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Comparison of wheat bran, apple pumice and food waste (combined bakery, snack, cereal and confectionary) baits containing carbaryl for controlling Mormon crickets: Studies of longevity and primary and secondary mortality.

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Introduction

The Mormon cricket continues to exhibit populations of notable outbreak proportions throughout much of its range in the west. Even though 781,516 and 534,479 acres were protected from Mormon crickets with treatments in 2003 and 2004 respectively, populations are expected to remain high next year with a substantial amount of treatment predicted to occur. Historically, treatments have been carbaryl wheat bran or steam rolled oat baits applied by ground equipment. However, in the last three years, significant aerial application has occurred with baits and the recently approved diflubenzuron (Dimilin 2L) spray. Even though the Dimilin spray has proved extremely effective (Foster et al. 2002) and popular the last three years, baits applied by ground or air are an important tool and accounted for 38,211 acres of the APHIS sponsored treatments applied to protect lands from Mormon crickets in 2004.

Flaky wheat bran bait (2% carbaryl) has been used in many states, but steam-rolled wheat and/or apple pumice bait (5% carbaryl) has recently gained popularity in some states, particularly Idaho and Utah. Apple pumice bait is available in two forms, pelletized and crumbled and was used for the first time in APHIS sponsored Mormon cricket programs in Idaho in 2002.

Studies in Idaho during 1976-1977 on immature and adult Mormon crickets (Foster et al. 1979) and Nevada in 1995 on immature Mormon crickets (Foster et al. 1996) have shown no advantage with 5% versus 2% carbaryl on wheat bran baits. However, changes in the

wheat bran bait have occurred over the years as a result of several changes in producers. Most notable is the use of more fine particles of feed grade wheat bran compared to the large or course flaky bakers grade wheat bran used in the 1970's and 1950's.

Data from studies with immature Mormon crickets conducted near Boise Idaho in 2003 (Foster et al. 2003) indicated no significant difference in mortality between 5% and 2% wheat bran bait and a 13% increase in secondary mortality with 5% compared to 2% apple pumice bait. It is noted that the difference in secondary mortality was not statistically significant in this study. However, discussions with APHIS personnel from both Idaho and Utah continue to indicate that the 5% concentration appears to produce quicker and/or higher mortality on adults. Additionally, Idaho personal indicated that visual observations of pelletized bait in the field suggest substantial longevity.

Development of additional data in Idaho will help to standardize the use of carbaryl concentrations on Mormon cricket bait and may lead to a new bait option or standard for Mormon cricket control. Lower use rates of carbaryl will have a reduced impact on the environment and should reduce the cost of the formulated bait. The following studies were conducted to compare the effectiveness of wheat bran and apple pumice baits containing 2% and 5% carbaryl for primary and secondary kill against adult Mormon crickets in Idaho. Additionally, a new bait derived from combined bakery, snack, cereal and confectionary waste by products was included in the studies. The effective residual life of the apple pumice pelletized bait was also evaluated.

Objectives

Evaluate and compare in field cages, the efficacy of apple pumice bait (crumbled), wheat bran bait, and a food waste bait (combined bakery, snack, cereal and confectionary waste) against adult Mormon crickets.

Evaluate and compare in field cages, the efficacy of 2% and 5% concentrations of carbaryl in baits against adult Mormon crickets.

Determine in field cages, the level of secondary kill that can be attributed to selected baits when adult Mormon crickets are exposed to potential meals of single bait-induced cadavers (Mormon cricket cadavers resulting from mortality produced by poison baits).

Determine in field cages, the effective residual life of pelletized apple pumice bait on immature Mormon crickets.

Materials and Methods

The study area was located ca. 15 miles east of Boise, Idaho on rangeland provided by Lori Atkins. The general location was selected because of the presence of Mormon

crickets, history of Mormon crickets in the area and availability of rangeland devoid of livestock.

Field Cage Apple Pumice Bait (5% pellets) Longevity Studies – immatures.

To determine the effective residual life of pelletized bait, Mormon crickets were exposed to whole pellets of apple pumice bait containing 5% carbaryl (Sevin 5% Bait, Wilbur Ellis) that had been aged under field conditions in Boise, Idaho for 0 to 74 days. Single pellets and immature Mormon crickets were confined in small bucket cages (two gallon bottomless buckets modified with screen sides and top) established on untreated improved rangeland (Figs. 1 and 2). Single pellets ranged from a treatment rate equivalent to 47.4 to 80.4 lbs/acre and averaged a treatment rate equal to 59.7 lbs/acre based on the size of pellet and cage. Average weights (based on 100 pellets) of different ages of bait can be seen in Figure 1. Ten cages were established for each of 7 exposure periods (0,4,11,18,25,32,39 days) and an untreated control. Each of the treatments including the untreated control was replicated 4 times. Therefore the replicated study utilized 320 cages. Each pellet of bait was introduced into the cage prior to introducing a single 2nd-3rd instar stage Mormon cricket to prevent cannibalism, a common occurrence when more than one cricket is confined in a cage. Cricket mortality was monitored daily for 9 days. This portion of the study was conducted from April, 29 through May, 8, 2004. Additionally, 35 days later an additional 10 cages (non-replicated) were similarly established for bait aged for 74 days. An additional 10 cages of untreated controls were also established at this time interval.

Field Cage Primary Kill Studies – adults.

Similarly, bucket cages were established to determine the primary mortality of more mature Mormon crickets exposed to 10 lbs/acre of 2% and 5% carbaryl in apple pumice (Sevin 2% and 5% Bait "Crumbles", Wilbur Ellis), wheat brand (Eco bran, Peacock Industries Inc.), and food waste (Tast-E-Bait, Advanced Organics Inc.) baits. Ten cages were established for each of the seven treatments including the untreated control. Each of the treatments including the untreated control, were replicated 4 times. Therefore, the study utilized a total of 280 cages. The appropriate amount of bait was pre-weighed for each cage in the laboratory and introduced into the cages prior to cricket introductions. Cages were stocked at the rate of one seventh instar stage or adult cricket per cage. Cricket mortality within cages was monitored daily for 10 days. The study was conducted from May 31 through June 9, 2004.

Field Cage Secondary Kill Studies – adults.

Similarly, field cages were established to determine the secondary mortality of Mormon crickets resulting from consumption of poisoned cadavers. In this study unexposed Mormon crickets were confined in untreated field cages with crickets freshly killed using the previously described treatments. The freshly killed crickets were obtained by confining single unexposed crickets to appropriate amounts of bait in 4.5 inch diameter x 3 inch high squat paper cups with screen tops in a temporary laboratory established for this purpose. All crickets were 7th instar stage or adult. Cadavers produced by Ecobait were washed in running water before placement in cages because fine particles of bait

were observed on the cadavers. Cadavers produced by other baits were simply shaken to remove any particles that may have adhered to the cadavers before placing them in cages. Again, all treatments were replicated 4 times with 10 cages per replicate utilizing a total of 280 squat cups and 280 bucket cages. An artificially killed (frozen overnight) cricket was included in the cages designated as untreated controls. A random field examination of 150 crickets showed the population used in the study to consist of 48% and 52% male and female crickets respectively. Cricket mortality within cages was monitored daily for 7 days. The study was conducted from June 3 through June 9, 2004.

Field Cage Unreplicated Studies – adults.
Several additional non-replicated field studies were conducted to assist in answering questions that arose during the major studies. These similarly relied on single crickets in bucket cages on rangeland (n=10) and are discussed within the major studies results section.

Analysis.
Analysis of all cage study data relied on a one-way analysis of variance and an all pair wise multiple comparison procedure (Tukey Test). Analyses were conducted on both unranked and ranked data.

Results and Discussion

Field Cage Apple Pumice Bait (5% pellets) Longevity Studies – immatures.
Pellets of bait placed on the ground and exposed to the elements for 0 through 39 days (replicated, Table 1) and 74 days (non-replicated, Table 4) (March 21 through June 3, 2004) resulted in statistically equivalent mortality to immature crickets. After crickets had been exposed to the baits for one day, mortality ranged from 63% to 75% and after 5 days of exposure mortalities had increased to 98% to 100% (Table 1). Baits from all intervals tested, resulted in significantly greater mortality to Mormon crickets compared to the untreated control population. The weight of 100 pellets exposed to the elements for each interval suggests a slight reduction in weight (Fig. 1), and had no impact on mortality expressed in this study. Precipitation recorded for the periods of bait exposure are shown (Fig. 4). Data from this study strongly suggest that pelletized bait that remains on the ground may remain strongly viable for controlling Mormon crickets for a substantial period of time.

