Section II. Chemical Control

For blocks of rangeland in the thousands of acres, aerial application of insecticides provides one of the most cost-effective methods of grasshopper management. Research has shown that aerial application of bait in the form of treated wheat bran can also be cost effective, especially in environmentally sensitive areas. (APHIS photo by Mike Sampson.)

II.1 Introduction to Chemical Control

NOTE: Acephate is no longer approved by EPA for rangeland grasshopper control.

R. Nelson Foster

Since the beginning of recorded history, outbreaks of grasshoppers have plagued humanity, coming in direct competition with people for life-sustaining food. Humans were initially helpless against grasshopper outbreaks. Natural control through grasshopper predators, parasites, diseases, and unfavorable weather conditions offered the only relief that could be expected.

Colonial America recorded grasshopper outbreaks in the mid-1700's. From 1718 to 1767, the founders of California missions faced near famine from grasshopper plagues (Schlebecker 1953). During 1874 to 1877, the outbreak of the Rocky Mountain locust (grasshopper) became widespread and severe. The U.S. Congress established the U.S. Entomological Commission to deal with grasshopper problems (Parker 1952). The first effective chemical control of U.S. grasshopper populations took place in 1885 with the use of bran and arsenic-based bait.

From then until the middle 1900's, poison baits that grasshoppers would eat were the most commonly used type of chemical control for combating these pests. Baits laced with arsenic were popular until 1943, when sodium fluosilicate became the active ingredient of choice.

Through increased research, baits were improved, and by 1950 the chlorinated hydrocarbons chlordane, toxaphene, and aldrin replaced sodium fluosilicate. Aerially applied sprays containing the newer chemicals saw use in the late 1940's and were so effective that bait treatments essentially disappeared in the 1950's (Parker 1952). Improved baits are now enjoying a renewed interest, primarily because of environmental concerns and improved application technology. By the mid to late 1960's, malathion spray applied at ultralow volume became the most common chemical for controlling grasshoppers on rangeland. In the early 1970's, the Sevin 4-Oil® formulation of carbaryl became available. By the early 1980's, acephate was added to the group of chemicals recommended for controlling grasshoppers.

There are several other chemicals highly toxic to grasshoppers, but they are not registered for use on rangeland, where treatments occasionally contact domestic livestock and wildlife. For grasshopper control programs that the U.S. Department of Agriculture (USDA), Animal and Plant Health Inspection Service (APHIS) oversees, only chemicals with minor impact on the environment and nontarget organisms are used. These chemicals give acceptable performance on grasshoppers. Currently, malathion, carbaryl, and acephate remain the three recommended chemicals for use in large-scale, aerially applied control programs against grasshopper outbreaks.

Because grasshopper outbreaks often are so extensive that individual land managers and owners alone cannot control them, Congress charged USDA in 1934 to help protect rangeland and cropland from the destructive populations of grasshoppers (U.S. Department of Agriculture 1979). In the 1980's, for example, the Federal Government sprayed millions of acres of public and private western rangeland for grasshopper control. Control programs on a smaller scale take place almost every year in some States. Congress authorized USDA involvement in large-scale, coordinated efforts against damaging outbreaks of grasshoppers by the Incipient and Emergency Control of Pests Act, 1927; the Organic Act of the Department of Agriculture, 1944; the Cooperation with State Agencies in the Administration and Enforcement of Certain Federal Laws Act, 1962; and the Food Security Act, 1985.

Currently, two major programs administrated by USDA exist for managing grasshoppers on or near rangeland areas. They are the Rangeland Grasshopper Cooperative Management Program and the Cropland Protection Program. USDA is also involved when grasshoppers reach certain levels on Conservation Reserve Program lands.

The work to develop alternatives to chemicals for suppression and control of grasshopper outbreaks is ongoing. However, advances are slow, and currently the proven options are few at best. The small number of effective tools and strategies for managing grasshoppers dictates continued reliance on chemical control as a major option within grasshopper management. When outbreaks reach crisis proportions, chemical control of some form may be the only remaining option.

A primary goal of integrated grasshopper management is to prevent the buildup of populations to damaging levels. However, some periodic outbreaks will inevitably occur, and some will require immediate intervention in the form of fast-acting chemical control. The traditional use of chemicals has been to control grasshoppers to the greatest possible extent. However, recent improvements in equipment and application methods and the development of a system for analyzing the economics of alternate strategies are expanding the role of chemicals. These developments may lead to strategies with objectives other than maximum control and ultimately will allow the use of a lower dosage of chemicals previously believed to produce unacceptable results.

The following section will explore some major techniques and issues related to current chemical control tools and tactics and will also discuss and propose some future tactics. The chapters in this Chemical Control section of the Grasshopper Integrated Pest Management User Handbook serve as a state-of-the-art source of information about the role chemical control has in integrated rangeland grasshopper management technology.

Suggested References

Parker, J. R. 1952. Grasshoppers. In: Insects: the Yearbook of Agriculture, 1952. Washington, DC: U.S. Department of Agriculture: 595–604.

Schlebecker, J. T. 1953. Grasshoppers in American agricultural history. Agricultural History 27: 85–93.

U.S. Department of Agriculture, Animal and Plant Health Inspection Service. 1979. Final environmental impact statement, USDA-APHIS-ADM-79-I-F. Rangeland Grasshopper Cooperative Management Program. Washington, DC: U.S. Department of Agriculture, Animal and Plant Health Inspection Service. 177 p.

II.2 Evaluation of Rangeland Grasshopper Controls: A General Protocol for Efficacy Studies of Insecticides Applied From the Air

NOTE: Acephate is no longer approved by EPA for rangeland grasshopper control.

R. Nelson Foster and K. C. Reuter

Introduction

Many chemical compounds are registered for use against grasshoppers, but only a few are used in the large-scale cooperative private–State–Federal rangeland grasshopper management programs directed by the U.S. Department of Agriculture's Animal and Plant Health Inspection Service (USDA/APHIS). APHIS chooses and approves compounds based on (1) effective performance against grasshoppers on rangeland, and (2) minimal or negligible impact on the environment and nontarget species. On rangeland, APHIS normally uses these compounds at the lowest active ingredient (AI) level listed on the label.

To be approved for use by APHIS, chemical insecticides must be evaluated for effectiveness, or efficacy. Efficacy testing determines the levels of performance for a specific compound formulation at different doses of active ingredient and in different application volumes of diluent (a diluting liquid or solid) per unit of surface area. Candidate treatments may be newly developed compounds, new formulations of currently used compounds, or registered compounds proposed for rangeland use for the first time. Based on 15 years of development, the following describes the protocol (procedure) used to evaluate candidate treatments for use on rangeland grasshoppers in APHIS-managed programs.

Geographic Location

The first step in an efficacy test is selecting a location for the study. The test is only as good as the location where it is conducted. The location should be typical of areas commonly treated in cooperative large-scale management programs. Also, the location should have a typical population mix of rangeland grasshoppers or a majority of species commonly considered as potentially damaging to rangeland. Average population levels should be at least 10–25 grasshoppers/yd^2. Lower populations may limit the level and type of statistical analysis performed on the data.

Test locations commonly are selected from areas experiencing a significant outbreak of grasshoppers and near where control programs are planned. These locations have two major advantages. First, such locations allow researchers to experience firsthand some of the local problems that may exist in controlling grasshoppers. Second, the proximity to a major control program activity allows a control program manager a firsthand view of the potential tool.

While there are distinct advantages in locating research and program activities near each other, doing so may cause problems. First, the large-scale program and the researcher may be competing for the same infested land. The program manager is interested in improving the control plot by simplifying boundaries or protecting its integrity from migration of grasshoppers from untreated plots in the research design. The researcher looks for desirable population and topographic features typical of a program. For the private party, a cost share will be required if the land is included in the control program, but charges are generally not assessed for land used in research. Close communication with the program manager is the only solution to these potential conflicts.

Sometimes, the test area may be located adjacent to the program area. In such cases, researchers must take extra precautions to ensure that no contamination from the control block will compromise the integrity of the test area. In many cases, it is easier to choose a test area separated from a nearby control block. With appropriate approval, both public and private lands can be used. Permission to use public lands usually requires additional procedures compared to private lands. Because of the brief period of time between locating a test area and beginning the test (occasionally as few as 3–4 days), researchers most often choose private land with approval of landowners, lessees, or others who may be involved. Tests on rangeland usually require the use of trail bikes and the temporary positioning of other equipment. Researchers discuss use of these items with and get approval from the landowner as one of the first steps in site selection.

Once general permission for use of the land is obtained, a preliminary survey on the parcel of land proposed for the test is conducted. The preliminary survey generally consists of conducting population estimates every $^1/_4$ mi and a cursory examination of terrain and vegetation types. This survey ensures adequate uniformity in the general vegetation types and grasshopper population levels for the study proposed. The absence of livestock during the study period is not a requirement but simplifies counting and eliminates the need to build temporary fences for protection of any required specialized equipment.

Close proximity of the test area to a landing strip or airport is extremely important. Many experiments require several changes in equipment and formulations, and since only 1–2 hours of application time may be available each day, ferrying distances should be kept to a minimum. Lodging close to the test area also is worth consideration. Daily travel will be needed during setup and application and usually for 2–4 weeks after the final application.

Types and Sizes of Experiments

Several general types and sizes of experiments take place when APHIS evaluates a candidate treatment for potential program use. The evaluation usually begins with replicated (repeated) small rangeland plots and eventually progresses to larger blocks. Each type of experiment is important in producing a complete evaluation and recommendation that both industry and the user communities will accept. Later, for treatments used in cooperative programs, APHIS evaluates each program to document the performance of the compound and the success of the program in which it was used.

Small-Scale Replicated Plot Studies.—After a compound has shown a potential for producing mortality to the target pest either in the laboratory or on small (less than 10 acres) field plots, the evaluation process graduates to replicated field plots of substantial size. At this stage in the development of a treatment, testing for the first time incorporates the aerial application aspect. APHIS typically designs the experiments to determine the (1) lowest effective dose of active ingredient, (2) minimum volume of application, and (3) optimal type of diluent (water, oil, or solid bait carrier). These experiments also serve to determine if proposed formulations are compatible with existing commercial aerial application equipment. Experiments also may be designed to determine the optimal nozzle type and size to be used with the final formulation.

Plots are typically square and 40 acres in size ($^1/_4$ mi by $^1/_4$ mi). This size allows for a buffer zone on all sides of the centrally located evaluation site. The buffer area protects the evaluation site from grasshoppers that have been exposed to different treatments and may migrate from adjacent plots. Additionally, buffer areas ensure that any drift contamination near the edges of plots will not jeopardize the integrity of the evaluation site. In studies of aerially applied insecticide on rangeland, smaller plots are simply inadequate for evaluating treatment impact on grasshopper populations. Plots larger than 40 acres may be used. Larger plots increase the protection of the evaluation area but rapidly use up valuable rangeland test acreage. In small-scale studies, using four replications of each aerially applied treatment is typical and is considered minimal.

An example of a typical small-scale study follows. Grasshopper mortalities resulting from three dosages of a candidate formulation at a fixed volume of application are compared with each other. Mortalities are also compared to those produced by a treatment currently used for controlling grasshoppers, called a standard. Mortalities resulting from all four treatments are compared with mortalities in untreated plots. These untreated plots will show the mortality rate that naturally occurs during the experiment. In this experiment, there are five different kinds of plots called “treatments” with each replicated four times. The entire experiment takes 20 plots and uses 800 acres. The untreated control plots are the most important in the experiment. All other treatments are judged against the controls. Control plots are part of the experimental design and must be included in the process of assigning treatments to specific plots. Other actual examples can be seen in Foster et al. (1983 unpubl.) and Jech et al. (1993).

Because densities of grasshoppers may vary considerably over the study area, it is important to ensure that any one treatment is not assigned exclusively to high or low grasshopper population levels. In small-scale experiments, the population-level values of the plots are typically arranged in descending order of density. In the case of the above example, each of the five treatments are randomly assigned to plots within the top five densities, five treatments to the next five densities, and so on until the desired number of replications have been performed. This ensures that all treatments are tested against similar population densities. Typically, one or more treatments of those tested in small replicated plot studies will be suitable for large-scale testing. (See table II.2–1 and fig. II.2–1.)

Large-Scale Simulated Program Studies.—After successful small-scale testing, the next step is to evaluate the candidate formulations under simulated program conditions. Doing this ensures that the level of performance seen in tightly controlled small-scale experiments can be expected when much larger acreages are treated. These tests challenge the formulation (1) under environmental and meteorological conditions expected during a program, and (2) for compatibility with commercial spraying equipment for extended periods of time. Successful performance in these studies may result in recommendations for program use.

In these experiments, application flights of at least 1 mi in length are desirable. Plot size typically ranges from 640 acres (a section) to 1,000 acres. With a plot of this size and a single aircraft such as an Ag Truck, researchers can use much or all of acceptable early morning application time in a single plot. The changing meteorological conditions that occur over this time period allow for assessment over the varying conditions that occur during a typical control program application day. Aircraft altitude (application height) in these studies will be similar to those APHIS uses during programs.

A typical large-scale study may consist of one or two different formulations of a candidate compound, a standard treatment, and an untreated control plot, each on a minimum of 640 acres. Because of the size of acreage involved in these tests, true statistical replication, in the general vicinity, is usually impossible. However, it is common to conduct the same test in other areas or States. Typically, the candidate and standard treatments, as well as the untreated control, are randomly assigned to one of several (in this case, three) adjoining plots. Before treatment, these plots are assessed to make sure they are suitable for the experiment. Unfortunately, in many cases, enough grasshopper-infested acreage is not available. In such cases, the untreated check sites are established outside of the treated plots and at a distance to ensure that there is no contamination from treatment.

A large-scale experiment usually relies on 9–10 evaluation sites per treatment plot. Without prior knowledge of plant communities, soil characteristics, or species composition of grasshoppers, the researchers determine the location of each evaluation site using topographic and county maps. These sites generally are distributed evenly over the entire plot (see fig. II.2–2). With this technique, each type of habitat is represented proportionately in the evaluation of each plot. An actual example can be found in Foster et al. (1993 unpubl.).

Efficacy Evaluation of Control Programs

Evaluation of performance continues even after treatments have been recommended for cooperative programs. APHIS evaluates each program to determine the performance of the treatment and to document the level of success of the program in which it was used.
Cooperative programs may vary greatly in size, from 10,000 acres to 100,000-plus acres, and may rely on several aircraft flying in formation for application. Evaluation of a program treatment is similar to that which occurs for program-simulated experiments. Evaluation sites are evenly distributed within the treatment area, while allowing for access by roads or trails. Sites are selected at 1 per 1,000 acres for the first 100,000 acres, and 1 per each 10,000 acres above 100,000 acres. Where programs are less than 10,000 acres, we recommend using a minimum of 10 treatment evaluation sites. We identify the evaluation sites before application. Evaluation of those sites is in addition to the more cursory visual mortality checks, commonly conducted on all cooperative control programs.

APHIS also establishes an equal number of untreated check sites that can be used for comparison in the evaluation. The untreated sites are mandatory. However, because a program goal is usually to treat all land infested with grasshoppers that cause damage at economic levels in a given area, untreated control sites within the treated block are not possible. Consequently, untreated control sites are situated outside, but near to, the boundary of the program block and surround the entire perimeter of the area tested.

Plot and Evaluation Site Setup

In both small- and large-scale simulated program studies, corner boundaries of all plots have flexible poles to which streamers of flagging tape are attached. We use two colors, usually orange and white, to increase visibility. Corners also are marked with a wooden stake labeled to identify the plots.

We mark evaluation sites with flexible poles and wooden stakes. In replicated small-plot studies, only a single color of tape is attached to the site markers to prevent confusion with corners. At each evaluation site, we use 0.1-m^2 aluminum rings (Onsager and Henry 1977) to delimit 40 areas for counting grasshoppers. Starting at the wooden stake, we arrange the rings about 5 yd apart in a large circle about 64 yd in diameter. Placement of individual rings is simply a random drop at the end of each 5-yd interval.

The circle arrangement provides for a curved transect of 200 yd which allows the sample counter to finish at the initial stake. Compared to techniques where counting areas are concentrated and uniform habitat is desired, this arrangement of sample rings allows for sampling a more diversified habitat. The circular arrangement also ensures that counting at all sites will be affected by wind and sun angles from all directions. Ring spacing of 5 yd between rings ensures that there is no disturbance to the next area to be counted during an ongoing count. In some programs, we may base pesticide effectiveness on estimates of grasshoppers in 18 visualized 1-ft^2 areas at evaluation sites rather than counts from rings. While not as accurate as counting from rings, the resulting data generally yield good estimates of the level of control achieved by the treatment.

Application

Calibration of the aircraft delivery system (spreader for baits and spraying systems for liquids) is the most important aspect of application. The accuracy of application in experiments and programs depends on repeatable precision obtained through the use of proven calibration procedures. Details of some of these procedures are in the chapters on “Calibration of Aerially Applied Sprays” (II.8) and “Equipment Modification, Swath Width Determination, and Calibration for Aerial Application of Bran Bait with Single-Engine Fixed-Wing Aircraft” (II.18) in this section of the User Handbook.

In small-scale replicated plot experiments, we consider the order of treatments. Similarly based formulations are grouped together in the sequence of application to minimize equipment cleanup and changeover time between treatments. We arrange the dosages tested in increasing or decreasing order depending on the complexity of mixing required for test formulations.

Conventional replication in an experiment requires all treatments to be applied once before repeating. Then all treatments are applied a second time before a third treatment is applied, and so forth. The arguments against this type of sequencing are numerous and usually win out to preserve time and money and to maintain a uniform grasshopper age structure against which the treatments are applied. Typically, we apply each treatment to all of its assigned plots before changing over equipment for the next formulation in the sequence of application.

