4	5	Adult	Total	%
Subfamily Gomphocerinae								
Acrolophitus hirtipes				3			3	0.06
Ageneotettix deorum	16	544	412	156	5		1133	23.55
Amphitornus coloradus		38	275	88	12		413	8.58
Aulocara elliotti		17	352	429	61	1	860	17.88
Aulocara femoratum	1	7	1				9	0.19
Cordillacris crenulata	1	4	3				8	0.17
Cordillacris occipitalis		21	175	851	175	5	1227	25.50
Eritettix simplex						3	3	0.06
Mermiria bivittata		3	7				10	0.21
Opeia obscura	10						10	0.21
Phlibostroma quadrimaculatum	24	106	7				137	2.85
Psoloessa delicatula						5	5	0.10
Subfamily Melanoplinae								
Melanoplus bowditchi			2				2	0.04
Melanoplus confusus					1	42	43	0.89
Melanoplus infantilis	3	23	45				71	1.48
Melanoplus occidentalis				4	8		12	0.25
Melanoplus packardii	2	15	29	7	1		54	1.12
Melanoplus sanguinipes	91	218	232	75	4		620	12.89
Phoetaliotes nebrascensis	8	2					10	0.21
Subfamily Oedipodinae								
Arphia pseudonietana	3						3	0.06
Hadrotettix trifasciatus	12	12					24	0.50
Metator pardalinus			10	7			17	0.35
Pardalophora haldemani						8	8	0.17
Spharagemon collare	1	8	6				15	0.31
Spharagemon equale		2	2				4	0.08
Trachyrhachys kiowa	1	49	56	4			110	2.29
Totals	173	1069	1614	1624	267	64	**4811**	
%	3.60	22.22	33.55	33.76	5.55	1.33		

Table 4. Mean percentage mortality of grasshoppers treated with selected diluents mixes of diflubenzuron Edgemont, South Dakota 2010.

	7d		14d		21d	
Treatment [1]	% mortality	adj. % mortality	% mortality	adj. % mortality	% mortality	adj. % mortality
Dimilin 1oz full coverage	79.3 a	75.7 a	93.5 a	90.5 a	95.6 a	93.3 a
Dimilin 1oz RAATs	85.5 a	81.9 a	94.8 a	91.4 a	95.3 a	90.7 a
Dimilin 1oz, WP, 50	78.4 a	68.7 a	93.5 a	89.9 a	95.6 a	93.6 a
Dimilin 1oz, EDT, 50	84.5 a	84.7 a	95.2 a	93.4 a	97.1 a	96.1 a
Dimilin 3/4oz, EDT, 50	87.3 a	87.5 a	96.0 a	94.6 a	95.1 a	93.4 a
Untreated	13.3 b		29.3 b		26.0 b	

[1] A one-way analysis of variance was conducted on the primary and ranked data as both non-adjusted and adjusted mortality. Means in a column followed by the same letter are not significantly different ($P \leq 0.05$) as determined by the Tukey HSD multiple comparison test.

Figure 1. Rangeland typical of the study area northwest of Edgemont, South Dakota.

Figure 2. USDA aircraft applying selected treatments near Edgemont, South Dakota.

Figure 3. Calibration of the USDA aircraft and spraying system.

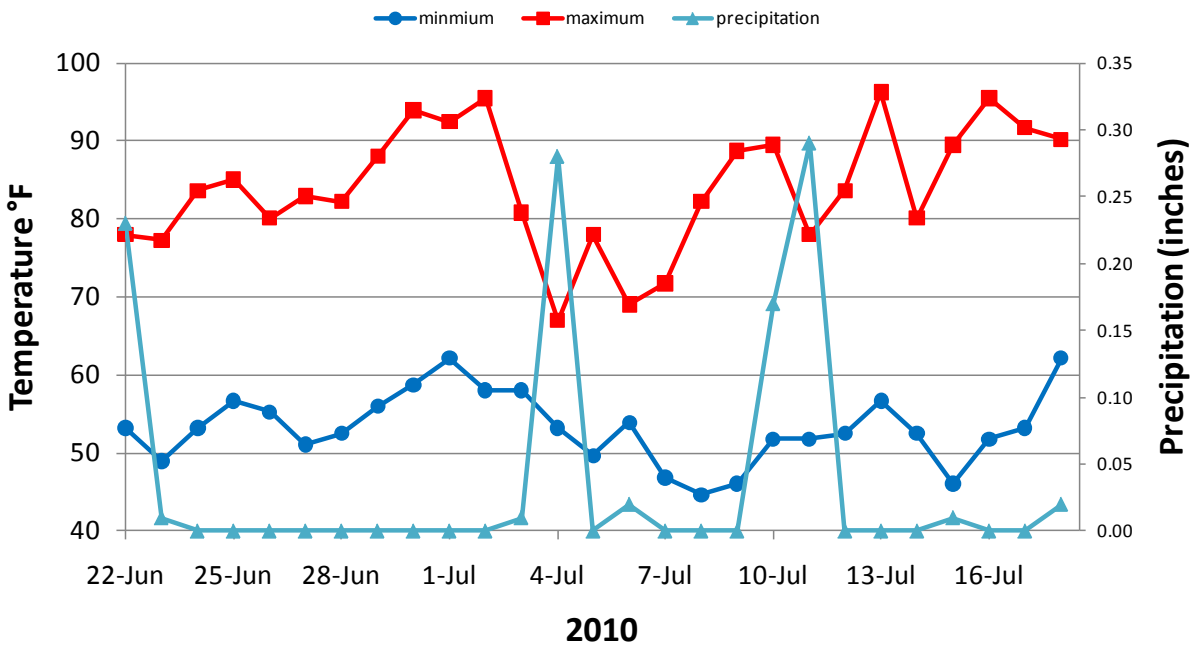

Figure 4. Daily minimum and maximum temperatures and precipitation recorded in the study area.

Figure 5. One of forty 0.1m^2 rings near the center of each plot used to estimate grasshopper densities in study plots near Edgemont, South Dakota, 2010.

Improving the economics of low volume and developing ultra-low volume ground application equipment for control of grasshoppers on rangeland

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July 2010 – Jan. 2011

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Abstract

Two commercial nozzles, Boominator 1250 and BoomJet 5880 modified with a timer activated solenoid valve for rapidly turning the system on and off during application were used to apply grasshopper treatments by ground equipment. Reduction in grasshopper densities were used to evaluate a comparison of the nozzles, with and without the timer activated valve in both 50% and 100% coverage treatments. The Boominator and BoomJet nozzels with or without a timer activated on off cycle produced statistically equivalent mortality. Significantly lower morality resulted with the 50% coverage treatments compared to the 100% coverage treatments.

With the Boominator and timer, a total volume of 0.51 gal/acre achieved what required 4.12 gal/acre in the unmodified system, an 8.1 times advantage in terms of acres that could be treated without remixing and reloading. With the BoomJet and timer, a total volume of 0.507 gal/acre achieved what required 2.025 gal/acre in the unmodified system.

This groundbreaking improvement saves ferrying, mixing and loading time as well as some diluting materials currently required of ground applications. The timer activated on/off solenoid valve modification can be easily adapted to any spray system and will greatly impact ground spray applications, especially, ultra-low volume sprays. Conversions have occurred and have been used in APHIS sponsored grasshopper programs in Arizona and North Dakota and modifications are currently occurring in several other states.

Introduction

Ultra-low volume (ULV) sprays (defined as less than 0.5 gallon per acre) were developed shortly after World War II for the control of desert locusts in East Africa (Mass, 1971). These first ULV sprays were applied by ground equipment and relied on the very fine atomization and drift of the spray. While successful and accepted in many parts of the world, these characteristics are currently unacceptable in United States Department of Agriculture (USDA) sponsored control efforts against grasshoppers and Mormon crickets on rangeland. The development of aerial ULV sprays in the United States, which rely on larger droplets than those produced in atomization sprays, was achieved by the Plant Pest Control Division of the USDA in cooperation with American Cyanamid in the early 1960's (Mass, 1971). These efforts led to the ULV aerial application of malathion at 8 fluid oz/acre against rangeland grasshoppers (Skoog and Cowen, 1968), a treatment still available today (USDA, 2002).

While a majority of the acres treated in USDA APHIS sponsored programs occurs by air, particularly in outbreak years, a significant amount of acres is treated by ground, particularly in non-outbreak years. Development has occurred in ground application equipment for rangeland use. However, as a result of the concern for drift, standard commercial equipment currently used by APHIS in ground applications deliver about 3 gallons/acre, many times what an aerial application would require. As a consequence, much higher amounts of diluent are required in ground applications compared to aerial application. These high volumes are expensive in terms of ferrying and loading times as well as the cost of some additional diluting materials. Being able to apply spray volumes by ground similar to those in aerial applications would provide distinct operational and economic advantages.

The solution lies in reducing the flow rates. Unfortunately, to prevent atomization and to achieve an economical swath width, larger droplets and thus higher rates of application are required. Foster et al. 2009 solved this problem with a novel solution. They simply installed a timer activated solenoid switch to quickly shut the spray system on and off i.e. by turning the spray system on for 0.1 sec and off for 0.1 sec a 50% reduction in flow rate could be achieved with little or no change in actual coverage.

In 2009, Foster et al tested several commercial spray tips, used for ground applications. They were evaluated for swath width on an ATV mounted commercial ground spraying system. The BoomJet nozzle, which produced the widest swath, was selected for further development. It was evaluated on the Jackrabbit Sprayer System which was modified with a 0.1 sec adjustable timer activated solenoid valve to quickly switch the spray on and off. Activation on and off at 0.1 sec intervals reduced flow rates 41% to 49%. Other intervals tested resulted in flow rates being reduced by as much as 79%. The timer off intervals tested allowed only one to 7 feet to be traversed by the ATV when the spray was off. The distance traversed when the spray system was off was irrelevant, since edge of pattern overspray and natural drift mixed the spray between the distances covered in the on/off cycles of the system. The modification produced ULV ground application rates similar to those used aerially.