Field Cage Primary Kill Studies – adults.
All baits studied resulted in significantly greater mortality compared to the untreated control population (Table 2). Numerically all three baits generally performed in dose rank order, particularly through the first 3 days after treatment. However, there was no significant difference in mortality resulting from the 2% and 5% concentrations of apple pumice “crumbles” and the food waste “Tast-E-Bait”. Also, there was also no significant difference between the 2% and 5% Eco Bran at 1,2, 9 and 10 days after treatment. Surprisingly, the 5% Eco bran resulted in significantly greater mortality than the 2% Eco bran at 3-8 days after treatment. All of the treatments produced statistically equivalent

mortality except for 2% Eco Bran which resulted in significantly lower mortality at 3-8 days after treatment. This difference between concentrations of Eco Bran is not consistent with results of studies conducted to compare the two doses on immature Mormon crickets at the same study area in 2003 (Foster et al. 2003). In that study there was no difference in mortality resulting from the two concentrations. Differences in mortality between baits cannot be explained by an inaccurate concentration of carbaryl. The concentration of carbaryl in all baits ranged from 15% less than desired with 2% and 5% Tast-E-Bait to 4% more than desired with "crumbles 5%". Chemical analysis of all baits used in this study are shown in Table 5. The authors note that Eco Bran used in this study visually appeared to consist of more fine particles than bait used in earlier studies. Because of this concern with fine particles, a small non-replicated field cage test was established to compare fine and course particles of Eco Bran as separated with a 20 mesh sieve. That test showed that fine particles of Eco Bran resulted in substantially lower mortality than course particles of the same formulation (Table 4) and may explain the differences seen between concentrations of Eco Bran and other baits in this study. It is important to note that at the end of this study (10 DAT), there was no significant difference in mortality resulting from any of the treatments studied. Additionally, a non-replicated test with 2% Tast-E-Bait containing molasses appeared to show no advantage in terms of increasing mortality or speed of mortality when compared with the non-molasses Tast-E-Bait in the replicated study (Table 4). Since both 'crumbles" and Tast-E-Bait particles contain greater mass in a single particle and therefore a larger dose of carbaryl per particle, a single bite of those baits may provide sufficient toxicity to result in death compared to Eco bran particles.

Field Cage Secondary Kill Studies – adults.

There was no significant difference in secondary mortality resulting from the two Eco Bran concentrations and untreated cadavers (Table 3). Also, the 2% concentration of "crumbles" produced no significant secondary mortality compared to untreated cadavers except at 6 and 7 days after treatment where it produced significantly higher mortality. However, the 5% "crumbles" and both concentrations of the Tast-E-Bait resulted in significantly higher mortality than produced by untreated cadavers. There was no significant difference between secondary mortality resulting from the "crumbles" 5% and Tast-E-Bait 2%. However, 5% Tast-E-Bait produced significantly greater secondary mortality than all other treatments and the untreated cadavers. Numerically all baits performed in dose rank order. With the exception of one, all bait induced cadavers had been fed upon at one day after exposure. The one exception was fed upon between one and two days after exposure. The lack of secondary mortality attributed to Eco Bran is consistent with the results from unpublished secondary kill studies conducted in Nevada in 1995 by the two senior authors (Foster et al. 1996). The secondary kill produced by the other baits was unexpected. In an attempt to help explain the differences in secondary mortality, a three day non replicated field cage test was conducted to generate data on unwashed cadavers produced by 5% Eco Bran and washed cadavers produced by 5% "crumbles" and 5% Tast-E-Bait, before exposure to Mormon crickets. Data from that test (Table 4) suggest that lack of washing cadavers with water may slightly increase secondary mortality resulting from Eco Bran, may have little effect on secondary mortality resulting from "crumbles" and may slightly decrease secondary mortality

resulting from Tast-E-Bait. The Eco Bran levels might be significantly greater than untreated controls but the mortality resulting from the Tast-E-Bait was judged by the authors to still be significantly higher than untreated controls. Only additional studies which insure that cadavers are completely free of bait particles will fully answer these questions.

Conclusions

Pellets of apple pumice bait containing 5% carbaryl demonstrated consistent and significant activity for environmental exposure periods from 0 through 74 days. Even though exposed pellets appeared to lose a slight amount of mass during the aging process, mortality of Mormon crickets exposed to these aged baits ranged from 98% to 100 % after 5 days of exposure. A pellet may have activity against Mormon cricket for as long as it remains visually intact. However, pellets may not be available for Mormon cricket consumption for such lengths of time if other consumers have taken the bait. Additional study will be required to determine the full potential and actual field longevity of apple pumice pellet bait.

Wheat bran, apple pumice and food waste baits produced effective primary mortality to adult Mormon crickets. However, Eco Bran bait showed numerically lower mortalities and took slightly longer to attain mortality levels demonstrated by "crumbles" and Tast-E-Bait. These differences may be a result of finer particle composition in Eco Bran bait noted during the studies. Other tests conducted during this study indicated that courser particles of bran produced higher mortality than fine particles. However, the lower mortality associated with fine particles may simply be a function of particle discovery by the insect.

"Crumbles" 5% and Tast-E-Bait 2% and 5% resulted in substantially significant secondary mortality to Mormon crickets while Eco Bran resulted in no significant secondary mortality. These differences are currently unexplained. However, they may be a result of procedures used to insure no adherence of bait to the cadaver or may reflect a higher level of toxicant in cadavers which fed on particles of greater mass compared to Eco Bran. Greater mass particles containing more toxicant may have allowed for transfer of a higher level of carbaryl to the secondary consumer, especially if a single bite of these type of particles provides substantially more than a lethal dose. It is reasonable to expect that as soon as the cricket consumes a dose sufficient to cause sickness, that feeding will discontinue even though death may not always occur. Therefore some bait may result in sickness and death and other bait in only sickness. Additional studies may be required to fully understand the differences in secondary mortality to adult Mormon crickets seen between the baits in this study.

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Table 1. Mortality of immature Mormon crickets treated with 5% apple pumice pellet bait aged for selected periods of time – Boise, Idaho 2004.

	Days after treatment – mean % mortality [2]				
Treatment [1]	1	2	3	4	5
39 days	60 a	80 a	93 a	98 a	100 a
32 days	73 a	95 a	95 a	95 a	100 a
25 days	68 a	82 a	93 a	98 a	100 a
18 days	73 a	90 a	90 a	93 a	98 a
11 days	55 a	78 a	88 a	93 a	100 a
4 days	63 a	83 a	95 a	98 a	98 a
Unexposed	75 a	88 a	93 a	95 a	100 a
Untreated	0 b	0 b	0 b	3 b	8 b

[1] Period of time bait was exposed to environmental elements, before exposed to immature Mormon crickets.
[2] Data was evaluated using analysis of variance with a Tukey multiple comparison method. Means in a column followed by the same letter are not significantly different ($P \leq 0.05$).

Table 2. Primary mortality of adult Mormon crickets exposed to selected carbaryl baits in field cages – Boise, Idaho 2004.

	Days after treatment – mean % mortality [1]									
Treatment	1	2	3	4	5	6	7	8	9	10
Eco Bran 2%	43 a	55 b	73 b	78 b	83 b	83 b	83 b	85 b	88 a	93 a
Eco Bran 5%	65 a	75 ab	90 a	93 a	95 a	95 a	98 a	98 a	98 a	98 a
Sevin Crumbles 2%	60 a	78 ab	95 a	100 a	100 a	100 a	100 a	100 a	100 a	100 a
Sevin Crumbles 5%	75 a	93 a	98 a	98 a	98 a	100 a	100 a	100 a	100 a	100 a
Tast-E-Bait 2%	45 a	75 ab	93 a	100 a	100 a	100 a	100 a	100 a	100 a	100 a
Tast-E-Bait 5%	63 a	85 ab	93 a	95 a	95 a	98 a	98 a	98 a	100 a	100 a
Untreated	0 b	0 c	0 c	0 c	0 c	3 c	5 c	8 c	18 b	25 b

[1] Data was evaluated using analysis of variance with a Tukey multiple comparison method. Means in a column followed by the same letter are not significantly different ($P \leq 0.05$).

Table 3. Secondary mortality of adult Mormon crickets exposed to selected bait induced single cadavers in field cages – Boise, Idaho 2004.

	Days after treatment – mean % mortality [1]						
Treatment	1	2	3	4	5	6	7
Eco Bran 2%	3 c	3 c	3 c	3 e	3 e	5 e	8 de
Eco Bran 5%	5 c	8 c	8 c	10 de	10 de	10 de	10 de
Sevin Crumbles 2%	3 c	18 bc	28 bc	28 cd	28 cd	30 cd	30 cd
Sevin Crumbles 5%	25 bc	40 b	50 b	58 b	60 b	60 b	63 b
Tast-E-Bait 2%	30 b	40 b	40 b	45 bc	45 bc	50 bc	53 bc
Tast-E-Bait 5%	55 a	75 a	83 a	85 a	88 a	88 a	88 a
Untreated	3 c	5 c	5 c	5 de	5 de	5 e	5 e

[1] Data was evaluated using analysis of variance with a Tukey multiple comparison method. Means in a column followed by the same letter are not significantly different ($P \leq 0.05$).

Table 4. Mean mortality of adult Mormon crickets exposed to non-replicated selected treatments of carbaryl bait and cadavers resulting from carbaryl bait – Boise, Idaho 2004.