Table II.2–1—Pretreatment grasshopper densities per square meter, arranged in descending order with randomly assigned treatments for each density group

Grasshopper density per m^2	Plot number	Assigned treatment
41	17	Treatment 2
41	16	Treatment 1
36	13	Treatment 3
36	1	Untreated
29	11	Standard
29	3	Treatment 1
25	18	Treatment 2
23	12	Treatment 3
22	6	Untreated
19	20	Standard
18	19	Treatment 1
18	2	Standard
14	7	Untreated
13	15	Treatment 3
13	4	Treatment 2
11	10	Untreated
9	5	Standard
9	9	Treatment 3
9	14	Treatment 2
6	8	Treatment 1

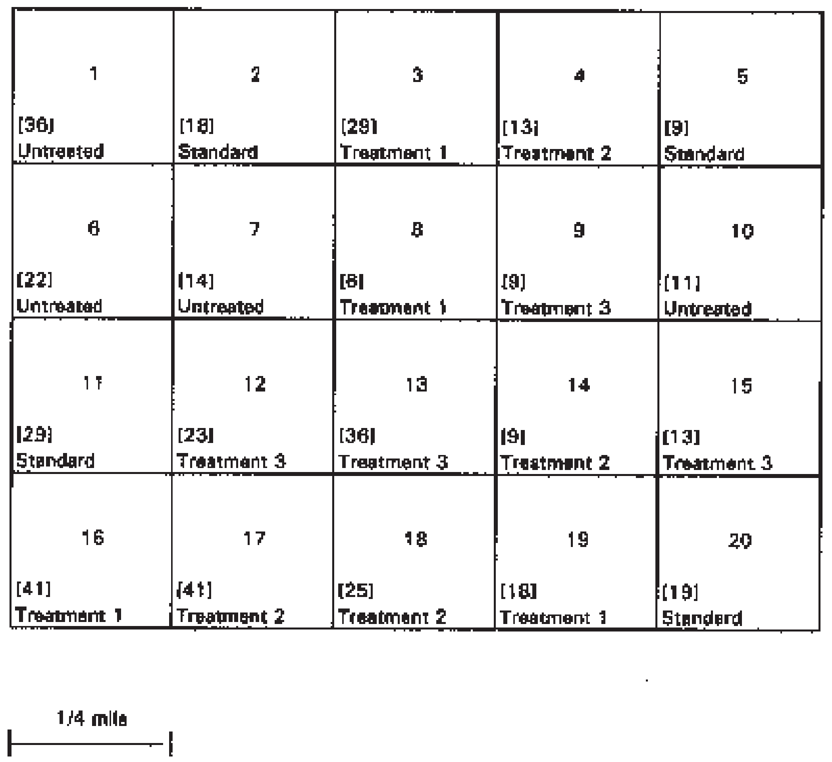


Figure II.2–1—Plot map showing pretreatment mean density of grasshoppers per square meter, in parentheses, and assigned treatments from table II.2–1.

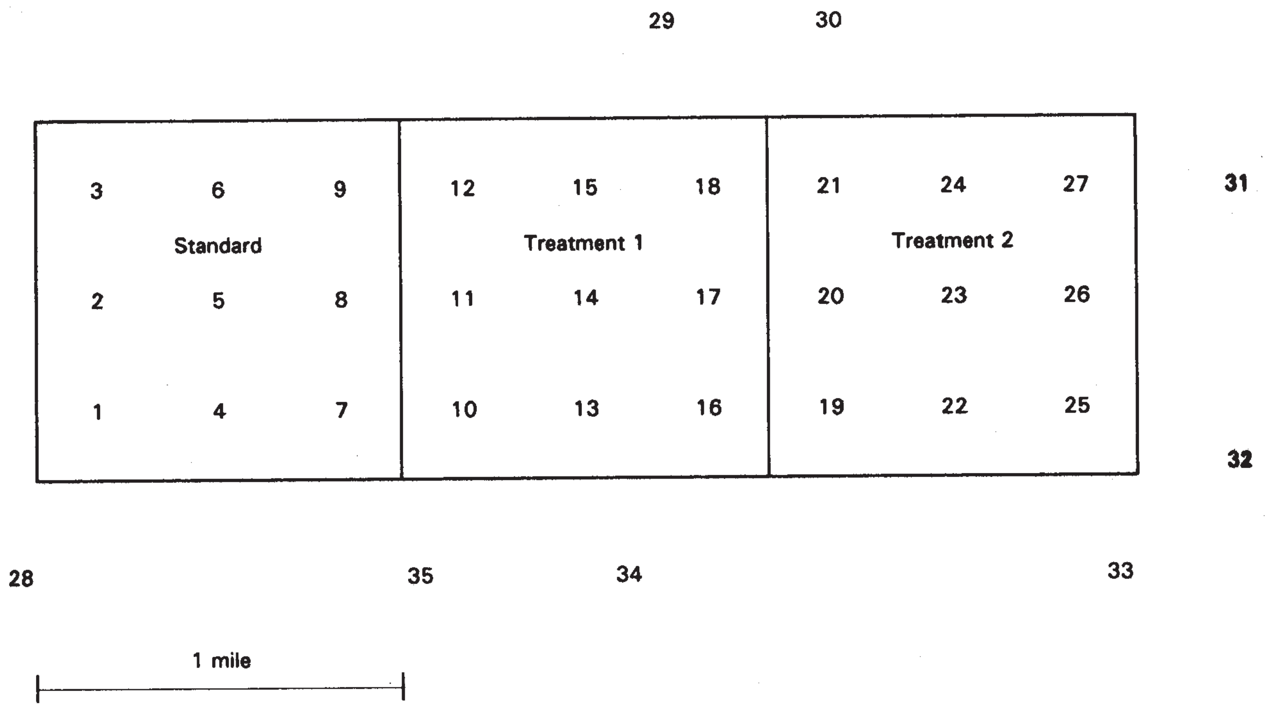


Figure II.2–2—Map showing 640-acre (1-section) plots showing evaluation sites numbered within the plots and numbered untreated evaluation sites located around the perimeter of the treated plots.

Deciding when to start and stop application is not only a decision made daily, but one made on each pass or run of an applying aircraft. Decisionmaking requires consideration of windspeed, ground and air temperatures, amount of moisture on vegetation, and the possibility of precipitation.

In some States, laws define some of the guidelines under which applications are made. Generally the smaller the plot size, the more restricted the guidelines for application become. Typically, with 40-acre replicated plots, application is stopped when winds exceed 3–4 miles per hour or ground temperatures exceed air temperatures. Monitoring spray-sensitive cards in adjacent plots or designated no-spray areas during application is important to determine unacceptable pesticide drift.

Aircraft Guidance

Guidance of aircraft during application varies from sophisticated electronic guidance systems used in many programs to simple but effective flag-waving provided by ground personnel in small plots. However, all guidance depends on the specific swath width assigned to a particular type of aircraft and equipment and the material being applied. Ground crews can determine the location of each swath by using measuring tapes or calibrated wheels or by accurately pacing a known distance equal to the desired swath width. Also, ground crews can make and mark these measurements ahead of time or as application is occurring.

The width of a swath is determined through extensive testing prior to small-plot or program application. Swath widths of 75 ft for most water-based formulations and 100 ft for most oil-based formulations are typical for small-plot work with a Cessna Ag Truck aircraft, for example. Swath width assignments for other types of aircraft are found in the USDA-APHIS-Aerial Application Prospectus. APHIS generally conducts applications at a height equal to 1 $^1/_2$ times the wingspan of the aircraft.

Recordkeeping

Recordkeeping is essential in assessing any treatment in both test work and program use. At the airport, it is important to maintain a record of the final calibration for comparison with the actual acreage covered and material used for each flight. In the field, it is important to measure and record numerous parameters: (1) beginning and ending time of actual application, (2) windspeeds during application, (3) ground and air temperatures during application, and (4) passes that the aircraft makes when applying material. In experimental work, these parameters should be measured and recorded at the beginning and ending of treatment for each plot treated. In programs where multiple aircraft are used, the number and location of partially or completely inoperable spray tips on each aircraft should immediately be reported to the official in charge. In test work, seeing such occurrences requires landing the aircraft to correct the problem.

Evaluation Site Data

The basic types of data collected are grasshopper species composition and density. The conditions, including weather, present during data collection are recorded. Depending on the specific study, we may collect other types of data for association with population estimates, such as vegetation composition and quality or spray droplet size and frequency.

We estimate the grasshopper population by counting the number of grasshoppers found in 40 0.1-m^2 rings at each site. We count and record each ring separately. In our evaluations, the order of counting is always the same, counterclockwise from the site stake. A more detailed description and discussion of procedures for counting grasshoppers is in the chapter on survey in the Decision Support Tools section of the User Handbook.

A typical square mile of infested rangeland will contain 15 to 40 different grasshopper species, some of which may not be causing damage. Estimating the relative abundance of each species is important in order to determine the need for control and the effectiveness of treatments on target species. Base estimates on samples taken from the population with a sweep net. Such sampling is done by taking equal numbers of low–slow (ground level) and high–fast (canopy level) sweeps uniformly along the margin of the circle of rings. Low–slow sweeps ensure the capture of early instar and slow-moving species, while high–fast sweeps ensure the capture of older instars and more-active species. Try to get a collection of at least 100 grasshoppers at each site. Do this by conducting 100–200 low–slow and high–fast sweeps each. Determine the density of the individual species by multiplying the frequency of occurrence, from the sweep sample, by the total density of grasshoppers at the site (counts from rings). Except in some program evaluations, take sweep samples whenever a grasshopper count is conducted.

Make pretreatment counts to determine the population levels against which posttreatment levels are compared. In small replicated plot studies, use the initial pretreatment count to assign treatments appropriately. These studies require additional pretreatment counts conducted closer to the date of treatment for comparison with posttreatment counts. If at all possible, take pretreatment counts 0–48 prior to treatment.

Counts from untreated and treated sites taken on the same day will allow for converting reduction calculations (posttreatment count divided by pretreatment count) to a percentage control value (Conin and Kuitert 1952). This formula is discussed in the chapter “Bait Acceptance by Different Grasshopper Species and Instars.” Using the untreated control-plot data in this fashion allows for adjustment for any natural mortality that occurs and will provide a value of the actual mortality that can be attributed to the treatment. Just as important, if not more so, this procedure will provide an adjusted value that accommodates the day-to-day meteorological changes (such as wind, temperatures, and precipitation) that affect the actual grasshopper counts.

The interval between treatment and the posttreatment count depends on the purpose of the evaluation and the treatment(s) used. With solid baits or fast-acting, short residual sprays, posttreatment intervals of 2, 4, and 7 days are typical. For slower acting or longer residual treatments, weekly intervals at 1, 2, 3, and 4 weeks posttreatment are typical. If two or more treatments that work at different speeds are to be compared, collect the data at similar posttreatment intervals for all treatments. In such cases, an end-of-study or season comparison is helpful in addition to evaluation at specific intervals.

Conclusion

The above protocol is not a detailed standard operating procedure but is intended to serve as a general guideline for several types of treatment evaluations on rangeland grasshoppers. The kinds of data and methods of collection discussed here will allow researchers and program evaluators to use numerous kinds and strategies of analysis.

References Cited

Connin, R. V.; Kuitert, L. C. 1952. Control of the American grasshopper with organic insecticides in Florida. Journal of Economic Entomology 45: 684–687.

Foster, R. N.; Reuter, K. C.; Gourd, J. M.; Enis, P. J. 1983. Field experiments on the toxicity of acephate for control of grasshoppers (Orthoptera: Acrididae) on rangeland. Canadian Entomologist 15: 1163–1168.

Jech, L. E.; Foster, R. N.; Colletto, D.; Walgenbach, D. D.; Roland, T. J.; Rodriguez, G. D.; Bohls, R.; Houston, R. D.; Meeks, W. K.; Queener, R. L.; Jackson, C. L.; Dines, J. L.; Puclik, M. J.; Scott, A. K. 1993. Field evaluation of diflubenzuron and carbaryl bran baits against grasshopper (Orthoptera: Acrididae) populations in South Dakota. Journal of Economic Entomology 86: 557–565.

Onsager, J. A.; Henry, J. E. 1977. A method for estimating the density of rangeland grasshoppers (Orthoptera, Acrididae) in experimental plots. Acrida 6: 231–237.

References Cited—Unpublished

Foster, R. N.; Reuter, K. C.; Black, L. R.; Daye, G.; Vigil, E. L.; Walz, A.; Radsick, B. 1993. Field evaluation of aerial application of two formulations of diflubenzuron for rangeland grasshopper control under simulated control program operational conditions. In: Cooperative Grasshopper Integrated Pest Management Project, 1993 annual report. Boise, ID: U.S. Department of Agriculture, Animal and Plant Health Inspection Service: 93–100.

II.3 Sprays *versus* Baits

R. Nelson Foster and Jerome A. Onsager

NOTE: Acephate is no longer approved by EPA for rangeland grasshopper control.

Chemicals can be applied in two different forms, liquid sprays or solid-based baits, to suppress or control populations of grasshoppers on rangeland. Both forms have distinct advantages and disadvantages, depending on the situation in which they are used. The diverse habitat, topographical features, meteorological conditions, economic concerns, and environmental constraints associated with grasshoppers on rangeland play an important role in choosing the best form of treatment. This chapter briefly discusses the advantages and disadvantages of both liquid and bait formulations and the eight major factors to be considered in the selection of a type of treatment.

Advantages and Disadvantages

Cost of Aerial Application.—Generally, contract costs are substantially lower for applying sprays than baits. These differences are primarily a result of the wider swaths used in spray application. Bait application costs also may be higher because an acre equivalent of bait typically occupies more space than a liquid. Some types of aircraft and bait-dispensing equipment produce about the same swath width with both sprays and baits. However, most of the few systems that have been evaluated to date produce a narrower swath with baits.

Of the spreader–aircraft combinations evaluated to date, the Bull Thrush (Thrush 1,200 hp) and a Transland 22007 spreader produced the bait swath most similar to the swaths from liquid sprays. The Bull Thrush has a spray swath of 150 ft for oil mixtures and 100 ft for water mixtures and produces a 100-ft swath with bran bait using the 22007 spreader. In contrast, the Turbine Thrush with the same swath widths for oil and water mixtures produced only a 45-ft swath with bran bait and a Transland 20250 spreader. Bait application can become more cost effective if new spreaders, which produce wider swaths, are used and/or if application objectives are changed to omit the old requirement of complete coverage of the treatment area.

Amount of Active Ingredient Required.—Baits typically require significantly less toxicant than sprays. For example, when carbaryl is used in a spray, it is typically applied at 0.375–0.5 lb of active ingredient (AI) per acre. When it is used in a bait, it is typically applied at 0.04 lb (by ground) to 0.03 lb (by air) of AI per acre. The lower amount of active ingredient is attractive from the standpoint of both cost and possible impact on the environment.

Level of Control.—On a typical assemblage of grasshopper species (the total population), sprays applied properly always produce a higher average level of mortality than baits. All species of grasshoppers do not feed equally on currently registered baits, and some species seem to avoid almost any contact with bait on the ground. For species susceptibility to bait, see the chapter “Bait Acceptance by Different Grasshopper Species and Instars” (II.12). Sprays typically produce higher levels of mortality on all species of grasshoppers, through both direct contact with the grasshopper itself and by the grasshopper’s feeding on contaminated vegetation (ingestion).

Grasshopper Density and Species Composition.—Sprays produce similar levels of mortality regardless of the grasshopper density. Baits cause highest mortality against low densities of grasshoppers where the dominant species readily consume bait. When very high densities of susceptible grasshoppers (greater than 30–40/yd^2) are treated with bait, there simply are not enough bait particles for all the grasshoppers. According to theoretical models, 1.5 lb of 2 percent carbaryl bait per acre can kill about 65 grasshoppers/yd^2 under perfect conditions. In actual practice, however, it is not likely that this dosage will kill more than 20 to 30 grasshoppers/yd^2. Increasing the amount of bait will increase the level of control slightly but usually not enough to be justified economically.

Nontarget Arthropods.—Sprays kill by both contact and ingestion; baits kill by ingestion. Sprays may affect to some degree both canopy-dwelling and ground-dwelling arthropods, such as insects and spiders. In particular, sprays have the potential to affect those arthropods that feed or rest on the vegetation that has been sprayed. Because baits fall through the vegetation to the ground and work by ingestion only, they may affect only some of the ground-dwelling arthropods that feed on the bait. Both treatments could produce some secondary poisoning of arthropods that scavenge upon affected grasshoppers.

Calibration of Equipment.—It is a misconception that calibration of bait-applying equipment is more difficult than calibration of spray equipment for liquid chemical insecticides. This common misconception is based on lack of experience with bait equipment and its calibration techniques and procedures. Insecticide applicators typically have much more experience with the equipment used to disperse sprays. The Aircraft and Equipment Operations unit of the U.S. Department of Agriculture's Animal and Plant Health Inspection Service lists, to date, 28 different types of fixed-wing aircraft that have been studied and approved for sprays. In contrast, only three different types have been approved for application of baits. With experience, applicators should encounter no substantial difference in the difficulty of equipment calibration for sprays or bait. (A procedure for calibrating bait equipment is found in this section's chapter on "Equipment Modification, Swath Width Determination, and Calibration for Aerial Application of Bran Bait With Single-Engine Fixed-Wing Aircraft" [II.18].)

Aerial Drift and Length of Application Day.—Sprays are much more susceptible than baits to wind-assisted drift and can be carried much greater distances. Drift is a function of wind and temperature at the time of application and the weight of the liquid or solid particle being dispensed. A rise in temperature increases the evaporation and reduces the droplet size in sprays. These changes result in increased buoyancy and drift. For further discussion on the effect of wind and temperature on sprays, see the chapter "Factors Affecting Application and Chemical Deposition" (II.7).

Changes in temperature do not affect the drift of bait. Bait can be very confidently directed to the area of treatment. It is not unusual to discontinue spray application when either wind or temperature conditions might result in unacceptable drift. Winds generally must reach levels that threaten the safety of flight operations before application of baits is discontinued.

Established buffers around bodies of water reflect the dangers of drift and the reduced risk when baits are used. In large-scale cooperative programs, baits can be used within 200 ft of water; sprays require a 500-ft buffer. Spray application usually happens early in the morning, shortly after sunrise, when meteorological conditions are acceptable. These conditions may last for only 1–3 hours. Application of bait can take place at any time during daylight hours, when safe operation of the equipment may be ensured.

Ease of Application.—In spray operations, the applicator must spot clogged nozzles. Applicators can prevent most clogging problems by ensuring that the spraying system is absolutely clean before the material to be sprayed is loaded. Baits require more attention during application. The pilot must manage the physical process of opening the hopper gate of the aircraft consistently. In addition, the pilot must constantly watch for signs of uneven flow of bait during application.

Baits must be carefully inspected for lumps before they are loaded into the aircraft. These lumps will cause partial or complete blockage at the aircraft gate opening and result in nonuniform flow during application. Bait requires more space than sprays. An acre's worth of bait (2 percent carbaryl at 1.5 lb/acre) occupies space equal to about 90 fluid oz, requiring about 3–11 times as much space as an acre's worth of spray material (acephate 32 oz/acre, carbaryl 20 oz, and malathion 8 oz).

How To Decide What To Do

In discussing the eight major considerations that could affect the choice of spray versus bait treatments, no priorities are offered here because no simple rules apply. There are situations where any one of the eight considerations may be the most important determinant of a decision to use either bait or liquid sprays. The complexity of the decision process was one of the reasons why the Grasshopper Integrated Pest Management Project developed Hopper, a computer-based decision support system (see "Decision Support Tools" section of this handbook).