The following study was conducted to further develop and evaluate the utility of timer activated solenoid switch based modifications in ground spraying equipment to deliver ultra-low volume sprays at volumes similar to those used in aerial applications.

Objectives

Reduce the total volume per acre requirements for ground treatments against grasshoppers on rangeland.

Compare efficacy resulting from ground applications using two standard commercial nozzles, one recently modified.

Compare the efficacy resulting from timer and non-timer modified ground spraying systems.

Compare the efficacy resulting from traditional full coverage and alternating treated and non-treated swath coverage using modified ground spraying systems.

Specifically compare the Boominator and modified BoomJet nozzles with and without the timer activated shut off valve at both traditional and reduced agent area treatment (RAATs) coverage.

Materials and Methods

Study Site

The study was conducted in Fall River County of southwestern South Dakota ca. 6 miles north and 7 miles west of the town of Edgemont on the Mark Tubbs ranch during the period of June 28 – July 22, 2010. The location was selected because of the diversity in grasshopper species and grasses, density of grasshoppers, history of grasshoppers in the area, better than average range condition, contiguous rangeland suitable for ground applied plot studies and proximity to several other ongoing studies.

Equipment

A commercial ground application spray system, Jackrabbit Pro ATV Sprayer (Warne Chemical and Equipment Co., Rapid City, SD) mounted on a Suzuki Vinson QuadRunner ATV was modified with an adjustable timer (Eaton timer #E5-248-C142, Carlton- Bates Company, Little Rock, AR) activated solenoid valve (ASCO Next Generation Solenoid Valve # 8262P212 ¼ inch 12-24 DC, Industrial Automation, Cornelius, NC) to quickly switch the spray on and off. Using a rapid on/off spray procedure essentially reduces the overall flow rate. During application in the field, the natural edge of pattern overspray and drift will mix the spray droplets between the small distances traveled during the off spray phases.

The spray system was fitted with standard commercial nozzles and tips for comparisons. The spray nozzles studied were twin nozzle Boominator 1250 and, Boomjet 5880 (body composed of 5 spray tips retrofitted with check valves **(Figures 1 and 2)**. Check valves were installed to prevent fluid between the solenoid valve and the tip leaking during the off phase. The 5 tip nozzle body consisted of two 1506 tips located at the 2 and 10 o'clock positions, two OC-06 tips

located at the 4 and 8 o'clock positions and a single 9502 tip located at the 6 o'clock position. The spray system was also fitted with a pressure regulator and a liquid filled pressure gauge to increase accuracy. A bypass of the solenoid valve was also installed for ease in changing between the standard and timer modified spray systems. The nozzles were mounted about 50 inches above ground and directly behind the spray tank or about two feet behind the spray tank for the Boominator and Boomjet, respectively**.** All nozzles and tips were supplied by Spray Systems Technology, Wheaton Ill except Boominator nozzles (supplied with Jackrabbit Pro ATV sprayer). Closeup images of the equipment and specific parts detailed in this report can be seen in Foster et al. 2009.

Treatments and experimental design.

The Dimilin 2L formulation of diflubenzuron was used in treatments for all comparisons. Flow rates varied greatly between commercial unmodified nozzles. As a result total the volume of mixes applied per acre were different between treatments. All treatment concentrations were adjusted to deliver one fluid oz of Dimilin 2L per acre when a full coverage treatment was occurring. A deposition aid, EDT Concentrate (Wilbur-Ellis), was added to all mixes at the rate of 3 quarts per 100 gal of finished mix. The basic experimental treatments were (1,2) Boominator without timer applied at 100% and 50% coverage, (3,4) Boominator with timer applied at 100% and 50% coverage, (5,6) BoomJet without timer applied at 100% and 50% coverage and (7,8) BoomJet with Timer applied at 100% and 50% coverage. The 50% coverage was achieved by leaving a full swath untreated between each treated swath. The application parameters used in each treatment application is shown in detail in **Table 1**.

Each of the 8 separate treatments was applied to a single 10 acre plot. Treatments occurred on June 30 and July 1 and relied upon electronic guidance for accuracy (Trimble EZ Guide ^{R} 250, Tremble Agricultural Division, Westminster, CO). The accuracy of the guidance system was confirmed by ground measurements during each of the treatments. Meteorological conditions during applications are shown in **Table 2**. The precipitation and daily minimum and maximum temperatures recorded by a temporary weather station established in the study area for the duration of the study are shown in **Figure 3.**

Field evaluation/sampling methods

The efficacy of each treatment (equipment configuration) was assessed using changes in the grasshopper populations. Generally, grasshopper density and species composition sampling followed protocols established by Foster and Reuter, 1996. Grasshopper populations in treated and untreated plots were counted and sampled 1 to 3 days before treatment and at 7, 14 and 21 days after treatment. Untreated control plots were also counted and sampled on any day a treated plot was monitored. Grasshopper densities were determined by counting grasshoppers in (40) 0.1 m^2 rings **(Figure 4)** arranged in four rows of 10 near the center of each 10 acre plot. Rows of rings were separated by about 10 yards and rings within rows were separated by about 5 yards.

The abundance of each species was determined from uniform sweep samples taken at each site (Foster and Reuter, 1996). Each sample consisted of 50 high and fast sweeps and 50 low and slow sweeps. Low and slow sweeps performed at ground level insured capture of very young instars and less active grasshopper species while high and fast sweeps performed at the canopy of the vegetation insured capture of older instars and the more active species. Sweep samples

were always collected immediately after grasshopper densities had been determined at each site on each visitation. Densities of individual species can be determined by multiplying the frequency of occurrence times the total density of grasshoppers at the same site. After collection, samples were cold stored until they could be sorted and identified in the lab.

Analysis

For the general population, data were expressed as percent mortality based on pretreatment counts in the same plot and were analyzed as such. For initial analysis each set of 10 rings in the 40 ring set-up on each plot was considered a replicate. Analysis was conducted on both non-ranked and ranked data. An analysis of variance was performed with the Tukey's HSD multiple comparison test used to separate means. Analyses were performed with Systat 6.1 For Windows. Further analysis was conducted using an incomplete replicated main effects model where main effects wee timer/no-timer, Boominator/BoomJet and 100% coverage/50% coverage (Steel and Torrie, 1960. These analyses were performed with JMP (2008).

Results and Discussion

Pretreatment densities from individual sites ranged from 8.8 to 12.5 and averaged 10.7 grasshoppers/m^2 in the treated plots. The density in the untreated plot was 20.8 grasshoppers/$m^{2.}$ At the time of treatment the population was composed of 1st instars (1.2 %), 2th instars (6.9 %), 3th instars (26.2 %), 4th instars (41.5 %), 5th instars (22.4 %), and adults (1.9 %). The total average instar age or population maturity index was 3.826 between third and fourth instar. The age mixture is considered to be very realistic of an ideally timed program treatment. The eight most dominant species were *Ageneotettix deorum* (33.4 %), *Cordillacris occipitalis* (22.9 %), *Aulocara elliotti* (16.4 %), *Melanoplus sanguinipes* (13.6 %), *Amphitornus coloradus* (7.1 %), *Melanoplus infantilis* (1.9 %), *Phlibostroma quadrimaculatum* (1.6 %) and *Trachyrhachys kiowa* (1.2 %). The relative abundance of all species and associated age structures in pretreatment samples is shown in **Table 3**.

All treatments produced mortality significantly greater than occurred in untreated populations except at 21 days after treatment (DAT) with the Boominator, no timer, 50% coverage and Boomjet, timer, 50% coverage at all DAT intervals **(Table 4).** With the Boominator this low value was unexpected, based on the 14 DAT data, which was higher. However, the initial 7 DAT data was also lower than other treatments at that time. It is thought that grasshopper movement could help explain this perceived outlier. Mortality produced by the BoomJet, timer, 50% coverage also was low and not significantly different from mortality in the untreated populations. However, this may be easily explained. During the treatment of that plot it was noted that the spray pressure dropped and upon completion of the application for that plot, the system contained more material that should have remained. A subsequent posttreatment calibration indicated that the last plot was treated at the rate 0.410 gal/acre instead of the 0.507 gal/acre, a 19% reduction from the original desired calibration. This less than desired application helps explain the low mortalities that resulted from this treatment. These low mortalities were the lowest seen in the study at any of the posttreatment intervals. Within the Boominator comparisons and the BoomJet comparisons, all treatments were statistically equivalent in producing mortality with the exceptions noted above.

In additional analysis using incomplete replicated main effects model there was no significant difference in mortalities resulting from treatments applied using a timer compared to treatments applied without the timer **(Figure 5).** Additionally, there was no significant difference in mortalities resulting from treatments applied with the Boominator nozzles compared to treatments applied with the BoomJet nozzle **(Figure 6).** However, treatments applied at 50% coverage resulted in significantly lower mortality than treatments applied at 100% coverage **(Figure 7).** The reduced mortality seen in the 50% coverage treatments was expected **(Tables 4 and 5).** In this experimental design, these treatments contain half as much spray as full coverage treatments (i.e. every other swath is not sprayed).

In aerially applied treatments where alternate swaths are purposely left untreated, Reduced Agent Area Treatments (RAATs), it is not unusual for a ca. 15 % difference in reduction (Foster et al. 2001) to occur between traditional full coverage treatments and RAATS. In aerial treatments the dosage may or may not be reduced in combination with the alternating untreated and treated swaths. Originally RAATs was touted as working because of grasshopper movement from untreated areas into treated areas. However, in aerial treatments, untreated swaths receive drift from the treated swaths and in fact very little area actually receives no treatment (Foster et al. 2001, Foster et al. 2002). We were concerned that with ground applications utilizing RAATs drift would not be as much a factor as it is in aerial treatments. However, based on our results, that may not be the case. Drift is occurring and some of the "untreated area" (skipped area) is receiving spray. Where drift may not be occurring, the treatment may be considered a more pure RAATS and grasshopper movement into a treated area is more easily achieved because the swaths are more narrow compared to swath widths used in aerial applications. Drift into ground applied untreated swaths may be similar to that seen in aerial applications. However, spray cards placed in the untreated areas during ground applications will be needed for full corroboration.