	Days after treatment – mean % mortality									
Treatment [1]	1	2	3	4	5	6	7	8	9	10
Tast-E-Bait 2% mol	50	80	90	90	90	100	100	100	100	100
Untreated	0	0	0	0	0	3	5	8	18	25
74 day exposure	90	100	100							
Untreated	0	0	0							
Eco Bran 2% fine	0	10	10	10						
Eco Bran 2% coarse	50	80	80	80						
Untreated	0	0	0	0						
Eco Bran 5% unwashed [2]	20	0	20							
Sevin Crumbles 5% washed	30	30	40							
Tast-E-Bait 5% washed	40	60	60							
Untreated	0	0	0							

[1] Studies were conducted May, 31 – June 9, 2004
[2] Secondary mortality study

Table 5. Laboratory analysis of carbaryl in selected Mormon cricket baits.

Bait	% carbaryl composition [1]
Eco Bran 2%	2.0
Eco Bran 2% (fine particle)	2.4-2.9
Eco Bran 2% (coarse particle)	1.8
Sevin Crumbles 2%	3.0
Sevin Crumbles 5%	5.2
Tast-E-Bait 2%	1.7
Tast-E-Bait 5%	4.5

[1] Data provided by USDA, Analytical and Natural Products Chemistry Laboratory, Gulfport, Mississippi.

Figure 1. Close-up view of field bucket cage used to confine Mormon cricket test insects near Mayfield, Idaho 2004.

Figure 2. View of field bucket cage setup used in Mormon cricket bait studies near Mayfield, Idaho 2004.

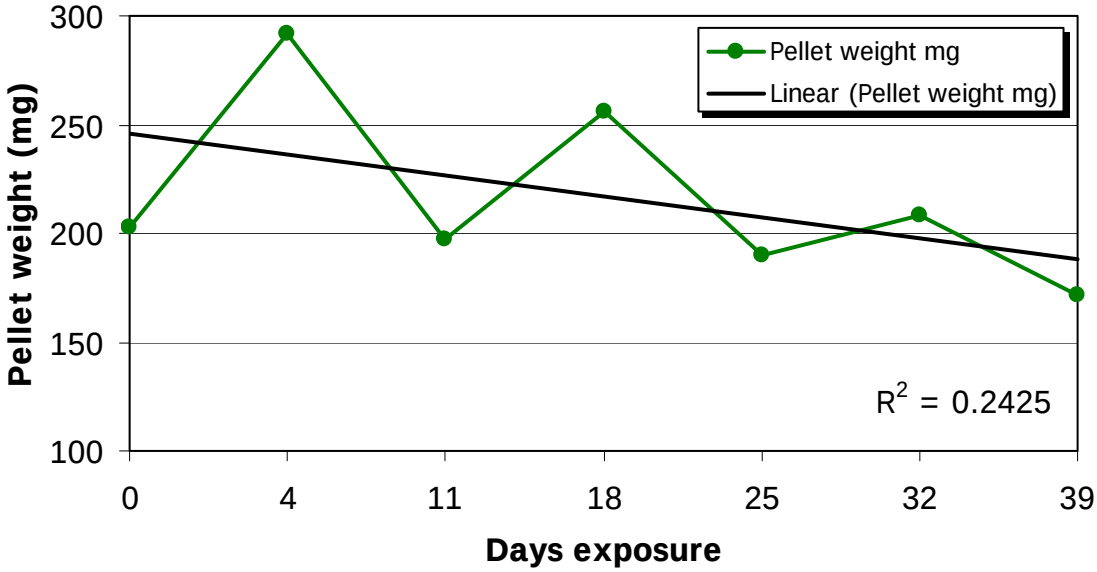

Figure 3. Mean weight of 100 pellets of apple pumice bait containing 5% carbaryl exposed to environmental elements at selected intervals of time.

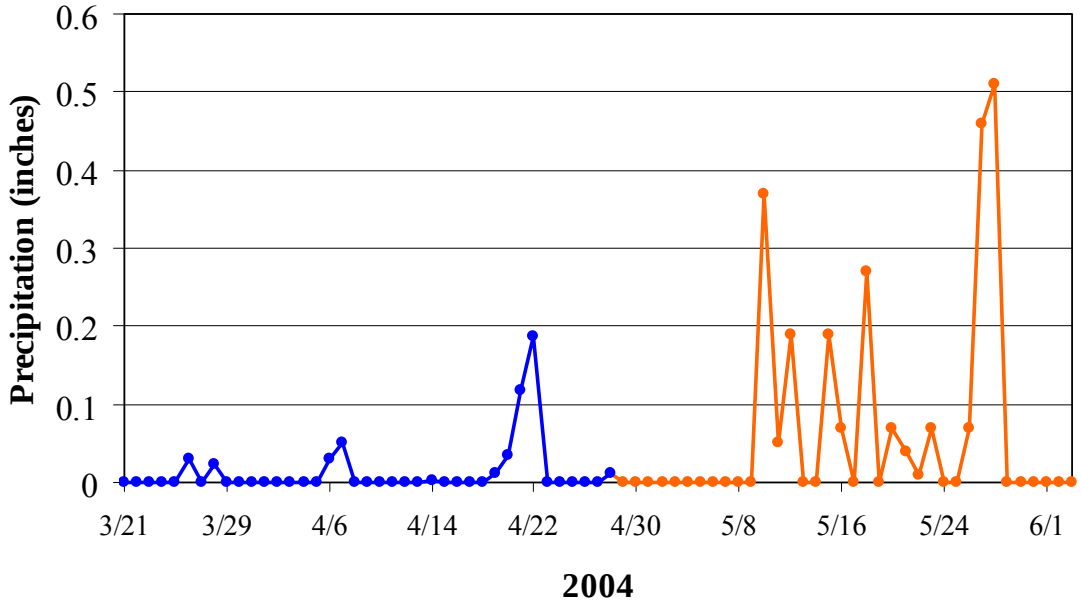

Figure 4. Daily precipitation for Boise, Idaho, 2004 during the period of pelletized bait exposure (exact location – blue; Boise airport – orange) before introduction into

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Field evaluation of the fungus *Beauveria bassiana* in unrefined canola oil and refined soybean oil and evaluation of potential attractants for use against grasshoppers on rangeland.

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Introduction

There are no generally accepted entomopathogenic treatments available for use against grasshoppers and Mormon crickets in the United States. Sensitive situations commonly encountered within the western states in potential program areas preclude traditional chemical insecticide treatments. The number of sensitive situations is increasing and in areas of grasshopper infestations their presence at best complicate and more often prevent much needed local or area-wide treatments of grasshoppers and/or Mormon crickets on rangeland.

In the early 1990's, extensive work on the development of the fungus *Beauveria bassiana* by Mycotech Corporation and USDA-APHIS "Methods" (Foster et al. 1996-1999) led to its registration in the US even though final development for wide scale acceptance and use was never achieved. Even though the "stressor concept " (Foster et al. 1996; Reuter et al. 1996) indicated potential promise, USDA-CPHST efforts in its development were redirected from 1995 until 2002. However, interest has recently been renewed with work conducted by the University of Wyoming which indicates that canola oil as an attractant and diluent may improve results. Collaborative work conducted by the University of Wyoming (Lockwood, 2003) and the USDA- ARS (Jaronski et al. 2003) has indicated

that an effective formulation may result by simply applying the spores in canola oil rather than paraffinic oil. While non-replicated, that work indicated substantial differences between *Beauveria bassiana* treatments applied in canola oil compared to untreated control populations. In 2004, joint APHIS and ARS replicated studies (Foster et al. 2003) conducted to verify the improvement of canola oil compared to a paraffinic oil diluent, showed that no significant increase in grasshopper mortality compared to untreated populations could be attributed to either of the oils studied. However, subsequent unpublished laboratory studies conducted by Stephan Jaronski, have revealed grasshoppers exhibited greater infection levels and consumption amounts when exposed to paper disks treated with raw canola oil and *Beauveria bassiana* compared to the refined canola oil and *Beauveria bassiana* mixture that had been used in both the 2003 and 2004 studies.

Because non-chemical options are highly desirable and significant controversy still exists regarding the attractancy and resulting impact on grasshopper treatment efficacy of some diluents, the following study was conducted to evaluate and determine in the field the best currently envisioned *Beauveria bassiana* mixture for use against grasshoppers on rangeland.

Objectives

Determine if the Emerald BioAgricultutal Corporation registered isolate and formulation of *Beauveria bassiana* delivered in soybean oil for dilution with other oils is effective against grasshoppers on rangeland.

Compare the registered isolate of *Beauveria bassiana* applied in soybean oil or raw (unrefined) canola oil for effectiveness against grasshoppers on rangeland.

Compare the effectiveness of uniform coverage and reduced agent area treatment (RAATs) (Foster et al. 2000) with 50% of the area treated using *Beauveria bassiana* against grasshoppers on rangeland.

Evaluate the droplet density and distribution in uniform and RAATS applications with *Beauveria bassiana.*

Evaluate unrefined and refined canola oil, cottonseed oil and “unsulphured” molasses for stimulating major grasshopper movement between untreated and treated rangeland.