The preferred procedure for deciding on bait versus liquid spray treatment is to gather as much information as possible on the eight considerations under discussion and key that information into Hopper. If specific data on certain questions are lacking, Hopper will generate "default" or representative values that will be reasonably close over a variety of rangeland sites. However, it is likely that accurate site-specific data will yield better recommendations than default values. Hopper will also accept specific data in the form of a range of values, with upper, middle, and lower levels being used to compare decisions under worst-case, best-case, and most likely scenarios. Finally, a manager is free to accept or reject the assessments of Hopper because there may be considerations that only the manager can evaluate for relative importance. However, Hopper's advice can help a manager maximize the chances of making a good decision.

II.4 A Review of Chemical Sprays in Cooperative Rangeland Control Programs

NOTE: Acephate is no longer approved by EPA for rangeland grasshopper control.

R. Nelson Foster and Jerome Onsager

The chemical sprays used against rangeland grasshoppers today and the current cooperative rangeland grasshopper management program are both results of an evolving solution to an age-old problem. That problem is one of how best to control or suppress damaging populations of grasshoppers over widespread areas. The following chapter will review the history and evolution of chemical sprays in rangeland grasshopper control to the present day.

History

In the United States, the history of grasshopper control is interwoven with that of the Mormon cricket. Control was conducted primarily to protect crops, but rangeland also was treated to save forage and prevent insect migration to nearby cropland. During the first half of the 20th century, control relied almost exclusively on poison baits. Although sprays such as paris green and sodium arsenate were used, these compounds fell from favor because the poisoned vegetation endangered livestock (Parker 1952). Both State and Federal assistance were provided for organizing and financing control efforts, particularly during outbreak years.

In the late 1940's and early 1950's, several major developments occurred that significantly changed the way grasshoppers were controlled.

1. Perhaps the most important was the development of the chlorinated hydrocarbon insecticides. They were extremely effective in small amounts against grasshoppers. They could easily be formulated into baits, acted quickly, and had a longer residual effect than previously used baits. Because of these qualities, chlordane and toxaphene in 1949 and aldrin in 1951 quickly replaced previous baits (Parker 1952).

2. Large-scale (thousands of acres) aerial application of bait became more commonplace. Compared to older wet baits, the new compounds could be formulated dry, which made distribution easier. In Montana and Wyoming during 1949–50, aerial application of chlordane and toxaphene baits were the major tools used against grasshoppers (Parker 1952).

3. Sprays of these compounds were also developed at the same time. In addition to being extremely effective, they were much cheaper than baits. Sprays of chlordane, toxaphene, and aldrin first were used in grasshopper control programs in 1947, 1948, and 1950, respectively (Parker 1952).

4. Organized, large-scale programs to control rangeland grasshoppers were started. In 1949, a cooperative program provided for the aerial treatment of toxaphene and chlordane baits to 40,000 acres in Wyoming. Within 2 years, the cooperative program had switched to aldrin spray (Pfadt and Hardy 1987).

5. In 1952, several State departments of agriculture and the U.S. Department of Agriculture (USDA) formed an agreement through a memorandum of understanding that the cooperative grasshopper control programs would be reserved for rangeland. Because of the low cost of the chlorinated hydrocarbons, treatment for crop protection could be borne by the private sector. In the past, government involvement in the form of direct financial aid had been available for treatment to both crop and rangeland. The federally sponsored cooperative grasshopper control program was now focused only on rangeland, both private and public (Dick S. Jackson, personal communication).

The acceptance of these new chlorinated hydrocarbon compounds was short lived. Almost as quickly as they appeared for control of rangeland grasshoppers, their use was discontinued. One of the initially attractive features of the chlorinated hydrocarbons, that of longevity, began to be recognized as a problem. The compounds began to accumulate in the food chain and thus posed a threat to not only the pests they were designed for but to nontarget organisms also. In 1962, Dieldrin, which had been used in cooperative rangeland grasshopper spray programs in 1960–62, was discontinued for use, along with other chlorinated hydrocarbons (Dick S. Jackson, personal communication).

In 1962, carbaryl in the form of the Sevin® 80 S spray formulation became available for use in the cooperative rangeland grasshopper programs. It was used on about 4,000 to 36,000 acres of rangeland annually from 1962 through 1967 (Foster et al. 1983). However, during this time, control was not as high or as consistent as that previously expected of the chlorinated hydrocarbons, and compatibility problems between the spray and aerial spraying systems were commonplace.

In the early 1960's, ultralow-volume (ULV) application—defined as less than 0.5 gal/acre (Maas 1971)—was refined for grasshopper control in the United States. By 1964, Malathion ULV® Concentrate had become the most frequently applied chemical spray for controlling grasshoppers on cooperative rangeland programs.

By 1972, the formulation of carbaryl had been greatly improved and the Sevin 4-Oil® formulation replaced the 80 S formulation as a recommended treatment in the rangeland grasshopper programs.

From 1979 through 1982, research led to the development of formulations of acephate sprays for use against grasshoppers. Acephate in the form of the Orthene® 75 S formulation was adopted as an option for controlling grasshoppers in the cooperative programs in 1982. However, it has been rarely used in the control programs to date. Compared to carbaryl and malathion, the mixing required for acephate made it less desirable.

Through the 1980's, malathion was the most frequently used spray for large-scale cooperative programs. Additional improvements in the formulation of carbaryl have increased its use so that today it is used almost as frequently as malathion in large-scale programs against grasshoppers in the United States.

The three chemical sprays currently approved by USDA's Animal and Plant Health Inspection Service (APHIS) for use on large-scale rangeland grasshopper control programs are acephate, malathion, and carbaryl.

Malathion

Malathion is the common name for the 0,0-dimethyl phosphorodithioate ester of diethyl mercaptosuccinate. It is a broad-spectrum organic phosphate insecticide–acaricide developed by American Cyanamid in 1950. Malathion is registered for control of a wide variety of insects on beef cattle, sheep, goats, swine, grain, fruit and vegetable crops, forests, rangeland, pastures, agricultural premises, poultry ranges, stored grains, and in homes and gardens.

The toxicity of chemicals is measured in relative terms by determining the amount of active ingredient (AI) (in weight) that will kill 50 percent of a test group of laboratory animals. This concept is referred to as the "acute oral LD_{50} (lethal dose)." The LD_{50} of malathion technical material on white albino rats is 1,375 mg per kg of the rats' body weight. This figure marks malathion as moderately toxic to mammals. Malathion exhibits slight to moderate toxicity to birds and moderate to high toxicity to some fish species and other aquatic organisms. It is highly toxic to most insects, including bees and all species of grasshoppers.

While several formulations of the pesticide are available, only the formulations of Cythion® ULV, Fyfanon® ULV, and Malathion ULV Concentrate have been used USDA/APHIS-managed cooperative programs.

For controlling grasshoppers on rangeland, malathion is typically sprayed at 8 fluid oz/acre. The per-acre dose of active ingredient at the application rate ranges from 0.58 lb to 0.61 lb, depending on the concentration of malathion in the particular formulation used.

Malathion provides control through both direct contact and ingestion, although when these types of mortalities are separated in experiments, ingestion results in a greater percentage of mortality (Pfadt et al. 1970).

Malathion is relatively nonpersistent in soil, water, plants, and animals. Residual activity (control) against grasshoppers can be seen for 2 to 5 days after treatment. Malathion is quick acting, usually producing high levels of control during the first and second days following application. When treatment occurs during good conditions for application, control can range from 92 to 96 percent.

Malathion should be used during warm and dry conditions. The air temperature for the expected daytime high should be higher than 80 °F, and rain should not be predicted for the day of treatment. With lower temperatures, the grasshoppers may feed less and be less likely to move into direct contact with spray droplets. Rain soon after an application can reduce mortality dramatically. Foster et al. (1981) discovered rain-related mortality rates as low as 33 percent.

An area of several thousand acres typically contains grasshoppers of as many as 40 different species. Because of the short residual activity of malathion, it is generally selected for use later in the season when the majority of the grasshopper species in an area to be treated have hatched. As a result, the earlier hatching species often have reached adulthood when the applications occur. In these cases, the overall average age of the population could typically be fourth instar to adult.

Waiting to treat a population until it is mostly made up of adults is not a problem unless the grasshoppers have started to mate and lay eggs. But once grasshoppers have reached the adult stage, by definition, forage loss in the area of treatment has taken place.

On small areas, such as “hot-spots,” where only a few species may be predicted to occur or in a large area where only early season species are expected to be the problem, an earlier treatment of malathion targeted to third instars could be preferable. In outbreak years, when economic infestations of large acreages in numerous places within a State occur, timing all treatments ideally becomes difficult. In large outbreak years, malathion may be used later in the season because earlier treatments were logistically impossible. Malathion is most often used late in the season for quick control of older grasshoppers when conditions are hot and dry.

Carbaryl

Carbaryl is the common name for 1-naphthyl N-methylcarbamate. It is a broad-spectrum carbamate insecticide developed by Union Carbide in 1956. Carbaryl is registered for control of a wide variety of insects on fruit and vegetable crops, forests, rangelands, pastures, agricultural premises, poultry houses, horses, dogs, cats, and ornamental and lawn plants, and indoors. Carbaryl demonstrates low to moderate toxicity to mammals (acute oral LD_{50} of technical material on white albino rats, 500 mg/kg), low toxicity to birds, and moderate toxicity to fish, but extreme toxicity to aquatic invertebrates. It is extremely toxic to many insects, including bees and all species of grasshoppers.

The Sevin 4-Oil and Sevin 4-Oil ULV formulations of carbaryl have been used by the USDA/APHIS-managed cooperative programs. For controlling grasshoppers on rangeland, it is typically sprayed at 15 to 20 fluid oz/acre at 0.375 lb AI to 0.5 lb AI. Control is provided through both contact and ingestion, although when the types of mortalities are separated in experiments, ingestion provides the majority of the mortality (Lloyd et al. 1974).

Carbaryl is relatively nonpersistent in the environment. Its residual activity against grasshoppers lasts for 14 to 21 days. Carbaryl is slower acting than malathion or acephate. Depending on conditions, mortality during the first 2 days after treatment may range from 30 to 80 percent. Under good application conditions, mortality may reach 90 percent. However, mortalities ranging from 95 to 99 percent have been recorded in experiments with excellent application conditions.

Carbaryl can be used over a broader range of general climatic conditions than malathion or acephate. Although carbaryl performs well at temperatures in the 60–80 °F range, it kills slower at lower temperatures. This trait may not be as bad as it seems. Under cooler conditions, both grasshopper development and the rate of forage destruction decrease. The Sevin 4-Oil formulation is relatively resistant to removal by rainfall after the spray has dried on the vegetation.

In two major experiments where Sevin 4-Oil was applied to wet vegetation, mortalities eventually exceeded 90 percent. Subtle changes have been made in the formulation of Sevin 4-Oil during the last few years, leading up to today’s Sevin 4-Oil ULV formulation. Along with improved handling characteristics, a trend toward slightly higher mortalities has accompanied these improvements.

Because of the residual activity of the Sevin 4-Oil ULV formulation, it can generally be selected for use both early and late in the season (third instar to adults). However, care must be taken not to use it against grasshoppers that are within a few days of laying eggs because the insects may lay eggs before dying.

Use of carbaryl spray against small hot-spots may not be advantageous if quick migration from the treated area is expected. However, if additional acres adjacent to the hot-spots are treated, use of carbaryl could be acceptable, especially if additional hatch is predicted.

As circumstances dictate, the 0.5-AI dose may be used for older instars and mature grasshoppers. The 0.375-AI dose may be used where younger stages of grasshoppers are present and early treatment can be accomplished or when lower or economically marginal densities of grasshoppers exist.

Where dense vegetation or difficult topography requires greater coverage, a volume of 20 fluid oz/acre should be used. A total volume-per-acre treatment as low as 15 oz/acre may be used when vegetation is sparse. The decision can be made only on a case-by-case basis and by the local personnel involved. The Sevin–ULV spray formulation is typically used under cool conditions in years when rain in the treatment area is not unusual.

Acephate

Acephate is the common name for 0,S-dimethyl acetylphosphoramidothioate, a broad-spectrum organic phosphate insecticide developed by Chevron Chemical Co. in 1972. Acephate controls a wide variety of insects on several grain and vegetable crops, forests, rangeland, pastures, grass, trees, shrubs, cotton, and ornamentals.

Acephate demonstrates low to moderate toxicity to most terrestrial and aquatic animals, including mammals (acute oral LD_{50} of technical material on white albino rats, 866 mg/kg). It is highly toxic to many insects, including bees and all species of grasshoppers.

While several formulations of the pesticide are available, only Orthene® 75S and Orthene Specialty Concentrate® will be addressed here. For controlling grasshoppers on rangeland, acephate is typically sprayed at an application dose of 0.094 lb of AI in 32 oz of water, plus an antidrift additive such as Orthatrol or Nalcotrol (at 9 fl oz per 100 gal of mix) and unsulfured molasses (at 3 percent of the total volume). The addition of unsulfured molasses to the formulation results in slightly quicker action. It is unclear whether this is a result of attractance, additional protection from photo degradation, increased anti-evaporation qualities, or a combination of these actions. Control is provided through both contact and ingestion. When the types of mortalities are separated in experiments, ingestion results in greater mortality (Foster et al. 1984).

In soil, acephate is readily degraded through biological activity: its half life is about 11 days in soils with moisture levels and organic content comparable to those in the West and Midwest. Residual activity against grasshoppers is intermediate, between that of malathion and carbaryl. Some activity can be seen for up to 10 days, but most mortality occurs by the fourth day after treatment. When treatment occurs during good conditions for application, mortality can range from 92 to 94 percent.

With acephate, maximum mortality is reached slower than with malathion but quicker than with carbaryl. Acephate can be used during warm and dry conditions. The air temperature for the expected daytime high should be higher than 75 °F, and rain should not be predicted for the day of treatment. Because of the longer residual activity compared to malathion, acephate can be used in some cases where the lack of residual activity would be a concern for malathion. Conditions for acephate's use more closely parallel those for malathion than for carbaryl. Acephate can be used on small hot-spots where some migration is expected and on third-instar to adult grasshoppers, provided that most females are not ready to lay eggs.

More is known about the efficacy of lower doses of acephate against grasshoppers than that of low-dose malathion or carbaryl. In some cases, such knowledge may allow greater flexibility in selecting lower dosages to fulfill economic considerations.

Duration of Control

When landowners or managers consider directly investing money to control grasshoppers on rangeland, one of the major questions is how long control will last following treatment. The question would not apply if large-scale outbreaks lasted for only 1 year, but they often last several years. The main question of control duration may be further divided into four basic questions:

1. What are the chances that grasshopper populations will remain as high or go higher next year?

2. If control measures are not applied and grasshoppers remain high, how long are they likely to stay high?

3. If control is used during an outbreak, how long are the benefits likely to continue?

4. What are some things that can jeopardize the length of control expected?

The answers to these questions vary with where you live and where your acreage is in the outbreak cycle. In the past, ranchers with rangeland prone to grasshopper infestations had to base decisions on intuition and experience. Now, particularly with the development of the Grasshopper Integrated Pest Management (GHIPM) Project, quantifiable data are available to provide a more precise decisionmaking process.

Kemp (1987) and Lockwood and Kemp (1987) and Lockwood et al. (1988) have published information on questions 1 and 2 for some counties of Montana and Wyoming. Their data are important. They found that the likelihood of grasshopper populations staying high or increasing from 1 year to the next is only about 56 percent in Garfield County, MT, but 96 percent in Johnson County, WY. In the absence of control, high populations are likely to stay high for 2.25 years in Gallatin County, MT, but up to 23 years in Sheridan County, WY.

Blickenstaff et al. (1974) and Pfadt and Hardy (1987) provided important clues to "best case scenario" answers to the question of control duration. In a study of the time interval between treatment and required retreatment of 1,200,000 acres of Wyoming rangeland, Blickenstaff's team reported an average retreatment rate of 3.8 percent per year. In other words, about 96 percent of the treated area probably enjoyed benefits for only 1 year, 92 percent for 2 years, and 81 percent likely received some benefits for at least 5 years. Similarly, Pfadt and Hardy (1987) reported at least partial protection of treated range for 3 to 6 years after treatment.

The above reports establish beyond doubt that the concept of multiple-year benefits is valid in some large cooperative programs conducted by State and Federal personnel. Such benefits are not guaranteed. Blickenstaff et al. (1974) reported six mechanisms that can negate, in total or part, the potential for future benefits:

1. Reinvasion by flight. This occurrence is a distinct possibility for highly mobile species like *Melanoplus sanguinipes*, which is a major component of infestation in some areas, like Arizona (Nerney 1960) or eastern Montana (Kemp 1992). However, in other areas, such as Platte and Goshen counties in Wyoming, *M. sanguinipes* comprised less than 5 percent of infestations that were suppressed for 3 to 6 years by treatments (Pfadt 1977).

2. Natural declines in untreated populations. The probability of this event is 100 percent minus the chances that infestation will stay the same or go up.

3. Occurrence of 2-year life cycles at high altitudes.

4. Extended hatching periods (note that this would be aggravated by poor timing of treatment or improper selection of a short-lived chemical when persistence is required).

5. Ability of survivors to increase rapidly (note that this would be aggravated by low levels of control).

6. Failure to treat infested areas in their entirety (note that APHIS prefers to treat entire infestations and has special provisions to allow such treatment).

In any one particular case, protection beyond the year of treatment depends on where in the outbreak cycle (buildup or decline) the program is conducted. If control tactics are not initiated until the populations are on the decrease, then protection is limited to the year of treatment because the population would be of no concern the next year (smaller or negligible population because of the continuing decrease). However, many large-scale treatments occur during the early or middle years of an outbreak. In these cases, multiple years of protection are expected and usually realized.

Conclusions

Traditionally, the use of chemical sprays against grasshoppers on rangeland has been that of a corrective tool. Sprays were used against grasshoppers in outbreak crisis situations as a last resort where the objective was to control the greatest number of grasshoppers.

With the development of the integrated pest management approach and the emerging technologies resulting from the GHIPM Project, chemical sprays are positioned for an expanded role in controlling grasshoppers. This new role will be preventive as well as corrective. Grasshopper treatments should be considered while populations are building. The historical mindset was one where managers waited for the pests to reach outbreak numbers before anything was done. In the future, the use of chemical sprays will be integrated with other strategies, such as managed livestock grazing and treatment of hot-spots for reducing damaging and outbreak-threatening populations of grasshoppers.

While enjoying an expanded role, the traditional use of sprays in emergencies probably never will be eliminated. Chemical sprays are but one weapon in the fight against grasshoppers, and pesticides will remain as an excellent insurance against damaging populations that require immediate attention in the form of fast-acting chemical control.

Selected References

Blickenstaff, C. C.; Skoog, F. E.; Daum, R. J. 1974. Long-term control of grasshoppers. Journal of Economic Entomology 67: 268–274.