Conclusions

All configurations and modifications in the spray system that we studied produced statistically equivalent and generally significantly greater mortality than seen in untreated populations. The Boominator and BoomJet nozzles with or without a timer activated on/off cycle produced statistically equivalent mortality. Significant lower morality resulted with the 50% coverage treatments compared to the 100% coverage treatments.

When using the Boominator and timer, a total volume of 0.51 gal/acre achieved what required 4.12 gal/acre in the unmodified system, an 8.1 times advantage in terms of acres that could be treated without remixing and reloading. When using the BoomJet and timer, a total volume of 0.507 gal/acre achieved what required 2.025 gal/acre in the unmodified system.

This groundbreaking improvement saves ferrying, mixing and loading time as well as some diluting materials currently required of ground applications. The timer activated on/off solenoid valve modification can be easily adapted to any spray system, and will greatly impact ground spray applications, especially, ultra-low volume sprays. Conversions have occurred and have

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Acknowledgements

The authors thank Dan Largent and Todd Edgington, Chemtura Cooperation, for providing the diflubenzuron used in the study and to Bob Eccles and Bill Bagley, Wilbur-Ellis, for providing the EDT Concentrate used in the study. Thanks are also extended to Randy Hedge, Edgemont, South Dakota, City/Airport Manager**,** for providing logistical assistance at the airport and to Bruce Helbig for assisting with some of the logistics associated with the study. Special thanks are extended to rancher Mark Tubbs for providing the rangeland for the study and for his continued support and cooperation since 1989.

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Table 1. Summary of treatments (equipment) and calibration parameters.

Equipment (plot) date treated	Swath width ft	Pressure psi	Ground speed mph	Acres/min	Flow gal/min	Gallons applied/ acre
Boominator 1250 no timer 100% coverage (A) 50% coverage (F) 6/30/2010	34	18	8	0.549	2.26	4.117
Boominator 1250 with timer (0.2 sec on, 0.9 sec off) 100% coverage (B) 50% coverage (C) 6/30/2010	48	15	8	0.650	0.33	0.508
BoomJet 5880 no timer two 50 mesh in line screens 100% coverage (D) 50% coverage (E) 7/1/2010	42	24	8	0.679	1.37	2.018
BoomJet 5880 with timer (0.2 sec on, 0.7 sec off) 100% coverage (H) 50% coverage (G) 7/1/2010	42	22	8	0.679	0.345	0.508

Table 2. Meteorological conditions recorded during ground application of a Dimilin treatment with selected ground application equipment configurations, near Edgemont, SD 2010.

					Temperatures °F					
			Time		Ground		Air		Wind (mph)	
Treatment	Plot	Date	Start	End	Start	End	Start	End	Start	End
Boominator no timer full coverage	A	6/30	6:50 am	7:36 am	66	71	71	76	1-2 E	3-4 E
Boominator no timer RAATs	F	6/30	7:53 am	8:11 am	74	77	76	81	4-6 ESE	4-5 ESE
Boominator with timer full coverage	B	6/30	2:25 pm	2:49 am	130	132	92	94	5-7 E	5-7 E
Boominator with timer RAATs	C	6/30	2:52 pm	3:02 pm	131	126	94	95	7-8 E	7-8 E
BoomJet no timer full coverage	D	7/1	6:14 am	6:35 am	66	72	68	76	1-2 SE	2 SE
BoomJet no timer RAATS	E	7/1	6:55 am	7:10 am	70	70	72	73	1-2 SE	1-2 SE
BoomJet with timer full coverage	H	7/1	9:43 am	10:04 am	103	105	82	82	3-4 E	3-4 E
BoomJet with timer RAATs	G	7/1	10:10 am	10:24 am	106	110	83	84	4 E	4-5 E

Table 3. Pre-treatment grasshopper species composition and age structure in the ground application study of selected spray equipment configurations, near Edgemont, SD 2010.

	Instar							
Grasshopper species	1	2	3	4	5	Adult	Total	%
Subfamily Gomphocerinae								
Ageneotettix deorum		7	82	101	4		194	33.39
Amphitornus coloradus			9	30	2		41	7.06
Aulocara elliotti			15	41	36	3	95	16.35
Cordillacris occipitalis			1	42	85	5	133	22.89
Eritettix simplex						1	1	0.17
Phlibostroma quadrimaculatum	1	3	3	2			9	1.55
Subfamily Melanoplinae								
Melanoplus confusus						2	2	0.34
Melanoplus infantilis	1	3	5	2			11	1.89
Melanoplus packardii		1		1	1		3	0.52
Melanoplus sanguinipes	5	21	29	22	2		79	13.60
Phoetaliotes nebrascensis		2					2	0.34
Subfamily Oedipodinae								
Hadrotettix trifasciatus		3					3	0.52
Metator pardalinus			1				1	0.17
Trachyrhachys kiowa			7				7	1.20
Totals	7	40	152	241	130	11	581	
%	1.20	6.88	26.16	41.48	22.38	1.89		

Table 4. Mean percentage mortality* of grasshoppers treated using selected ground application configurations, Edgemont, SD 2010.

Treatment	Days after treatment 7	14	21
Boominator - no timer - 100% coverage	70 a	83 a	87 a
Boominator - timer - 100% coverage	50 ab	61 a	86 a
Boominator - no timer - 50% coverage	28 ab	60 a	44 bc
Boominator - timer - 50% coverage	43 ab	64 a	71 ab
Untreated population	9 b	-3 b	-8 c
BoomJet - no timer - 100% coverage	78 a	82 a	87 a
BoomJet - timer - 100% coverage	63 ab	88 a	83 a
BoomJet - no timer - 50% coverage	76 a	71 a	78 ab
BoomJet - timer - 50% coverage	21 bc	45 ab	48 b
Untreated population	9 c	-3 b	-8 c

* A one-way analysis of variance was conducted on the primary data. Means in a column followed by the same letter are not significantly different ($P \leq 0.05$) as determined by the Tukey HSD multiple comparison test.

Table 5. Mean grasshopper mortalities associated with the main effect comparisons that were analyzed.

	Percent Mortality 7 Day	14 Day	21 Day
with Timer	44.09	64.43	71.94
without Timer	63.05	73.95	73.73
Boominator	47.59	66.91	71.77
BoomJet	59.55	71.47	73.89
RAATs	41.87	59.81	60.08
Blanket Coverage	65.27	78.57	85.58

Figure 1. The twin-nozzle Boominator 1250 spray system.

Figure 2. The BoomJet 5880 spray system (body composed of 5 spray tips retrofitted with check valves).

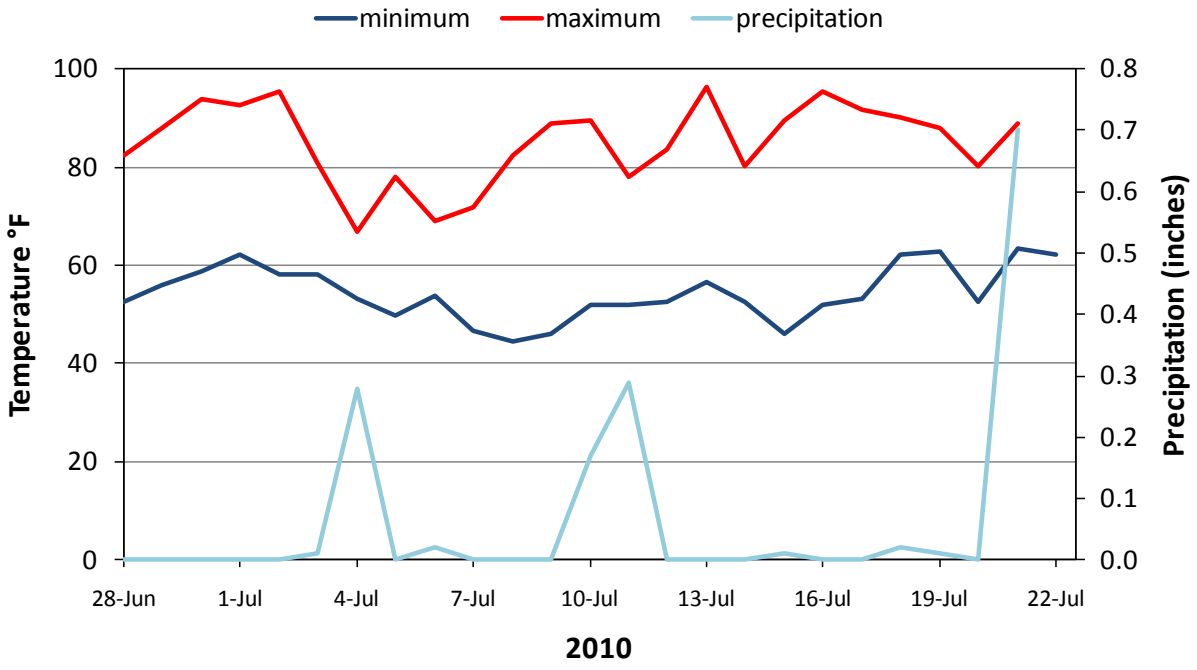

Figure 3. Weather data collected during the monitoring period for this study.

Figure 4. Density estimates were determined by counting grasshoppers in 0.1 m^2 rings in each of the ten-acre plots.