Materials and Methods

The center of the study areas was located in Fall River county of southwestern South Dakota approximately 11 miles west and 8 miles north of the town of Edgemont on the Mark Tubbs ranch. This specific location was identical to that used in 2003 studies (Foster et al. 2003) and was selected to take advantage of the residual background levels of *Beauveria bassiana* resulting from the previous treatments. The general location was selected because of the density of grasshoppers, history of grasshoppers and the abundance of contiguous grasshopper infested rangeland.

Beauveria bassiana Field Study.

The Emerald BioAgricultural Corporation GHA (128924) strain of *Beauveria bassiana,* Mycotrol O Emulsifiable Suspension Mycoinsecticide (supplied at 2 x10^{13} spores per 32 fluid oz of mix containing soybean oil (Golden Pest Oil) as the undiluted carrier), was applied to 40 acre rangeland plots in the following treatments: (1) 1 x 10^{13} spores/acre in 32 fluid oz/acre of formulation containing additional soybean oil applied to 50% of the plot. Treatment applied to one plot on July 15 and three plots on July 17. (2) 1 x 10^{13} spores/acre in 32 fluid oz/acre of formulation containing unrefined canola oil applied to 50% of the plot. Treatment applied on July 16. (3) 1 x 10^{13} spores/acre of formulation containing unrefined canola oil applied to 100% of the plot. Treatment applied on July 17. and (4) 32 fluid oz/acre of unrefined canola oil applied to 100% of the plot. Treatment applied on July 17. Treating 50% of a plot was achieved by calibrating the aircraft for a 100 foot wide swath and spacing the aircraft during treatment at 200 feet. All treatments were replicated four times. Untreated control plots were included in the experimental design.

All treatments were applied with an USDA, APHIS aircraft (Cessna Ag-Truck equipped with a standard commercial spraying system) which was operated by an APHIS pilot who is highly experienced with precision work for research. The aircraft was also equipped with differentially corrected guidance and recording systems. However, primary guidance was provided by ground personnel that measured each swath and gathered meteorological data during application. The aircraft was additionally equipped with winglets (DBA-Ag Tips; Clark Oberholtzer, Alberta Canada). Prior to application, the aircraft spray system was calibrated to operate under parameters which resulted in delivery of spray within one percent of the desired rate per acre for each of the treatments applied. Calibration for each of the treatments was accomplished by collecting and measuring the amount of material sprayed through each nozzle for each treatment set up, for a predetermined amount of time and making adjustments in pressure until the desired output was achieved. The aircraft was calibrated for delivering a 100 feet wide swath for all treatments.

All treatments were applied using 15 nozzles and stainless steel 8004 Flat Fan Tee Jet nozzle tips oriented straight down and operated at 32psi of pressure. A 50 mesh in line strainer was used for the entire spray system and each nozzle was equipped with a slotted screen. All treatments were applied from an altitude of 30 to 70 feet**.** Winds during application ranged from < 1.0 to 4.5 mph and averaged 2.0 mph. Winds for specific plots and other meteorological conditions recorded during application of the treatments are

summarized in Table 1. During the study, minimum temperatures ranged from 46° to 68° and averaged 59° F while maximum temperatures ranged from 64° to 102° and averaged 89° F. Detailed temperatures and precipitation recorded during the study can be seen in Fig. 1.

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 counted and sampled on each day a treated plot was monitored. Grasshopper densities were determined by counting grasshoppers in (40) 0.1 m^2 rings arranged in a circle near the center of each plot. Rings were separated from adjacent rings by ca. 5 yards. Individual plots were counted by the same person for the duration of the study.

The abundance of each species was determined from uniform sweep samples taken at each site (Foster and Reuter, 1996). Each sample consisted of 20 high and fast sweeps and 20 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.

Near the center of one plot of each of the different treatments, Tee Jet oil sensitive spray cards were placed ca. 18 inches above the ground in a 400 yard long line located perpendicular to the line of flight to characterize spray deposition. Cards were separated from adjacent cards by ca. 5 yards and placed immediately prior to application and were collected shortly after application and returned to the laboratory for analysis. Using a template, five, one square centimeter areas on each card, were counted to determine the density of spray droplets deposited.

Attractant Study.

Four parallel transects (each considered a replication) of 0.1 m^2 rings for determining grasshopper densities were established and treated to evaluate attractiveness of refined canola oil, cottonseed oil and water containing 3% by volume of Grandma's Unsulphured Molasses. An untreated control was included in the design. Transects were separated from adjacent transects by 50m. Within each transect, 4 sets of 40 rings were established with rings separated from adjacent rings by 5 m and sets separated by 50m. Each of the sets of rings within a transect (replicate) were sprayed with one of the above treatments or left as an untreated control. Treatments were applied using an ATV with a single wand mounted nozzle fitted with a size 800067 Tee Jet Flat Fan spray tip calibrated to deliver 280 ml/min (156 fluid oz/acre) at 10 mph. with a 3 feet wide swath. The position of each treatment within a transect (replicate), was randomly selected. Pre-treatment counts were conducted the day before treatment and post-treatment counts were

conducted at 1, 2, 3, 4, and 7 days after treatment. This study was conducted from July 13 – July 21. Additionally, two more transects in the same area were similarly established to evaluate unrefined canola oil against untreated populations from July 19 –July 26.

Analysis

Field data were expressed as percent survival based on pretreatment counts in the same plot or were 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.

Field data was analyzed using an analysis of variance with the Tukey multiple comparison test to separate means. All field analyses were performed with SYSTAT for Windows (SPSS Inc. 1997).

Results and Discussion

Beauveria bassiana field study.

Pretreatment densities from individual sites ranged from 17.2 to 20.6 and averaged 18.8 grasshoppers/m ^{2} in the treated plots and from 19.1 to 26.5 and averaged 23.2 grasshoppers/m^2 in the untreated plots. At the time of treatment, the population was composed of 1.0 % first instars, 1.0 % second instars, 1.4 % third instars, 2.9 % fourth instars, 17.2 % fifth instars and 76.5 % adults. The total mean age was 5.9. The five most dominant species were *Ageneotettix deorum* (42%), *Aulocara elliotti* (31%), *Cordillacris occipitalis* (7%0, *Amphitornus coloradus* (5%), and *Aulocara femoratum* (2%). The relative abundance of all species in pretreatment samples is shown in Table 3.

At one, two and three weeks after treatment, none of the *Beauveria bassiana* treatments showed a significant population reduction compared to the untreated populations (Tables 4 and 5). Populations actually increased in many cases. There were no significant differences between any of the treatments at 2 or 3 weeks after treatment. The only significant differences between treatments in this study occurred at 7 days after treatment. At one week after treatment, the *Beauveria bassiana* and canola (100% coverage) treatment resulted in a population increase significantly greater than occurred in untreated populations (Table 3). Additionally, when mortalities were corrected for untreated population changes, the *Beauveria bassiana* and canola (100% coverage) treatment

showed a significantly greater population increase than the increases seen in populations treated with *Beauveria bassiana* and canola (50% coverage)(Table 4). If attraction to canola results in major grasshopper movement, greater increased populations in the *Beauveria bassiana* and canola (100% coverage) compared to the same treatment with 50% coverage may be explained. However, these differences in population increases were not seen at subsequent post treatment intervals and there was no difference between population levels of grasshoppers treated with straight canola oil (100% coverage) and the untreated populations.

While these results are inconsistent with those reported by Lockwood (2003) and Jaronski et al. (2002) for a collaborative study conducted in Wyoming they are consistent with data from studies in South and North Dakota reported by Foster et al. (1991, 1992, and 1993). In those studies no statistical difference in reductions of grasshopper populations could be detected between unconfined populations treated with *Beauveria bassiana* at 1 x 10^{13} spores per acre when compared to untreated populations, except when a sub-lethal stressor was added to the formulation in a Nebraska study (Foster et al. 1996). Our results are also consistent with results reported by Foster and Jaronski et al. (2003) from studies conducted in South Dakota in 2003. In those studies there was no statistical difference in population reductions among the *Beauveria bassiana* treatments or between those treatments and untreated control populations, even though laboratory evaluations showed there was sufficient grasshopper exposure to conidia to cause death.

Examination of spray cards revealed a mean number of 15.1 and 13.6 droplets/cm^2 were deposited in the *Beauveria bassiana* with canola oil at 100% coverage and the canola oil without *Beauveria bassiana* at 100% coverage plots, respectively (Table 6). *Beauveria bassiana* with soybean or canola oil applied at 50% coverage resulted in 3.7 and 4.4 droplets/cm^2, respectively. Deposition in the 50% coverage plots was less than expected. Based on the full coverage plots, we expected ca. 6-8 droplets /cm^2 to be deposited on the spray cards. However, during evaluation it was noted that droplets on some cards were becoming more difficult to see and might be disappearing as time intervals increased between droplet deposition and microscopic examination. Data in Table 6 appear to support that observation. In both 50% and 100% coverage treatments, the largest number of droplets was recorded for the shortest interval between card exposure and examination. Additionally, spray droplets found on essentially all of the spray cards in both 100% and 50% coverage plots indicated that no area actually escaped deposition of some spray even though coverage was reduced to 50% and meteorological conditions for application were excellent in this study.