Foster, R. N.; Henderson, J. A.; Huddleston, E. W.; Bullard, R. G. 1981. Effect of Triton X-190 and water on malathion and carbaryl related rangeland grasshopper mortalities, 1978. Insecticide and Acaricide Tests 6: 136.

Foster, R. N.; Reuter, K. C.; Kinzer, J. G.; Fischer, J. M. 1984. Manner of pickup of acephate by *Melanoplus occidentalis* (Orthoptera: Acrididae) from aerially sprayed rangeland. Canadian Entomologist 116: 1 149–1151.

Foster, R. N.; Reuter, K. C.; Gould, J. M.; Enis, P. J. 1983. Field experiments on the toxicity of acephate for control of grasshoppers (Orthoptera: Acrididae) on rangeland. Canadian Entomologist 115: 1163–1168.

Kemp, W. P. 1987. Probability of outbreak for rangeland grasshoppers (Orthoptera: Acrididae) in Montana: application of Markovian principles. Journal of Economic Entomology 80: 1100–1105.

Kemp, W. P. 1992. Temporal variation in rangeland grasshopper (Orthoptera: Acrididae) communities in the steppe region of Montana, USA. Canadian Entomologist 124: 437-450.

Lockwood, J. A.; Kemp, W. P. 1987. Probabilities of rangeland grasshopper outbreaks in Wyoming counties. Bull. B-896: Laramie, WY: University of Wyoming and Wyoming Agricultural Experiment Station. 17 p.

Lockwood, J. A.; Kemp, W. P.; Onsager, J. A. 1988. Long-term, large-scale effects of insecticidal control on rangeland grasshopper populations (Orthoptera: Acrididae). Journal of Economic Entomology 81: 1258–1264.

Lloyd, J. E.; Pfadt, R. E.; Ali, M. 1974. Manner of pickup of ULV carbaryl by *Aulocara elliotti* from aerially sprayed rangeland. Journal of Economic Entomology 67: 596–597.

Maas, W. 1971. ULV application and formulation techniques. Amsterdam, Netherlands: N. V. Phillips-Duphar, Crop Protection Division. 164 p.

Nerney, N. J. 1960. Grasshopper damage on short-grass rangeland at the San Carlos Apache Indian Reservation, Arizona. Journal of Economic Entomology 53: 640–646.

Parker, J. R. 1952. Grasshoppers. In: Insects: the Yearbook of Agriculture, 1952. Washington, DC: U.S. Department of Agriculture: 595–604.

Pfadt, R. E. 1977. Some aspects of the ecology of grasshopper populations inhabiting the short grass plains. Tech. Bull. 310: St. Paul, MN: Minnesota Agricultural Experiment Station: 73–79.

Pfadt, R. E.; Hardy, D. M. 1987. A historic look at rangeland grasshoppers and the value of grasshopper control programs. In: Capinera, J. L., ed. Integrated pest management on rangeland: a shortgrass prairie perspective. Boulder, CO, and London: Westview Press 183–195.

Pfadt, R. E.; Lloyd, J. E.; Ali, M.; Sharafi, G. 1970. Manner of pickup of ULV malathion by grasshoppers from aerially sprayed rangeland. Journal of Economic Entomology 63: 1210–1214.

Thomson, W. T. 1992. Agricultural chemicals: Book I Insecticides. Fresno, CA: Thomson Publications. 301 p.

U.S. Department of Agriculture, Agricultural Research Service. 1959. Residues in fatty tissue, brain and milk of cattle from insecticide applied for grasshopper control on rangeland. Journal of Economic Entomology 52: 1206–1210.

U.S. Department of Agriculture, Animal and Plant Health Inspection Service, Plant Protection and Quarantine. 1987. Rangeland Grasshopper Cooperative Management Program. Final Environmental Impact Statement—1987. Washington, DC: U.S. Department of Agriculture, Animal and Plant Health Inspection Service.

Directory of Personal Communications

Dick S. Jackson, Oregon State Department of Agriculture, 220 SW. Third St., Hermiston, OR 97838.

II.5 Success With Reduced Rates of Carbaryl, Malathion, and Acephate Sprays

NOTE: Acephate is no longer approved by EPA for rangeland grasshopper control.

K. Christian Reuter and R. Nelson Foster

Carbaryl, malathion, and acephate have become the chemical insecticide control alternatives in the U.S. Department of Agriculture, Animal and Plant Health Inspection Service's (APHIS) grasshopper cooperative-management programs. Extensive field and laboratory testing of these chemicals over the years have shown that they are very effective in controlling grasshoppers (Skoog et al. 1965; Onsager 1978; Foster et al. 1981 a and b; 1983, 1984, 1985, 1986). Generally, with proper timing of application and acceptable climatic conditions, these treatments will kill at least 90 percent of grasshoppers in the treatment area.

All three chemicals exhibit relatively low toxicity to mammals and have been approved by the Environmental Protection Agency for rangeland grasshopper control. The third factor accounting for the popularity of these three chemicals is their ready availability from suppliers. Often during outbreak situations, and on short notice, there are demands for large quantities of an insecticide to be used anywhere in the Western United States.

Lowering the application rates of these chemicals would be desirable because of reduced costs of the product as well as lessened impact on nontarget organisms. Until viable nonchemical control tools are available for large-scale programs, however, managers of rangeland must take advantage of existing control tools and strive to make them more efficient.

Carbaryl

Current labeling recommends per-acre application rates of carbaryl at 0.375 to 1.0 lb (12–32 fluid oz) active ingredient (AI) in at least 15 oz of spray volume for rangeland grasshopper control. APHIS cooperative programs are restricted to rates of 0.375 to 0.5 lb AI per acre. Sevin 4-Oil® (Rhone-Poulenc) is generally the formulation of choice for rangeland programs at a standard rate of 0.5 lb AI per acre in 20 oz total volume.

In a recent study, Reuter et al. (1993) showed that a 25-percent-reduced rate of an oil formulation of carbaryl was statistically as effective as the standard rate of carbaryl on rangeland grasshoppers. At 1 week after treatment, this reduced formulation had lowered the grasshopper population by 95 percent. At 3 weeks after treatment, mortality remained at 95 percent. In another study (Onsager 1978), a water-diluted formulation of carbaryl at a 50-percent-reduced rate (0.25 lb AI per acre) compared favorably with the standard rate, yielding mortalities of 76 percent at 7 days and 91 percent at 21 days after treatment. There are no data available on the effects of these reduced rates on nontarget organisms, but it is naturally assumed that there would be a reduced impact. Continued control in these studies 1 to 3 weeks after treatment indicate some persistence of the chemical even at a reduced rate. Persistence would be advantageous in controlling additional hatch or migration, especially in early season control efforts.

Malathion

Current labeling recommends per-acre application rates of malathion at 0.58 to 0.87 lb AI (8–12 fluid oz) for rangeland grasshopper control. Criteria in APHIS' cooperative programs restrict treatments to 0.58 lb AI per acre or 8 fluid oz/acre. Several ultralow-volume (ULV) formulations are available and range from 91 to 95 percent active ingredient. In the past, Cythion® ULV was generally the brand name formulation of choice for rangeland programs. At this time, Fyfanon® ULV is the brand name formulation available for programs.

In a study by Foster et al. (1989), results showed that 25- and 50-percent reductions of malathion with an inflight encapsulation material (a polymeric medium) were statistically as effective as the standard rate of malathion on rangeland. At 25 percent less active ingredient, the treatment reduced the grasshopper population 95 percent at 7 days and 92 percent at 21 days. At 50 percent less active ingredient, the treatment reduced the population 92 percent at 7 days and 85 percent at 21 days. Increased persistence of the active ingredient, even at reduced levels, could be economically and environmentally attractive. In a crop protection study by Herbaugh et al. (unpublished data), results with a strip treatment of 4 oz of malathion per acre on rangeland grasshoppers adjacent to cropland showed 74-percent mortality at 2 days after treatment.

Acephate

Current labeling recommends per-acre spray application rates of acephate at 0.094 to 0.125 lb AI in a minimum of 0.5 gal of carrier. APHIS cooperative programs use the minimum of 0.094 lb AI, originally delivered in 1 qt of carrier. Orthene® 75S is the brand-name formulation of choice for rangeland programs and is formulated with Nalcotrol® (an antidrift additive) at 9 fluid oz Nalcotrol per 100 gal of mix plus unsulfured molasses at 3 percent of total volume.

Foster et al. (1979) demonstrated that results from acephate applied at rates 33 and 67 percent below the standard rate were statistically comparable to the standard 12 to 13 days after treatment (78 percent and 60 percent mortality, respectively), although the reduced rates did not produce mortality as consistently among replications as the standard rate. Orthene is generally thought to persist in the field from 7 to 10 days after application. Persistence of Orthene is somewhat less than that of Sevin-4 Oil but greater than that of Cythion, which lasts only for a few days.

Discussion

Large-scale grasshopper outbreaks generally demand immediate attention and significant reductions in a short time. These demands can be met with carbaryl, malathion, or acephate sprays as each can greatly reduce grasshopper populations in a week or less, and each is readily available from suppliers. The same cannot be said for carbaryl bran bait, *Nosema locustae* (a biological control organism), bran bait, or other alternatives in the developmental stages. Carbaryl bran bait is readily available but not particularly effective against high densities of diverse grasshopper assemblages. *Nosema locustae* has never consistently proven effective for grasshopper control, and production capabilities would be a limiting factor for large-scale programs.

Success with reduced rates of these established chemical sprays is both environmentally and economically attractive. Further reductions in treatment rates are certainly attainable with the advent of improved formulations and additives in conjunction with sound applied research. Although reduced rates may yield lower control, the availability of Hopper software (Grasshopper Decision Support System) makes it possible to evaluate each treatment option in accordance with various management scenarios. Lower control percentages may ultimately prove to be acceptable in terms of economic benefits and costs.

References Cited

Foster, R. N.; Henderson, J. A.; Huddleston, E. W.; Bullard, R. G. 1981a. Effect of Triton X-190 and water on malathion and carbaryl related rangeland grasshopper mortalities, 1978. Insecticide and Acaricide Tests 6: 136.

Foster, R. N.; Onsager, J. A.; Reuter, K. C.; Roland, T. 1985. Field evaluation of an aqueous formulation of carbaryl for rangeland grasshopper control, 1983. Insecticide and Acaricide Tests 10: 237.

Foster, R. N.; Reuter, K. C.; Gourd, J. M.; Enis, P. J.; Wooldridge, A. W. 1983. Field experiments on the toxicity of acephate for control of grasshoppers (Orthoptera: Acrididae) on rangeland. Canadian Entomologist 115: 1163–1168.

Foster, R. N.; Reuter, K. C.; Henderson, J. A.; Wooldridge, A. W. 1981b. Orthene with Nalcotrol for control of grasshoppers on rangeland 1979. Insecticide and Acaricide Tests 6: 137.

Foster, R. N.; Reuter, K. C.; Smith, M. E.; Swain, J. L.; Dyer, R. 1984. Comparison of acephate formulations for control of adult grasshoppers on rangeland, 1983. Insecticide and Acaricide Tests 9: 288.

Foster, R. N.; Reuter, K. C.; Walgenbach, D. D.; Bohls, R. A.; Swain, J. L.; Roland, T. J. 1989. Field comparison for rangeland grasshopper control, 1986. Insecticide and Acaricide Tests 14: 265–266.

Foster, R. N.; Staten, R. T.; Reuter, K. C.; Henderson, J. A. 1979. Low rates of Orthene for control of grasshoppers on rangeland, 1979. Insecticide and Acaricide Tests 6: 137.

Onsager, J. A. 1978. Efficacy of carbaryl applied to different life stages of rangeland grasshoppers. Journal of Economic Entomology 71: 269-273.

Reuter, K. C.; Foster, R. N.; Jech, L. E.; Walgenbach, D. D.; Walgenbach, D. R.; Roland, T. J. 1993. Field evaluation of a reduced rate of carbaryl spray on rangeland grasshoppers (Orthoptera: Acrididae). Journal of the Kansas Entomology Society 66(2): 231–236.

Skoog, F. E.; Cowen, F. T.; Messenger, K. 1965. Ultra-low-volume aerial spraying of dieldrin and malathion for rangeland grasshopper control. Journal of Economic Entomology 58: 559–565.

References Cited—Unpublished

Foster, R. N.; Reuter, K. C.; Staten, R. T.; Swain, J. L.; Roland, T. J.; Walgenbach, D. D.; Bohls, R. A.; Villaveces, A. 1989. Field evaluation of controlled released malathion against grasshopper populations (Orthoptera: Acrididae) in South Dakota, 1986. In: Pink Bollworm and Range Pests Station, 1989 annual report, Phoenix, AZ: U.S. Department of Agriculture Animal and Plant Health Inspection Service.

Herbaugh, L. L.; Foster, R. N.; Reuter, K. C.; Roland, T. J.; Bennett, D. 1986. Evaluation of selected liquid sprays and baits to control migration of grasshoppers from rangeland to adjacent cropland (unpublished report).

II.6 Using Hopper To Adapt Treatments and Costs to Needs and Resources

John Larsen and R. Nelson Foster

NOTE: Acephate is no longer approved by EPA for rangeland grasshopper control.

Total treatment cost may be the most critical factor in determining whether grasshopper control on rangeland is feasible, especially because profits from grazing lands are usually much lower than profits from croplands on a per-acre basis. The simplest ways to reduce treatment costs are to use less insecticide or to treat less land. Both solutions require the land manager to accept reduced grasshopper control compared to the level of mortality achieved through traditional control methods. However, reduced grasshopper mortality as a result of less vigorous treatment may be practical when the treatment produces a favorable benefit–cost ratio, adequate forage production, and an acceptable reduction in the number of grasshopper eggs produced by the survivors of the treatment.

Hopper is a recently developed computer-based decision support tool that allows users to conduct sophisticated, precise, and repeatable economic analyses of proposed treatment actions. In the treatment decisionmaking process, Hopper can help users choose from among a greater number of options by analyzing a range of reduced treatments.

There are two techniques for reducing total treatment expenses—interval swath spacing and direct dosage reduction. These techniques can be used separately or jointly in adapting grasshopper control treatments to individual financial resources and circumstances. When these techniques are used, the traditional goal of controlling the maximum number of grasshoppers no longer applies.

Interval Swath Spacing

This technique leaves, by design, an untreated strip of infested land (interval) of predetermined width between treated swaths. The technique has a high potential for reducing costs. Both the cost of the insecticide and the cost of application are reduced because less acreage is treated.

The potential savings of this technique become apparent when its costs are compared to costs of traditional control techniques on a fixed size of rangeland. For example, if the pesticide used costs $2/acre and application of the pesticide costs $2/acre, on a 10,000-acre block of rangeland with traditional control techniques, the total treatment costs would be $40,000 (table II.6–1).

Using interval swath spacing on the same 10,000-acre block and leaving 20 percent of the block (2,000 acres) untreated in narrow intervals between the treated swaths reduces treatment costs to $32,000 (table II.6–1).

Table II.6–1—Costs to treat a 10,000-acre block of rangeland when minimum grasshopper control is the goal and when interval swath spacing and direct dosage-reduction techniques are employed. Costs in this table are for example purposes only.

	Pesticide costs		Application costs[1]		Total treatment cost
	$/acre		*$/acre*		
Traditional technique					
All 10,000 acres treated with conventional pesticide dosage	$2 ($20,000	+	$2 $20,000)	=	$40,000
Interval swath technique					
20% of the 10,000 acres left untreated; conventional pesticide dosage used	$2 ($16,000	+	$2 $16,000)	=	$32,000
Reduced dosage technique					
All 10,000 acres treated with a 25% reduction in pesticide applied	$1.50 ($15,000	+	$2 $20,000)	=	$35,000
Combined technique					
20% of the 10,000 acres left untreated; 25% less pesticide applied to the 8,000 treated acres	$1.50 ($12,000	+	$2 $16,000)	=	$28,000

[1] Figures in this column include $0.30/acre for costs associated with typical aerial spray applications (travel, pay, vehicles, flagging, etc.).

Direct Dosage Reduction

This technique simply uses less pesticide per treated acre. For example, on the same 10,000-acre block of rangeland, the pesticide cost of $2/acre for the traditional program results in a total pesticide cost of $20,000. With a direct dosage reduction of 25 percent, the total pesticide cost is $15,000 (75 percent × $2/acre × 10,000 acres). With both traditional and direct-dosage-reduction techniques, the application costs are identical—$20,000. Total treatment costs are $40,000 for a traditional program and $35,000 for a direct-dosage-reduction program.

Combining Techniques

Both of the techniques discussed above demonstrate substantial savings compared to a traditional program. But, by using both techniques jointly, further treatment cost savings can be realized. For example, on the same 10,000 acres, let's assume that both a 25-percent reduction in direct dosage is used and that 20 percent of the block is left untreated in narrow intervals between treated swaths. For example, a pesticide that is traditionally used at 8 fluid oz/acre is used at 6 fluid oz/acre (a 25-percent reduction). Table II.6–1 illustrates these additional savings of treatment costs when compared to traditional treatment.

This example of using interval swath spacing and reduced pesticide together results in a total cost of $28,000 for the treatment. Additionally, there is a 40-percent reduction in pesticide applied on the 10,000-acre block. (For example, in a traditional program, 10,000 acres × 8 fluid oz/acre = 80,000 total fluid oz and combined techniques 8,000 acres × 6 fluid oz/acre = 48,000 total fluid oz.)

Cost reductions on this scale could be highly significant in deciding whether or not pesticide treatment is economically feasible in a given situation. By keeping costs low, land owners and managers can make grasshopper control more affordable on rangelands.

Comparison of Typical Traditional and Combined-Techniques Programs

The following list illustrates a typical cooperative grasshopper management program for the early 1990's when maximum control of grasshoppers is the goal and malathion is the insecticide chosen.

10,000 acres	
Pesticide cost	$1/acre
Application costs	$1/acre
Associated costs (travel, pay, vehicles, flagging, etc.)	$0.30/acre
Total treatment cost	**$2.30/acre**

($23,000 for a 10,000-acre block)

In an example of a combined program of interval swath spacing and direct dosage reduction, a 20-percent interval swath is used (20 percent of the block is left untreated in narrow intervals between treated swaths). In addition, the per-acre amount of pesticide applied is reduced by 25 percent. This example reduces the overall cost per acre within the 10,000-acre block by 30 percent and the pesticide applied by 40 percent (table II.6–1).

Managers could implement this example by directing the pilot of a spray aircraft who normally flies a 100-ft swath to space the swaths at 120 ft with the 100-ft calibration. This gives a 20-ft untreated interval between treated swaths. A 25-percent reduction in pesticide applied per acre could be achieved by lowering the dosage rate from 8 to 6 fluid oz/acre.