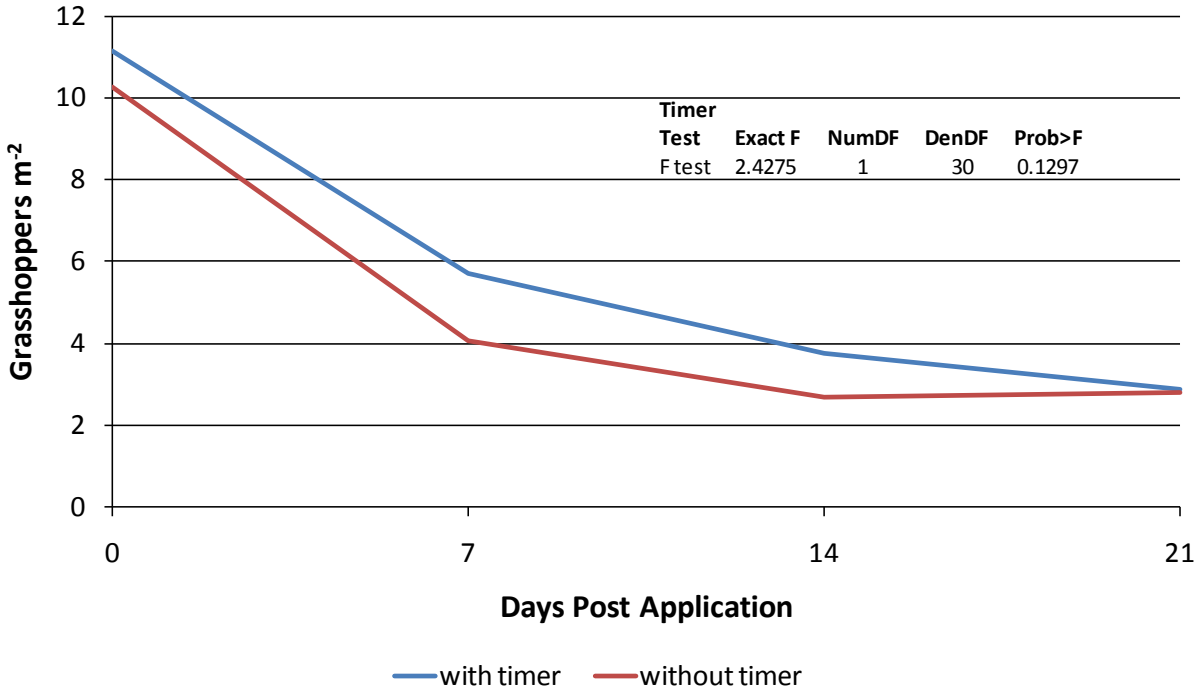

Figure 5. Reduction in grasshopper densities with and without a timer activated solenoid shutoff in ground application spray systems.

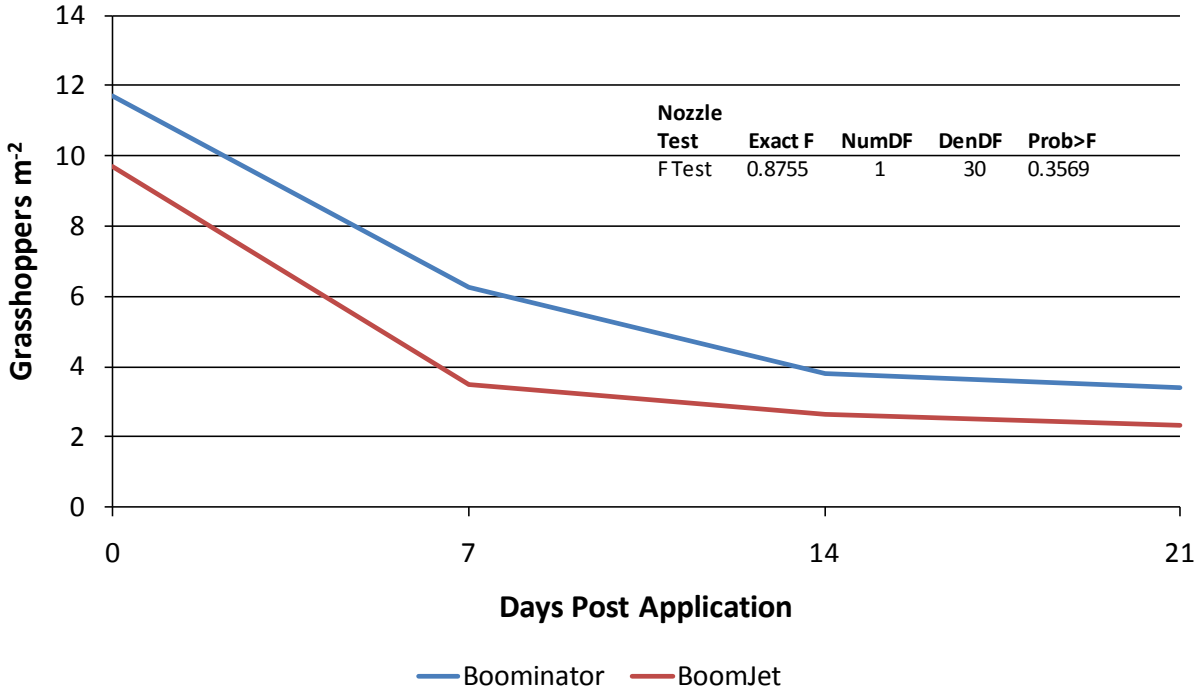

Figure 6. Reduction in grasshopper densities using Boominator and BoomJet nozzles in ground application spray systems.

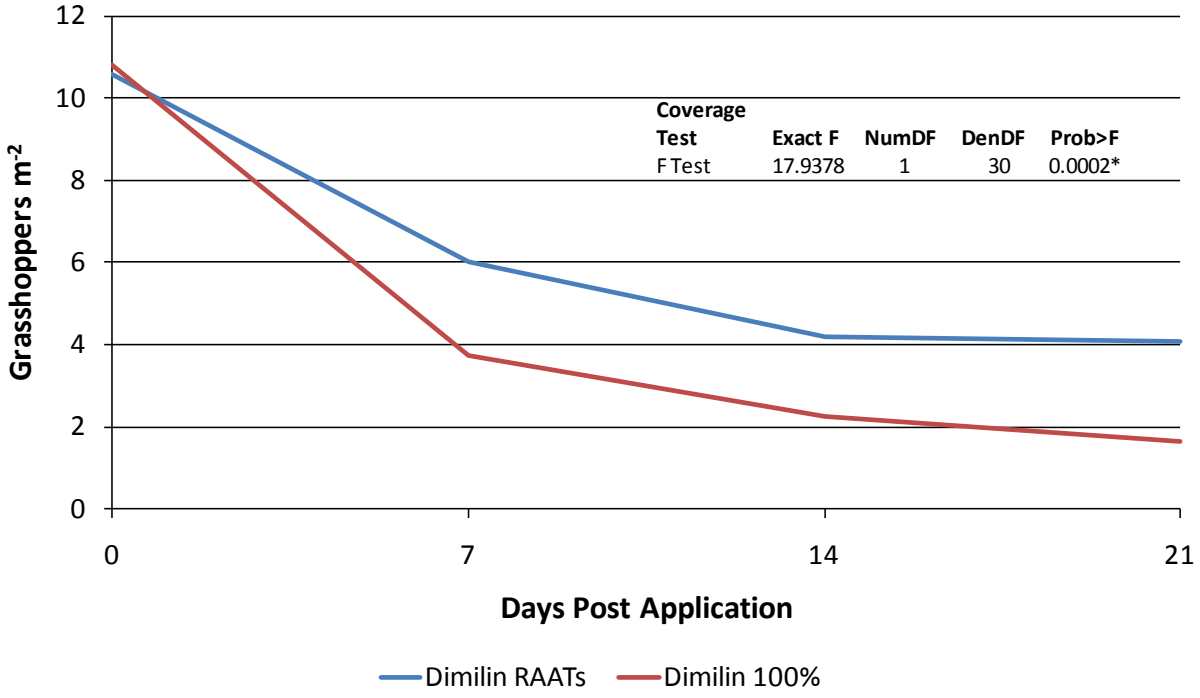

Figure 7. Reduction in grasshopper densities with 100% and 50% coverage treatments with ground application spray systems.

Dec. 2010

Field evaluation of one commercial and two newly discovered strains of *Metarhizium* applied by ground equipment against grasshoppers on rangeland in northern Utah

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Introduction

Both grasshoppers and Mormon cricket occur on western rangelands and are an integral part of the natural rangeland community. Outbreaks of both are cyclic and sometimes populations of these pests reach such high levels and cause such damage that federally sponsored cooperative efforts may be required for relief. The USDA programs that combat these pests, when they get out of control, currently rely exclusively on traditional insecticide sprays and/or baits. It is not uncommon for environmentally sensitive situations to exist in potential control program areas and to preclude traditional chemical insecticide treatments. The number of sensitive situations is increasing and in areas of grasshopper or Mormon cricket infestations this presence at best complicates and more often prevents much needed local or area-wide treatments on rangeland. Treatments acceptable in these areas would be extremely important when both local and area-wide control efforts are required.

The development of non-chemical entomopathogens has long been desired as an alternative to traditional pesticides for control and management of grasshoppers and Mormon crickets on rangeland in the United States. While both *Paranosema locustae*, a protozoan parasite of grasshoppers, and *Beauveria bassiana*, a fungus with a broad host range, have been registered for use against these pests, neither one has gained acceptance for use. The fungus *Metarhizium acridum*, which has activity specific to Orthopterans has been found in Australia (Milner, 1997), Africa (Lomer et al. 1997), Brazil (Magalhaes et al. 1997), Peru (Magalhaes et al. 2003) and

Mexico (Hernandez-Velazquez et al. 1997) is registered for use in several countries. However, it has not been found in the U. S. nor have those foreign strains been registered for use in the U.S.