Attractant Study.

Only the cottonseed oil treated plots showed significant population increases compared to the untreated populations at one day after treatment. Compared to the untreated populations, no significant differences in populations occurred with any of the treatments during the remainder of the study at 2, 3, 4, and 7 days after treatment. It is worthy to note that populations were declining in all of the plots during the study, and was most likely attributable to the deteriorating condition of the vegetation and the advanced stage of grasshoppers and their general movement to more desirable vegetation. The authors

determine these results to be inconclusive because of the general movement which obscured any possible population differences resulting from attraction. The study should be repeated on younger grasshoppers earlier in the season before loss of vegetation can stimulated major grasshopper movement.

Conclusions

In this study there was no statistical difference in population reductions among the *Beauveria bassiana* treatments or between those treatments and untreated control populations or populations treated with unrefined canola oil without *Beauveria bassiana*. Less spray droplets were recorded on the 50% coverage plots than expected. However, the authors suggest this may be related to the varying time intervals between deposition on and examination of spray cards. The largest number of spray droplets was recorded for the shortest interval between card exposure and examination. Spray cards from different treatments should be examined at similar post treatment intervals to avoid confounding results in the future. Additionally, spray droplets found on essentially all of the spray cards in both 100% and 50% coverage plots indicated that no area actually escaped deposition of some spray even though coverage was reduced to 50% and meteorological conditions for application were excellent in this study. In attractancy studies, only cottonseed oil treated plots showed significant population increases compared to untreated populations at one day after treatment. No differences were seen at 2, 3, 4 and 7 days after treatment. However the authors consider these results inconclusive because of the general movement of grasshoppers out of the area. Additional studies should be conducted to further evaluate the attractancy of selected candidates.

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Figure 1. Daily minimum and maximum temperatures and precipitation recorded in the study area near Edgemont, South Dakota, 2004.

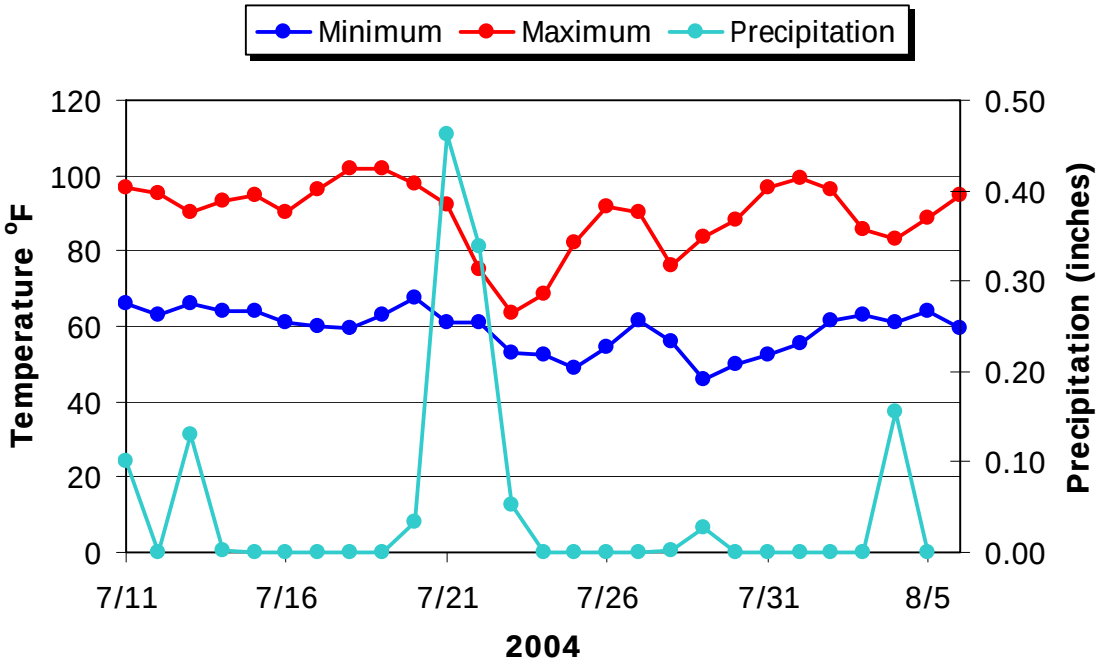

Table 1. Meteorological conditions recorded during aerial application of treatments in the grasshopper study near Edgemont, South Dakota, 2004.

						Temperatures °F.						
	%	Plot		Time (AM)		Ground		Air		Pilot	Wind (mph)	
Treatment [1]	cov.	no.	Date	Start	End	Start	End	Start	End		Start	End
Bb canola	50	9	16-Jul	5:06	5:13	61	60	62	62	61	3 W	4 W
		18	16-Jul	5:14	5:21	58	58	62	61	60	2-3 W	1-3 W
		20	16-Jul	5:32	5:39	59	60	63	63	61	2-4 W	3-5 W
		15	16-Jul	5:38	5:45	60	62	62	62	61	3 W	3-4 W
Bb canola	100	5 + 6	17-Jul	5:05	5:15	60	59	66	62	61	1-3 SW	<1 SW
		3 + 4	17-Jul	5:18	5:31	60	60	63	63	62	1-2 NW	1 NW
Bb soybean	50	2	15-Jul	5:10	5:17	64	64	68	67	65	2 SW	2 SW
		10	17-Jul	6:10	6:16	60	62	63	65	61	0-2 SW	0-1 SW
		7	17-Jul	6:16	6:22	61	62	63	64	64	1-2 W	1 W
		12	17-Jul	6:25	6:31	65	65	68	70	65	1-2 S	<1 SE
Canola only	100	14	17-Jul	7:25	7:31	71	73	72	75	67	2-3 W	2 W
		8	17-Jul	7:30	7:39	70	69	71	73	67	1-2 NW	0
		19	17-Jul	7:40	7:47	74	76	76	78	68	1-2 W	<1 NW
		11	17-Jul	7:49	7:57	73	73	72	75	69	1 NW	2-3 NW

[1] *Beauveria bassiana* treatments all applied at 1.0E+13 spores per acre.

Table 2. Grasshopper species composition and age structure prior to applications in the treated plots.

	Instar							
Species (as of 7/11/2004)	1	2	3	4	5	Adult	**Total**	%
Gomphocerinae								
Ageneotettix deorum		1	10	46	312	649	1018	42.24
Amphitornus coloradus					10	110	120	4.98
Aulocara elliotti			3	2	15	732	752	31.20
Aulocara femoratum			3	3	10	39	55	2.28
Cordillacris occipitalis					1	173	174	7.22
Eritettix simplex						3	3	0.12
Mermiria bivittata			4		1	1	6	0.25
Opeia obscura			4	4	3	1	12	0.50
Phlibostroma quadrimaculatu	2		2	3	10	7	24	1.00
Psoloessa delicatula	18					4	22	0.91
Melanoplinae								
Melanoplus angustipennis					1		1	0.04
Melanoplus bowditchi						1	1	0.04
Melanoplus confusus						13	13	0.54
Melanoplus infantilis					2	5	7	0.29
Melanoplus occidentalis						1	1	0.04
Melanoplus packardii			2	1	4	2	9	0.37
Melanoplus sanguinipes				3	26	78	107	4.44
Oedipodinae								
Arphia conspersa	3						3	0.12
Hadrotettix trifasciatus				1	3	3	7	0.29
Hippiscus ocelote					1		1	0.04
Pardalophora haldemani	2	23				5	30	1.24
Spharagemon collare			1	2	8	4	15	0.62
Spharagemon equale			1	1			2	0.08
Trachyrhachys kiowa			3	4	7	11	25	1.04
Xanthippus corallipes						2	2	0.08
Totals	25	24	33	70	414	1844	**2410**	
%	1.04	1.00	1.37	2.90	17.18	76.51		

Table 3. Efficacy of *Beauveria bassiana* with selected diluents using conventional and RAATs aerial application spacing on replicated 40 acre plots.

Treatment [1]	Days after treatment – mean % mortality [2]		
	7	14	21
Bb canola 50%	-12 ab	-3 a	21 a
Bb canola 100%	-16 b	-19 a	11 a
Bb soybean 50%	-7 ab	-5 a	15 a
Canola only 100%	9 ab	0 a	43 a
Untreated	26 a	-4 a	21 a

[1] *Beauveria bassiana* @ 1.0E+13 spores per acre, diluent and spray coverage
[2] Data evaluated utilizing analysis of variance with the Tukey multiple comparison method. Means in a column followed by the same letter are not significantly different ($P \leq 0.05$).

Table 4. Efficacy of *Beauveria bassiana* with selected diluents using conventional and RAATs aerial application spacing on replicated 40 acre plots (adjusted for untreated control mortality).