The following two examples compare data from two different Hopper test runs. Example A is for current grasshopper treatments used on the U.S. Department of Agriculture, Animal and Plant Health Inspection Service, Plant Protection and Quarantine-administered cooperative grasshopper management program. Example B is for the same scenario but with a 20-percent interval-swath-spaced treatment and a 25-percent reduction in pesticide applied per acre treated (combined interval swath spacing and direct dosage reduction).

The Hopper test run data show yield in pounds per acre, total cost of treatment, return (dollar value saved by treatment), benefit–cost ratio (B/C) (returns divided by cost), and grasshopper eggs per square yard. You can calculate the net return by subtracting cost from return. In most cases, net returns will also be important to your decision. Keep in mind that these are only example test runs. Each real-world situation is different. You will need to do several test runs on Hopper to get an idea of the appropriateness of reduced treatments for any given situation. Notice that the mortality values entered are different among these examples. This difference is important as the expected mortality value you enter when using Hopper has a large impact on the analysis. As a rule of thumb, if you use interval swathing, the expected level of mortality in the intervals left untreated is conservatively set at zero.

Example A

The following is a list of parameter definitions and values as currently seen on the Hopper 4.0 screen on a computer:

```
Weather at time of treatment                          hot and dry
Survey Date                                              06/22/93
Treatment Date                                           06/30/93
Environmentally sensitive (no chemicals)           Isolated Areas
Managed Bees in the area                                       No
Protect beneficial insects                                     No
Average stage at survey                                      3.06
Average stage at treatment                                   3.67
Percent early season target species                         40.00
Closed canopy                                                  No
Egg hatch completed                               greater than 90%
Grasshoppers density is greater than 22/yd²                   Yes
Weed biocontrol insectaries present                            No
```

The following is a list of economic definitions and values you would find on one of the Hopper screens:

Forage and Grasshopper Models
Sheridan Historical Levels of Trt

```
GRASS FEEDING HOPPERS (#/yd²)                                  15
MIXED FORAGE FEEDING HOPPERS (#/yd²)                           20
PEAK EDIBLE FORAGE PRODUCTION                                 550
FORAGE PROD. MULTIPLIER                                      1.00
% Warm Season Grass                                            40
% Cool Season Grass                                            40
% Forbs                                                        20
Normal Soil Moisture (% by Wt.)                                23
Inches of Rain to fill dry soil to field capacity               5
Soil Water Holding Capacity (% by Wt)                          25
Days for saturated soil to dry to 10% Water                    65
```

```
                                  TREATMENT COSTS

            Treatment                    Cost         Mortality %
            Acephate                    $2.30              91
            Carbaryl Bait               $4.50              73
            Carbaryl Spray              $3.50              92
            Malathion                   $2.30              90
            Nosema Bait                 $4.75              —

Survey date: 06/22/93 Stage: 3.1, Treatment date: 06/30/93 Stage: 3.7.  Yield
Without Treatment:  449 #/acre. Acres to be treated: 16044.  Eggs per sq yd
without treatment: 29.8

Treatment       Yield      Cost       Return          B/C Ratio              Eggs
               (lbs/a)      ($)        ($)        Current  + 2 Years       per yd²
Acephate         533      36900      44848         1.22       3.27           1.8
Carbaryl Bait    514      72196      35310         0.49       1.32           8.2
Carbaryl Spray   524      56153      40196         0.72       1.93           2.8
Malathion        534      36900      45072         1.22       3.29           1.8
Nosema Bait      480      76207      16895         0.22       0.60          13.3
```

Example B

The following is a list of parameter definitions and values as currently seen on the Hopper 4.0 screen on a computer:

```
Weather at time of treatment                          hot and dry
Survey Date                                              06/22/93
Treatment Date                                           06/30/93
Environmentally sensitive (no chemicals)           Isolated Areas
Managed Bees in the area                                       No
Protect beneficial insects                                     No
Average stage at survey                                      3.06
Average stage at treatment                                   3.67
Percent early season target species                         40.00
Closed canopy                                                  No
Egg hatch completed                               greater than 90%
Grasshopper density is greater than 22/yd²                    Yes
Weed biocontrol insectaries present                            No
```

The following is a list of economic definitions and values you would find on one of the Hopper screens.

```
                    Forage and Grasshopper Models
                  Sheridan Historical Levels of Trt

       GRASS FEEDING HOPPERS (#/yd²)                                15
       MIXED FORAGE FEEDING HOPPERS (#/yd²)                         20
       PEAK EDIBLE FORAGE PRODUCTION                               550
       FORAGE PROD. MULTIPLIER                                    1.00
       % Warm Season Grass                                          40
       % Cool Season Grass                                          40
       % Forbs                                                      20
       Normal Soil Moisture (% by Wt.)                              23
       inches of Rain to fill dry soil to field capacity             5
       Soil Water Holding Capacity (% by Wt)                        25
       Days for saturated soil to dry to 10% Water                  65

                             TREATMENT COSTS

            Treatment                Cost        Mortality %
            Acephate                $1.61            73
            Carbaryl Bait           $4.50            73
            Carbaryl Spray          $2.45            75
            Malathion               $1.61            72
            Nosema Bait             $4.75            —

Survey date: 06/22/93 Stage: 3.1, Treatment date: 06/30/93 Stage: 3.7.  Yield
Without Treatment:  449 #/acre. Acres to be treated: 16044.  Eggs per sq yd
without treatment: 29.8

Treatment       Yield      Cost      Return         B/C Ratio          Eggs
               (lbs/a)     ($)        ($)      Current  + 2 Years    per yd²
Acephate         517      25830      36696       1.42       3.82         6.3
Carbaryl Bait    514      72196      35310       0.49       1.32         8.2
Carbaryl Spray   496      39307      25122       0.64       1.72        10.5
Malathion        516      25830      35938       1.39       3.74         7.0
Nosema Bait      480      76207      16895       0.22       0.60        13.3
```

Decisions and Conservation Practices

Another practical aspect of these reduced treatment strategies may be the conservation of nontarget organisms. In pest management, conservation techniques are practices that conserve nontarget organisms. Conservation techniques, such as treatments with reduced active ingredient and interval swath spacing, may significantly reduce the pesticide exposure of nontarget insects.

Natural enemies of grasshoppers, such as parasites and predators, may be affected to a lesser degree when conservation practices are employed. Interval swath spacing could be employed within treated areas to create refuges that may provide significant protection for naturally occurring and released biological control agents. These conservation practices may provide useful grasshopper integrated pest management options in areas where the presence of biological control agents is important to pesticide use decisions. These practices may become more important in the future as biological control of rangeland weeds is implemented on a wider scale in rangeland areas where grasshopper management is also a problem.

You should consider reduced treatment options when some level of reduced grasshopper control can be accepted and for conservation and/or economic purposes. To enter useful data into Hopper, users need to have a good understanding of how these reduced treatment techniques affect both treatment cost and expected mortality. Reduced treatment options provide an opportunity to adapt treatment programs to resources and site-specific circumstances. The models in Hopper produce much of the information needed in such decisionmaking.

Considerations

While reducing the amount of pesticide used to control grasshopper pests is extremely attractive, use caution when deciding to leave a significant portion of the pest population. In geographic locations where grasshoppers seldom or never cause problems 2 or more years in a row, or during times when the overall trends for the general area indicate grasshopper populations to be in decline, such a strategy could be used with minimal risk. In these cases, grasshoppers remaining after reduced treatments pose little chance of propagating a problem for the next season, and single-year economic analysis can be used to support significantly reducing pesticide use.

In locations where grasshopper populations historically cause damage over several years, or in years when general grasshopper populations show no indication of quickly declining on their own, the potential risk associated with a reduced-pesticide strategy should be carefully considered. The risk is one of leaving enough grasshoppers to propagate populations of damaging levels that could require treatment the next year. The argument for leaving some grasshoppers may be supported by a favorable benefit–cost analysis for the season of treatment.

If the remaining grasshoppers result in populations that require treatment the next year, the strategy may be seriously questioned. But even if populations the next season reach damaging levels, the benefit–cost ratio could still be favorable in the succeeding year if treatment was again required. However, even though benefit–cost analysis for 2 years in a row may have proven economical, treating the same acreage 2 years in a row, even at reduced pesticide level, would probably be much more expensive than treating one time with a standard rate of pesticide for maximum control in the initial year.

The strategies of interval swath spacing and reduced doses of pesticide offer exciting possibilities and afford numerous advantages if employed under the right conditions. The trick is deciding where and when risking the need for a second-year (next-year) treatment is too high. Attention to the history of the area and knowledge of current grasshopper population trends will help in making this decision.

II.7 Factors Affecting Application and Chemical Deposition

Robert Sanderson and Ellis Huddleston

Control of spray deposition is vital if pesticides are to be delivered safely and effectively to the intended target. Numerous studies have shown that drift (off-target movement of material) and deposition of pesticides are affected by application equipment, release height, windspeed, air turbulence, air temperature, humidity, and formulation characteristics. It is important for pest managers and applicators to understand the factors that influence the movement of spray droplets on their journey to the target. Drift can become a critical factor when environmentally sensitive areas are in or near spray operations.

Droplet Size

Droplet size is recognized as the major factor in the transport to and the collection of spray by the target. Agricultural sprays contain droplets of varying sizes, but the selection of proper equipment, spray delivery pressure, and nozzle selection play important roles in maintaining a reasonably uniform droplet size. In agricultural sprays, droplets are usually measured in micrometers (µm)—units that are often referred to as microns. Large droplets are influenced primarily by gravity and tend to fall within the target area, whereas small droplets, falling more slowly, are susceptible to wind or turbulence effects and can be moved off target.

A 200-µm droplet would require only 5.4 seconds to fall a distance of 3 m while a 20-µm droplet would take 230 seconds. With only a 1.5-m/second wind, the 20-µm droplet could drift 338 m while the 200-µm droplet would drift only a few meters. Droplets below 100–150µm are generally considered to be the primary driftable portion of the spray. The following table describes droplet characteristics.

Although drift potential may be reduced by increasing the size of droplets, spray coverage on target surfaces may not be as effective at a given volume application rate if most of the liquid volume is contained in very large droplets. Good spray coverage on the target is necessary for efficient insect or weed control. The number of droplets per unit area is a function of droplet size. The relationship between droplet volume and diameter (d) is expressed by the equation

$$\text{Volume} = \Pi d^3/6.$$

Doubling a droplet's diameter will increase its volume by a factor of eight. Therefore a 400-µm droplet has a volume eight times that of a 200-µm droplet. Alternatively, eight 200-µm droplets contain the same volume of spray as a single 400-µm droplet. This formula is an important consideration when determining or assessing deposits on target surfaces.

If thorough coverage is required for pest control, small droplets will be more effective than large droplets, but small ones will be more susceptible to off-target movement by the wind. The droplet size selected for a particular application is often a compromise between coverage with smaller droplets and reduced drift with larger droplets.

Nozzles

Application equipment is very important in determining the droplet sizes contained in the spray. Most agricultural nozzles produce a spray containing a range of droplet sizes, referred to as the droplet size spectrum. The droplet size spectrum is often described by the volume median diameter (vmd or $D_{v0.5}$), which is the droplet size at which one-half of the total spray is in larger droplets and one-half is in droplets smaller than the vmd. A parameter often used to express the range of droplet sizes in the spray is the relative span and is given by the expression $(D_{v0.9}–D_{v0.1})/D_{v0.5}$. Large relative span values indicate wide range of droplet sizes. Typical relative span values for agricultural sprays are in the range 0.8–1.2.

The main types of nozzles used in agriculture are hydraulic, which uses pressure to atomize; gaseous, which uses shear between two fluids; and rotary, which uses centrifugal force. When they are used at practical field application rates, all nozzles produce a range of droplet sizes. Under certain conditions, rotary atomizers can produce a reasonably narrow droplet size spectrum, giving rise to the term "controlled droplet application."

The hydraulic or pressure nozzle is the type most often used in aerial and ground application of pesticides. Droplets are produced by forcing liquid through a small opening, or orifice, under pressure. The size and type of the nozzle tip determine the flow rate and to some extent the droplet size produced. The fan tip produces a flat fan of spray; the disc-core nozzle produces a hollow cone pattern.

In general, a larger nozzle orifice will produce a spray with a larger mean droplet size. Increasing the operating pressure for a given nozzle will increase the flow rate, decrease the mean droplet size, and generally increase the proportion of small droplets. Nozzles on aircraft tend to produce sprays with smaller mean droplet size at similar pressures because of additional shear forces due to the high-speed movement of the aircraft through the air. Increased flying speed or directing the orientation of nozzles forward into the airstream will produce sprays with a smaller droplet size.

As nozzles are used, abrasion and erosion will increase the orifice size and alter the flow rate and droplet size. Nozzles should be checked frequently for calibration and discarded if the flow rate has increased by more than 10 percent.

Examples of rotary atomizers are the Micronair and the Beecomist. The droplet size produced by rotary atomizers is dependent on rotational speed. Higher rotational speeds produce smaller droplets. Rotary nozzles can produce sprays with a smaller mean droplet size than those pressure nozzles can.

Evaporation

Droplets can become smaller as they move toward the target due to evaporation of the spray material. Evaporation, especially in the low-humidity conditions of the Southwest, results in rapid reduction in the size of water droplets. The evaporation rate increases as temperature rises or humidity decreases. At a temperature of 86 °F and relative humidity of 50 percent, a 50-µm droplet of water will completely evaporate in 4 seconds while only falling 15 cm. Spray deposition within the target area can drastically decrease as the temperature increases during the day, an important factor to take into account during a spray operation. Table II.7–2 describes evaporation characteristics.

Evaporation rate is affected by formulation properties as well as air temperature and relative humidity. An oil droplet is less volatile than a water droplet and would not decrease in size so rapidly. Suppliers of a number of spray additives claim their products reduce evaporation. In most cases, these claims lack scientific validation, but the addition of a nonvolatile substance may provide some drift control by preventing the droplet from evaporating to extinction. For example, a 400-µm droplet with 12.5-percent nonvolatile composition would stabilize at 200 µm because of the nonvolatile fraction.

Effects of Formulation Properties

Properties of the pesticide formulation or mixture can influence droplet size. Formulations with low viscosity (thickness) or surface tension generally produce sprays with slightly smaller mean droplet size because less energy is required to break up and atomize the material. Formulations that contain emulsifiers usually have low surface tension and tend to produce sprays with smaller mean droplet size. Also, many of the solvents used in pesticide formulations are highly volatile. Their incorporation into the spray mix can accelerate the decrease in droplet size due to evaporation, and using these volatile additives may increase the drift potential of certain formulations.

Numerous adjuvants (additives) are available for mixing with pesticide sprays as “spray modifiers.” For example, spray thickeners are often added to pesticide sprays in an attempt to reduce the proportion of small, driftable droplets. These adjuvants generally increase the viscosity of the spray mixture, resulting in the production of large droplets; however, studies have shown that adjuvants can also increase the number of very fine droplets. The diverse functions, chemistry, concentrations, and interactions of thickeners, surfactants, and surface active agents make it difficult to predict the effect of these products on droplet size and spray deposition.

Dispersal of Spray

Weather plays an important role in spray dispersal and deposition. Wind displaces spray material, and the distance spray material moves depends on droplet size, the strength of the wind, and the spray release height. Strong winds and higher spray release heights will cause droplets to move a greater distance. Strong winds can cause even large droplets to move off target and become a hazard. Spray operations should be shut down if windspeeds increase excessively. As an example, the U.S. Department of Agriculture's Animal and Plant Health Inspection Service normally stops spraying with ultra-low-volume pesticides when the windspeed reaches 10 miles per hour. Other conditions and State laws may dictate even lower windspeeds.

There is always some downwind displacement of spray droplets, even in light winds. If spray applications are made by moving into the wind, this displacement will move spray back behind the sprayer. If applications are made in a crosswind, the spray will be moved slightly downwind from the sprayer. This occurrence is known as swath displacement and should be taken into account when switching on and off the sprayer. With crosswind swath displacement, multiple spray passes are needed to obtain the desired deposition.

Table II.7–1—Selected characteristics of various size spray droplets of water

Droplet diameter	Terminal velocity	Fall time from 3 m	Drift distance (3-m fall with 5-km/h wind)	Drops/cm^2 from 10 a/ha application
(µm)	*(M/sec)*	*(Sec)*	*(M)*	*(No./cm^2)*
10	0.003	1,020	1,372	190,990
50	0.075	40	54	1,530
100	0.279	11	15	192
200	0.721	5.4	5	24
500	2.139	1.6	2	1.5

Table II.7–2—Evaporation characteristics for water droplets under two environmental conditions

Droplet size	Time to extinction	Fall distance	Time to extinction	Fall distance
(µm)	*(Sec)*	*(M)*	*(Sec)*	*(M)*
50	14	0.5	4	0.15
100	57	8.5	16	24
200	227	136.5	65	39

Air Temperature

In strong winds, frictional turbulence produces mechanical stirring of the air and promotes strong mixing in the atmosphere that tends to lessen the effects caused by any localized temperature differences. In lighter winds, especially where there is intense radiation, temperature can vary significantly with height. Temperature variations are caused by solar radiation and heat exchange between air, soil, and vegetation. The change in temperature with height is called the vertical temperature gradient. The temperature gradient has an important effect on atmospheric stability because it can increase or decrease air mixing. Under normal atmospheric conditions, the air is warmer at ground level and gets cooler with an increase in height due to the decrease in air pressure with height. Under these conditions, the temperature decrease is approximately 1.8 °F for every 100-m height increase. This factor is known as the adiabatic lapse rate.

If the temperature decreases more rapidly, there is a superadiabatic lapse rate, characterized by strong convection currents and turbulence. Under these conditions, the air layer is said to be unstable. High levels of spray drift can occur when a large number of small droplets are caught in the convection currents and fall out of the target zone.

If the temperature change is less than the adiabatic lapse rate, the air layer is considered stable. Under certain conditions, temperature can increase with height. This condition, known as inversion, is extremely stable. Inversions can occur only over a limited height range because there must be an overall drop in temperature with increase in height. Inversions usually occur when the wind is zero or very slight and may develop by the “sinking” of cold, dense air pushed in by weather fronts, or by radiational cooling of the surface, especially on clear nights. Off-target spray drift can occur under these condition because the inhibited mixing permits the formation of a mass or cloud of small droplets that can move great distances with little dispersal.

II.8 Calibration of Aerially Applied Sprays

Billy Tanner and T. J. Roland

Calibration is the process of measuring and adjusting the amount of pesticide your equipment will apply to the target area. Pesticide applicators need to be sure they are using the correct amount of pesticide: Too little can result in inadequate control; too much can result in injury to people, plants, or animals, illegal residues, excess runoff or movement from the target, and lawsuits and fines.

