Field and Economic Evaluation of Operational Scale Reduced Agent and Reduced Area Treatments (RAATs) for Management of Grasshoppers on South Dakota Rangeland, 1997-1999

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Abstract

Strategies that utilize lower than traditional doses of insecticides in combination with swaths of applied insecticide that leave untreated areas between each swath are one way to significantly reduce the cost of controlling grasshoppers on rangeland. By leaving untreated areas, this strategy provides reserves for naturally occurring biological control agents and facilitates an economical integrated management approach for dealing with damaging populations of grasshoppers on rangeland. This three year study was conducted in different locations and years to develop and demonstrate on a large scale operational level, the utility of reduced area / agent treatments (RAATs) for significantly reducing costs to manage damaging populations of grasshoppers. In 1997 these reduced agent/area treatments (RAATs) resulted in about 15% lower mortality than traditional treatments while reducing pesticide use and cost by 60% with malathion and 75% with carbaryl. Total treatment costs were reduced by 38% with malathion and 66% with carbaryl. Economic analysis showed the greatest benefit/cost ratio in 1997 was obtained with RAATs malathion (1.14) followed by RAATs carbaryl (1.05), traditional malathion (0.84) and traditional carbaryl (0.51). In 1998, RAATs treatments resulted in about 10% to 15% lower mortality than traditional treatments while reducing pesticide use and costs by 60% with malathion and 62.5% with carbaryl. Total treatment costs were reduced by 38% with malathion and 58% with carbaryl. Economic analysis showed the greatest benefit/cost ratio in 1998 was obtained with RAATs malathion (1.25), followed by RAATs carbaryl (1.05), traditional malathion (1.04) and traditional carbaryl (0.65). In 1999 RAATs treatments resulted in about 2% to 7% lower mortality than traditional treatments while reducing pesticide use and costs by 60% with diflubenzuron and 67% with carbaryl. Total treatment costs were reduced by 56% with diflubenzuron and 59% with carbaryl. Economic analysis showed the greatest benefit/cost ratio inb 1999 was obtained with RAATs diflubenzuron (2.09), followed by RAATs carbaryl (1.84), traditional diflubenzuron (0.97), and traditional carbaryl (0.90). In these economic analyses, values greater than one indicate a positive return on the treatment investment in the year of treatment. The implementation of these kinds of treatments will provide excellent opportunities for dramatically changing the way that grasshoppers are managed on rangelands. Additional development and refinement will further improve the economics and natural biological control base of such integrated management strategies.

Introduction

Wide scale outbreaks of rangeland grasshoppers in the western United States are cyclic. The combined acreage of private, state and federal lands in cooperative programs treated to control grasshopper outbreaks in 1972-1973, 1979-1981, and most recently in 1985-1986 totaled about 4.8 million, 13.8 million, and 20 million acres respectively (USDA,1987). The increasing cost to control grasshoppers, declining financial support from traditional government programs and the certainty of substantial outbreaks in the western U.S. make grasshoppers on western rangelands of extreme concern for many ranchers and farmers. Currently the cost of treatment is so expensive that actions against large populations of grasshoppers rarely occur in a timely manner. Treatments usually occur only as a last resort, emergency type action, if they occur at all.

Regardless of whether the control is for prevention, area wide management, or emergency situations, significantly less expensive treatments and strategies for managing these range pests must be developed. Traditionally, the goal of any grasshopper treatment on rangeland was maximum control. However, attitudes are changing. With the development of Hopper, a computer based decision support system, which provides a cost/benefit analysis for proposed treatments (Berry et al. 1996), new tools and strategies with goals other than traditional maximum control can be economically evaluated. Hopper was one of numerous tools that resulted from the recently completed multi-agency, multi-year, Grasshopper Integrated Pest Management Program (GHIPMP) directed by the United States Department of Agriculture, Animal and Plant Health Inspection Service (Cunningham and Sampson, 1996-1999).

One of the most recent strategies proposed for lowering cost and originally identified during the GHIPMP as Interval Swath Spacing and Direct Dosage Reduction (Larsen and Foster, 1966) is now most commonly termed Reduced Agent and Area Treatments (RAATs) (Lockwood and Schell,1997). With this strategy, maximum control is not the goal. Lower than traditional insecticide doses are used in combination with alternated treated and untreated swaths. By leaving untreated areas this strategy provides reserves for naturally occurring biological control agents and facilitates an integrated management approach for dealing with damaging populations of grasshoppers.

Several small plot tests conducted by Lockwood and Schell (1997) to study this strategy showed great promise. Their data indicated that one half of the traditional dose of carbaryl applied to 50% of the infested area produced virtually the same level of control as that produced by the traditional dose on 100 % of the infested area. Additionally, their data indicated that one half of the traditional dose of malathion applied to 80% of the infested area produced a level of control similar to that produced by the traditional dose on 100 % of the infested area.

While these studies were exciting to say the least, larger operational size plots for studying this strategy needed to be evaluated. Carbaryl and malathion have been the most widely accepted chemicals of choice for large scale control efforts against grasshoppers on rangeland for several years and were obvious first choices for evaluation. In a joint University of Wyoming and USDA APHIS, Phoenix Plant Protection Center study (Lockwood et al. 2000), both standards were initially evaluated in addition to an experimental compound, Fipronil. In 1999 state labels for the use of diflubenzuron became available in eleven western states. Diflubenzuron was considered a natural candidate for RAATs use because of its residual activity which would be available for late hatching and/or moving grasshoppers, and its apparent inactivity against adult non-target arthropods, which are present during grasshopper treatments. Previous studies (Foster et al. 1991 and 1993) had demonstrated the remarkable success of diflubenzuron sprays against rangeland grasshoppers, and had recommended its inclusion in the next USDA APHIS Environmental Impact Study with eventual program use upon final registration by the EPA.

The following three years of study was conducted to further develop and demonstrate on a large scale operational level, the utility of RAATS for significantly reducing costs to manage damaging populations of grasshoppers on rangeland in different locations and years. Carbaryl and malathion were both evaluated in 1997 and1998. Carbaryl and diflubenzuron were evaluated in 1999. The following report will document the operational and scientific parameters of the study and will provide efficacy data for economic modeling in future decision making situations.

Materials and Methods

<u>General</u>

The study occurred in southwestern (1997 and 1999) and northwestern (1998) South Dakota on private rangeland utilized for cattle grazing. In all three locations the terrain and vegetation was typical of these areas and of historic large scale cooperative private/state/federal grasshopper control programs in western South Dakota and in areas in the adjoining states of Wyoming, Nebraska, and North Dakota. All plots were typical of the mixed grass plain of western South Dakota. The principal dominant grasses of the areas were western wheat grass, *Agropyron smithii* Rydb.; blue grama, *Bouteloua gracilis* (H.B.K.); needle and thread, *Stipa comata* Trin. and Rupr.: green needlegrass *Stipa viridula* Trin.; and buffalo grass, *Buchloe dactyloides* Nutt.) Engelm.

The general plot design was consistent for all three locations/years. At each location, four contiguous 640 acre (1 mile x 1 mile) rangeland plots (sections) made up the treated area of the study (Figure 1). The adjacent area surrounding the treated land served as an untreated check area for comparison.

All treatments were applied with an USDA, APHIS aircraft (Cessna Ag-Truck equipped with a standard commercial spraying system) and was operated by an APHIS pilot who was 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. In 1999, 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.

Study Site and Treatments-1997

The center of the study was located in Fall River County of southwestern South Dakota, approximately 11 miles west and 7 miles north of the town of Edgemont. The study this year utilized land provided by the Tubbs, Anderson, and Schultz ranches and the U. S. Forest Service. One of the untreated check sites was located on the Forest Service land. The general location was chosen because of the density of grasshoppers, history of grasshopper problems, and the abundance of contiguous rangeland.

The Fyfanon ULV formulation of malathion was applied at 0.61 lb AI/ac (8 fluid ounces) to 100% of one 640 acre plot and at 0.30 lb AI/ac (4 fluid ounces) to 80% of another 640 acre plot on July 19 and 22 respectively. Treating 80% of the plot was achieved by calibrating the aircraft for a 100 feet wide swath and spacing the aircraft during treatment at 125 feet. The Sevin XLR Plus formulation of carbaryl was applied at 0.50 lb AI/ac (16 fluid ounces + 16 fluid ounces of water) to 100% of the third 640 plot and at 0.25 lb AI/ac (8 fluid ounces + 8 fluid ounces of water) to 50% of the fourth 640 acre plot, on July 23 and 24 respectively. Treating 50% of the plot was achieved by calibrating the aircraft for a 100 feet wide swath and spacing the aircraft during treatment at 200 feet. All water used in mixes with carbaryl were buffered to a pH of 7.0 using LI 700 surfactant, penetrant, acidifier (Loveland Industries Inc.,Greely CO).

The aircraft was calibrated for a 100 feet wide swath for all treatments. During application the aircraft was spaced at 100 feet and 125 feet for the traditional malathion treatment (8 fluid oz/ac to 100% of the plot) and the RAATs malathion treatment (4 fluid oz/ac to 80% of the plot) respectively. The aircraft was spaced during application at 100 and 200 feet for the traditional carbaryl treatment (0.50 lb AI/ac to 100% of the plot) and the RAATs carbaryl treatment (0.25 lb AI/ac to 50% of the plot) respectively. All treatments were applied through flat fan Tee Jet stainless steel nozzle tips. The traditional and RAATs malathion treatments were applied at 120 mph and 41 psi with 8 and 4 (8002) size tips respectively. The traditional and RAATs carbaryl treatments were applied at 120 mph and 38 psi with 20 and 10 (8003) size tips respectively. Winds during application ranged from 0-1 mph, 0-3 mph, 0-6 mph, and 0-3 mph for malathion traditional, malathion RAATS, carbaryl traditional, and carbaryl RAATs treatments respectively. Other meteorological conditions recorded during application of the treatments are summarized in Table 1. Range vegetation was wet during all applications. All treatments were applied from an altitude of 40 to 70 feet.

Study Site and Treatments-1998

The center of the study site this year was located in northwestern South Dakota, approximately 2.5 miles southeast of the Harding County Airport near the town of Buffalo. The entire study utilized land provided by the Ludlow Grazing Association and the Ray and Linda Gilbert, Ed Hunsucker, Ray Anderson, Dennis Brengle, Ed and Don Bruha ranches. The general location was selected because of the density of grasshoppers, grasshopper species complex, history of grasshoppers in the area and the abundance of contiguous rangeland.

The Fyfanon ULV formulation of malathion was applied at 0.61 lb AI/ac (8 fluid ounces) to 100% of one 640 acre block and at 0.30 lb AI (4 fluid ounces) to 80% of another 640 acre plot, on July 9-10 and 12 respectively. Treating 80% of the plot was achieved by calibrating the aircraft for a 100 feet wide swath and spacing the aircraft during treatment at 125 feet. The Sevin XLR Plus formulation of carbaryl was applied at 0.50 lb AI/ac (16 fluid ounces + 16 fluid ounces of water) to 100% of the third 640 acre plot and at 0.375 lb AI/ac (12 fluid ounces + 12 fluid ounces of water) to 50 % of the fourth 640 acre plot, on July 14 and 13 respectively. Treating 50% of the plot was achieved by calibrating the aircraft for a 100 feet wide swath and spacing the aircraft during treatment at 200 feet. All water used in mixes with carbaryl were buffered to a pH of 7.0 using LI 700 surfactant, penetrant, acidifier (Loveland Industries Inc., Greeley CO).