Treatment [1]	Days after treatment – mean adjusted % mortality [2]		
	7	14	21
Bb canola 50%	-16 a	-8 a	13 a
Bb canola 100%	-71 b	-20 a	-17 a
Bb soybean 50%	-50 ab	-10 a	-9 a
Canola only 100%	-42 ab	-6 a	22 a

[1] *Beauveria bassiana* @ 1.0E+13 spores per acre, diluent and spray coverage
[2] Data evaluated utilizing analysis of variance with the Tukey multiple comparison method. Means in a column followed by the same letter are not significantly different ($P \leq 0.05$).

Table 5. Mean spray droplet deposition of selected treatments.

Treatment	Count/cm^2	Date counted	Date treated	Days between treatment & count
50% soybean	3.7	July 19	July 15(1) 17(3)	2 – 4
50% canola	4.2	July 18	July 16	2
100% canola	13.6	July 19	July 17	2
100% canola Bb	15.1	July 18	July 17	1

Table 6. Changes in grasshopper populations in untreated and candidate attractant treated swaths.

Treatment	Days after treatment - % population change				
	1	2	3	4	7
Canola (refined) [1]	2 ab	-11 a	-29 a	-35 a	-57 a
Cottonseed oil	24 a	-7 a	-18 a	-21 a	-38 a
Unsulphured molasses	-9 ab	-14 a	-12 a	-14 a	-66 a
Untreated	-28 b	-21 a	-17 a	-27 a	-38 a
Raw canola [2]	11	-1	-70	-64	-59
Untreated	1	-25	-79	-64	-56

[1] Data evaluated utilizing analysis of variance with a Tukey multiple comparison method. Means in a column followed by the same letter are not significantly different ($P \leq 0.05$).
[2] Data evaluated with a Mann-Whitney test ($P \leq 0.05$). No significant differences were detected.

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Evaluation of selected diluents and doses of malathion against adult grasshoppers under drought and poor rangeland conditions in northwestern Goshen County, Wyoming.

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Introduction

Recent developments in reduced agent-area treatments (RAATs) strategies (Foster et al. 2000; Lockwood et al. 2000) have greatly improved the economics of grasshopper treatments. However, room for additional improvement, particularly with malathion, still exists. With the RAATs strategy, maximum control is not the goal (Larsen and Foster, 1996-1999) and greater attention is afforded to actual cost benefit parameters through economic analyses (Berry et al. 1996). Additionally, lower than traditional insecticide doses are used in combination with alternated directly treated and untreated swaths. However, material is unintentionally deposited in the area not directly treated and this material has an impact on the overall effectiveness of RAATs strategies. Carbaryl and diflubenzuron treatments are used in RAATs treatments that cover a maximum of 50% of the acreage to be protected while malathion is used in a treatment that covers 80% of the acreage to be protected. Generally, this design is considered to be a result of the persistence of the insecticide used. Shorter persistence requires smaller areas left untreated between swaths. However, when malathion is used in RAATs treatments, a total volume of 4 fl oz/acre is applied compared to 16-31 fl oz/acre with carbaryl and

diflubenzuron, respectively. The small total volume used with malathion appears insufficient to accommodate a larger spacing of the aircraft during application. Simply increasing the total volume of a malathion mix applied by adding a diluent may provide a sufficient volume of material to increase the swath spacing to approximate the spacing used with other chemicals; therefore decreasing the maximum amount of acreage that must be directly treated.

During a study to compare several doses of malathion and encapsulated malathion (Foster et al. 2000), data was developed which strongly indicated that the standard formulation of malathion Fyfanon ULV can be further developed for use in RAATs strategies by adding a cotton seed oil diluent to increase the total volume applied per acre while still further reducing the amount of AI applied per acre. Their data indicate that reductions from the current 4 fluid oz per acre of malathion to 3 or 2 and perhaps even 1 fluid oz per acre may be possible if cotton seed oil diluent is added. A reduction to the two oz AI level with 8 fluid oz of cotton seed oil and treated as RAATs in 50% coverage is estimated to cost a remarkable $0.64 for formulation and $0.78 for application per treated acre ($0.71 per protected acre in RAATs). This compares to the traditional uniform coverage of 8 fl oz/ac of malathion at a total of $2.86/ac. Such a treatment would become the least expensive aerial treatment for rangeland grasshoppers and would average one fluid oz AI per acre, an incredible one third as much AI per acre as mosquito treatments that rely on malathion.

While being environmentally desirable, a lower active ingredient requirement with resulting cost reductions will improve the economics of malathion use and will help promote stronger competition among companies that supply chemical tools for grasshopper suppression on private, state and federal rangeland. The following study was conducted to further evaluate, in replicated studies, the data generated in 2002 and to evaluate the selected treatments under a worst case scenario against adult grasshoppers under drought and poor rangeland conditions.

Objectives

Determine in the field, the potential for increasing mortality with low doses of Fyfanon ULV by increasing the total volume applied / acre with a cotton seed or canola oil dilluent.

Specifically, evaluate and compare the standard traditional malathion treatment of 8oz/acre applied to 100% of the acreage and 2, 3 and 4 fl oz/acre of malathion applied in a total volume of 10 fl oz/acre of cotton seed oil to 50% of the acreage for activity against grasshoppers.

Specifically, valuate and compare the standard RAATS treatment of 4oz/acre of malathion applied to 80% of the acreage and 2, 3 and 4 fl oz/acre of malathion applied in a total volume of 10 fl oz/acre of cotton seed oil to 50% of the acreage for activity against grasshoppers.

Specifically, evaluate and compare 3 fl oz/acre of malathion plus 7 fl oz/acre of cotton seed oil and 3 fl oz /acre plus 7 fl oz/acre of canola oil for activity against grasshoppers.

Specifically, evaluate and compare 2 fl oz/acre plus 8 fl oz /acre of cotton seed oil and 8 fl oz/acre of malathion both applied to 100% of the acreage for activity against grasshoppers.

Methods and Materials

Study Site

The center of the study was located in northwestern Goshen County, Wyoming approximately 12.5 miles west and 1 mile south of the town of Jay Em, on the Don McDowell, Lavon Cochran and Jaron Fredricks ranches. The general location was selected because of grasshopper density, adult age, history of grasshopper problems, and abundance of contiguous grasshopper infested land.

Treatments and Experimental Design

The undiluted Fyfanon ULV formulation was used for comparison and in all mixes with cotton seed oil or canola oil. The treatments studied were 2, 3 and 4 fl oz/acre of Fyfanon ULV increased to a total volume of 10 fl oz /acre for application with cotton seed oil and 3 fl oz/acre of Fyfanon ULV increased to total volume of 10 fl oz/acre for application with canola oil (0.155, 0.232, 0.309 and 0.232 lb AI/ac, respectively). These treatments were applied at 50% coverage. Additional treatments studied were 2 fl oz/acre of Fyfanon ULV increased to a total application volume of 10 oz/acre with cotton seed oil and applied at 100% coverage; 4 fluid oz /acre of undiluted Fyfanon ULV applied at 80% coverage; and 8 fl oz/acre of undiluted Fyfanon ULV applied at 100% coverage (0.155, 0.309 and 0.618 lb AI/ac respectively). All treatments were aerially applied to square 40 acre grasshopper infested rangeland plots and were replicated four times. Four untreated plots were included in the experimental design. The replicated study consisted of 32 forty acre plots. To insure than any one treatment was not assigned exclusively to plots with high or low grasshopper densities and that all treatments are tested against similar population densities, pretreatment counts were arranged in descending order, divided into groups of eight, and each of the 8 treatments, including the untreated control, were randomly assigned to one of the eight plots within each group.

The 4 oz at 80% coverage, 8 oz at 100% coverage and 4 oz plus 6 oz cotton seed oil at 50% coverage were applied on June 29. The 3 oz plus 7 oz cotton seed oil applied at 50% coverage, 2 oz plus 8 oz cotton seed oil applied at 100% coverage and 2 oz plus 8 oz cotton seed oil applied at 50% coverage were applied on July 2. The 3 oz plus 7 oz canola oil applied at 50% coverage was applied on July 3. 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. 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. All applications occurred from an altitude of 40 to 60 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. The aircraft was calibrated for a 100 feet wide swath for all treatments. Treating 100%, 80% and 50% of a plot was achieved by calibrating the aircraft for a 100 foot wide swath and spacing the aircraft during treatment at 100, 125 and 200 feet respectively during application.

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 7 different treatments is summarized in Table 1. Winds during application ranged from 0 to 4 mph and averaged 1.5 mph. Other 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 1.

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 1, 3 and 7 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 m2 rings 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 sweep samples taken, uniformly at each site (Foster and Reuter, 1996). Each sample consisted of 20 high and fast sweeps and 20 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 survival based on pretreatment counts in the same plot and were 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.

Percentage control data were converted to rank data (Conover and Iman, 1981). An analysis of variance was performed with the Tukey multiple comparison test used to separate means. All analyses were performed with Systat 6.1 For Windows.