Calibration was a frightening word to most early aerial applicators. Their procedures were to mix, load, and fly. Pilots continually adjusted boom pressure and swath width as they went along to make the pesticide come out right for the acreage. Some areas were overdosed; others were underdosed or completely missed. Advancing technology, education, demands by ranchers and farmers, pesticide laws, and label requirements are forcing the modern-day aerial applicator to be calibration conscious.

An aircraft with a properly calibrated dispersal system reduces the workload of the pilot. He or she has enough to watch from the cockpit without constantly monitoring the amount of chemical remaining in the hopper and adjusting boom pressure to make chemical and acreage come out right.

The manufacturers of various nozzles, atomizers, and spray tips provide calibration formulas and/or procedures to calibrate their equipment properly. The formula used by the Plant Protection and Quarantine unit of the U.S. Department of Agriculture’s Animal and Plant Health Inspection Service to calibrate aerial liquid systems is simple and accurate.

Before calibration procedures begin, learn the airspeed, swath width, application rate per acre, spray tip size (output per minute per nozzle), and the flow factor for the chemical being used. With these known factors, you can use the following calibration formulas:

- (Miles per hour × swath width in feet) ÷ 495 (a constant) = **acres per minute**

- (Acres per minute × rate per acre in ounces) ÷ 128 (oz in 1 gal) = **gallons per minute**

- Gallons per minute ÷ nozzle output = **number of nozzles to install using water**

- Number of nozzles for water × chemical flow factor = **number of nozzles to install on the aircraft for the chemical being used.**

A Practical Example of Aerial Spray Calibration

Cessna Ag Truck
Airspeed = 120 miles per hour (mi/h)
Swath width = 100 ft
Pesticide = malathion
Application rate = 8 oz/acre
Nozzle tip size = 8002 flat fan
Nozzle output = 0.2 gal/minute using water at 40 pounds per square inch (lb/in^2)
Correction flow factor for malathion = 1.1

Step 1. Calculate the acres per minute that the aircraft will cover.

(120 mi/hour × 100 ft) ÷ 495 = **24.24 acres/minute**

Step 2. Calculate the number of gallons per minute that the aircraft will put out at the desired rate per acre.

(24.24 acres/minute × 8 oz/acre) ÷ 128 (oz in 1 gal) = **1.52 gal/minute**

Step 3. Calculate the number of nozzles required to apply water at 8 oz/acre and pressure set at 40 lb/in^2.

1.52 gal/minute ÷ 0.2 (output per minute per nozzle) = **7.58 nozzles for water**

Step 4. Calculate the number of nozzles to install correcting for viscosity (flow factor—see table II.8–1 at the end of this chapter) of the chemical being used.

7.58 (nozzles) × 1.1 (flow factor) = **8.3 nozzles**

Step 5. Round to the nearest whole number.

8.3 rounded down to **8 nozzles to install on the aircraft.**

Step 6. Conduct a calibration run either static (run the system on the ground and collect discharge from each nozzle into containers to determine the actual output per minute) or fill the spray tank to a known reference mark and fly the aircraft for 1 min. Refill the tank to the known reference mark and determine the amount used. If the output was light or heavy, make small adjustments to the pounds-per-square-inch setting to achieve the correct output per minute. The final calibration check should be accomplished during actual application with a small load. The following information and flow factor table will help calibration for most sprays and aircraft.

Useful Information and Calculations

128 oz/gal ÷ rate per acre (ounces) = acres/gal
128 oz ÷ 8 oz = 16 acres/gal
128 oz ÷ 12 oz = 10.67 acres/gal
128 oz ÷ 16 oz = 8 acres/gal
128 oz ÷ 20 oz = 6.4 acres/gal
128 oz ÷ 32 oz = 4 acres/gal
128 oz ÷ 40 oz = 3.2 acres/gal
128 oz ÷ 96 oz = 1.33 acres/gal

- Total program acres ÷ acres per gallon = total gallons required

- Airspeed (mi/hour) × swath width in feet ÷ 495 (a constant) = acres per minute

- Acres per minute ÷ acres per gallon = gallons per minute

- Gallons per load ÷ gallons per minute = dispersal time per load

- Gallons dispersed ÷ acres covered × 128 = rate per acre in ounces

- Swath width in feet ÷ 8.25 = acres per mile

- Acres per mile ÷ acres per gallon = gallons per mile

- Gallons per mile × swath length in miles = gallons per swath

- Aircraft load in gallons ÷ gallons per swath = number of swaths per load

To convert knots to miles and miles to knots, multiply
Knots × 1.15 (a constant) = mi/hour
Example: 160 knots × 1.15 = 184 mi/hour
mi/hour × 0.868976 (a constant) = knots
Example: 135 mi/hour × 0.868976 = 117 knots

- 1 mi^2 = 640 acres
- 1 acre = 43,560 ft^2 = 0.405 hectare (ha)
- 1 ha = 2.471 acres
- 1 gal/acre = 9.35 L/ha
- 1 gal = 128 fluid oz = 8 pints = 4 quarts
- 1 gal = 3.785 L = 3,785 Ml
- 1 mi = 5,280 ft = 1,610 m = 1.61 km

Table II.8–1—Flow factor table for spraying solutions other than water

Weight of solution	Specific gravity	Conversion factors
(lb/gal)		
7.0	0.84	0.92
8.0	.96	.98
8.34	1.00	1.00
9.0	1.08	1.04
10.0	1.20	1.09
10.65—28% Nitrogen	1.28	1.12
11.0	1.32	1.14
12.0	1.44	1.20
14.0	1.68	1.29

II.9 Ground Equipment for "Hot-Spot" Treatments With Chemical Sprays

Ellis Huddleston, Robert Sanderson, and James Ross

Aerial application of ultra-low-volume (ULV) malathion at 8 oz/acre has proven to be a very successful method of controlling grasshoppers in the United States and other parts of the world. Using aircraft is the most efficient way to treat large infestations.

In the integrated pest management (IPM) mode, program managers often strive to reduce grasshopper numbers on small areas to lessen the chances of spread of the infestation or to protect valuable forage and crops. In much of the Western United States, aircraft simply are not available or are far too expensive to treat small infestations (up to 1,000 acres). Ground application or no control are the only options. Conventional row-crop sprayers with booms are not sturdy enough for treating rangeland and are not adapted to volumes in the ULV range for malathion.

In an IPM program to control range caterpillar in New Mexico, (a wind-assisted dispersal system for "hot-spot" treatment with ground equipment was successfully developed. This approach is used on thousands of acres each year. New Mexico State University has adapted this approach to rangeland grasshopper control and also found it to be very successful for black grassbug control in New Mexico.

Equipment

We conducted experiments in western New Mexico in late May–early June 1986, on predominantly blue gramma grass rangeland. The principal grasshoppers were *Aulocara elliotti* (bigheaded grasshopper) and *Melanoplus sanguinipes* (migratory grasshopper), and most were adults at the time of spraying. The experiments included a completely random design with a minimum of five replicates per treatment. Square 40-acre plots were treated using a swath spacing of 100 ft.

A mist blower (Model MM55-S, Automatic Equipment Mfg. Co., Pender, NE) was mounted in a trailer pulled behind a half-ton pickup truck. A motorized backpack mist blower (Solo Port 423, Solo Inc., Newport News, VA) was mounted in the back of the truck. The truck was driven at 10 miles per hour (mi/hour) perpendicular to the prevailing wind with both sprayers calibrated to deliver 8 oz/acre of ULV malathion. Grasshopper density was checked 1 day prior to treatment and 1 day after treatment. We counted densities in 40 0.1-m^2 rings in a circle 165 ft in diameter in the center of each plot. Mortality was estimated from pre- and posttreatment counts.

Control

The MM55-S mist blower provided excellent control when used in windspeeds of 4 to 20 mi/hour. For six replications of the test, the average grasshopper mortality was 93 percent with a range of 87 to 100 percent. Two additional replicates evaluated adverse conditions in which effectiveness was greatly reduced (64 percent compared with 93 percent) when this piece of equipment was used with 100-ft swaths in light and variable winds. The Solo 423 was found to provide 95-percent control (range 91 to 100 percent) when used at windspeeds in excess of 5 mi/hour. The results of a single trial were similar to those for the MM55-S mist blower in light and variable winds.

Using the Equipment in the Field

Results showed that both the MM55-S and the Solo 423 mist blowers delivered ULV malathion at the same volume per acre as aircraft and provided control at least equal to that of malathion delivered from aircraft. Both pieces of equipment were equally effective, and both require a steady, fairly strong wind to be effective.

ULV malathion is available in 5-gal containers at a 1994 cost of about $24/gal (Helena Chemical Co., Terra Int.). At 8 oz/acre, the chemical cost is $1.50/acre. Because no mixing is required, unused material can be stored in the original container and should have a shelf life of at least 2 years if stored properly.

Using a 100-ft swath and 10 mi/hour vehicle speed, mist sprayers can cover 2 acres/min. Counting lost time turning, coverage of 80–100 acres/hour is possible. The MM55-S has a cab-mounted remote control that changes the spray from right to left, so whenever the driver turns, he or she can direct the spray downwind. A device to attach the Solo 423 to the tailgate and ropes and pulleys to change the direction of the spray should be easy to build. One rancher in New Mexico has a mist blower that is similar to the MM55-S but does not have a remote control to switch the spray directions. He simply drives forward on one swath and backs up on the next.

Calibration of a sprayer is simply making sure that the sprayer is delivering the correct amount of spray per acre. For the example used here (100-ft swath and 10 mi/h), the sprayer will cover 2 acres/min.

Here's how that figure was calculated:
10 mi/hour = 52,800 ft/hour ÷ 60 = 880 ft/minute × 100-ft swath = 88,000 ft^2/minute.
88,000 ÷ 43,560 ft^2 in an acre = 2.02 acres/minute.
2 acres/minute × 8 oz/acre = 16 oz/minute = 1 pt/minute.

Solo does sell a ULV attachment for the Solo Port 423. Instead, a metering orifice or flow regulator can be inserted in the plastic line between the tank and the nozzle. These orifices and accessories are available from suppliers of agricultural sprayer parts. The larger mist blowers use a pump and pressure regulator, which may be adequate. If not, use a metering orifice.

ULV malathion flows enough like water that water can be used for the initial calibration. For the Solo, pour 3 gal of water in the tank and make sure the supply hose is full. Run the sprayer for 2 minutes and measure the amount of water left, including that in the supply tube. This calibration normally will use 1 qt. You may need a larger or smaller orifice to get the desired rate. For the mist blowers with pumps, you can use a similar procedure or you can catch the output from the nozzle without the fan blowing. Changing the pressure and/or the metering orifice will change the flow rate. During spraying operations, applicators should check the flow rate of the ULV malathion and make required adjustments.

Mist blowers are an effective way to control grasshoppers on rangeland with ground equipment. We prefer the relatively inexpensive motorized backpack mist blower because of cost and versatility. Users can adapt the blower to all-terrain vehicles, and a mist blower is handy for spraying trees and small gardens.

II.10 Treating Localized Hot-Spots of Rangeland Grasshoppers: A Preventative Strategy With Promise

Jeffrey A. Lockwood, Michael J. Brewer, and Scott P. Schell

The Problem

In most years, and in most locations, most grasshopper species are innocuous or even beneficial to grassland ecosystems, but large-scale outbreaks can inflict serious economic damage to western rangelands. Figure II.10–1 illustrates the duration of grasshopper outbreaks in Wyoming. Some areas show grasshopper activity for up to 20 of the last 50 years. Although the grasshopper population on a broad scale collapsed across the Western United States in 1988–89 and has remained low through 1994, historical records suggest that the population is likely to resurge in this decade (fig. II.10–2).

Current economic conditions and mounting environmental concerns strongly suggest that the massive grasshopper treatment programs of the past 40 years will not be repeated. Therefore, economically viable, environmentally sound alternatives need to be found in the immediate future.

A Solution?

Scientists' understanding of North American rangeland grasshopper outbreaks is in its infancy. According to Alan Berryman's outbreak theory (1987), insect outbreaks take one of two forms, and the form of an outbreak is critical to pest management.

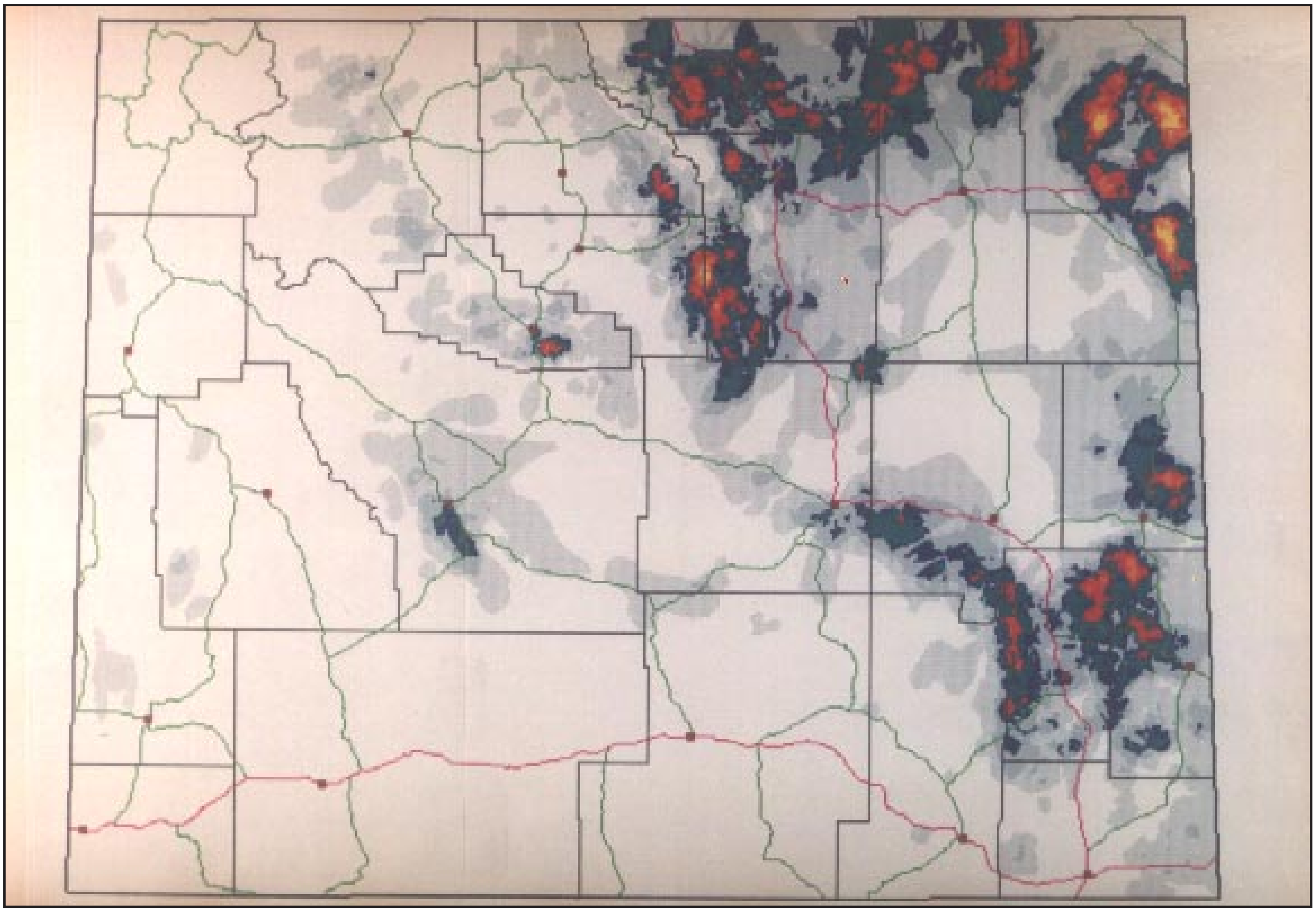


Figure II.10–1—Spatial distribution of rangeland grasshopper outbreaks in Wyoming from 1944 to 1993 (white = no infestations, light gray = 1–2 yr infested, gray = 3–4 yr infested, black = 5–6 yr infested, bluish green = 7–8 yr infested, blue = 9–10 yr infested, red = 11–12 yr infested, orange = 13–14 yr infested, and yellow = 15–20 yr infested). Interstate highways are magenta, and main State roads are yellow-green. County borders are in black, and county seats are brown squares.

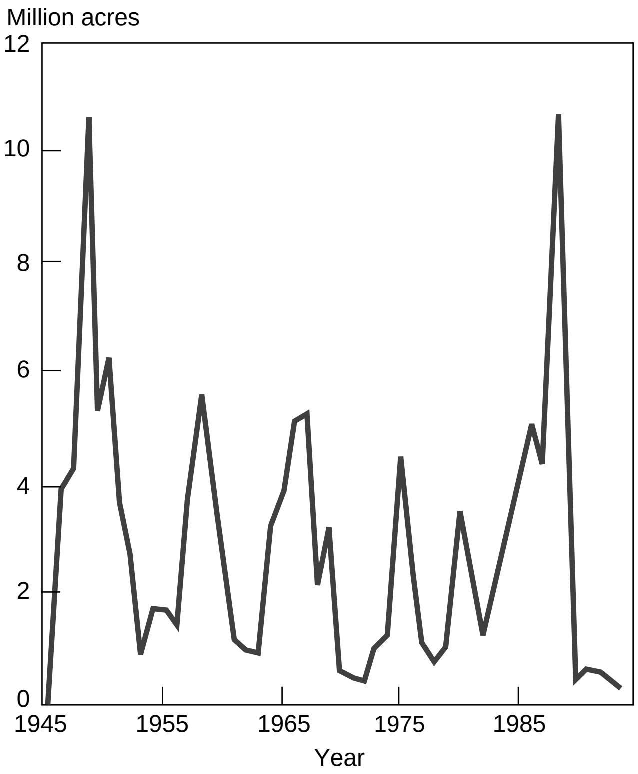


Figure II.10–2—History of rangeland grasshopper outbreaks in Wyoming. Note the erratic pattern of infestation (>8 grasshoppers/yd^2), including the massive outbreak in 1987 and the remarkably low area of infestation since 1989.

The first is the eruptive outbreak, characterized as starting from a "hot-spot" that expands through a self-perpetuating process to encompass increasingly large areas. This type of outbreak occurs with the mountain pine beetle and the gypsy moth. With eruptive dynamics, large-scale outbreaks can be prevented if the hot-spots are controlled. This strategy is analogous to suppressing small fires caused by lightning strikes to prevent large-scale forest fires. The treatment of hot-spots from which outbreaks arise has been an effective tool in the management of several pests of natural and agricultural resources, including African locusts. Indeed, it appears that the extinction of the Rocky Mountain locust was the consequence of agricultural practices having effectively (albeit unwittingly) destroyed through cultivation of soils the highly localized eruptive foci of this species in the 1800's.