Another entomopathogenic fungus, *M. brunneum* (formerly *M. anisopliae*) Strain F52, has been registered in the U.S. for control of Coleoptera in horticulture and managed turf, and for soft bodied ticks, by Earth Biosciences Corp. (now Novozymes Biologicals, Salem VA). In laboratory bioassays with immature Mormon crickets, Foster et al. (2011) observed that the F52 strain was highly infectious and virulent, more so than *B. bassiana* GHA, and equivalent to *M. acridum*, the Australian strain, therefore presenting a potential alternative.

The most popular current belief concerning ineffective results of *B. bassiana* against unconfined field populations of grasshoppers supposes that infected insects can thermoregulate and increase body temperatures higher than their typical levels by positioning themselves to increase sun exposure (Inglis et al. 1996; Inglis et al. 1999). This behavior results in a body temperature that is non-conducive to fungal growth for much of each day. Additionally, fungal growth can slow greatly after sundown because body temperatures, as tracked in past field studies, may drop below the optima for the fungi. The combination of both occurrences yield only a few hours each day during which grasshopper body temperatures may be conducive for fungal growth. As a result, the mycosis takes so long to advance to a fatal degree that detection of population reductions attributable to the fungus, compared to a natural population decline, is difficult at best. Simply put: For a fungi to work as a control agent the strain must be active against the target pest and the fungi must be able to replicate at the host pest environ temperatures in a timely period.

During the last few years scientists from USDA APHIS PPQ CPHST Phoenix Lab, USDA ARS, Northern Plains Agricultural Research Laboratory (NPARL), and Utah State University (USU) have been collaborating to better understand the parameters under which the native fungi *Beauveria bassiana* and *Metarhizium brunneum (formerly M. anisopliae)* show useful activity against grasshoppers or Mormon crickets on rangeland (Foster et al. 2004 a, b: Foster et al. 2006, 2007, 2008, 2009). That effort has been energized by the major effort of the USDA APHIS PPQ Western Region which, in the process of conducting normal grasshopper surveys, collects and ships soil samples to USU for isolation and identification of potential fungal pathogens for development. This partnership is an attempt to discover a domestic strain of *Metarhizium acridum* as well and other strains that may be useful against grasshoppers, Mormon crickets and other pests. To date, that effort from the western 17 states has resulted in the collection and processing of 26,349 soil samples that have yielded 1,949 new pathogens (Roberts et al. 2011.

The CPHST, ARS and USU team has conducted several field cage studies (Foster et al. 2006, 2007, 2008, 2009) with candidate isolates against adult or immature Mormon crickets. In those studies a Field Aerial Application Spray Simulation Tower Technique (FAASSTT) was used to apply the treatments to hundreds of mini-plots with newly designed thermal neutral cages that confined individual insects. Those studies confirmed the progression of the disease commensurate with conducive fungal growth temperatures but produced varying results and demonstrated that initial significant and final acceptable mortality can vary greatly.

To more closely simulate actual program use, the following study was conducted using commercial ground application spray equipment to apply several isolates of *Metarhizium* to 10 acre plots of grasshopper infested rangeland.

Objectives

Determine the efficacy of *Metarhizium brunneum* (F52), *Metarhizium robertsi* (DWR346) and *Metarhizium robertsi* (DWR356) against rangeland grasshoppers in Utah.

Compare the efficacy between strains, and between strains and untreated populations.

Evaluate the effects of the selected strains against individual grasshopper species in the population assemblage.

Determine the post treatment period required until significant initial mortality and final effective mortality resulting from the selected strains is seen.

Methods and Materials

Study site.

The study site was located in Howell Valley, Box Elder County, near Tremonton UT (Figure 1). The location was selected because of the diversity in grasshopper species and grasses, density of grasshoppers and contiguous rangeland suitable for ground applied plot studies. It is typical of the long open valleys north of the Great Salt Lake. The average annual precipitation is 5 to 12 inches (125 to 305 mm) in the valleys with higher amounts in the surrounding mountains. Most of the precipitation occurs in the late-winter and early spring months as snow. This area supports desert shrub, sagebrush semi-desert, and woodland vegetation. The vegetation was composed of nearly monospecific stands of the two dominant plants, sagebrush, *Artemisia triplex confertifolia* and winterfat, *Ceratoides lanata*. The area has been developed for irrigated wheat and alfalfa, dry land wheat, and grazed rangeland since the 1870s. Managing the habitat require close attention to maintaining a good vegetation cover in order to minimize soil erosion in the area and consequently reduce the impact of invasive exotic plants. The habit also supports a variety of upland game including grouse, pheasant and mule deer. The coordinates are north latitude 41.721, -112.418 west longitude, 4600 ft (1400 m) above sea level.

Treatments and study design

The DWR346 and DWR356 strains of *Metarhizium robertsi* (provided by Donald Roberts, Utah State University) and the F52 strain of *Metarhizium brunneum* (provided by Novozyme Biologicals) were each ground applied to a 10 acre rangeland plot. An additional plot treated with the oil carrier was also included in the design. Each plot was surrounded by a ground applied treatment of carbaryl (Sevin XLR Plus) to minimize possible grasshopper movement into the treated areas. Figures 2 and 3 show the location of the plots and the untreated sites in the study area and the details of the sampling area in each plot, respectively.

Testable quantities of *M. robertsi*, DWR346, (Lot#ARS10-01(ARS Sidney MT), DWR356 (Lot#ARS10-01(ARS Sidney MT) and *M. brunneum* F52 (Lot # ARS10-01 (ARS Sidney MT), were produced by Stefan Jaronski at the USDA, ARS NPARL in Sidney, MT. The conidia were formulated in the lab in emulsifiable vegetable oil (Golden Pest Natural Oil) at 1×10^{12} conidia per quart. In the field the formulated material was mixed with water for application. Each treatment consisted of one quart of Golden Pest Natural Oil containing 1×10^{12} conidia and 7 quarts of water (total of two gallons) applied / ac.

All treatments including the carbaryl buffers were applied using a commercial ground application spray system; Jackrabbit Pro ATV Sprayer (Warne Chemical and Equipment Co., Rapid City, SD) mounted on a Suzuki Vinson QuadRunner ATV. The spray system was modified to deliver material through a single nozzle Field Jet ¼ KLCSS 5 (Spray Systems) and calibrated to deliver 2 gallons per acre at 6 mph, and 22psi with a 25 ft wide swath.

When we arrived to apply the treatments on 12 July 2010, it was noted that the 'bench', an old lake Bonneville shore line area, adjacent to our study area, was being aerially treated with diflubenzuron (Dimilin 2L) by helicopter for rangeland grasshoppers and that treatment was nearly complete (Figure 2, upper right corner of image). It was decided that the biopesticide treatments would continue as planned, since it was not feasible to reset the plots. All of the study hardware was in place and precount sweep samples had been collected. Treatments started early on the 12th of July and finished before noon (see Table 1 for application conditions). The 110 ft wide buffer, surrounding each plot, was treated with SEVIN® brand XLR Plus carbaryl insecticide, the following day, 13th of July, at the label rate of Sevin XLR Plus (12 fl oz per acre). The total mix contained acidic buffered water applied at two gallons per acre.

After all applications had occurred, vegetation samples were collected from along the borders on the north and east fence lines, representing areas that may have received drift from the unanticipated aerial rangeland treatments (Fig. 2). Additional vegetation samples from the north side near the midline rings in each plot were also collected. All samples were sent to the USDA APHIS PPQ CPHST Gulfport Laboratory for analysis to detect diflubenzuron contamination. The locations for the samples of interest are indicated by orange markers in Figure 2, the green markers indicate there was no diflubenzuron detected.

Sampling methods

Grasshopper populations were evaluated by density and species composition following the method of Foster and Reuter, (1996) outlined with changes as follows. To assess density, forty 0.1 m^2 rings were placed in four rows of ten rings per row in the center of each plot. Rows were separated by 30 feet and rings within rows were separated by 15 feet (Figure 3). Grasshoppers were counted on approach by the observer as they jumped from the rings. Finally, each ring arena was carefully examined to assure that no individuals were missed and the number of grasshoppers observed was recorded. Counts were conducted 2 days before treatment and on selected days up to 45 days after treatment.

To determine the species composition at each ring site, 2 sets of sweep samples were collected using the outer sets of rings as a guide. The first fifty 180° sweeps were taken low and slow near the margin of the rings and a second set of fifty were taken high and fast outside the first pass around the rings. Low and slow sweeps performed at ground level insured capture of very young

instars and less active grasshopper species while high and fast sweeps performed at the canopy of the vegetation insured capture of older instars and the more active species. Sweep samples were always collected immediately after grasshopper densities had been determined at each site on each visitation. After collection, samples were cold stored until they could be sorted and identified in the lab. Densities of individual species can be determined by multiplying the frequency of occurrence times the total density of grasshoppers at the same site.

After completion of applications the CPHST Phoenix Lab personnel returned to Arizona. Utah State University personnel under the direction of D. Roberts lead by C. Keyser completed the data collection including grasshopper counts and sweep samples.

Results

Field evaluation Analysis

Analysis of the vegetations samples conducted by L. Mosser of the CPHST Gulfport Lab indicates that only two samples from the borders of the plots nearest the rangeland grasshopper aerially applied control efforts, produced detectable, but unquantified, levels of diflubenzuron (Figures 2 and 4) (pers. com. K. Caraher). All other samples had no detectable amounts of diflubenzuron. The biopesticides test plots were apparently uncontaminated.