The aircraft and spraying system were calibrated for a 100 feet wide swath for all treatments. During application, the aircraft was spaced at 100 feet and 125 feet for the traditional malathion treatment (8 fluid oz/ac to 100% of the plot) and the RAATs malathion treatment (4 fluid oz/ac to 80% of the plot) respectively. The aircraft was spaced during application at 100 feet and 200 feet for the traditional carbaryl treatment (0.50 lb AI/ac to 100% of the plot) and the RAATs carbaryl treatment (0.375 lb AI/ac to 50% of the plot) respectively. All treatments were applied through flat fan Tee Jet stainless steel nozzle tips. The traditional and RAATs malathion treatments were applied at 120 mph and 42 psi with 8 and 4 (8002) size tips respectively. Nozzles were directed straight down for the 8 oz treatment and rotated 45 degrees into the slip stream for the 4 oz treatment. The traditional and RAATs carbaryl treatments were applied at 120 mph and 38 psi with 20 and 15 (8003) size tips respectively. All carbaryl treatments utilized nozzles directed straight down. Winds during application ranged from 0-4 mph, 4-7 mph, 1-4 mph, and 0-2.5 mph for malathion traditional, malathion RAATs, carbaryl traditional, and carbaryl RAATs treatments respectively. Other meteorological conditions recorded during application of treatments are summarized in Table 2. Range vegetation was wet during all applications. All treatments were applied from an altitude of 30 to 70 feet.

Study Site and Treatments-1999

The center of the study was again located in Fall River County of southwestern South Dakota, approximately 8.5 miles west and 7 miles north of the town of Edgemont. This area was adjacent to the area that was used in 1997 but included no land that was used in the earlier study. The study this year utilized land provided by Bob and Mark Tubbs, Jeff Schultz, Rory Brown and Everett Porter. The general location was selected because of the density of grasshoppers grasshopper species complex, history of grasshoppers in the area and the abundance of contiguous rangeland.

The Dimilin 2L formulation of diflubenzuron was applied at 0.015625 il AI/ ac = 7.1 grams /ac (1.0 fluid ounces) to 100% of one 640 acre plot and at 0.0117 lb AI/ac = 5.3 grams/ac (0.75 fluid ounces) to 50% of another 640 acre plot on June 26 and 28, respectively. Both treatments were applied in a total volume of 31 fluid oz/ac according to state label requirements. The label specified application of 16 to 32 fluid oz/ac with a minimum of 7 fluid oz of emulsified vegetable or paraffinic oil/ac mixed with at least 2 parts of water for each part of oil. Specifically, our one ounce treatment was formulated to contain one fluid ounce of Dimilin 2L, 10 fluid ounces of Clean Crop Oil Concentrate, and 20 fluid ounces of water/acre. The three – fourth ounce treatment was formulated to contain 0.75 fluid oz of Dimilin 2L, 10 fluid oz of Clean Crop Oil Concentrate, and 20.25 fluid oz of water/acre. Treating 50% of the plot was achieved by calibrating the aircraft for a 100 feet wide swath and spacing the aircraft during treatment at 200 feet.

The Sevin XLR Plus formulation of carbaryl was applied at 0.375 lb AI/ac (12 fluid ounces) to 100% of the third 640 acre plot and at 0.25 lb AI/ac (8 fluid ounces) to 50% of the fourth 640 acre plot on June 29 and July 1, respectively. Both treatments were applied at a 1:1 ratio with water i.e. 24 fluid oz/ac and 16 fluid oz/ac, respectively. All water used in mixes with carbaryl was buffered to a pH of 6.7 using LI 700 surfactant, penetrant, acidifier (Loveland Industries Inc., Greeley CO). Again, treating 50 % of the plot was achieved by calibrating the aircraft for a 100 foot wide swath and spacing the aircraft during treatment at 200 feet.

The aircraft and spraying system were calibrated for a 100 feet wide swath for all treatments. During application the aircraft was spaced at 100 feet for traditional treatments and 200 feet for RAATs treatments. All treatments were applied through flat fan Tee Jet stainless steel nozzle tips oriented straight down. Both diflubenzuron treatments were applied at 125 mph and 36 psi with 20 (8003) size tips. The full coverage and RAATs carbaryl treatments were applied at 125 mph and 40 psi with 15 and 10 (8003) size tips respectively. All nozzles were equipped with 50 mesh strainers. Winds during application ranged from 1-3 mph, 1-3 mph, 1-4 mph, and <1-5 mph for diflubenzuron traditional diflubenzuron RAATs, carbaryl traditional and carbaryl RAATs treatments respectively. Other meteorological conditions recorded during application are summarized in Table 3. All treatments were applied from an altitude of 40 to 60 feet.

Sampling Methods

Generally, grasshopper density and composition sampling followed protocols established by Foster and Reuter, 1996. Grasshopper populations in treated and untreated sites were counted and sampled 1 to 3 days before treatment and on a weekly basis for 4 weeks after treatment. When malathion treatments were studied in1997 and 1998, populations were additionally counted and sampled at 3 days after treatment. Untreated check sites were also counted and sampled on any day a treated site was monitored. Grasshopper densities were determined by counting grasshoppers in (40) 0.1 m^2 rings separated from each other by ca. 5 yards and arranged in linear transects situated perpendicular to the line of flight at 12 sites within each 640 acre plot (Fig.2) In the treated plots, ca. 45 feet of separation was provided between transects in the same line. The three lines of 4 transects in each plot were separated from each other by one-fourth mile and were located no closer than one-fourth mile to the plot boundary. Twelve untreated check sites were established around the perimeter of the treated plots for comparative purposes and for adjusting treated population density estimates (Fig.1) Untreated sites were located no closer than one-fourth mile to the boundary of a treated plot. Rings in untreated sites were arranged in a circle with rings 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 100 high and fast sweeps and 100 low and slow sweeps (1997 and1998) or 50 high and fast sweeps and 50 low and slow sweeps (1999). 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.

Additionally, at all treated sites, water or oil sensitive spray cards were placed ca. 18 inches above each ring to determine the degree of spray exposure that each separate ring area received. Cards were placed immediately prior to application and were collected shortly after application and returned to the laboratory for analysis. Using a template, two, one square centimeter areas on each card, were counted under a microscope at 8x magnification to determine the density of spray droplets deposited.

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. The Kruskal-Wallis one way analysis of variance with a non-parametric Tukey type multiple comparison was also used in an additional analyses (Zar, 1974). All efficacy analyses were performed with Systat 6.0 For Windows.

Economic analysis of each of the treatments was conducted by using Hopper, a computer decision support system developed for rangeland grasshopper management (Berry et al. 1996). Each of three separate ranch models/ecosystems (Northern Great Plains, Northern Highland Prairie and Central Great Plains) were used in the analysis. These models (Fig. 9) of ranch operations typical of each of the ecosystems (Davis and Skold, 1996) were selected because of the proximity of the demonstration sites to the areas from which data were collected for developing the models.

All economic analyses relied on 30 year average weather data from Dickinson, N.D., a forage production multiplier of 0.5 to help simulate conditions closer to drought years than average years, the mean grasshopper density of the study area surveyed on the day before the first treatment for that year occurred and treated on the median day of all the treatments applied that year, insecticide cost values provided by the companies (Tables 4 & 5) and the means of mortalities recorded at 2 weeks after application, Table 6 (1997), 1-4 weeks after application, Table 7 (1998) and 2-4 weeks after application, Table 8 (1999), for each of the selected treatments. In 1997 two week data was considered most representative because of migration into the plots after treatment. In 1999 first week data was not averaged into the mean mortality because mortality attributed to diflubenzuron was not fully expressed until week two.

More specifically, in 1997 a grasshopper density of 19/yd^2 surveyed on July 18 and treated on July 22 at a mean age of 5th instar was used. In 1998 a grasshopper density of 21/yd^2 surveyed on July 8 and treated on July 12 at a mean age of 4th instar was used. In 1999 a grasshopper density of 27/yd^2 surveyed on June 25 and treated on June 29 at a mean age of 4th instar was used. Default values provided for each of the separate ranch models were used when other information was required.

The economic analysis provides information on total profit, a benefit/cost ratio for the year of treatment (current) and prorated over 3 years of benefit (+ 3 years) and the number of grasshopper eggs predicted to result from the survivors of the particular treatment strategy employed. In these analyses values greater then one indicate a positive return on the treatment investment. The values are an estimate of the return for every $1.00 spent to control/manage grasshoppers.

Results and Discussion

Edgemont-1997

Pretreatment densities from individual sites ranged from 8 to 32 grasshoppers/m^2 in the treated blocks and from 9 to 27 grasshoppersrs/m^2 in the untreated sites. The mean densities of separate blocks ranged from 15 to 23 grasshoppers/m^2 in the treated blocks and were 16 grasshoppers/m^2 in the untreated sites. At the time of treatment the population was composed predominately of fourth instars (10%), fifth instars (23%) and adults (51%). The total mean instar age was 4.92. The four most dominant species were *Melanoplus sanguinipes 31%, Ageneotettix deorum 22%, Opeia obscura 9%, Trachyrhachys kiowa 6%, Eritettix simplex 5%,* and *Melanoplus gladstoni 5%.* The relative abundance of all species in pretreatment samples are shown in Table 9.

Within one week of application and for the majority of the study all treatments resulted in substantial reductions in grasshoppers (Tables 6, 10 and 11). Untreated check populations decreased an average of 0.9 % per day during the study. Values shown in Tables 6 and 11 have been adjusted by using untreated check population densities to reflect natural changes occurring in the populations. The level of control achieved for all treatment could be considered somewhat conservative in that all treatments were applied to wet vegetation. Most remarkable is the traditional treatment of malathion which received almost 1.5 inches of rain starting at 10-11 hours after application. Figure 3 shows the precipitation recorded by a temporary weather station in the treated area for the duration of the study. Daily minimum and maximum temperatures recorded for the duration of the study are shown in Figure 4.

Throughout the study and as expected there were no significant differences between mortalities resulting from the traditional treatment of malathion and carbaryl except at 14 days after application where carbaryl resulted in significantly higher mortality. There were also no significant differences between mortalities resulting from the RAATs treatment with malathion and the RAATs treatment with carbaryl, except at 7 to 8 days after application where malathion RAATs resulted in significantly higher mortality. For both malathion and carbaryl, the traditional treatments resulted in significantly higher mortalities than the corresponding RAATs treatments (table 6). With additional analyses, statistical results were similar to that in the initial analysis except at 7-8 and 14 days after treatment where the traditional carbaryl treatment outperformed the traditional malathion treatment. Also, at 14 days the RAATs carbaryl treatment statistically outperformed the RAATs malathion treatment (Table 11).

From 2 to 4 weeks after treatment all mortalities in the study showed a strong decreasing trend. While some hatch was occurring after treatment it was limited to overwintering species; primarily *Eritettix simplex* and *Psoloessa delicatula* and to a very minor degree *Arphia conspersa* and *Pardalophora haldemani*. These late hatching species accounted for very little of the decrease in mortality seen after two weeks in this study. Most of the decrease was due to migration into the treated area from the surrounding area. If the entire infestation had been treated, as would occur in a large scale cooperation program, migration would have been minimized if not prevented entirely.

In an attempt to remove the impact of migration, mean mortality values were calculated for only the center most 4 sites in each treatment block (Table 12). Even with the additional one fourth mile buffer between evaluation sites and the untreated check area, migration into the treated area was evident between 14 to 28 days after treatment. This amount of migration was not unexpected. The dominant species, *Melanoplus sanguinipes,* is highly migratory.