Results and Discussion

Pretreatment densities averaged 26.8 grasshoppers/m^2 for all of the plots in the study. At the time of treatment, the population was composed of 0.02 % first instars, 0.18 % second instars, 2.08 % third instars, 7.68 % fourth instars, 29.18 % fifth instars and 60.86 % adults. The total mean age was 5.48. The five most abundant species were *Aulocara elliotti* (79%), *Ageneotettix deorum* (5%), *Melanoplus sanguinipes* (5%), *Melanoplus occidentalis* (3%) and *Phlibostroma quadrimaculatum* (2%). The relative abundance of all species in pretreatment samples is shown in Table 3.

While mortalities increased through time as expected, the overall general results were unexpected. All treatments resulted in greater mortality than seen in the untreated controls except, the 4 oz plus 6 oz cotton seed oil at 50% at 7 days after treatment, the 3 oz plus 7 oz cotton seed oil at 50% at 1 day after treatment and the 3 oz plus 7 oz canola oil at 50% at 1,3 and 7 days after treatment (Table 4). All treatments resulted in statistically equivalent mortality at 1 and 7 days after treatment. At 3 days after treatment the standard 8 oz at 100% performed statistically better than the 3 oz plus 7 oz canola oil at 50%. all treatments other than the standard 8 oz at 100% resulted in statistically equivalent mortality.

When data were corrected for changes in the untreated populations (Table 5), at 1, 3 and 7 days after treatment, no differences in mortalities were seen between any of the treatments including the 8 oz at 100% except the 3 oz plus 7 oz canola oil at 50% which resulted in lower mortality than the 8 oz at 100% but resulted in statistically equivalent mortality to all other treatments.

All of these data are inconsistent with results seen with similar treatments studied near Edgemont, South Dakota on un-replicated plots in 2002 (Foster et al. 2002) (Fig. 2). Those treatments consistently resulted in mortalities higher than 80% except a 3 ounce

malathion treatment that produced mortality above 75%. However, there were major differences between the two studies. In the 2002 South Dakota study, 1st, 2nd 3rd, 4th, and 5th instars and adult grasshoppers comprised <1, <1, 6, 26, 37, and 30 percent, respectively, of the total population compared to 61% adults (total mean population age of 5.48) in the 2004 Wyoming study. Adults are generally more difficult to control than less mature grasshoppers and may account for some of the reduced mortally seen in the 2004 Wyoming study. To insure no inferior product was used in 2004, samples were submitted to Cheminova Inc. for analysis. Those results indicated that the product was at or very near expected levels of active ingredient and therefore did not contribute to the low mortality levels. The authors believe that more importantly, range conditions were very dissimilar between the two studies. Minimal bare ground and significant plant canopy was present in 2002 while mostly bear ground with very little vegetation was present in the 2004 study. (Figs. 3 and 4). While many believe that the mode of action of malathion is direct contact, the major component of mortality is due to ingestion (Pfadt et al. 1970) In that study the mean mortality of three grasshopper species fed sprayed vegetation was 94% compared to a mean mortality of 15% for the same three species when only sprayed with malathion. Because so little vegetation was available in our study and grasshopper were adult and averaged ca. $27/m^2$ square, the authors believe that sufficient ingestion of vegetation and toxicant did not occur to result in expected levels or mortality. It is important to note that even though countless studies over the years have included malathion treatments as standards for comparison, in over 25 years of experience the senior author has never personally treated such numbers or proportions of adults on such poor rangeland. However, these results are consistent with other unpublished reports by local applicators.

In an attempt to confirm this suspicion, an additional plot originally not selected for the study because of lower grasshopper densities but with significant grass and little bare ground (Fig. 5) was treated with malathion at the 8 oz/acre and 100% coverage rate on the last day of treatments. Results, showed 76, 81 and 92 % mortality at 1, 3 and 7 days after treatment, respectively. This compares with 62, 69 and 76% mortality for the identical treatment and post treatment time intervals in the study and supports our suggestion for the cause of low mortality.

Conclusions

The standard dose and the selected lower doses of malathion evaluated in this study resulted in mortality levels substantially lower than expected and compared to similar treatments studied in 2002. Laboratory analysis of the active ingredient level of the material used in the study shows the material used not to be in question. Additionally, adult grasshoppers which comprised ca. 100% of the population are believed to have accounted for only a slight, if any reduction, in mortality. The authors strongly suggest that the substantial reduction in mortality is most likely attributable to minimal vegetation available for collection of spray droplets and subsequently for ingestion by the grasshoppers. The data suggest that malathion should not be used in situations where

grasshoppers and drought damage has reduced range conditions to mostly bare ground with minimal vegetation, especially when a preponderance of the population are adults.

Because of the potential for improving the economics of malathion and impact on the environment, a full evaluation of these selected treatments is still warranted and should be conducted on a younger assemblage of grasshoppers, but more importantly should be conducted on more typical rangeland conditions where less bare ground and significant vegetation is present.

The currently used formulation of malathion (Fyfanon ULV) is typically applied undiluted at 8 (traditional) or 4 (RAATS) fluid oz per acre. Further reductions in AI use levels and percentage of acreage directly treated using the current Fyfanon ULV formulation or a longer lasting formulation of encapsulated malathion would greatly enhance the usefulness and economics of malathion in RAATs technologies and would help assure strong competition between the chemical tools available for private, state and federal use in grasshopper suppression on rangeland.

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Table 1. Summary of treatments and calibration parameters.

Treatment AI/acre	Coverage	Fyfanon ULV fl oz/ac	Diluent[1] fl oz/ac	Total fl oz/ac	Nozzle no.	Tip size	Nozzle screen size	Pressure psi	Aircraft speed	Swath width
0.618	100	8	0	8	8	8002	50	40	120	100
0.309	80	4	0	4	4	8002	50	40	120	100
0.309	50	4	6 cso	10	10	8002	50	30	120	100
0.232	50	3	7 cso	10	10	8002	50	30	120	100
0.232	50	3	7 co	10	10	8002	50	30	120	100
0.155	100	2	8 cso	10	10	8002	50	30	120	100
0.155	50	2	8 cso	10	10	8002	50	30	120	100

[1] cso = cottonseed oil; co = canola oil

Table 2. Meteorological conditions recorded during aerial application of treatments in the grasshopper study near Jay Em, Wyoming 2004.

						Temperatures °F.						
	%	Plot		Time (AM)		Ground		Air		Pilot	Wind (mph)	
Treatment [1]	cov.	no.	Date	Start	End	Start	End	Start	End		Start	End
8oz	100	1	29-Jun	5:10	5:20	49	50	50	50	51	N 2-3	N 2
		8+16	29-Jun	5:20	5:40	45	48	53	52	52	N 2-3	N 2-3
		22	29-Jun	5:43	5:51	50	51	51	52	52	N <1	N 2
4oz	80	15	29-Jun	6:14	6:22	51	51	53	54	52	N 2-3	N <1
		26+29	29-Jun	6:22	6:33	51	55	53	57	54	N 3-4	N 3
		34	29-Jun	6:40	6:48	53	54	57	56	53	N <1	N 2-3
4oz+6oz cso	50	32	29-Jun	7:55	8:01	64	63	68	65	58	SE <1	S <1
		24+25	29-Jun	8:01	8:13	65	64	67	67	59	E 2	S 1-2
		7	29-Jun	8:21	8:26	65	66	66	70	60	SE 2-3	SE <1
3oz+7oz cso	50	17	2-Jul	5:05	5:13	51	51	57	57	60	NW 1-2	NW 2-3
		10	2-Jul	5:11	5:19	52	51	53	54	60	NW 2	N 1
		11	2-Jul	5:22	5:28	49	53	55	57	60	N 1	N 1-2
		30	2-Jul	5:35	5:40	52	54	60	58	59	E 1-2	N 1-2
3oz+8oz cso	50	12	2-Jul	6:43	6:50	59	58	62	64	61	N 1	N 1
		33	2-Jul	6:51	6:57	60	65	70	71	60	W <1	W <1
		27	2-Jul	7:05	7:10	70	69	72	71	60	E 2-3	E 1-2
		35	2-Jul	7:12	7:19	62	59	66	65	60	0	0
2oz+8oz cso	100	28	2-Jul	7:22	7:32	69	71	70	71	61	SE <1	SE <1
		3	2-Jul	7:32	7:42	61	64	66	67	63	0	0
		23	2-Jul	7:45	7:54	70	72	71	71	62	SE 1-2	ESE 1-2
		9	2-Jul	7:56	8:08	72	71	73	73	65	SE 1	SE 2-3
3oz+7oz co	50	4	3-Jul	5:06	5:12	49	51	54	56	60	W 1-2	NW 1
		39	3-Jul	5:14	5:20	50	50	58	56	60	W 2-3	W 0-3
		13	3-Jul	5:22	5:30	52	50	57	60	60	NW 1	NW 1
		18	3-Jul	5:30	5:38	52	55	59	60	60	W 0-3	SW 1-3
8oz [2]	100	36	3-Jul	6:30	6:38	58	61	60	63	60	NW 3	0

[1] Fluid ounces of malathion (Fyfanon ULV) + oil diluent; cso = cottonseed oil and co = canola oil.
[2] One 40 acre plot sprayed on denser vegetation than other replicates.