The second form of outbreak dynamics is termed "gradient." Gradient outbreaks occur when pest populations fluctuate over broad areas in response to external conditions, without growth from a local hot-spot. This type of outbreak is seen in forest insects, such as many cone and seed insects, some defoliators, and "nonaggressive" bark beetles. If gradient dynamics lie at the heart of grasshopper outbreaks, then little can be done with respect to prevention. By analogy, local, tactical actions will not prevent droughts.

Over the last several years, the hot-spot treatment strategy has been studied in Wyoming through the collaborative efforts of the University of Wyoming and the U.S. Department of Agriculture (USDA), Animal and Plant Health Inspection Service (APHIS), Grasshopper Integrated Pest Management Project (Lockwood and Schell, in press). In the context of traditional APHIS operations, Lockwood and Schell defined a hot-spot as an area of less than 10,000 acres of rangeland infested with at least 8 grasshoppers/yd^2. Although the results of this experiment are not yet definitive, the investigators believe that continuing, long-term studies of grasshopper population dynamics will eventually clarify the process of outbreak formation. At present, there is sufficient information to provide some preliminary insights and recommendations.

Current Knowledge

Evidence for Eruptive Dynamics.—There are four lines of evidence that support the process of an eruptive outbreak dynamic. First, the existence of highly localized infestations is a necessary precursor to an eruptive outbreak. The discovery of numerous hot-spots (table II.10–1, fig. II.10–3), from which larger areas could become colonized, suggests the potential for eruptive dynamics. Although they are a necessary condition for eruptive dynamics, the existence of these hot-spots cannot be considered sufficient evidence of this outbreak form.

Next, the observation that two of the nine hot-spots for which there are data over at least 2 yr sustained or expanded with time demonstrates that these infestations can give rise to larger outbreaks (table II.10–1).

Although only one hot-spot developed into an outbreak, it should be noted that eruptive dynamics do not require that all or most of the hot-spots give rise to large-scale outbreaks. By analogy, very few lightning strikes result in major forest fires.

Third, no continued outbreak was found in the areas around hot-spots treated with insecticides (table II.10–1). If outbreaks were gradient, then treating a localized site should simply result in a “hole” in a larger region of high densities.

Finally, it appears that at least one grasshopper species (the bigheaded grasshopper, *Aulocara elliotti)* has high rates of reproduction at both very low densities and moderately high densities. This “bimodal” reproductive feature is necessary for the self-perpetuating dynamics of an eruptive outbreak.

Evidence for Gradient Dynamics.—The possibility of gradient outbreaks is supported by four lines of evidence. First, two large-scale outbreaks (greater than 15,000 acres) were found that were apparently not preceded by a hot-spot (table II.10–1). One might argue that these areas were simply very large hot-spots, but there was no evidence of continued expansion (there were no topographic or other features limiting expansion in all directions), as would be expected from eruptive dynamics.

Next, seven out of nine documented hot-spots for which at least 2 yr of data exists disappeared the season after their discovery, even without treatment (table II.10–1). This finding suggests that expansion of hot-spots into eruptive outbreaks is not common. But as with forest fires, sometimes it only takes one lightning strike to cause major destruction.

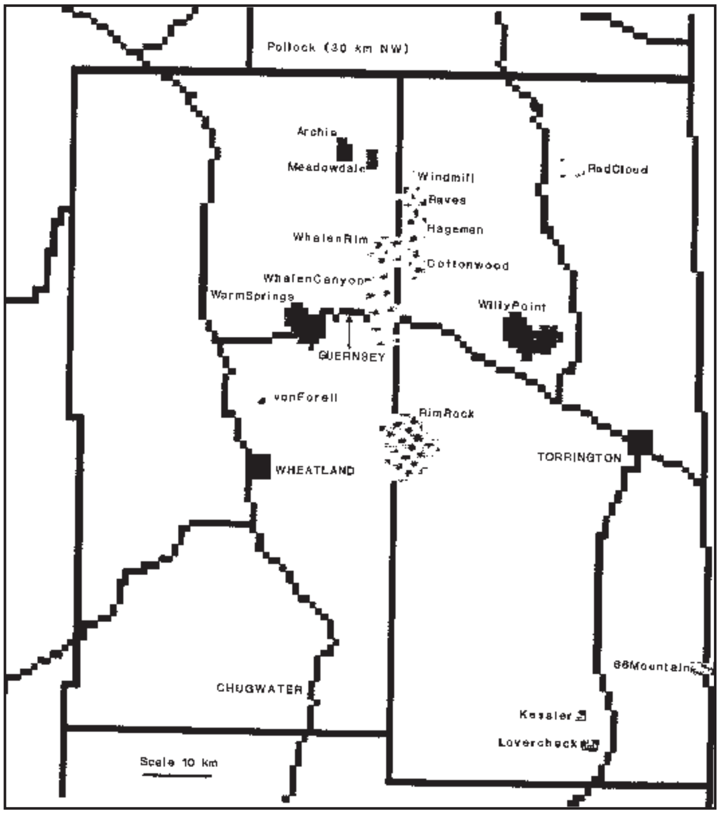


Figure II.10–3—Locations of hot-spots in Platte and Goshen counties in southeastern Wyoming (light shading = 1990, moderate shading = 1991, black shading = 1992). Hot-spots and outbreaks reduced to <10,000 acres are labelled with upper- and lower-case letters; weather stations are labelled in upper-case letters.

Table II.10–1—Dynamics of control (untreated) and treated grasshopper hot-spots and outbreaks in southeastern Wyoming

			Area			
Site	Category	Status	1990	1991	1992	1993
			Acres			
Rave	Hot-spot	Untreated	500	0	0	0
vonForell	Hot-spot	Untreated	500	0	0	0
Red Cloud	Hot-spot	Untreated	1,900	0	0	0
Whalen Canyon	Hot-spot	Untreated	7,920	10,340	1,460	0
Hageman	Hot-spot	Treated	2,140	0	0	0
Pollock	Hot-spot	Treated	2,400	0	0	0
Willy Point	Outbreak	Untreated	38,880	34,080	9,430	4,960
Kessler	Hot-spot	Untreated	0	[1]170	0	0
66 mountain	Hot-spot	Untreated	0	[1]790	0	0
Lovercheck	Hot-spot	Untreated	0	[1]240	0	0
Cottonwood	Hot-spot	Untreated	0	790	0	0
Windmill	Hot-spot	Untreated	0	1,340	1,370	0
Whalen Rim	Hot-spot	Treated	0	1,150	0	0
Rim Rock	Outbreak	Untreated	0	17,760	9,310	[2]0
Archie	Hot-spot	Untreated	0	0	460	0
Warmsprings	Hot-spot	Untreated	0	0	5,380	3,840
Meadowdale	Hot-spot	Treated	0	0	1,030	0
Table Mt.	Outbreak	Untreated	0	0	18,530	2,400
Kincaid Draw	Hot-spot	Untreated	0	0	0	640

[1] Hot-spot collapsed during heavy spring rains in 1991.
[2] Hot-spot collapsed during heavy summer rains in 1993.

Third, the species composition of a hot-spot can change dramatically between years—a discovery that suggests that dominant species may be tracking available resources. For example, a species that prefers needle grasses, *Amphitornus coloradus*, comprised only 2 percent of the hot-spot communities in a dry year (when needle grasses were sparse) but comprised 16 percent in a wet year (when needle grasses were abundant). This resource-tracking phenomenon is consistent with gradient outbreak dynamics.

Finally, most hot-spots have unique soil and topographic properties, compared to adjacent lands. Hot-spots generally occur in foothills with relatively poor soils. Thus, it appears that external factors (rather than a self-perpetuating process) give rise to these localized infestations.

A Hybrid Case?

The evidence regarding the processes that give rise to large-scale outbreaks supports both gradient and eruptive dynamics. This continuing ambiguity calls into question the viability of the current outbreak theory. Unfortunately, the matter becomes more complex as a function of spatial scale.

The scale of resolution used in our study was derived from the management needs of USDA; cooperative programs with APHIS are standardly triggered once a grasshopper outbreak exceeds 10,000 acres. Perhaps the populations examined at finer or coarser resolutions are regulated by different processes and exhibit unique dynamics. Additionally, the rate of change in the density, area, and species composition of an infestation may be related to its size; small infestations may include fewer species and change more rapidly than large outbreaks.

Indeed, such differences in the rates of change may be seen within the size range of hot-spots. For example, small hot-spots may be more susceptible to suppression by mobile predators (a 25-acre infestation of *Camnula pellucida* was eliminated by the immigration and feeding of starlings over a 2-wk period). We found that no hot-spot less than 1,200 acres persisted for more than a single year, and the only hot-spot to increase in size began at 8,000 acres.

As scientists continue to investigate the outbreak dynamics of rangeland grasshoppers, it may be important to consider the possibility that the population dynamics of these insects cannot be effectively classified using the existing theory. This theory was developed based primarily on forest pests, and there are potentially important ecological differences between forest and rangeland pest outbreaks. For example, forest pest outbreaks often involve a single insect species feeding on a single tree species, while rangeland grasshopper outbreaks often involve 10 or more species feeding on dozens of plant species. Given the complexity of rangeland grasshopper communities, it is possible that some species have eruptive potential while others exhibit gradient dynamics.

Management Practices

Although there is uncertainty about the outbreak dynamics of rangeland grasshoppers, some management strategies can be inferred from existing data. Available evidence provides some insights regarding survey strategies, treatment tactics, and programmatic obstacles with respect to a hot-spot management program. However, it should be kept in mind that these inferences are derived from work conducted in southeastern Wyoming from 1990 to 1993, and grasshopper population dynamics may be different in other times and regions.

Hot-Spot Detection

We believe that four approaches may be useful in improving the efficiency of searching for localized hot-spots. First, hot-spots are most likely to occur in areas of historically chronic infestations (figs. II.10–3 and –4). Historical maps of grasshopper outbreaks may provide vital clues as to the areas in which survey efforts should be concentrated. Unfortunately, there does not appear to be a single, consistent outbreak species on which to focus attention. The species composition of hot-spots varies dramatically between sites and years. Slantfaced grasshoppers are the most common species in hot-spots of southeastern Wyoming (especially *Ageneotettix deorum, Amphitornus coloradus, Aulocara elliotti,* and *Cordillacris* spp.). However, we also have found hot-spots dominated by spurthroated and bandwinged species *(Melanoplus sanguinipes* and *Trachyrhachys kiowa,* respectively).

Next, several features of ecosystems and habitats are associated with hot-spots. Hot-spots generally occur in foothills, the areas of transition between mountains and plains. Areas with 8 to 10 in of annual precipitation also appear to be most likely to support hot-spots. At a finer scale, hot-spots are clearly associated with poorer soils.

Within a region, soils with relatively low nitrate, phosphate, and potassium should be considered prime candidates for hot-spots. Low salt levels and high clay content may also be associated with grasshopper hot-spots. There do not appear to be substantial differences in the plant communities inside and outside of hot-spots.

Third, hot-spots apparently develop, persist, and occasionally expand during periods of normal to dry weather and collapse with the onset of wet conditions. These phenomena suggest more intense surveys in years with dry conditions.

Finally, landowners and managers need training to survey for grasshoppers. The exclusive use of federally funded scouts for the intensive surveys required to locate hot-spots over large expanses of land is cost prohibitive. With materials in this handbook, land users can take an active role in pest management, thereby allowing site-specific strategies to be effective. Along with training, systems need to be developed for the coordinated communication of potential hot-spots to APHIS and local pest-management authorities.

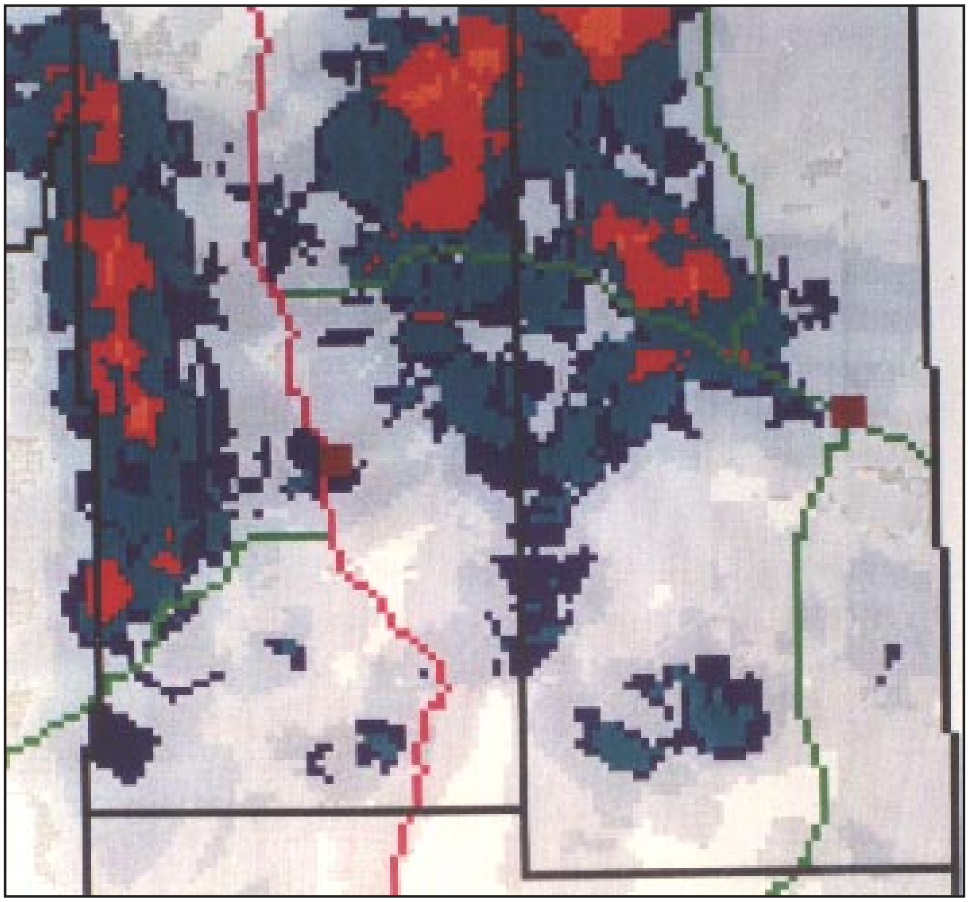


Figure II.10–4—Expanded view of southeastern Wyoming from 1960 through 1993 (Platte and Goshen counties; see figure II.10–1 for spatial reference; white = no infestations, light shading = 1–2 yr infested, dark shading = 3–4 yr infested, purple = 5 yr infested, green = 6–7 yr infested, red = 8–9 yr infested, orange = 10–11 yr infested, and yellow = 12–15 yr infested).

Treatment Strategies

With regard to the tactics of treating hot-spots for the purpose of preventing larger scale infestations, three elements bear consideration. First, it appears that most hot-spots collapse without treatment. In particular, hot-spots of less than 1,000 acres have not been found to persist or expand with time. So these areas should probably not be treated, although it may be prudent to monitor them.

Second, the annual expansion of persistent hot-spots is relatively limited, with a documented maximum of 30 percent, although the rate of expansion could be greater prior to a large-scale outbreak. Given the documented rates and likelihoods of expansion, it would appear that no hot-spot should be treated in the year of discovery. Only if the infestation persists into the subsequent year should treatment be considered.

Finally, the benefits of small-scale insecticide treatments with respect to the preservation of beneficial arthropods may potentially offset the relatively higher costs per acre of hot-spot treatments. With regard to beneficial insects, treating small areas reduces the number of beneficial insects killed by insecticides and increases the recolonization rate. These beneficial organisms may be responsible for the sustained suppression of a hot-spot after treatment. Given that the inadvertent, large-scale suppression of beneficial arthropods through the use of broad-spectrum liquid insecticides has been found to aggravate grasshopper outbreak dynamics in Wyoming (Lockwood et al. 1988), the benefits of small-scale treatments are potentially substantial.

Obstacles to Implementation

The implementation of a hot-spot program is confounded by four obvious obstacles: the Federal cost-share program, the requisite sampling intensity, the "principle of the commons," and the current state of knowledge. Fortunately, all of these problems have potential solutions.

First, the Federal cost-share program discourages preventive practices and local survey efforts and encourages large-scale treatments by triggering APHIS involvement when outbreaks exceed 10,000 acres. For the treatment of hot-spots to become an accepted grasshopper management strategy, the cost-share formula must reward participants in small-scale programs. In its most simple form, such a cost-share formula could be inversely proportional to the number of acres infested, so that the Federal cost-share would increase as the number of infested acres decreases:

$$\text{Federal cost-share proportion} = \frac{1}{\text{thousand infested acres}}$$

For example, a treatment of 10,000 acres would result in a 10-percent Federal cost-share (1/10 = 0.10 = 10 percent), while a treatment of 2,000 acres would result in a 50-percent Federal subsidy (1/2 = 0.50 = 50 percent).

Second, the intensity of survey necessary to discover the relatively small areas of infestation that constitute hot-spots effectively precludes such a program being conducted solely by USDA/APHIS. Adequately surveying Platte and Goshen counties in Wyoming required the equivalent of six full-time field scouts in May and June of each survey year. This dedication of personnel is not viable for even the high-risk rangelands, let alone for the entire West. Ranchers and land managers must become active participants in a coordinated survey effort for a hot-spot program to be a viable management strategy. Again, a cost-share formula that rewards local participation or at least does not discourage such activity would be beneficial.

Third, the principle of the commons (derived from European grazing practices) suggests that people generally act to maximize their individual gains when given access to a common or collective resource. In terms of a hot-spot program, there is a potential conflict between individual and collective interests.

Because hot-spots are not uniformly distributed and treating a hot-spot potentially protects and benefits adjacent lands from future damage, this strategy tends to individualize the costs and collectivize the benefits. One solution to this problem is to collectivize the costs, perhaps through the formation or utilization of grazing and pest-management districts in order to support the higher short-term costs of survey and treatment in a hot-spot program.

Fourth, not enough long-term data have been gathered to provide a definitive answer to the viability of the hot-spot strategy. Current field data are not adequate to determine the population ecology of most rangeland grasshopper species, and existing information can be used to support aspects of both eruptive and gradient dynamics.

Summary

The Western United States has been in an interoutbreak period since 1987, so the processes leading to the extreme infestations (such as 50,000 acres) associated with the major outbreak periods have yet to be observed. With continued tracking of rangeland grasshopper dynamics, investigators may be able to determine the feasibility of a preventive approach to grasshopper outbreaks. For now, local experiments with this strategy should be encouraged as a means of confirming the usefulness of hot-spot programs across different rangeland systems.

Selected References

Barbosa, P.; Schultz, J. C., eds. 1987. Insect outbreaks. New York: Academic Press. 578 p.