Examination of spray cards revealed that a mean number of 39.8 droplets/cm^2 and 13.8 droplets/cm^2 were deposited in the traditional malathion and RAATs malathion plots respectively. In carbaryl plots, 7.4 droplets/cm^2 and 2.1 droplets/cm^2 were deposited in the traditional carbaryl and RAATs carbaryl plots respectively (Table 13). As expected, RAATs treatments, with spaces of 20 feet and 100 feet between swaths, produced sufficient lateral displacement of the spray even with winds as low as 0-3 mph, to achieve some level of deposition in most of the skipped area. Droplets were recorded on 100% of the spray cards in the RAATs malathion plot, including those cards that occurred in the 20% of the acreage not "directly" treated. In the RAATs carbaryl plot, droplets were recorded on the sampled areas of 94% of the spray cards, including those that occurred in the 50% of the acreage not "directly" treated.

Economic analysis of these results indicate that substantial improvement in return can be achieved with RAATs strategies when compared to traditional strategies. (Table 14).The order of performance of all four evaluated treatments (in terms of greatest return per invested dollar) was consistent for the three ranch models used in the analysis. In the Northern Great Plains scenario the economic analysis for the current year showed the greatest benefit/cost (B/C) ratio was obtained with the malathion RAATs method (1.14), followed by the carbaryl RAATs method (1.05), malathion traditional (0.84), and carbaryl traditional (0.51). In the year of treatment, only RAATs methods showed B/C ratios greater than 1.0. However, when evaluated over a three year period following treatment, all treatments resulted in a positive B/C ratio. It is important to note that in almost all cases, a rancher expects to receive benefits from a control treatment beyond the year of treatment.

The results are not surprising. The traditional malathion treatment utilized 5120 fluid ounces of material (100% of 640 acres x 8ozs) while the RAATs counterpart utilized only 2048 fluid ounces of material (80% of 640 acres x 4ozs), a 60% decrease in pesticide use and cost. The traditional carbaryl treatment utilized 10240 fluid ounces of material (100% of 640 acre x 16ozs) while the RAATs counterpart utilized only 2560 fluid ounces of material (50% of 640 acre x 8ozs), a 75% decrease in pesticide use and cost. Additional cost savings that should be associated with each RAATs treatment are 20% less acres to treat with malathion and 50% less acres to treat with carbaryl. The total treatment costs were reduced by 38% with malathion and 66% with carbaryl (table 5).

The number of eggs produced from grasshoppers surviving individual treatments was directly related to speed and level of control achieved by the individual treatment. Both RAATs treatments resulted in the production of more eggs than the traditional treatments. Malathion RAATS treatments resulted in ca. 3 times as many eggs as the traditional option, while carbaryl RAATs treatments resulted in ca. 4 times as many eggs as the traditional option. According to Hopper, if no treatments had occurred, 20.3 eggs/yd^2 would have been produced.

<u>Buffalo-1998</u>
Pretreatment densities from individual sites ranged from 12 to 35 grasshoppers/m^2 in the treated blocks and from 12 to 45 grasshoppers/m^2 in the untreated sites. The mean densities of separate blocks ranged from 17.1 to 23.5 grasshoppers/m^2 in the treated blocks and were 22.3 grasshoppers/m^2 in the untreated sites. At the time of treatment the population was composed predominately of of 3rd instars (23%), 4th instars (23%), and 5th instars (31%) at the time of treatment (total average instar age was 3.89). This age mixture is considered to be very realistic of an ideally timed program treatment. The five most dominant species were *Ageneotettix deorum* (24%), *Phoetaliotes nebrascensis* (19%), *Opeia obscura* (11%), *Melanoplus sanguinipes* (11%), and *Orphulella speciosa* (6%). The relative abundance of all species in pretreatment samples are shown in Table 15.

Within one week of application and for the remainder of the study all treatments resulted in substantial reductions in grasshoppers (Tables 7, 16 and 17). Values shown in Tables 7 and 17 have been adjusted by using untreated check population densities to reflect natural changes occurring in the populations. Untreated check populations increased ca. 0.9%/day during the study, an indication of some hatch subsequent to treatment. Figure 5, shows the precipitation recorded in the treated area for the duration of the study. The daily minimum and maximum temperatures recorded for the duration of the study are shown in Figure 6.

Throughout the study and as expected there was no significant difference between mortalities resulting from the traditional treatments of malathion and carbaryl except at 14 days after treatment where the traditional treatment of carbaryl performed significantly better than the traditional treatment of malathion (Table7). From 7 days after treatment through 28 days after treatment mean percentage control attributed to traditional malathion and carbaryl treatments averaged 95% and 96% respectively. There were also no significant differences between mortalities resulting from the RAATS treatment with malathion and the RAATS treatment with carbaryl, except at 21 to 23 days and 28 days after treatment where the carbaryl RAATS treatment resulted in significantly higher mortality. From 7 days after treatment thru 28 days after treatment mean percentage control attributed to RAATS malathion and RAATS carbaryl treatments averaged 80% and 82% respectively. For both malathion and carbaryl, the traditional treatments resulted in significantly higher mortalities than the corresponding RAATS treatments. With additional analysis, statistical results were similar to those in the initial analysis except at 14 days after treatment where the traditional treatments of carbaryl and malathion performed equally(Table 17).

Examination of the spray cards revealed that a mean number of 29.4 droplets/cm^2 and 9.0 droplets/cm^2 were deposited in the traditional malathion and RAATS malathion plots respectively (Table 18). Based on the number recorded in the traditional block, we expected to see about 11.8 droplets/cm^2 (80% of 50% of 29.4) in the RAATS plot. In carbaryl plots, 7.0 droplets/cm^2 and 2.4 droplets/cm^2 were deposited in the traditional carbaryl and RAATs carbaryl plots respectively. Based on the number recorded in the traditional block, we expected to see about 2.6 droplets/cm^2 (50% of 75% of 7.0) in the RAATS plots. The malathion depositions were somewhat lower than those seen in the 1997 demonstration near Edgemont, where the traditional treatment resulted in 39.8 droplets/cm^2 and the RAATS treatment resulted in 13.8 droplets/cm^2 Table 13. However, the traditional carbaryl depositions in this study (7.0/cm^2) were very similar to that seen in Edgemont (7.4/cm^2). The RAATS carbaryl deposition (2.4/cm^2) was greater than seen in Edgemont in 1997 (2.1/cm^2) but the 1998 demonstration utilized a higher volume/acre treatment, 24 ozs total volume compared to the 1997 demonstration, 16 ozs total volume/acre. Additionally, compared to 1997, winds, during application in 1998 were higher during malathion applications but lower during carbaryl applications.

As expected with spaces of 25 feet and 100 feet between swaths, sufficient lateral displacement of the spray occurred even with winds as low as 0 to 4 mph, to achieve some level of deposition in most of the skipped area. Droplets were recorded on the sampled areas of essentially all (477 of 480) of the spray cards in the RAATS malathion plots including those that occurred in the 20% of the acreage not “directly” treated. In the RAATS carbaryl plot, droplets were recorded on the sampled areas of 82% of the spray cards (393 of 480) including those that occurred in the 50% of the acreage not “directly” treated. About 2% (11 of 480) of the spray cards in the traditional carbaryl treated plot showed no deposition while all of the spray cards in the traditional malathion plot revealed deposition.

Economic analysis of these results indicate that substantial improvement in return can be achieved with RAATS strategies when compared to traditional strategies (Table 19). The order of performance of all four evaluated treatments (in terms of greatest return per invested dollar) was consistent for the three ranch models used in the analyses. In the Northern Highland Prairie scenario the economic analysis for the current year showed the greatest benefit/cost ratio was obtained with the malathion RAATS method (1.25), followed by the carbaryl RAATS method (1.05), malathion traditional (1.04) and carbaryl traditional (0.65). In the year of treatment only RAATS methods showed B/C ratios greater than 1.0, except for a traditional treatment of malathion in the Northern Highland Prairie scenerio. This positive B/C ratio, for RAATs treatments, was evidenced for the Northern Highland Prairie and Northern Great Plains scenarios but not the Central Great Plains scenario. However, when evaluated over a 3 year period following treatment, all treatments resulted in a positive B/C ratio. Again, it is important to note that in almost all cases a rancher expects to receive benefits from a control treatment beyond the year of treatment.

The results of this study are not surprising. Less insecticide, use will result in a lower percentage of control, but at a substantial cost reduction. The traditional malathion treatment utilized 5120 fluid ounces of material (100% of 640 acres x 8ozs) while the RAATS counterpart utilized only 2048 fluid ounces of material (80% of 640 acres x 4ozs), a 60% decrease in pesticide use and cost. The traditional carbaryl treatment utilized 10240 fluid ounces of material (100% of 640 acre x 16oz/ac) while the RAATS counterpart utilized only 3840 fluid ounces of material (50% of 640 acre x 12oz/ac), a 62.5% decrease in pesticide use and cost. Additional cost savings associated with each RAATS treatment are 20% less acres to treat with malathion and 50% less acres to treat with carbaryl. Total treatment costs were reduced by 38% with malathion and 58% with carbaryl.

The number of eggs produced from grasshoppers surviving individual treatments was directly proportional to the B/C ratio and the percentage of control resulting from the individual treatment. While malathion RAATS showed a slightly higher B/C ratio compared to carbaryl RAATS, the eggs per yd^2 produced from survivors of a malathion RAATS treatment (9.6) was almost twice that seen in the carbaryl RAATS treatment (5.1). According to Hopper, if no treatments had occurred, 19.4 eggs/yd^2 would have been produced.

Compared to the demonstration conducted in 1997 near Edgemont, South Dakota both traditional and RAATS malathion treatments resulted in control about 5% higher in this study. This was not unexpected because a significant amount of rain occurred shortly after treatments in 1997. In 1998 both traditional and RAATS carbaryl treatments resulted in control very similar to that seen in 1997, even though a higher RAATS dose (0.375 vs. 0.250 lb. AI/acre) was used in 1998. In all cases in 1998, percentage control values remained stable after peaking and indicated less migration than had occurred in 1997. This is consistent with the most migratory species present. *Melanoplus sanguinipes* composed 11% of the population in 1998 compared to 31% in 1997. Additionally, in 1998 all malathion treatments relied on spray nozzles being directed 45° forward into the slip stream, in an attempt to create a larger number of droplets. In the 1997, study malathion treatment nozzles were directed straight down. In a separate study conducted near the demonstration, numerically greater numbers of droplets were shown to be produced by rotating nozzles 45° forward for application (Reuter et al, 1998).

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Pretreatment densities from individual sites ranged from 7 to 47 grasshoppers/m^2 in the treated area and from 8 to 36 grasshoppers/m^2 in the untreated sites. The mean densities of separate blocks ranged from 23.1 to 30.4 grasshoppers/m^2 in the treated blocks and were 20.8 grasshoppers/m^2 in the untreated sites. At the time of treatment the population was composed predominately of 4th instars (59%), 5th instars (21%) and 3rd instars (16%). The total average instar age was 4.06. The age mixture is considered to be very realistic of an ideally timed program treatment. The seven most dominant species were *Ageneotettix deorum* (69%), *Amphitornus coloradus* (8%), *Cordillacris occipitalis* (6%), *Opeia obscura* (4%), *Melanoplus sanguinipes* (3%*), Trachyrhachys kiowa* (3%) *and Melanoplus packardii* (2%). The relative abundance of all species in pretreatment samples are shown in Table 20.