Table 3. Grasshopper species composition and age structure prior to treatment, near Jay Em, Wyoming 2004.

	Instar							
Species (6/28-7/1/2004)	1	2	3	4	5	Adult	**Total**	%
Gomphocerinae								
Aeropedellus clavatus						1	1	0.02
Ageneotettix deorum			21	86	152	22	281	4.57
Amphitornus coloradus				5	35	10	50	0.81
Aulocara elliotti			39	196	1314	3323	4872	79.30
Aulocara femoratum		2	1		2		5	0.08
Cordillacris crenulata				2	5	1	8	0.13
Cordillacris occipitalis					6	9	15	0.24
Phlibostroma quadrimaculatum		4	15	61	61	1	142	2.31
Psoloessa delicatula						2	2	0.03
Melanoplinae								
Hepserotettix viridis			9	31	29		69	1.12
Melanoplus angustipennis				3			3	0.05
Melanoplus bivittatus			1				1	0.02
Melanoplus confusus						64	64	1.04
Melanoplus infantilis			7	24	30	7	68	1.11
Melanoplus keeleri		1	2				3	0.05
Melanoplus occidentalis			1		10	176	187	3.04
Melanoplus packardii		2	6	13	25	5	51	0.83
Melanoplus sanguinipes			14	40	113	110	277	4.51
Melanoplus "species"		1					1	0.02
Oedipodinae								
Metator pardalinus			3	2	6	1	12	0.20
Hadrotettix trifasciatus		1	2	8	3		14	0.23
Pardalophora haldemani	1					7	8	0.13
Spharagemon collare			1				1	0.02
Spharagemon equale			2				2	0.03
Trachyrhachys kiowa			4	1	2		7	0.11
Totals	1	11	128	472	1793	3739	**6144**	
%	0.02	0.18	2.08	7.68	29.18	60.86		

Table 4. Mortality of grasshoppers treated with selected doses and diluent mixes of malathion – Jay Em, Wyoming 2004.

Treatment [1]	Days after treatment – mean % mortality [2]		
	1	3	7
8oz @ 100%	62 a	69 a	76 a
4oz @ 80%	37 a	54 ab	57 a
4oz + 6oz cso @ 50%	39 a	44 ab	37 ab
3oz + 7oz cso @ 50%	25 ab	38 ab	49 a
3oz + 7oz canola @ 50%	23 ab	17 bc	31 ab
2oz + 8oz cso @ 100%	47 a	62 ab	61 a
2oz + 8oz cso @ 50%	31 a	50 ab	56 a
Untreated	-11 b	-16 c	-13 b

[1] Fluid ounces malathion + diluent and spray coverage
[2] Analysis of variance with Tukey multiple comparison method. Means in a column followed by the same letter are not significantly different ($P \leq 0.05$).

Table 5. Mortality of grasshoppers (adjusted with untreated controls) treated with selected doses and diluent mixes of malathion – Jay Em, Wyoming 2004.

Treatment [1]	Days after treatment – mean adjusted % mortality [2]		
	1	3	7
8oz @ 100%	67 a	75 a	80 a
4oz @ 80%	45 ab	66 ab	70 ab
4oz + 6oz cso @ 50%	46 ab	54 ab	47 ab
3oz + 7oz cso @ 50%	32 ab	41 ab	50 ab
3oz + 7oz canola @ 50%	29 b	26 b	12 b
2oz + 8oz cso @ 100%	52 ab	64 ab	62 ab
2oz + 8oz cso @ 50%	38 ab	53 ab	57 ab

[1] Fluid ounces malathion + diluent and spray coverage
[2] Analysis of variance with Tukey multiple comparison method. Means in a column followed by the same letter are not significantly different ($P \leq 0.05$).

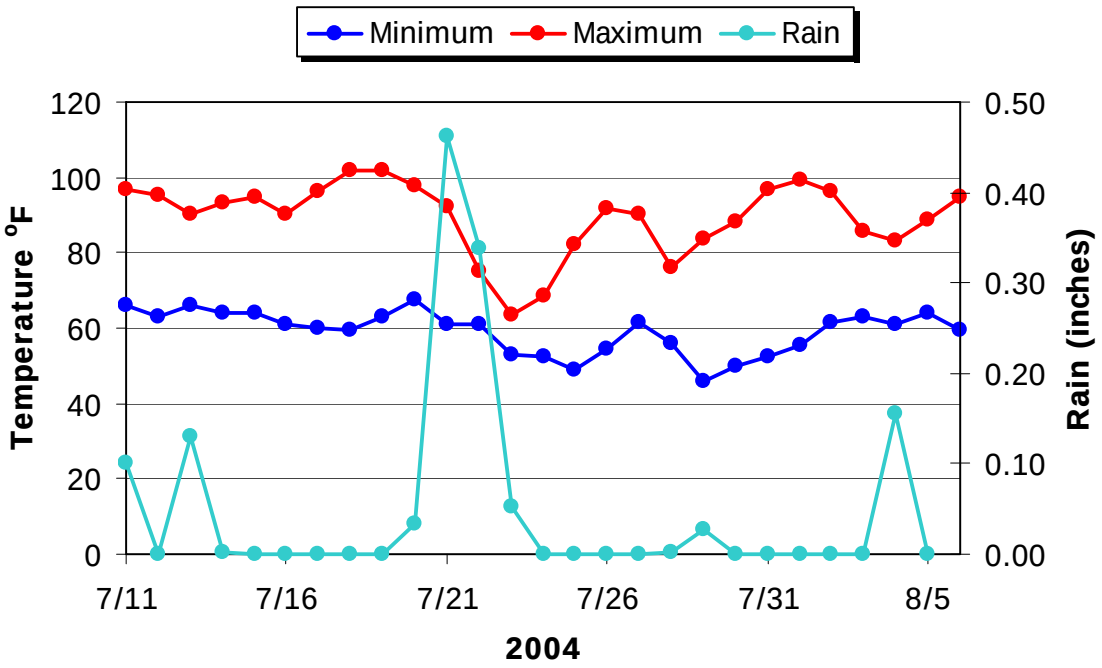

Figure 1. Minimum and maximum temperatures and precipitation recorded at the study area near Jay Em, Wyoming 2004.

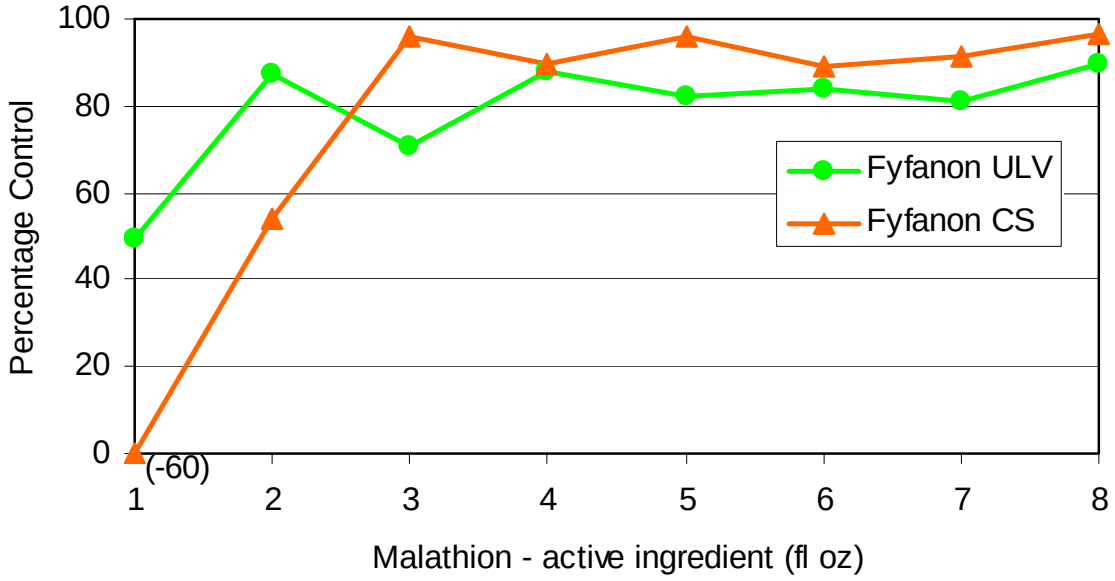

Figure 2. Adjusted mortality of grasshoppers treated with 8 doses of 2 formulations of malathion at means of 3, 6, 9 and 12 days after treatment. (From Foster et al. 2002.)

Figure 3. An example of typical range vegetation conditions near Edgemont, South Dakota in 2002.

Figure 4. An example of range vegetation during drought conditions encountered in this study near Jay Em, Wyoming 2004.

Figure 5. Additional non-replicated 40 acre plot with more typical range vegetation treated for comparison with sparse vegetation plots near Jay Em, Wyoming 2004.