Temperatures for the time of year were near seasonal norms for both high and low temperatures. The high and low averaged 90.0 and 53.6 °F respectively (Figure 5). Howell Valley received some precipitation on the 30th of July and again on the 23rd of August. However, the precipitation was insufficient to stimulate plant growth. Moisture at this time is unusual. The species composition was restricted to nine species in the pre-count samples (Table 3). The dominant species were *Melanoplus sanguinipes*, *Aulocara femoratum*, and *Aulocara elliotti*, composing 53.72%, 28.14% and 16.05 %, respectively and accounting for 97.91% of the 430 individual grasshoppers recovered. The average age of the dominant species, in order were; 3.80, 4.12, and 5.35. The pretreatment mean number per m^2 for the DWR 356, DWR 346, F52, oil check and untreated plots were 8.9, 12.2, 14.3, 14.3 and 13.2, respectively. Note, the F52 and oil check plots had the same density. The population was not considered a heavy infestation but from the time that the treatments were applied, the forage began to senesce and some dispersal flights of the adults were noted (Figure 6).

Movement of grasshoppers obviously confounded the results. Data analysis for the first 21 days of the experiment indicate that no separation of the treatments, including the untreated sites, occurred. Several methods were attempted. The initial analysis consisted of ranking the data, averaging the ranks of the sums of each of the 4 rows of rings and then analyzing the ranks in an analysis of variance. The same data was rearranged and a repeated measure analysis was performed with no separations occurring. A similar approach was tried with the raw counts and means using a Chi-square comparison. No convincing trends were developed in the exploratory analysis.

Visual examination of the data (Figure 6) indicates that grasshoppers increased in the DWR 356 plot while declining in the other plots. This plot had lowest elevation of all plots and therefore vegetation may have had better access to ground water. As a result the micro habitat may be

slightly better than the surrounding fields even though the plants appear to be dry. Based on its proximity to the lower valley wetlands, this plot may also receive moist air from the meadows to the west of the plot and road during the early morning. Grasshoppers may also be originating from the roadside margin and dispersing to the field, further confounding the results (Figure 2).
The most obvious complication in this study was the presence of high populations of spiders. Spiders are a general insect predator and can have an effect on grasshopper populations (Lavigne and Pfadt, 1966; Bilsing, 1920; Kuitert and Connin, 1953; Parker, 1957; Parker and Connin. 1964). While spiders are commonly seen on rangeland, in the authors' experience, populations of the size we observed in this study are highly usual. Three species were predominate (1) *Argiope trifasciata* (Forskal) (2) *Xysticus gulosus* Keyserling and (3) undetermined. Most were fairly large, and formed large above ground webs which were easily observed to trap large numbers of grasshoppers of all ages. While spiders were not counted during ring counts, they were counted in sweep samples (Figures 7-11). Sweep samples showed grasshopper levels were higher than spider levels before treatment in all plots except the DWR 356 plot, where they were essentially equivalent. The ratio of accumulated spider feeding days and grasshopper feeding days (number of spiders and grasshoppers present on each day and totaled for the duration of the study) and ratio of spiders to grasshoppers in each plot are shown in Table 4. Throughout the study, both the oil only and DWR356 plots, demonstrated grasshoppers at higher relative levels than spiders. In all other plots grasshoppers were at about (1.75-4X) the level of spiders before treatment but dropped below spider levels between July 19 and August 2. It is important to note that while the daily consumption rate of grasshoppers by spiders in our study is unknown, the potential for grasshopper captures in webs existed daily and thus greatly reduced the population over time.

Conclusions

The grasshopper population was beginning to move when the treatments were applied. This is common in drying vegetation at this time of year and confounded analyses and results. Elevated temperatures (environmental or host) greatly slow, delay or stop fungal replication in the host. Many of the ambient temperatures experienced during our study were not conducive to rapid fungal replication. The late season sparse vegetation and accompanying higher soil temperatures exacerbated the problems associated with higher ambient temperatures. Under these higher temperatures significantly longer periods of time are required to reach a sufficient number of fungal growth days to produce mortality. In our study, spiders were a major predator and had an obvious dramatic effect on grasshopper populations. The combination of this unexpected high level of predation, grasshopper movement and long periods of time before mortality could occur confounded evaluation and statistical separation of fungal treatments from each other as well as untreated populations. However, valuable experience was gained with the application technology and the temperature issues associated with the biopesticides in this study. Future studies will focus on more optimal target age structures, environmental temperatures and isolates with more attractive thermal windows of activity that are consistent with typical conditions in the western US.

Acknowledgements

The authors wish to thank Lisa Mosser, Senior Analytical Chemist, USDA, APHIS, PPQ, CPHST, Gulfport Laboratory, Gulfport MS, for analyzing the range grass samples for the presence of diflubenzuron. Thanks are also extended to Lori Spears, Department of Biology and Ecology Center, Utah State University, for identifying the spiders captured during the study.

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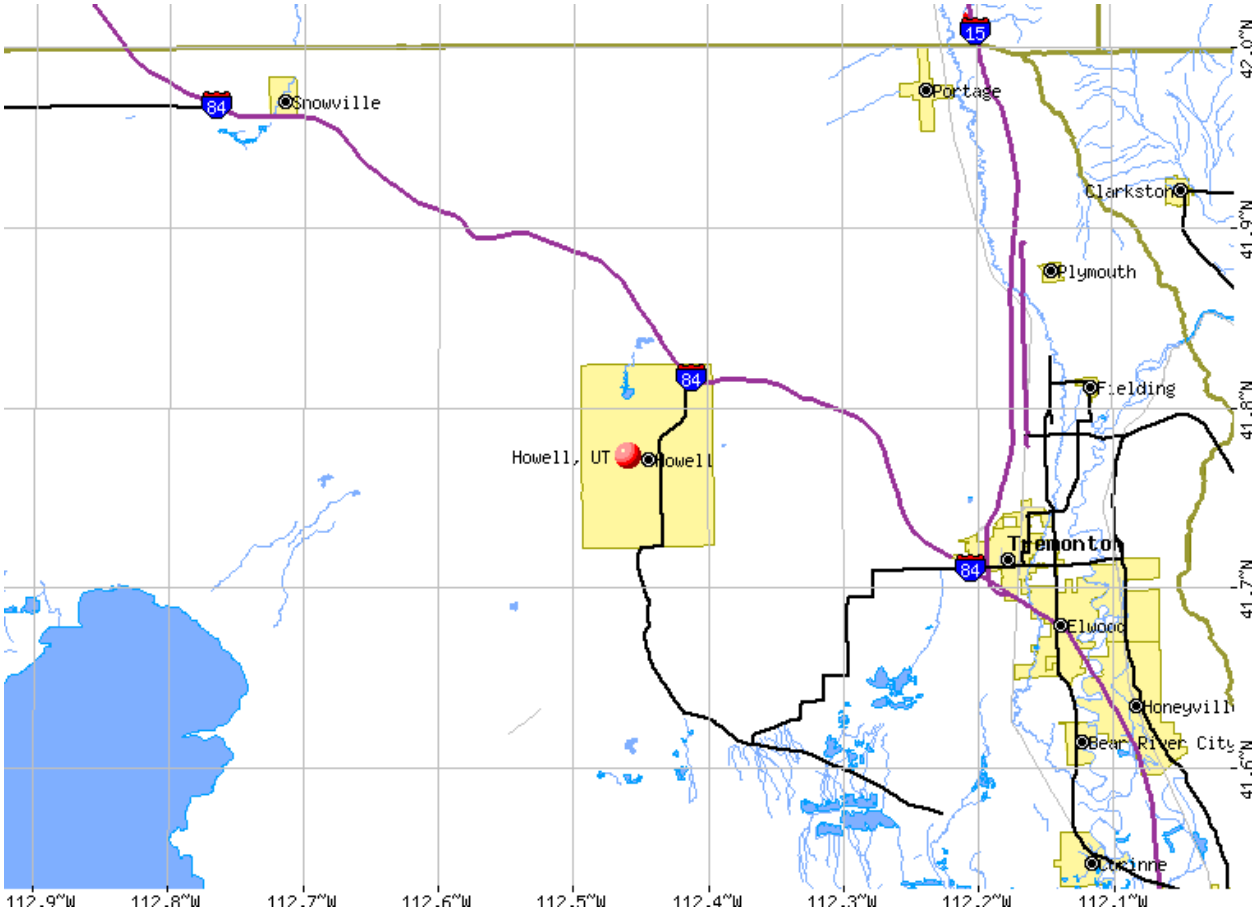