Within one week of application and for the remainder of the study all treatments resulted in substantial reductions in grasshoppers (Tables 8, 21 and 22). Values shown in Tables 8 and 22 have been adjusted by using untreated check population densities to reflect natural changes occurring in the populations. Untreated check populations were fairly stable but decreased an average of 0.4% per day during the study.

During the 6 day period when treatments occurred, the study area received 0.10, 0.03, 0.14 and 0.06 inches of precipitation on June 27, 28, 30 and July 1, respectively. The relationships of rains and application of treatments are shown in Figure 7. During the study, daily low temperatures ranged from 43.7^{o}F to 65.3^{o}F and averaged 55.1^{o}F and daily high temperatures ranged from 71.2^{o}F to 103.1^{o}F and averaged 88.5^{o}F. Minimum and maximum temperatures recorded for the duration of the study are shown in Figure 8.

At one week after application both carbaryl treatments performed significantly better than both of the diflubenzuron treatments (Table 8). Additionally, the traditional carbaryl treatment resulted in significantly higher mortality than the RAATS carbaryl treatment. From 14 days after treatment through 28 days after treatment, there was no significant difference between mortalities resulting from the traditional treatments of carbaryl and diflubenzuron except at 21 days after treatment where carbaryl produced 96.5% mortality and diflubenzuron produced 99.7% mortality. However, diflubenzuron RAATS resulted in significantly higher mortality than RAATS carbaryl from 14 to 28 days after treatment. Even though most of the mortality for both RAATS treatments was achieved by 14 days, steady increases occurred through 28 days. At 28 days after treatment the carbaryl RAATS treatment resulted in significantly less mortality than the other 3 treatments, which were statistically equivalent to each other. However, the level of control produced by all treatments could be considered acceptable. With additional analysis, statistical results were similar to that in the initial analysis except at 7 days after treatment where carbaryl traditional and RAATs treatments were equivalent (Table 22).

Examination of the spray cards revealed that a mean number of 5.05 droplets/cm^2 and 1.85 droplets/cm^2 were deposited in the traditional carbaryl and RAATS carbaryl plots respectively (Table 23). Based on the number recorded in the traditional blocks, we expected to see about 1.69 droplets/cm^2 (50% of 67% of 5.05) in the RAATS plot. These results compared similarly to those for the traditional dose in a 1998 study (4.69 droplets/cm^2) and the same RAATS dose in a 1997 study (2.1 droplets/cm^2). At the time of this report, difficulty discerning individual spray droplets on the water sensitive spray cards used for Dimilin treatments was being encountered and are not reported here. As expected with spaces of 100 feet between swaths, sufficient lateral displacement of the spray occurred even with winds as low as less than 1 mph, to achieve some level of deposition in most of the skipped area. Droplets were recorded on the sampled areas of most (89.4%) of the spray cards in the RAATS carbaryl plots including those that occurred in the 50% of the area not "directly" treated. The actual percentage of spray cards showing droplets was substantially higher than this value. Many cards had droplets but they did not occur in the two 1 cm^2 sampling areas counted on each card. About 2% of the spray cards in the traditional carbaryl treated plot showed no deposition.

Economic analyses of the results indicates that substantial improvement in return can be achieved with RAATS strategies when compared to traditional strategies (Table 24). The order of performance of all four evaluated treatments (in terms of greatest return per invested dollar) was consistent for all 3 ranch models used in the analyses. In the Northern Great Plains scenario the economic analyses for the current year showed the greatest benefit /cost ratio was obtained with the diflubenzuron RAATS method (2.09), followed by the carbaryl RAATS method (1.84), diflubenzuron traditional (.97) and carbaryl traditional (0.90). In the year of treatment only RAATS methods showed benefit/cost ratios greater than 1.0. Positive benefit /cost ratios for RAATS treatments in the year of treatment occurred with all three ranch scenarios. However, when evaluated over a 3 year period following treatment, all treatments resulted in a positive benefit/cost ratio. Once again, it is important to note that in almost all cases a rancher expects to receive benefits from a control treatment beyond the year of treatment.

The results of this study are not surprising. Less insecticide use will result in a lower percentage of control, but at a substantial cost reduction. The traditional carbaryl treatment utilized 7680 fluid ounces of material (100% of 640 acres x 12 ounces) while the RAATs counterpart utilized only 2560 fluid ounces of material (50% of 640 acres x 8 ounces), a 67% decrease in pesticide use and cost. The traditional diflubenzuron treatment utilized 640 fluid ounces of material (100% of 640 acres x 1 ounce) while the RAATs counterpart utilized only 240 ounces of material (50% of 640 acres x 0.75 ounce), a 60% decrease in pesticide use and cost. Additional cost savings associated with each RAATs treatment are 50% less acres to treat. Total treatment costs were reduced by 59% with carbaryl and 56% with diflubenzuron.

The number of eggs produced by grasshoppers surviving individual treatments was directly related to the percentage of control resulting from the treatments. However, all treatments resulted in ca. 1 or less eggs/yd^2 being produced by survivors of the treatments . If no treatment had occurred, Hopper indicates that 16.9 eggs/yd^2 would have been produced.

Compared to the demonstration conducted in 1997 on adjacent land near Edgmont, the RAATS carbaryl treatment resulted in slightly higher mortality, at 14 days after treatments (81% vs 88%). However, in this study, control values remained stable after peaking, an indication of less migration than was seen in 1997. This is consistent with the species composition recorded for both years. The highly migratory *Melanoplus sanguinipes* which was present at 31% in 1997 composed only 3% of the total population in 1999. The control values for the traditional carbaryl treatments were very similar in both studies, even though a lower standard dose(0.375lb AI/ac vs

0.50lb AI/ac) was used in 1999. Compared to the same carbaryl RAATS treatment applied in a 1998 demonstration near Buffalo, S.D.(Foster et al. 1998b), our results were very similar at 21 to 28 days after treatment. However, again the results in 1999 were slightly higher (88% vs. 82%) at 14 days after treatment compared to the 1998 study.

The standard treatment of diflubenzuron in this study performed slightly better (99%vs 93% control), than the same dose in a 25 W formulation traditional application, study conducted in 1991 (Foster et al. 1991). It also performed slightly better (99% vs 92%) than the same dose in the same formulation but diluted with diesel fuel in an 1993 traditional application study (Foster et al. 1993).

Conclusions

The general evidence is clear. Reduced agent / area treatment strategies can substantially reduce the amount of pesticide applied per treated acre, the amount of infested area requiring treatment and the overall cost of control actions while demonstrating higher economic returns than traditional treatments. RAATs techniques offer a great potential for managing grasshoppers at an affordable cost while minimally impacting the environment and should be considered when any treatment decisions for damaging populations of grasshoppers are considered.

The mortality data presented from this study can be used with Hopper or other economic analyses to help determine economic and biological soundness of these RAATs and traditional treatment options for future scenarios under consideration. For increased accuracy we suggest that the most accurate weather data possible be used with Hopper. Average weather data in Hopper may tend to reflect non-outbreak years. Many grasshopper problems occur in non-typical years which may have higher than normal average temperatures. Adjusting daily temperatures in Hopper to reflect the current or projected situation could improve the accuracy of economic and biological outputs calculated with Hopper.

It is worthy to note that prior to the mid 1980's even though many private/state/federal cooperative programs resulted in control levels above 90%, that results as low as 80% were considered acceptable and were not unusual. Therefore, even levels of control near 80% should not be a new experience. However, for RAATS to achieve levels in this range may depend on strict adherence to acceptable application parameters. Twenty plus years of experience in and around rangeland programs have revealed that lack of adherence to accepted application parameters may reduce control levels as much as 15%, from 95% to 80%. Inappropriate application of RAATS treatments could result in control levels significantly lower than 80% and totally unacceptable depending on the specific situation. However, only detailed economic analyses at these low levels of control will reveal which options provide the best cost /benefit ratio.

Acknowledgements

The authors thank Rob Schwehr, Aventis CropScience, for providing carbaryl and cost figures, John Bruce, Cheminova Inc. (USA), for providing malathion and cost figures, and John Connell and Tim Wieland, Uniroyal Chemical Co., for providing diflubenzuron and cost figures. Thanks are extended Bob Shoemaker, Platt Co., Wyoming, Weed and Pest District Director, for providing application cost figures. Additionally we thank the following for assistance in the collection of field data: Dave Nelson (North Dakota Department of Agriculture), Dominic Colletto and Lonnie Black (USDA-APHIS, Phoenix Arizona), Cassady King (New Mexico State University), Terry Reule (USDA-APHIS, Bismark, North Dakota), George VanDal (USDA-APHIS, Pierre, South Dakota), and Aaron McClure, Matt Hall, Natalie Greynolds and M. Wallace (South Dakota Department of Agriculture).

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Table 1. Meteorological conditions recorded during aerial application of treatments in the grasshopper study near Edgemont, SD, 1997.

	Aerial treatments [1]			
	malathion 8 - 100	malathion 4 – 80	carbaryl 16 – 100	carbaryl 8 – 50
Spray date	7/19/97	7/22/97	7/23/97 [2]	7/24/97
Time				
Start	5:32 AM	5:27 AM	5:30 AM/6:35 AM	5:36 AM
Finish	6:29 AM	6:15 AM	6:05 AM/7:03 AM	6:11 AM
Air temp. (aircraft)				
Start	62° F	65° F	70° F	69° F
Finish	64° F	66° F	72° F	70° F
Air temp. in plot				
Start	60° F	61° F	67° F	67° F
Finish	63° F	65° F	72° F	68° F
Ground temp.				
Start	60° F	60° F	67° F	69° F
Finish	66° F	66° F	74° F	71° F
Wind (mph)/direction				
Start	< 1 / E	2 – 3 / S	2 – 4 / SE	< 1 / E
Finish	< 1 / E	< 1 / S	4 – 6 / S	2 – 3 / E

[1] Fluid ounces of undiluted material applied/acre and percentage of acreage treated.
[2] This plot required two loads to complete the application.

Table 2. Meteorological conditions recorded during aerial application of treatments in the grasshopper study near Buffalo, SD, 1998.

	Aerial treatments [1]			
	malathion 8 - 100	malathion 4 - 80	carbaryl 12 – 50	carbaryl 16 – 100
Spray date	7/10/98 [2]	7/12/98	7/13/98	7/14/98 [3]
Time				
Start	4:55 AM	5:50 AM	5:07 AM	5:40 AM/6:50 AM
Finish	5:55AM	6:38 AM	5:48 AM	6:40 AM/7:22 AM
Air temp. (aircraft)				
Start	60° F	62° F	58° F	69° F
Finish	62° F	64° F	58° F	72° F
Air temp. in plot				
Start	63° F	58° F	57° F	65° F
Finish	61° F	64° F	57° F	72° F
Ground temp.				
Start	62° F	58° F	55° F	64° F
Finish	61° F	62° F	56° F	71° F
Wind (mph)/direction	3 – 4 / NE	4 – 5 / W	< 1 / NE	2 – 4 / W
Start	1 – 2 / S	4 – 6 / W	2 – 3 / SW	1 – 2 / SW
Finish				

[1] Fluid ounces of undiluted material applied/acre and percentage of acreage treated.
[2] Started application in this plot on 7/9/98 (6 passes) but terminated the treatment due to high winds.
[3] This plot required two loads to complete the application.

Table 3. Meteorological conditions recorded during aerial application of treatments in the grasshopper study near Edgemont, SD, 1999.

		Aerial treatments [1]			
		diflubenzuron 1.0 - 100	diflubenzuron 0.75 - 50	carbaryl 12 - 100	carbaryl 8 - 50
Spray date		6/26/99 [2]	6/28/99	6/29/99	7/1/99
Time					
	Start	6:20AM / 7:09AM	5:05AM	5:00AM	5:11AM
	Finish	6:47AM / 7:36AM	5:40AM	6:01AM	5:45AM
Air temp. (aircraft)					
	Start	60° F	50° F	58° F	50° F
	Finish	61° F	52° F	59° F	50° F
Air temp. in plot					
	Start	63° F	48° F	53° F	47° F
	Finish	67° F	48° F	58° F	48° F
Ground temp.					
	Start	63° F	48° F	54° F	47° F
	Finish	69° F	52° F	59° F	48° F
Wind (mph)/direction					
	Start	1 - 2 / W	1 - 3 / NW	1 - 2 / SE	3 - 5 / NW
	Finish	2 - 3 / SW	1 - 3 / NW	2 - 4 / SE	< 1 / NW

[1] Fluid ounces of undiluted material applied/acre and percentage of acreage treated.
[2] This plot required two loads to complete the application.

Table 4. Estimated costs of insecticides and diluents.

Chemical [1]	Cost
malathion (Fyfanon ULV)	$21.00 / gallon
carbaryl (Sevin XLR Plus)	$22.27 / gallon
diflubenzuron (Dimilin)	$213.76 / gallon
Clean Crop Concentrate	$4.00 / gallon

[1] Provided by Cheminova, Rhone-Poulenc and Uniroyal

Table 5. Estimated costs of aerially applied traditional and RAATs treatments of carbaryl, diflubenzuron and malathion against rangeland grasshoppers, 1997 – 1999.

Treatment Strategy	Specific Mix	Chemical cost per acre protected [1]	Application cost per acre protected [2]	Total cost per acre protected
Traditional malathion to 100% of acreage 8 fl oz/acre treated (0.61 lb AI/acre)	8 fl oz per treated acre TV = 8 oz	1.31	1.55	2.86
RAATs malathion to 80% of acreage 4 fl oz/acre treated (0.30 lb AI/acre)	4 fl oz per treated acre TV = 4 oz	0.52	1.24	1.76
Traditional carbaryl to 100% of acreage 16 fl oz/acre treated (0.50 lb AI/acre)	16 fl oz + 16 fl oz H_2O per acre TV = 32 oz	2.78	1.55	4.33
Traditional carbaryl to 100% of acreage 12 fl oz/acre treated (0.375 lb AI/acre)	12 fl oz + 12 fl oz H_2O per acre TV = 24 oz	2.09	1.55	3.64
RAATs carbaryl to 50% of acreage 8 fl oz/acre treated (0.25 lb AI/acre)	8 fl oz + 8 fl oz H_2O per treated acre TV = 16 oz	0.70	0.78	1.48
RAATs carbaryl to 50% of acreage 12 fl oz/acre treated (0.375 lb AI/acre)	12 fl oz + 12 fl oz H_2O per treated acre TV = 24 oz	1.04	0.78	1.82
Traditional diflubenzuron to 100% of acreage 1 fl oz/acre treated (0.015625 lb AI/acre) 7.1g/acre treated	1 fl oz + 10 fl oz oil + 20 fl oz H_2O per treated acre TV = 31 oz	1.67 Dimilin 0.31 Oil 1.98 Total	1.55	3.53
RAATs diflubenzuron to 50% of acreage 0.75 fl oz/acre treated (0.0117 lb AI/acre) 5.3g/acre treated	0.75 fl oz + 10 fl oz oil + 20.25 fl oz H_2O per treated acre TV = 31 oz	0.63 Dimilin 0.16 Oil 0.79 Total	0.78	1.57

[1] See Table 4
[2] Application cost per directly treated area = $1.55/acre. Based on an average of 4 estimates obtained for private applications in Wyoming.

Table 6. Mean percentage control of grasshoppers treated with selected RAATs and traditional strategies near Edgemont, SD, 1997.

		Percent Control at Days After Treatment [1]				
Treatment	Rate [2]	3	7-8	14	21	28 [3]
malathion	8 – 100 [4]	88 a	88 ab	89 b	90 a	77 a
malathion	4 – 80	75 b	82 b	73 c	63 b	26 b
carbaryl	16 – 100 [4]		94 a	96 a	90 a	87 a
carbaryl	8 - 50		70 c	81 c	66 b	54 b

[1] Corrected for natural mortality. Analysis performed on rank transformation of the data. Tukey multiple comparison test used to separate means. Means in the same column followed by the same letter are not significantly different ($P \leq 0.05$). Untreated check population decreased ca. 26% during study.
[2] Fluid oz. of undiluted material applied/acre and percentage of acreage treated.
[3] Determined from 4 of 12 sites/treatment.
[4] Traditional rate

Table 7. Mean percentage control of grasshoppers treated with selected RAATs and traditional strategies near Buffalo, SD, 1998.

		Percent Control at Days After Treatment [1]				
Treatment	Rate [2]	3	7	14	21-23	28
malathion	8 – 100 [3]	91.1 a	94.6 a	94.3 b	95.5 a	95.3 a
malathion	4 - 80	79.9 b	80.8 b	79.1 c	78.5 c	81.0 c
carbaryl	16 – 100 [3]		92.3 a	97.1 a	96.8 a	97.2 a
carbaryl	12 - 50		70.3 b	81.6 c	88.3 b	86.8 b

[1] Corrected for natural mortality. Analysis performed on rank transformation of the data. Tukey multiple comparison test used to separate means. Means in the same column followed by the same letter are not significantly different ($P \leq 0.05$). Untreated check population increased ca. 32% during the study.
[2] Fluid ounces of undiluted material applied/acre and percentage of acreage treated.
[3] Traditional rate

Table 8. Mean percentage control of grasshoppers treated with selected traditional and RAATs treatments near Edgemont, SD, 1999.

Treatment	Rate [2]	Days after treatment [1]			
		7	14	21	28
diflubenzuron	1.0 – 100 [3]	61.0 c (61.0)	98.1 a (98.1)	99.7 a (99.7)	99.2 a (99.2)
diflubenzuron	0.75 - 50	61.4 c (60.2)	95.0 b (94.6)	97.6 b (97.6)	98.5 a (98.6)
carbaryl	12 – 100 [3]	94.9 a (94.9)	97.6 a (97.5)	96.5 b (96.4)	96.7 a (97.0)
carbaryl	8 - 50	84.8 b (85.9)	87.9 c (88.2)	89.7 c (89.8)	89.5 b (90.7)

[1] Corrected for natural mortality (unadjusted values in parentheses). A one-way analysis of variance was performed on a rank transformation of the data. A Tukey multiple comparison test was used to separate means. Means in the same column followed by the same letter are not significantly different ($P \leq 0.05$). The untreated check population decreased an average of 0.4% per day.

[2] Fluid ounces of undiluted material applied/acre and percentage of acreage treated.

[3] Traditional rate

Table 9. Grasshopper species composition and age structure in the treated plots and untreated sites before treatment near Edgemont, SD, 1997.

			Instars					
Species	Total	Pct	1	2	3	4	5	Adult
Subfamily Gomphocerinae								
Acrolophitus hirtipes	1	0.01						1
Ageneotettix deorum	2173	22.04				4	135	2034
Amphitornus coloradus	261	2.65					6	255
Aulocara elliotti	31	0.31						31
Aulocara femoratum	16	0.16					2	14
Cordillacris crenulata	25	0.25					1	24
Cordillacris occipitalis	367	3.72					1	366
Eritettix simplex	534	5.42	366	168				
Mermiria bivittata	8	0.08					2	6
Opeia obscura	904	9.17		2	18	93	440	351
Orphulella speciosa	5	0.05						5
Parapomala wyomingensis	9	0.09					3	6
Phlibostroma quadrimaculatum	96	0.97		8	5	15	34	34
Pseudopomala brachyptera	2	0.02					1	1
Psoloessa delicatula	257	2.61	249	8				
Subfamily Melanoplinae								
Hesperotettix viridis	5	0.05					5	
Hypochlora alba	9	0.09			1	3	2	3
Melanoplus "species"	1	0.01	1					
Melanoplus angustipennis	117	1.19				8	27	82
Melanoplus bivittatus	3	0.03						3
Melanoplus bowditchi	7	0.07				1	1	5
Melanoplus confusus	47	0.48						47
Melanoplus dawsonii	1	0.01		1				
Melanoplus femurrubrum	116	1.18	2	6	20	30	44	14
Melanoplus gladstoni	483	4.90	1	74	263	127	17	1
Melanoplus infantilis	119	1.21				2	23	94
Melanoplus keeleri	4	0.04			3		1	
Melanoplus occidentalis	11	0.11						11
Melanoplus packardii	67	0.68			3	9	30	25
Melanoplus sanguinipes	3031	30.74		3	129	598	1298	1003
Phoetaliotes nebrascensis	314	3.18	1	11	69	113	110	10
Subfamily Oedipodinae								
Arphia conspersa	25	0.25	7	15	3			
Arphia pseudonietana	68	0.69	2	25	6	11	19	5
Bandwing *"unknown"*	6	0.06		3	1	1	1	
Chortophaga viridifasciata	2	0.02		2				
Hadrotettix trifasciatus	17	0.17					5	12
Metator pardalinus	4	0.04					1	3
Pardalophora haldemani	49	0.50	38	10				1
Spharagemon collare	14	0.14				2	1	11
Spharagemon equale	48	0.49				3	21	24
Trachyrhachys kiowa	598	6.07			1	6	24	567
Trimerotropis latifasciata	3	0.03						3
Brachystola magna	1	0.01					1	
Total	9859		667	336	522	1026	2256	5052
Pct			6.77	3.41	5.29	10.41	22.88	51.24

Table 10. Mean density/m^2 of grasshoppers after application of traditional treatments and RAATs with carbaryl and malathion near Edgemont, SD, 1997.

Treatment	Rate [1]	Days After Treatment					
		Pre	3	7-8	14	21	28
malathion	8 – 100 [2]	18.1	2.1	2.1	2.1	1.7	1.8
malathion	4 - 80	15.4	3.7	2.7	4.5	4.6	7.1
carbaryl	16 – 100 [2]	23.2		1.6	1.0	1.8	2.4
carbaryl	8 - 50	22.1		6.5	4.7	5.2	8.6

[1] Fluid oz. of undiluted material applied/acre and percentage of acreage treated.
[2] Traditional rate

Table 11. Mean percentage control of grasshoppers treated with selected RAATs and traditional strategies near Edgemont, SD, 1997.

Treatment	Rate [2]	Percent Control at Days After Treatment [1]				
		3	7-8	14	21	28 [3]
malathion	8 – 100 [4]	88 a	88 b	89 b	90 a	77 a
malathion	4 - 80	75 b	82 c	73 d	63 b	26 b
carbaryl	16 – 100 [4]		94 a	96 a	90 a	87 a
carbaryl	8 - 50		70 d	81 c	66 b	54 b

[1] Corrected for natural mortality. A Kruskal-Wallis one-way analysis of variance with a nonparametric Tukey-type multiple comparison was performed on the data for each interval except at three days where a Mann-Whitney test was used. Means in the same column followed by the same letter are not significantly different ($P \leq 0.05$). Untreated check population decreased ca. 26% during study.
[2] Fluid oz. of undiluted material applied/acre and percentage of acreage treated.
[3] Determined from 4 of 12 sites/treatment.
[4] Traditional rate

Table 12. Mean percentage control of grasshoppers treated with selected RAATs and traditional strategies (two center sites/treatment only) near Edgemont, SD, 1997.