Figure 1. Map of the general location

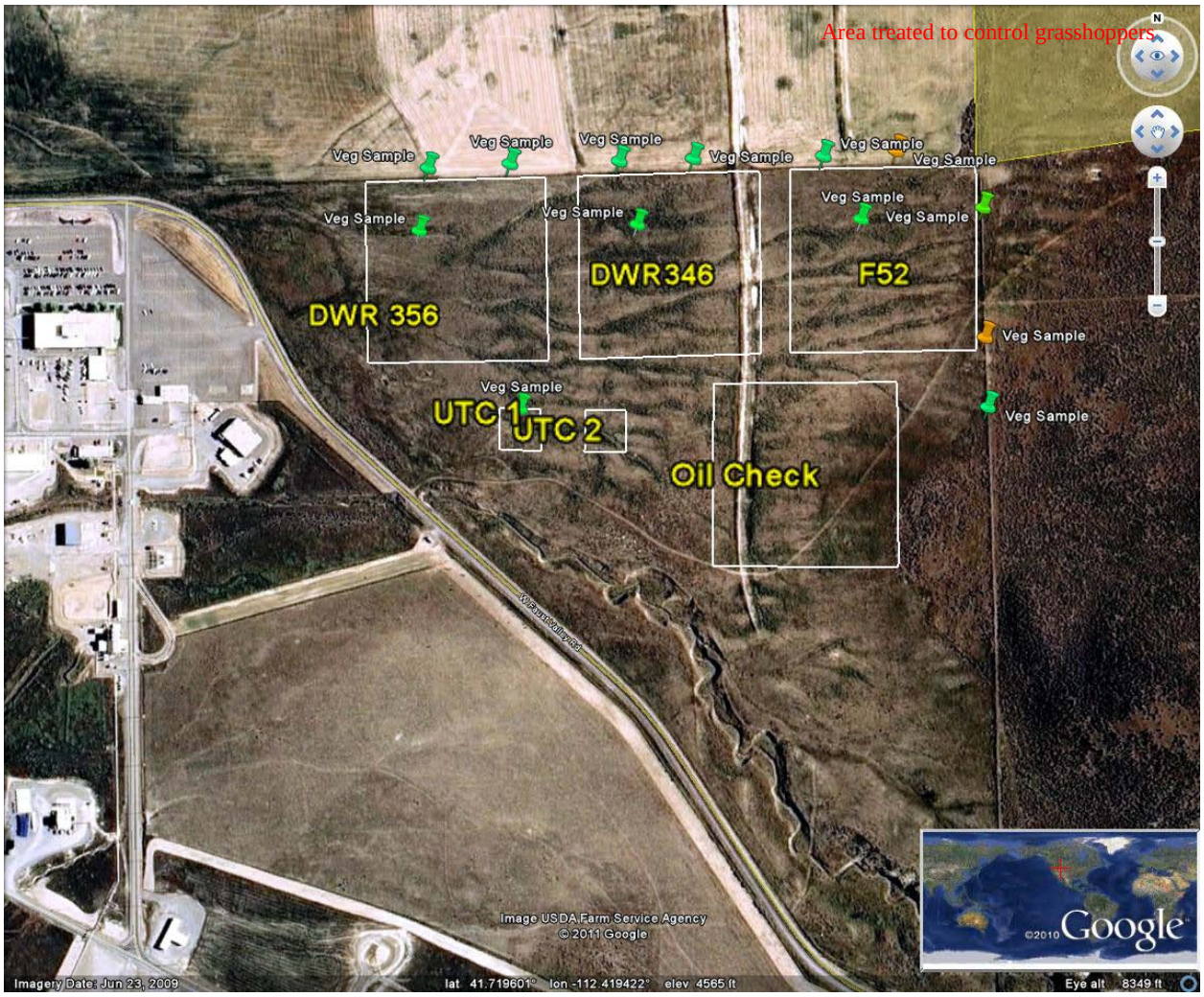

Figure 2. Satellite Image of the study area with vegetation sample sites. Green indicates no detectable diflubenzuron; orange indicates samples with less than quantifiable amounts of diflubenzuron. Aerial treatments for grasshoppers occurred in upper right corner of the image.

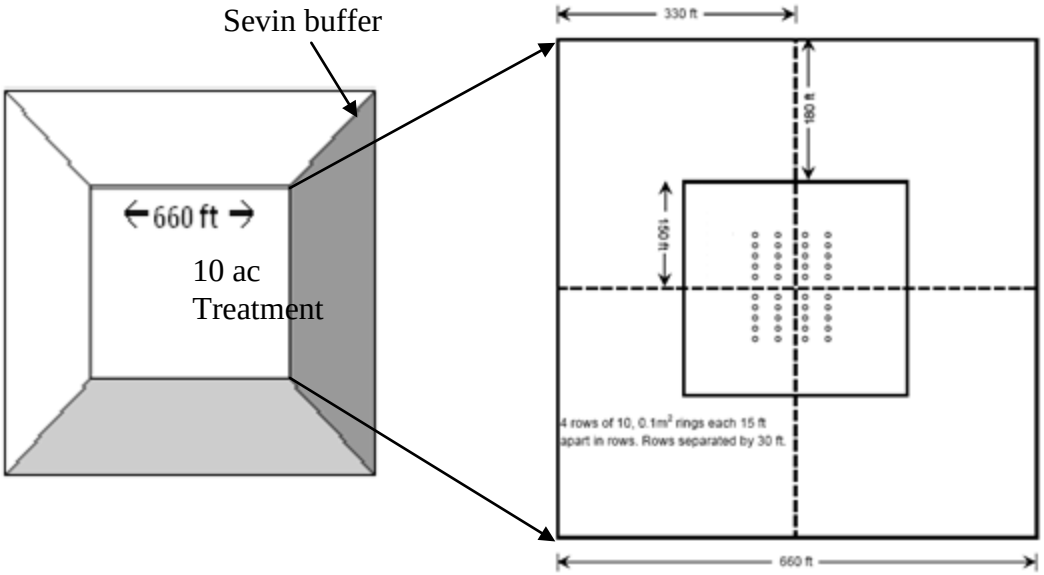

Figure 3. A diagram showing relationship between the ten acre plots receiving the biopesticide treatment and the protective treated buffers.

United States Department of Agriculture
Animal & Plant Health Inspection Service
Plant Protection & Quarantine
Center for Plant Health Science & Technology
Gulfport Laboratory

September 7, 2010

Objective: To determine possible Diflubenzuron contamination of grass samples from a ten acre study in Tremonton, Utah. Area adjacent to study plots had been aerially treated on July 10 and 11, 2010. Study plot samples were taken July 12, 2010.

Procedure: Samples were submitted from the Grasshopper Suppression Program for analysis of diflubenzuron. CPHST-GL Technical Procedure TPA-356, "Determination of Diflubenzuron in Vegetation" was used to conduct the analysis.

Results:

Group # 4949

Sample ID	ppm
1-North Boundary #1	<0.6 ppm
2-North Boundary #2	BQL
3-North Boundary #3	<0.6 ppm
4-North Boundary #4	<0.6 ppm
5-North Boundary #5	<0.6 ppm
6-North Boundary #6	<0.6 ppm
7-North Boundary #7	<0.6 ppm
8-North Boundary #8	<0.6 ppm
9-Plot #1 North Side	<0.6 ppm
10-Plot #2 North Side	<0.6 ppm
11-Plot #3 North Side	<0.6 ppm
12-Plot A and B	<0.6 ppm
13-East Fence #1	<0.6 ppm
14-East Fence #2	BQL

Conclusions:

- Samples 2 and 14 were determined to be BQL (Below Quantitation Level). This means that the samples were positive for diflubenzuron, but were below the instrumental quantitation as defined by TPA-356.

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Figure 4. Documentation of the diflubenzuron contamination at Howell Valley, UT, 2010.

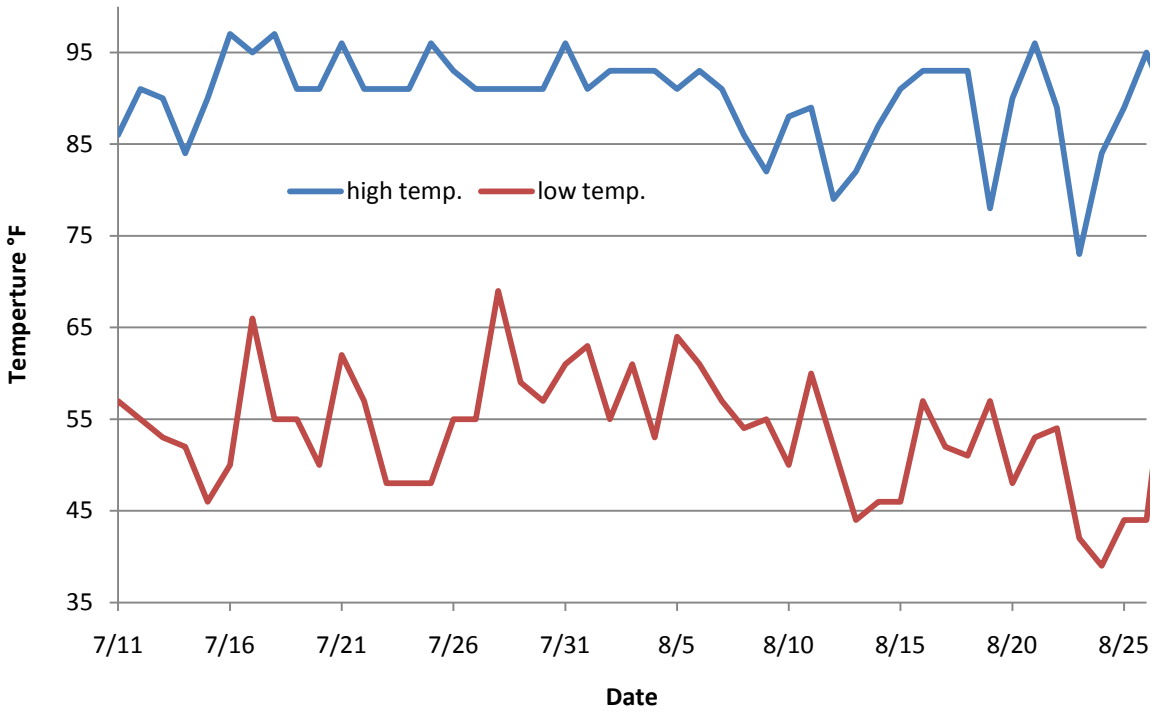

Figure 5. High and Low temperature recorded at Tremonton, Utah.