Treatment	Rate [2]	Percent Control at Days After Treatment [1]				
		3	7 - 8	14	21	28
malathion	8 – 100 [3]	91	91	90	87	70
malathion	4 - 80	65	75	71	38	18
carbaryl	16 – 100 [3]		91	94	85	84
carbaryl	8 - 50		63	75	52	48

[1] Corrected for natural mortality.
[2] Fluid oz. of undiluted material applied/acre and percentage of acreage treated.
[3] Traditional rate

Table 13. Mean number of spray droplets per cm^2 from aerially applied rangeland grasshopper treatments deposited on spray cards. Edgemont, SD, 1997.

Treatment	Rate [1]	Tip (No.)	Droplets/cm^2	Expected Droplets/cm^2
malathion	8 – 100 [2]	8002 (8)	39.8	
malathion	4 - 80	8002 (4)	13.8	80% of half = 15.9
carbaryl	16/16 – 100 [2]	8003 (20)	7.4	
carbaryl	8/8 - 50	8003 (10)	2.1	50% of half = 1.85

[1] Total fluid oz. of spray material applied/acre and percentage of acreage treated (all Sevin XLR treatments were diluted 1:1 with water buffered to a pH of 7).
[2] Traditional rate

Table 14. Economic variables and results associated with selected treatment strategies employed in the Edgemont, SD study, 1997.

Treatment	Benefit/Cost ratio Current	Benefit/Cost ratio + 3 years	Eggs/yd^2 *	Cost/acre	% Control
		Northern Great Plains			
Malathion RAATS	1.14	3.88	3.6	1.76	73
Carbaryl RAATS	1.05	3.57	4.7	1.48	81
Malathion Traditional	0.84	2.84	1.2	2.86	89
Carbaryl Traditional	0.51	1.73	1.1	4.33	96
		Northern Highland Prairie			
Malathion RAATS	0.95	3.25	3.6	1.76	73
Carbaryl RAATS	0.75	2.56	4.7	1.48	81
Malathion Traditional	0.76	2.57	1.2	2.86	89
Carbaryl Traditional	0.44	1.51	1.1	4.33	96
		Central Great Plains			
Malathion RAATS	0.78	2.67	3.6	1.76	73
Carbaryl RAATS	0.72	2.46	4.7	1.48	81
Malathion Traditional	0.57	1.95	1.2	2.86	89
Carbaryl Traditional	0.35	1.19	1.1	4.33	96
		Mean of Ranch Models			
Malathion RAATS	0.96	3.27	3.6	1.76	73
Carbaryl RAATS	0.84	2.86	4.7	1.48	81
Malathion Traditional	0.72	2.45	1.2	2.86	89
Carbaryl Traditional	0.43	1.48	1.1	4.33	96

* Eggs/yd^2 without treatment = 20.3

Table 15. Grasshopper species composition and age structure in the treated sites before treatment near Buffalo, SD, 1998.

			Instars					
Species	Total	Pct	1	2	3	4	5	Adult
Subfamily Gomphocerinae								
Aeropedellus clavatus	201	1.60				1		200
Ageneotettix deorum	2947	23.52		10	47	418	2146	326
Amphitornus coloradus	378	3.02			9	47	255	67
Chorthippus curtipennis	38	0.30		4	4	16	12	2
Cordillacris occipitalis	72	0.57					12	60
Eritettix simplex	9	0.07						9
Mermiria bivittata	24	0.19	1	6	10	4	3	
Opeia obscura	1438	11.48	35	137	513	630	123	
Orphulella speciosa	767	6.12	1	28	152	404	182	
Phlibostroma quadrimaculatum	5	0.04		2	1	1	1	
Pseudopomala brachyptera	1	0.01					1	
Subfamily Melanoplinae								
Hesperotettix viridis	161	1.29			3	24	124	10
Hypochlora alba	280	2.23	2	13	57	89	118	1
Melanoplus angustipennis	376	3.00	2	29	118	147	75	5
Melanoplus bivittatus	107	0.85		3	32	44	19	9
Melanoplus confusus	26	0.21						26
Melanoplus dawsonii	384	3.06	1	16	63	147	118	39
Melanoplus femurrubrum	207	1.65	18	54	65	54	15	1
Melanoplus gladstoni	487	3.89	103	275	109			
Melanoplus infantilis	117	0.93			4	34	59	20
Melanoplus keeleri	13	0.10		3	8	2		
Melanoplus packardii	476	3.80		19	114	194	147	2
Melanoplus sanguinipes	1319	10.53	6	80	302	405	431	95
Phoetaliotes nebrascensis	2360	18.84	198	791	1215	154	2	
Subfamily Oedipodinae								
Arphia pseudonietana	141	1.13	4	36	63	38		
Bandwing "unknown"	4	0.09	4					
Camnula pellucida	11	0.06		2	4	1	2	2
Chortophaga viridifasciata	8	0.14	6	2				
Spharagemon collare	18	0.29			2	3	13	
Spharagemon equale	36	0.94		1	10	19	6	
Trachyrhachys kiowa	118	0.03	1	1	8	32	70	6
Total	12529		382	1512	2913	2908	3934	880
Pct			3.05	12.07	23.25	23.21	31.40	7.02

Table 16. Mean density/m^2 of rangeland grasshoppers after application of traditional treatments and RAATs with carbaryl and malathion near Buffalo, SD, 1998.

		Days After Treatment					
Treatment	Rate [1]	Pre	3	7	14	21-23	28
malathion	8 – 100 [2]	17.15	2.00	1.35	1.48	1.17	1.17
malathion	4 - 80	21.13	5.98	5.58	6.33	6.79	5.71
carbaryl	16 – 100 [2]	23.44		1.88	0.73	0.75	0.56
carbaryl	12 - 50	18.63		6.27	4.10	2.65	2.69

[1] Fluid ounces of undiluted material applied/acre and percentage of acreage treated.
[2] Traditional rate

Table 17. Mean percentage control of grasshoppers treated with selected RAATs strategies near Buffalo, SD, 1998.

		Percent Control at Days After Treatment [1]				
Treatment	Rate [2]	3	7	14	21-23	28
malathion	8 – 100 [3]	91.1 a	94.6 a	94.3 a	95.5 a	95.3 a
malathion	4 - 80	79.9 b	80.8 b	79.1 b	78.5 c	81.0 b
carbaryl	16 – 100 [3]		92.3 a	97.1 a	96.8 a	97.2 a
carbaryl	12 - 50		70.3 b	81.6 b	88.3 b	86.8 b

[1] Corrected for natural mortality. A Kruskal-Wallis one-way analysis of variance with a nonparametric Tukey-type multiple comparison was performed on the data for each interval except at three days where a Mann-Whitney test was used. Means in the same column followed by the same letter are not significantly different ($P \leq 0.05$). Untreated check population increased ca. 32% during the study.
[2] Fluid ounces of undiluted material applied/acre and percentage of acreage treated.
[3] Traditional rate

Table 18. Mean number of spray droplets per cm^2 from four aerially applied rangeland grasshopper treatments near Buffalo, SD, 1998.

Treatment	Rate	Tip (No.)	Droplets/cm^2	Expected Droplets/cm^2
malathion	8 – 100 [1]	8002 (8) SD	29.4	
malathion	4 - 80	8002 (4) 45°	9	80% of ½ = 11.8
carbaryl	16/16 – 100[1]	8003 (20) SD	7	
carbaryl	12/12 - 50	8003 (15) SD	2.4	50% of ¾ = 2.6

[1] Traditional rate

Table 19. Economic variables and results associated with selected treatment strategies employed in the Buffalo, SD, 1998.

Treatment	Benefit/Cost ratio Current	Benefit/Cost ratio + 3 years	Eggs/yd^2 *	Cost/acre	% Control
		Northern Great Plains			
Malathion RAATS	1.18	4.02	9.6	1.76	80
Carbaryl RAATS	1.01	3.45	5.1	1.82	82
Malathion Traditional	0.93	3.17	4.2	2.86	95
Carbaryl Traditional	0.59	2.00	1.5	4.33	96
		Northern Highland Prairie			
Malathion RAATS	1.25	4.27	9.6	1.76	80
Carbaryl RAATS	1.05	3.57	5.1	1.82	82
Malathion Traditional	1.04	3.52	4.2	2.86	95
Carbaryl Traditional	0.65	2.20	1.5	4.33	96
		Central Great Plains			
Malathion RAATS	0.80	2.73	9.6	1.76	80
Carbaryl RAATS	0.70	2.36	5.1	1.82	82
Malathion Traditional	0.64	2.18	4.2	2.86	95
Carbaryl Traditional	0.41	1.38	1.5	4.33	96
		Mean of Ranch Models			
Malathion RAATS	1.08	3.67	9.6	1.76	80
Carbaryl RAATS	0.92	3.13	5.1	1.82	82
Malathion Traditional	0.87	2.96	4.2	2.86	95
Carbaryl Traditional	0.55	1.86	1.5	4.33	96

* Eggs/yd^2 without treatment = 19.4

Table 20. Grasshopper species composition and age structure in the treated plots and untreated sites near Edgemont, SD, 1999.

Species	Total	Pct	Instars 1	2	3	4	5	Adult
Subfamily Gomphocerinae								
Acrolophitus hirtipes	1	0.01	0	0	0	0	0	1
Ageneotettix deorum	7183	69.00	0	38	1107	5186	848	4
Amphitornus coloradus	819	7.87	0	0	49	252	517	1
Aulocara elliotti	23	0.22	0	0	0	8	14	1
Cordillacris occipitalis	646	6.21	0	0	1	39	446	160
Eritettix simplex	10	0.10	0	0	0	0	0	10
Mermiria bivittata	54	0.52	0	0	17	25	12	0
Opeia obscura	462	4.44	0	26	228	164	44	0
Orphulella speciosa	4	0.04	0	0	3	1	0	0
Phlibostroma quadrimaculatum	100	0.96	0	14	32	52	2	0
Psoloessa delicatula	1	0.01	0	0	0	0	0	1
Subfamily Melanoplinae								
Hesperotettix viridis	4	0.04	0	0	3	1	0	0
Melanoplus bivittatus	26	0.25	0	0	1	10	15	0
Melanoplus bowditchi	63	0.61	0	0	7	28	27	1
Melanoplus confusus	9	0.09	0	0	0	0	3	6
Melanoplus infantilis	10	0.10	0	3	2	4	1	0
Melanoplus packardii	216	2.07	0	0	34	89	91	2
Melanoplus sanguinipes	327	3.14	0	0	38	127	162	0
Melanoplus "species"	48	0.46	3	27	16	2	0	0
Phoetaliotes nebrascensis	34	0.33	0	14	18	2	0	0
Subfamily Oedipodinae								
Arphia pseudonietana	11	0.11	0	9	2	0	0	0
Encoptolophus costalis	1	0.01	0	1	0	0	0	0
Hadrotettix trifasciatus	7	0.07	0	0	3	4	0	0
Hippiscus ocelote	43	0.41	0	11	29	3	0	0
Pardalophora haldemani	3	0.03	0	0	0	0	0	3
Spharagemon collare	43	0.41	0	0	10	20	13	0
Trachyrhachys kiowa	262	2.52	0	3	51	170	38	0
Total	10410		3	146	1651	6187	2233	190
Pct			0.03	1.40	15.86	59.43	21.45	1.83

Table 21. Mean density/m^2 of rangeland grasshoppers after application of traditional treatments and RAATs with carbaryl and diflubenzuron near Edgemont, SD, 1999.

			Days After Treatment			
Treatment	Rate [1]	Pre	7	14	21	28
diflubenzuron	1.0 – 100 [2]	27.6	11.5	0.5	0.1	0.2
diflubenzuron	0.75 – 50	23.3	9.0	1.2	0.5	0.3
carbaryl	12 – 100 [2]	26.4	1.4	0.7	1.0	0.8
carbaryl	8 – 50	30.6	4.3	3.6	3.1	3.0

[1] Fluid oz. of undiluted material applied/acre and percentage of acreage treated.
[2] Traditional rate

Table 22. Mean percentage control of grasshoppers treated with selected traditional and RAATs treatments near Edgemont, SD, 1999.

		Days after treatment [1]			
Treatment	Rate [2]	7	14	21	28
diflubenzuron	1.0 – 100 [3]	61.0 b (61.0)	98.1 a (98.1)	99.7 a (99.7)	99.2 a (99.2)
diflubenzuron	0.75 - 50	61.4 b (60.2)	95.0 b (94.6)	97.6 b (97.6)	98.5 a (98.6)
carbaryl	12 – 100 [3]	94.9 a (94.9)	97.6 a (97.5)	96.5 b (96.4)	96.7 a (97.0)
carbaryl	8 - 50	84.8 a (85.9)	87.9 c (88.2)	89.7 c (89.8)	89.5 b (90.7)

[1] Corrected for natural mortality (unadjusted values in parentheses). Analysis performed was a Kruskal-Wallis one-way analysis of variance with a nonparametric Tukey-type multiple comparison for each interval. Means in the same column followed by the same letter are not significantly different ($P \leq 0.05$). Untreated check population decreased an average of 0.4% per day.
[2] Fluid ounces of undiluted material applied/acre and percentage of acreage treated.
[3] Traditional rate

Table 23. Mean number of spray droplets per cm^2 from two aerially applied rangeland grasshopper treatments, Edgemont, SD, 1999.

Treatment	Rate	Droplets/cm^2	Droplets expected/cm^2 – various studies		
			1997	1998	1999
carbaryl	12/12 100% [1]	5.05		4.69	
carbaryl	8/8 50%	1.85	2.1		1.69

[1] Traditional rate

Table 24. Economic variables and results associated with selected treatment strategies employed in the Edgemont, SD study, 1999.

Treatment	Benefit/Cost ratio		Eggs/yd^2	Cost/acre	% Control
	Current	+ 3 years			
Northern Great Plains					
Diflubenzuron RAATS	2.09	7.10	0.3	1.57	97
Carbaryl RAATS	1.84	6.27	1.1	1.48	89
Diflubenzuron Traditional	0.97	3.31	0.3	3.53	99
Carbaryl Traditional	0.90	3.06	0.3	3.64	97
Northern Highland Prairie					
Diflubenzuron RAATS	1.56	5.30	0.3	1.57	97
Carbaryl RAATS	1.18	4.03	1.1	1.48	89
Diflubenzuron Traditional	0.75	2.55	0.3	3.53	99
Carbaryl Traditional	0.67	2.28	0.3	3.64	97
Central Great Plains					
Diflubenzuron RAATS	1.41	4.79	0.3	1.57	97
Carbaryl RAATS	1.24	4.23	1.1	1.48	89
Diflubenzuron Traditional	0.66	2.23	0.3	3.53	99
Carbaryl Traditional	0.61	2.07	0.3	3.64	97
Mean of Ranch Models					
Diflubenzuron RAATS	1.69	5.73	0.3	1.57	97
Carbaryl RAATS	1.42	4.84	1.1	1.48	89
Diflubenzuron Traditional	0.79	2.70	0.3	3.53	99
Carbaryl Traditional	0.73	2.47	0.3	3.64	97

* Eggs/yd^2 without treatment = 16.9

Figure 1. General schematic of the study showing four 640-acre plots and the grasshopper density evaluation sites.

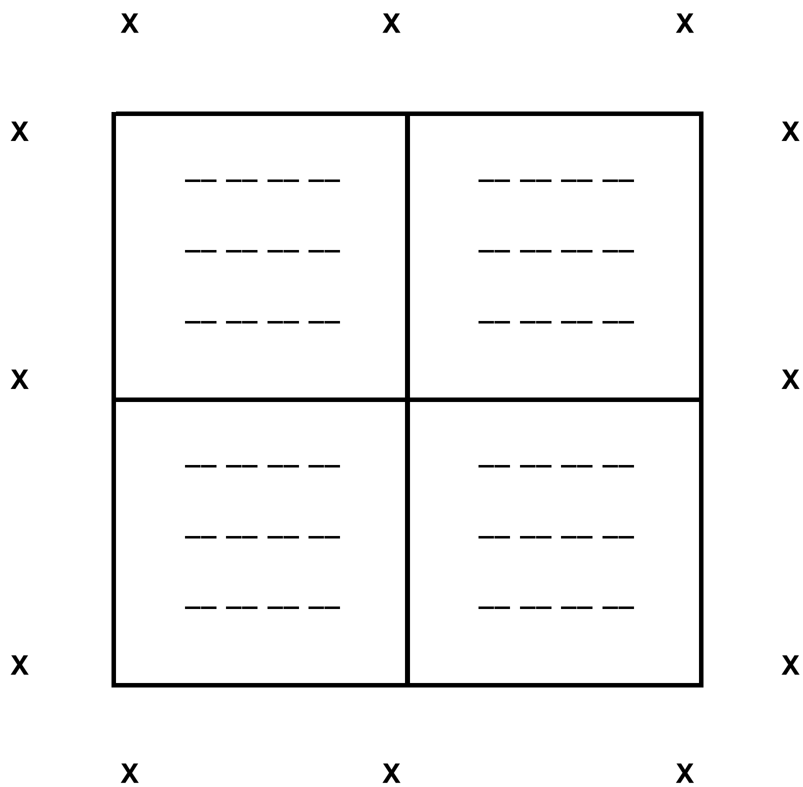


Figure 2. Detailed location of grasshopper evaluation sites within one 640-acre plot.

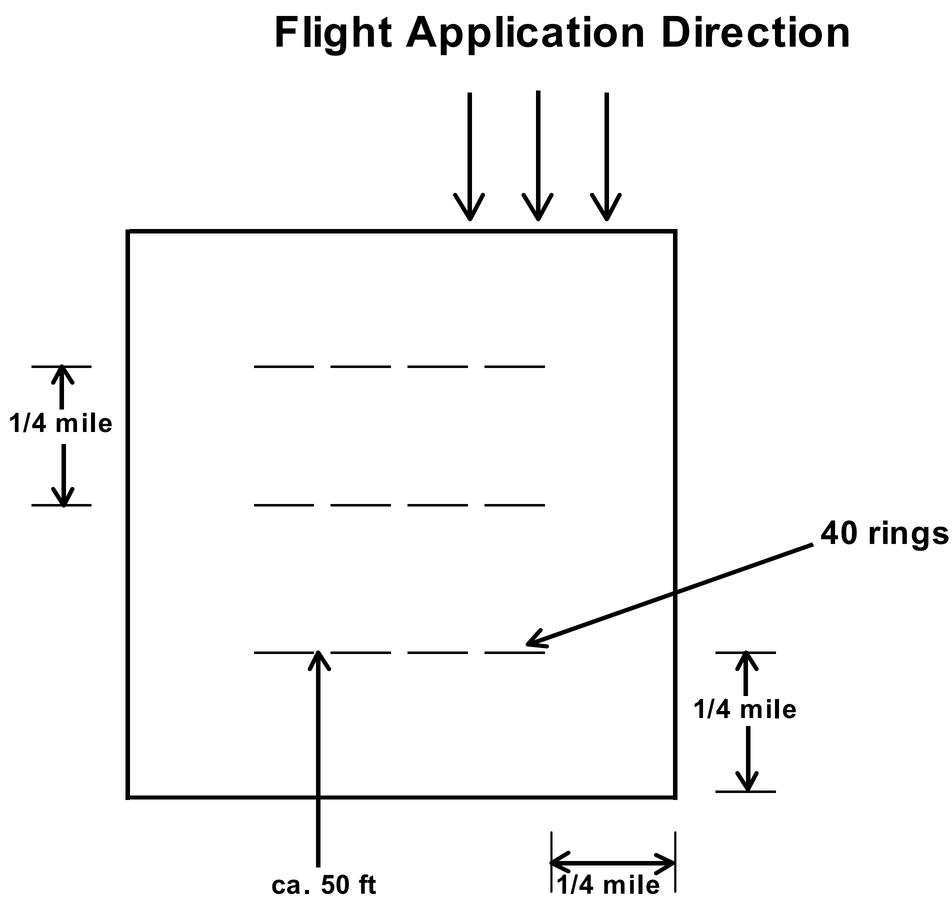


Figure 3. Date of treatment applications and daily precipitation in the study area near Edgemont, SD, 1997.

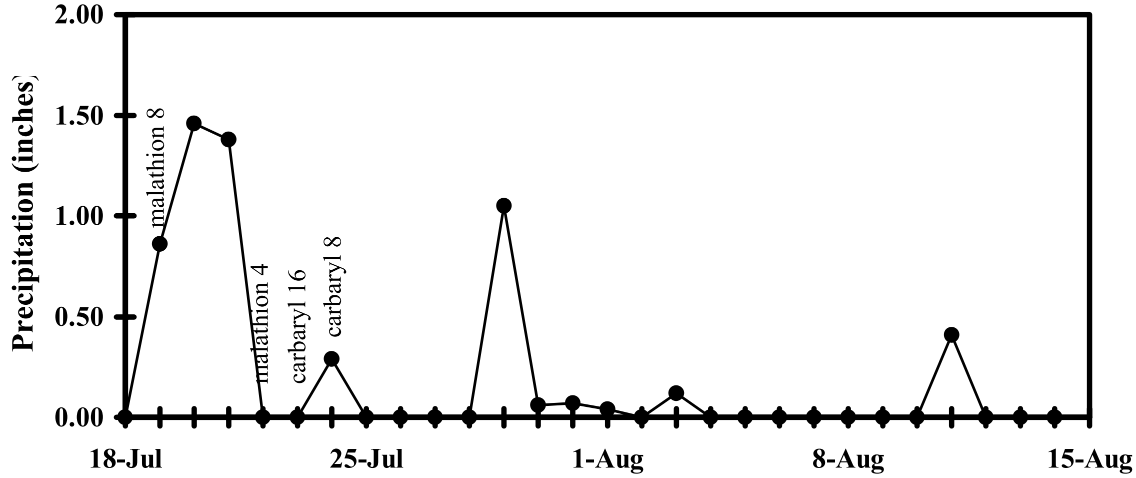


Figure 4. Daily minimum and maximum temperatures recorded in the study area near Edgemont, SD, 1997.