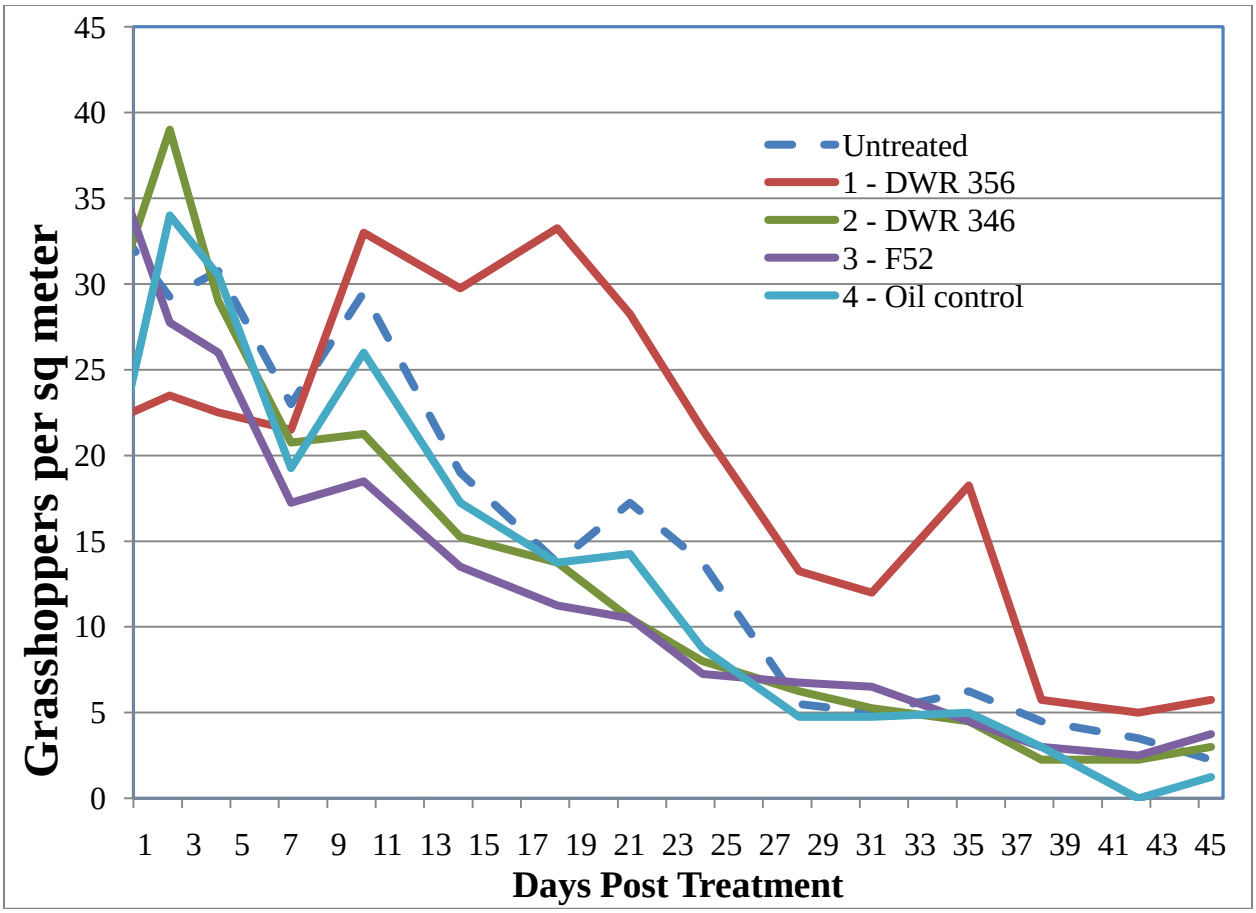

Figure 6. Population trends among the plots treated with the biopesticides and their associated controls, Howell Valley, UT, 12 July through 26 August, 2010.

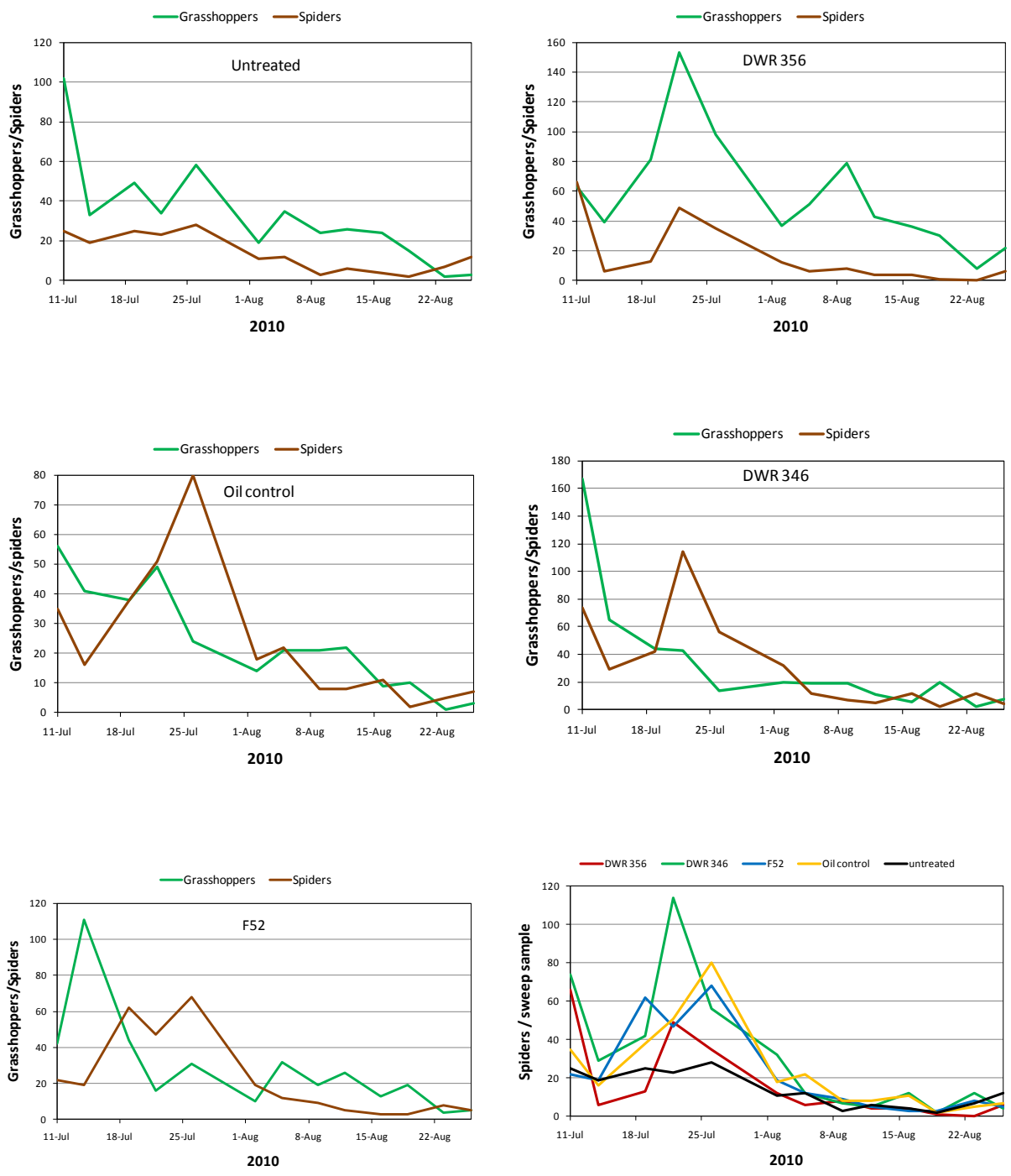

Figure 7. Grasshopper and spider populations from sweep samples in the 10-acre trial plots - Howell Valley, Utah 2010.

Table 1. Meteorological conditions during applications (beginning, middle, final) of the treatments in Howell Valley, UT, 2010.

	Start	Temp				Middle	Temp				Final	Temp				
Treatment	Time	Air	Ground	Wind	Direction	Time	Air	Ground	Wind	Direction	Time	Air	Ground	Wind	Direction	Passes
F52	9:20	82	84	2.4	S	9:40	80	85	4-6	S	10:05	85	90	4-7	S	27
DWR 346	7:30	61	59	0	NA	7:48	64	63	0	NA	8:15	68	63	0	NA	26
DWR 356	10:40	86	91	3-6	S	11:00	88	106	5-6	S-SW	11:30	89	112	3-5	S-SW	28
Oil Check	6:05	58	48	0	NA	6:28	54	46	0	NA	6:51	56	55	0	NA	25

Table 2. Meteorological conditions during applications of the buffers in Howell Valley, UT, 2010.

14 July 2010

Buffers	Time	Air	Ground	Wind	Description
Begin	6:35	54	45	<1	Long East-West run
End	6:50	57	58	<1	
Begin	6:55	53	48	<1	#1 East West run
Begin	7:10	58	55	<1	Between 1 and 2
Begin	7:20	62	61	<1	Between 2 and 3
Begin	7:35	63	59	<1	East Side #1

Note: Load 2 gallons more and treat a north buffer along the north fence; no temperatures recorded

Table 3. Grasshopper species captured in the precount samples from the Utah biopesticide trials and the average age for each species.

Grasshopper species	1	2	3	4	5	M	F	TOTAL	PCT	Average Age
Ageneotettix deorum				1				1	0.23	4.00
Amphitornus coloradus					1			1	0.23	5.00
Aulocara elliotti			3	8	20	24	14	69	16.05	5.35
Aulocara femoratum	1	5	22	44	48	1	0	121	28.14	4.12
Dissosteira carolina			1	1				2	0.47	3.50
Melanoplus packardii						1		1	0.23	6.00
Melanoplus sanguinipes	3	20	67	75	63	2	1	231	53.72	3.80
Oedaleonotus enigma					1	0	2	3	0.70	5.67
Spharagemon collare					1			1	0.23	5.00
Total	4	25	93	129	134	28	17	430		4.16
Percent of Population	0.01	0.06	0.22	0.30	0.31	0.07	0.04			

Table 4. Accumulated number of grasshopper and spider days[1] determined from sweep samples - Howell Valley, Utah 2010.

Plot	accumulated grasshopper and spider days		ratio: grasshoppers/spider
Untreated	grasshoppers	1459.5	2.28
	spiders	640.0	
Oil control	grasshoppers	1072.0	0.91
	spiders	1183.5	
DWR 356	grasshoppers	2731.5	3.97
	spiders	688.5	
DWR 346	grasshoppers	1295.5	0.90
	spiders	1443.0	
F52	grasshoppers	1362.5	1.20
	spiders	1138.0	

[1] Number of spiders and grasshoppers estimated to be present on each day and totaled for the duration of the study.