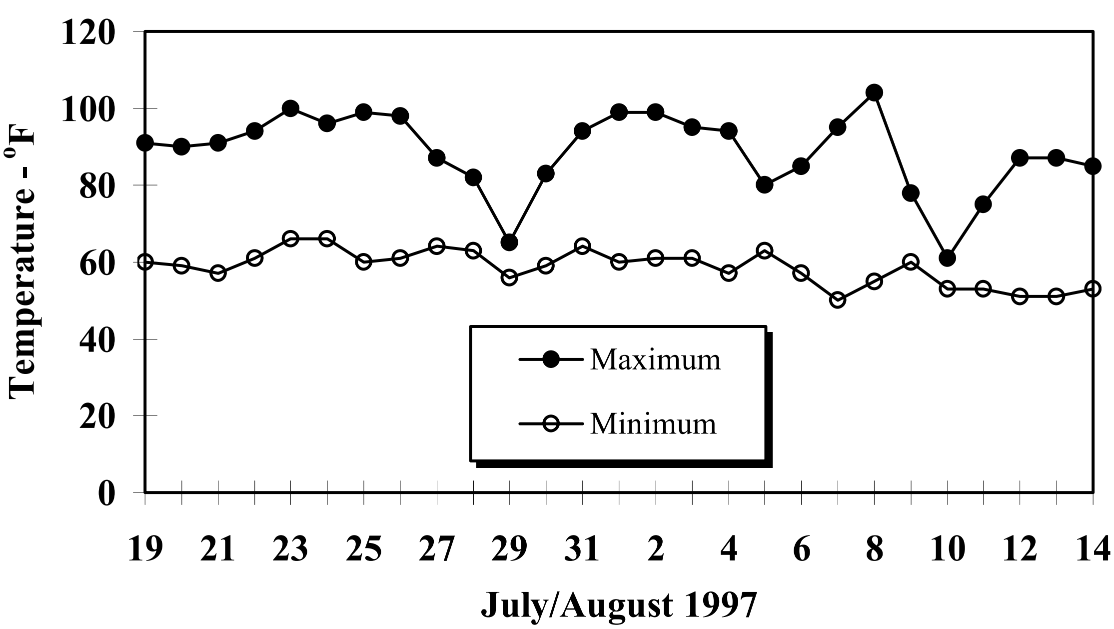


Figure 5. Date of treatment applications and daily precipitation in the study area near Buffalo, SD, 1998.

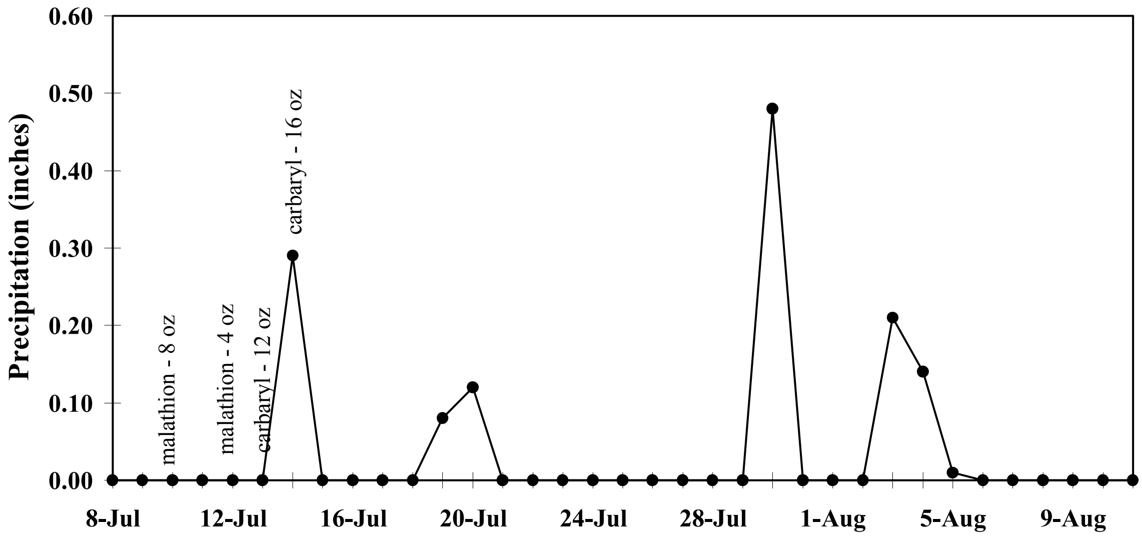


Figure 6. Daily minimum and maximum temperatures recorded in the study area near Buffalo, SD, 1998.

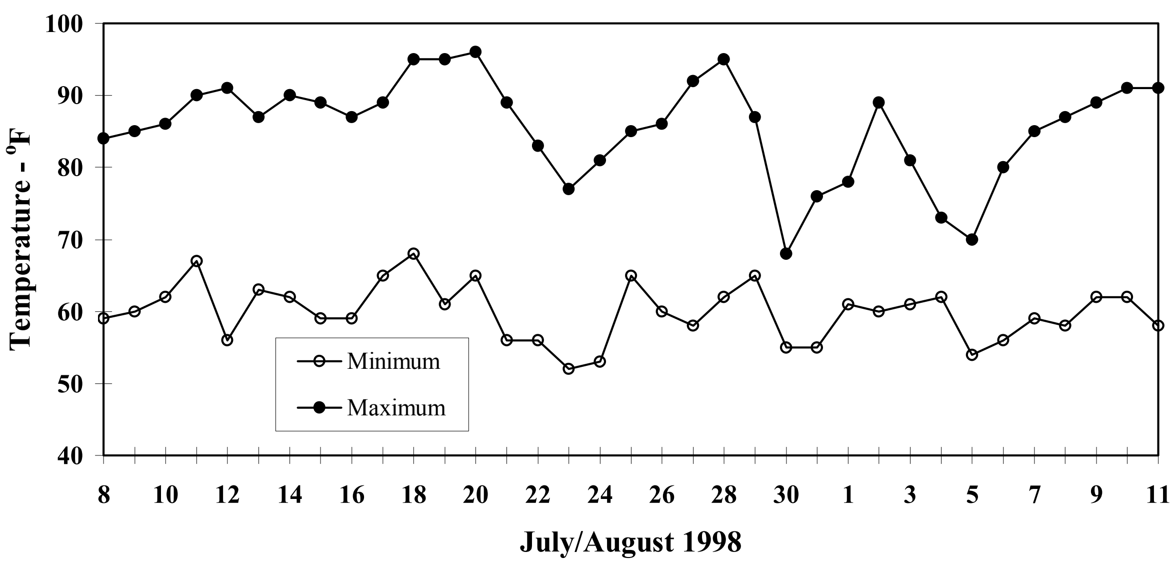


Figure 7. Date of treatment application and daily precipitation in the study area near Edgemont, SD, 1999.

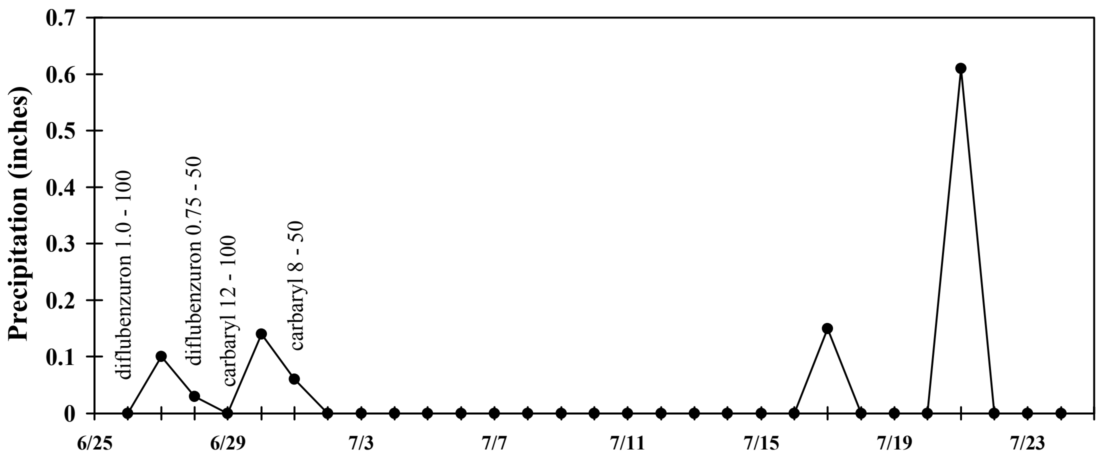


Figure 8. Daily minimum and maximum temperatures recorded in the study area near Edgemont, SD, 1999.

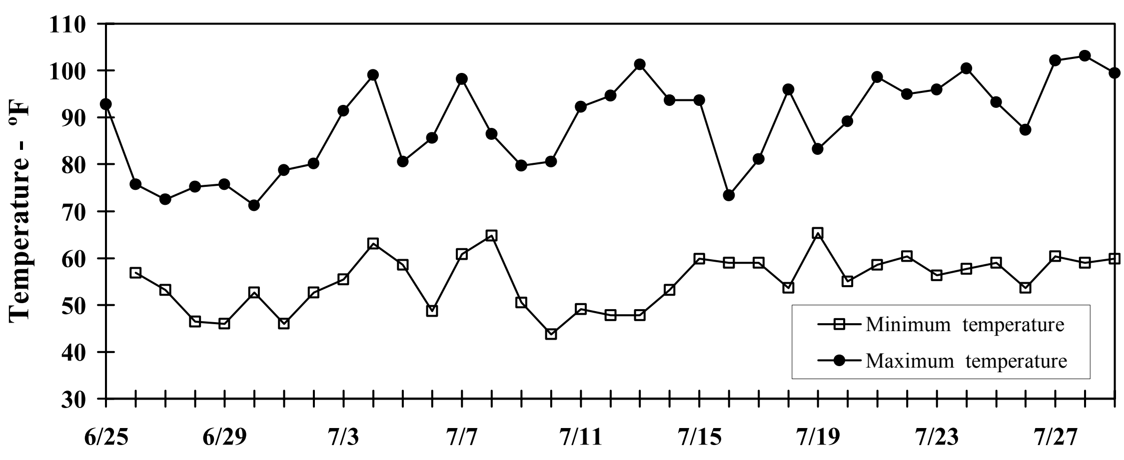
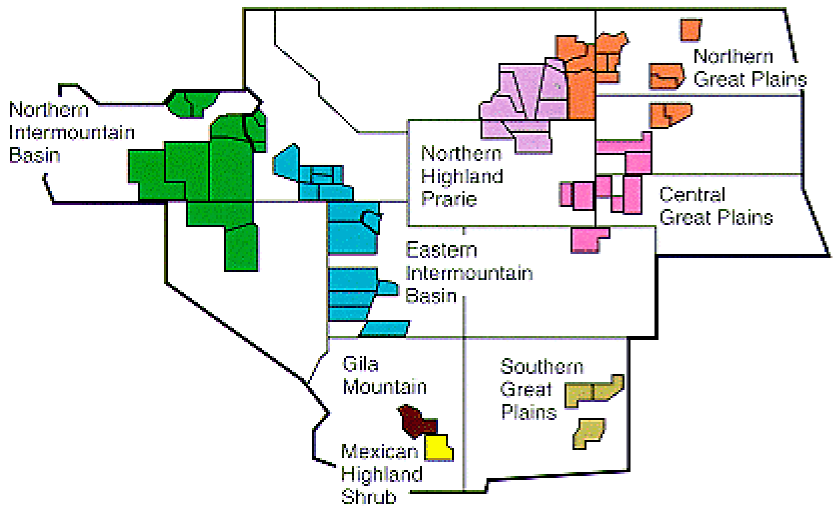


Figure 9. Map of the Western United States showing the eight generalized range-type regions.



Taken from (Davis and Skold, 1996.)