Berryman, A. A. 1987. The theory and classification of outbreaks. In: Barbosa, P.; Schultz, J. C., eds. Insect outbreaks. New York: Academic Press: 3–30.

Hewitt, G. B.; Onsager, J. A. 1983. Control of grasshoppers on rangeland in the United States—a perspective. Journal of Range Management 36: 202–207.

Joern, A.; Gaines, S. B. 1990. Population dynamics and regulation in grasshoppers. In: Chapman, R. F.; Joern. A., eds. Biology of grasshoppers. New York: Wiley: 415–482.

Lockwood, J. A.; Kemp, W. P.; Onsager, J. A. 1988. Long-term, large-scale effects of insecticidal control on rangeland grasshopper populations. Journal of Economic Entomology 81: 1258–1264.

Lockwood, J. A.; Schell, S. P. In press. Outbreak dynamics of rangeland grasshoppers: Eruptive, gradient, both, or neither? In: Proceedings, 6th meeting of the Orthopterists' Society; Hilo, HI.

II.11 Baits for Controlling Rangeland Grasshoppers: An Overview

R. Nelson Foster

NOTE: Acephate is no longer approved by EPA for rangeland grasshopper control.

The first use of baits for grasshopper control began in the late 1800's. In 1878, the U.S. Entomological Commission reported bait experiments with mixtures of paris green and flour. In 1885, a bran bait containing arsenic, sugar, and water was used against grasshoppers in the San Joaquin Valley of California (Coquillet 1886). Over the next several decades, there was extensive testing to improve baits.

The work to improve baits concentrated on testing substances for attractiveness to grasshoppers and substitutes or diluents (diluting agents) for bran. Some of these substances were molasses (beet and cane), salt, calcium chloride, citrus fruits, lemon and vanilla extracts, geraniol nitobenzine, amyl acetate, propyl acetate, butyl acetate, apples, apple flavoring, anise, corn oil, fusel oil, saccharin, sugar, vinegar, stale beer, sawdust, shorts (grain byproducts), whey, soap, and even horse manure (Shotwell 1942). Some of the substrates studied to replace bran were sawdust, cottonseed hulls, rolled wheat, ground wheat screenings, citrus meal, chopped and ground alfalfa, ground flax fiber, ground peanut shells, bagasse, pear and apple pomace, peat moss, ground beet pulp, ground corncobs, chopped cornstalks, cornmeal, soybean meal, pea bran, oat hulls, and low-grade wheat flour (Parker 1952).

Over the years, different toxic substances were studied for effectiveness against grasshoppers. These toxins included paris green, white arsenic, dry and liquid sodium arsenate, barium fluosilicate, and sodium fluosilicate (Shotwell 1942). However, until 1942, when sodium fluosilicate became the preferred toxic agent, arsenic was most often used (Parker 1952). The chlorinated hydrocarbon insecticides introduced in the 1940's soon replaced the previously used toxic agents. Because sprays of these insecticides were so effective, widespread use of baits discontinued by 1950.

New insecticides that were equally effective, but environmentally safer, later replaced the chlorinated hydrocarbons. The development of acceptable spray agents and spray technology, even though extremely efficient, did not eliminate the use of bran bait completely. Bait commonly was used against Mormon cricket (a longhorn grasshopper) in the 1970's and continues today.

Although liquid sprays are very effective and economically superior, baits offer several environmental advantages, and work has continued to improve them. Ewen (1990) reviewed some of the more recent reported results with baits. His review included studies on the organophosphates (dimethoate, pyridaphenthion, fenitrothion, and malathion), the carbamates (propoxur, carbofuran, carbaryl, and cloethocarb); and the synthetic pyrethroids (fenvalerate and cypermethrin). In addition to these chemicals, chlorpyrifos and acephate, both organic phosphates, and diflubenzuron, an insect growth regulator, have also recently been studied in bait formulations. Studies of these toxicants in baits are noted in the references at the end of this chapter.

Of the toxicants recently studied, dimethoate, fenitrothion, carbofuran, cloethocarb, chlorpyrifos, diflubenzuron, and carbaryl are very effective in bait formulations against susceptible species of grasshoppers. However, most of these toxicants are not currently registered for use in baits against grasshoppers. Carbaryl is currently registered for use in the United States against grasshoppers and is commonly used on rangeland when bait treatments are indicated. It has been extensively used as a preventive "hot-spot" treatment in the Grasshopper Integrated Pest Management Project's North Dakota demonstration area. Dimethoate is registered for use in Canada in baits against grasshoppers.

Even though extensive research has been conducted with baits, two general areas of concern still detract from their widespread use against grasshoppers. Grasshopper populations on rangeland are seldom composed of only species that readily consume baits, and control of bait-consuming species is usually less with baits than with sprays. The cost of applying baits, particularly by air, usually exceeds the cost of applying sprays. Also, because applicators have less experience with baits, they perceive more difficulty in calibrating equipment for baits than for sprays.

On the other hand, baits have some considerable environmental advantages. The increased interest in protecting the environment and reducing the effects on nontarget species make baits more attractive than in the past. Compared to sprays, baits require less active ingredient to achieve reduction in grasshopper populations and are much more specific toward grasshoppers and affect significantly fewer nontarget organisms than sprays. Baits are also easier to direct toward the target area than sprays. Also, the increased knowledge that allows for use of treatments that do not provide almost total control of pest species adds to the attractiveness of baits. Other chapters in this section describe the recent developments, methods, and potential strategies for the use of bait formulations for controlling grasshoppers.

Suggested References

Capinera, J. L.; Hibbard, B. E. 1987. Bait formulations of chemical and microbial insecticides for suppression of crop-feeding grasshoppers. Journal of Agricultural Entomology. 4: 337–344.

Coquillet, D. W. 1886. Report on the locust of the San Joaquin Valley, California. Washington, DC: U.S. Commission on Agriculture Annual Report: 1885: 289–303.

Ewen, A. B. 1990. A synthesis paper on the use of insecticides formulated as baits for grasshopper control in Canada and the USA. Boletin de Sanidad Vegetal Plagas (Fuera de Serie) 20. 83–89.

Ewen, A. B.; Mukerji, M. K. 1987. Field evaluation of carbofuran bait against grasshopper (Orthoptera: Acrididae) populations in Saskatchewan. Canadian Entomologist 119: 537–540.

Ewen, A. B.; Mukerji, M. K. 1980. Evaluation of *Nosema locustae* (Microsporida) as a control agent of grasshopper populations in Saskatchewan. Journal of Invertebrate Pathology 35: 295–303.

Jech, L. E.; Foster, R. N.; Colletto, D.; Walgenbach, D. D.; Roland, T. J.; Rodriguez, G. D.; Bohls, R.; Houston, R. D.; Meeks, W. K.; Queener, R. L.; Jackson, C. L.; Dines, J. L.; Puclik, M. J.; Scott, A. K. 1993. Field evaluation of diflubenzuron and carbaryl bran baits against grasshopper (Orthoptera: Acrididae) populations in South Dakota. Journal of Economic Entomology 86: 557–565.

Johnson, D. L.; Henry, J. E. 1987. Low rates of insecticides and *Nosema locustae* (Microsporidia: Nosematidae) on baits applied to roadsides for grasshopper (Orthoptera: Acrididae) control. Journal of Economic Entomology 80: 685–689.

Mukerji, M. K.; Ewen, A. B. 1984. Field evaluations of cypremethrin and carbaryl as sprays and baits for grasshopper (Orthoptera: Acrididae) control in Saskatchewan. Canadian Entomologist 116: 5–9.

Mukerji, M. K.; Ewen, A. B.; Craig, C. H.; Ford, R. J. 1981. Evaluation of insecticide-treated bran baits for grasshopper control in Saskatchewan (Orthoptera: Acrididae). Canadian Entomologist 113: 705–710.

Onsager, J. A.; Henry, J. E.; Foster, R. N.; Staten, R. T. 1980a. Acceptance of wheat bran by species of rangeland grasshoppers. Journal of Economic Entomology 73: 548–551.

Onsager, J. A.; Henry, J. E.; Foster, R. N. 1980b. A model for predicting efficacy of carbaryl bait for control of rangeland grasshoppers. Journal of Economic Entomology 73: 726–729.

Parker, J. R. 1952. Grasshoppers, In: Yearbook of Agriculture. Washington, DC: U.S. Department of Agriculture: 595–604.

Quinn, M. A.; Kepner, R. L.; Walgenbach, D. D.; Bohls, R. A.; Pooler, P. D.; Foster, R. N.; Reuter, K. C.; Swain, J. L. 1989. Immediate and second-year effects of insecticide spray and bait treatments on populations of rangeland grasshoppers. Canadian Entomologist 121: 589–602.

Shotwell, R. L. 1942. Evaluation of baits and bait ingredients used in grasshopper control. Tech. Bull. 796. Washington, DC: U.S. Department of Agriculture: 51.

Suggested References—Unpublished

Colletto, D.; Jech, L.; Foster, R. N.; Houston, R.; Puclik, M.; Scott, A. 1990. Efficacy of three different toxicants on three carriers in combinations for grasshopper control on improved rangeland near Medora, N.D., 1990. In: Cooperative Grasshopper Integrated Pest Management Project, 1990 annual report. Boise, ID: U.S. Department of Agriculture, Animal and Plant Health Inspection Service: 164–168.

Colletto, D.; Jech, L.; Foster, R. N.; Roland, T. J.; Jackson, C.; Patterson, J.; Meeks, W. 1989. Preliminary insecticidal value field trials on rangeland grasshoppers near Edgemont, South Dakota, 1989. In: Cooperative Grasshopper Integrated Pest Management Project, 1989 annual report. Boise, ID: U.S. Department of Agriculture, Animal and Plant Health Inspection Service: 190–193.

Jech, L. E.; Foster, R. N.; Colletto, D.; Drake, S.; Houston, R.; Black, L. 1991. Field trials of defatted corn and flaky wheat bran treated with either carbaryl or acephate for control of rangeland grasshoppers near Wheatland, Wyoming, 1991. In: Cooperative Grasshopper Integrated Pest Management Project, 1991 annual report. Boise, ID: U.S. Department of Agriculture, Animal and Plant Health Inspection Service: 87–89.

Jech, L. E.; Foster, R. N.; Colletto, D.; Walgenbach, D. D.; Bohls, R.; Rodriguez, G.; Burgess, J.; Meeks, W.; Queener, R. 1988. Field trials of chlorpyrifos and carbaryl bran baits for control of grasshopper on rangeland near Buffalo, South Dakota, 1988. In: Cooperative Grasshopper Integrated Pest Management Project, 1989 annual report. Boise, ID: U.S. Department of Agriculture, Animal and Plant Health Inspection Service: 194–206.

II.12 Bait Acceptance by Different Grasshopper Species and Instars

Jerome A. Onsager, R. Nelson Foster, and Larry Jech

The Grasshopper Integrated Pest Management (GHIPM) Project provided unique resources and opportunities that allowed investigators to gather a large amount of data on the responses of rangeland grasshoppers to carbaryl bait. A total of 39 different species were recorded in 24 different control experiments at 14 different sites in the western parts of North Dakota and South Dakota. All species were not present in sufficient numbers to provide useful information, but the data base allowed GHIPM-funded investigators to study many questions that could not have been examined without it.

Data Collection

The monitoring procedure was to establish from 4 to 10 monitoring sites, each consisting of 40 0.1-m^2 rings spaced about 5 m apart in circles, both in plots that were scheduled for treatment and in adjacent plots that remained untreated. Density counts and sweep-net collections were made as close as possible (usually 24 hours) before scheduled treatments, and again as close as possible to 48 hours after treatment. The information from all sample sites per plot for each sampling date was then combined for further study.

Each sweep sample was examined to determine the species and stage of development for every grasshopper in the sample. Each total density count was then converted to density per instar per species by multiplying observed total density times the appropriate proportions of composition within the sweep samples. The procedure is identical to that described in chapter II.2, “Evaluation of Rangeland Grasshopper Controls,” except that density was estimated for each instar of a species as well as for all individuals of a species.

Computer tabulations of different species recorded in different experiments revealed a potential for 253 independent determinations of species-specific response to carbaryl bait. Pretreatment and posttreatment data for each species in each experiment were then examined to assess which of the possible determinations would be meaningful. A total of 101 potential data sets were declared useless, leaving 152 legitimate determinations.

Reasons for rejecting some data sets included initial presence in such low density that subsequent reduction would not be measurable (in most cases, at least five specimens in pretreatment samples were required), absence of specimens at untreated sample sites (which prohibited estimation of mortality in the absence of treatment), and higher estimated mortality in untreated plots than in treated plots (a common artifact of sampling error among low-density samples).

The 152 data sets accepted as legitimate provided opportunities to study a variety of questions about response to carbaryl bait. The simplest assessment concerned the average percent control among all individuals of a species. This average percent control was calculated with a variation of the formula by Connin and Kuitert (1952):

Percent control = $100(1 - (Ta \times Ub \div Tb \div Ua))$, where
Tb is density in treated plots before treatment,
Ta is density in treated plots after treatment,
Ub is density in untreated plots before treatment, and
Ua is density in untreated plots after treatment.

The formula does not yield “simple” or “raw” control data—that is, the percentage of the total infestation that “disappeared” in treated plots. Rather, it yields “adjusted” control data: the percentage of the total infestation that most likely was killed by carbaryl bait.

The formula is useful for two major reasons. First, grasshopper infestations suffer some mortality each day due to natural causes, so the formula “removes” that natural mortality from consideration. The formula essentially uses data from untreated sites to estimate what the posttreatment counts at treated sites would have been in the absence of treatment. Percent control then represents the difference (if any) between expected and observed posttreatment density in treated plots. Second, without the formula, the percent control that is estimated will be grossly different, depending on how much time elapses between pretreatment and posttreatment counts. These problems can be illustrated with an example.

Let us assume that an infestation of 30 grasshoppers/yd^2 comprises 6 *Aeropedellus clavatus,* 15 *Melanoplus sanguinipes,* and 9 *Amphitornus coloradus.* We decide to treat half and leave half, and we sample both halves on the day before treatment (day –1), and on days 2, 3, 4, and 5 after treatment. Table II.12–1 shows typical density data.

Table II.12–1—A representative example of typical grasshopper density data in untreated plots versus plots that were treated (on day zero) with carbaryl bait

Time (days after treatment)	*A. clavatus* Untreated plot	*A. clavatus* Treated plot	*M. sanguinipes* Untreated plot	*M. sanguinipes* Treated plot	*A. coloradus* Untreated plot	*A. coloradus* Treated plot	All species Untreated plot	All species Treated plot
–1	6	6	15	15	9	9	30	30
+2	3.68	2.95	13.69	3.42	7.71	7.56	25.08	13.93
+3	3.13	2.51	13.28	3.32	7.33	7.18	23.74	13.01
+4	2.66	2.13	12.88	3.22	6.96	6.82	22.5	12.17
+5	2.26	1.81	12.49	3.12	6.61	6.48	21.36	11.41

Looking only at the raw density for “All species” in only the treated plot, a reader might believe that this bait treatment achieved about 54- to 62-percent average control of the infestation. The fallacy is that if a similar strategy is applied to data from untreated plots, a reader could estimate 16- to 29-percent control where nothing was done. Use of the formula yields more conservative and more realistic estimates of about 44- to 46-percent adjusted control of “All species.”

Raw estimates for individual species can also be very misleading. For example, *A. clavatus* usually is the first species that hatches in the spring. By the time of typical bait treatments to control later-hatching major pest species, *A. clavatus* often is present as very old adults that suffer very high daily mortalities likely associated with the process of aging. Raw estimates indicate 51- to 70-percent population reduction, but adjusted estimates reveal only 20-percent control due to the bait, meaning the raw estimates placed control at 2.5 to 3.5 times higher than it actually was.

Notice in the example that discrepancies between raw and adjusted mortalities for *A. coloradus* are even greater than they were for *A. clavatus.* This is because adjusted response to treatment (2-percent control) was less than the daily loss due to natural mortality (5 percent per day). In such a case, raw estimates yield greatly distorted results. As one might then expect, raw estimates are closest to adjusted estimates in cases like the *M. sanguinipes* example, where natural mortality was relatively low (3 percent per day) and adjusted control was relatively high (75 percent). Nevertheless, it should be noted that all raw estimates for *M. sanguinipes* still were too high, and the degree of error increased as the amount of time between pretreatment and posttreatment samples was increased. Similar errors are guaranteed to occur in real life (in field experiments or commercial control projects) if natural mortality is ignored.

Relative Susceptibility of Different Species

The results of GHIPM experiments were combined with a number of previous studies by the authors and others (see Swain [1986] and Quinn et al. [1989]) to produce table II.12–2. It divides grasshoppers into three broad classes of susceptibility. The “sensitive” class contains species that readily seek out and eat wheat bran bait and therefore usually suffer a high degree (average = 56–87 percent) of adjusted (true) mortality. The “vulnerable” class contains species that usually either suffer only a moderate degree (30–55 percent) of adjusted mortality or else exhibit such great variation among different tests that one cannot safely depend on more than moderate results. The “nonsusceptible” class (less than 30-percent adjusted mortality) contains species that eat little or no bait and therefore usually are not markedly affected by bait.

Most of the experiments that contributed to table II.12–2 were applied when the majority of target pest grasshopper species were in third, fourth, or fifth instars. A few very early species like *A. clavatus* and *M. confusus* typically were treated as adults or fifth instars, while some relatively late species like *P. nebrascensis* and *P. quadrimaculatum* were occasionally treated as first or

Table II.12–2—Classification of grasshopper species according to susceptibility to carbaryl wheat bran bait

Class and expected levels of control	Species
Sensitive (>55-% control) Control is expected to average about 70%. Worst-case and best-case scenarios will be about 55% and 85%, respectively.	*Ageneotettix deorum* *Anabrus simplex* *Aulocara elliotti* *Camnula pellucida* *Hadrotettix trifasciatus* **Melanoplus bivittatus* *Melanoplus confusus* *Melanoplus dawsoni* *Melanoplus foedus* **Melanoplus infantilis* **Melanoplus occidentalis* **Melanoplus packardii* *Melanoplus sanguinipes* *Spharagemon equale* *Stenobothrus brunneus* **Mermiria bivittata*
Vulnerable (30- to 55-% control) Control is expected to average about 42%. Worst-case and best-case scenarios will be about 12% and 72%, respectively.	**Aulocara femoratum* *Eritettix simplex* *Melanoplus femurrubrum* *Oedaloenotus enigma* *Opeia obscura* *Phoetaliotes nebrascensis* *Psoloessa delicatula*
Nonsusceptible (<30-% control) Control is expected to average about 15%. Worst-case and best-case scenarios will be about 0% and 30%, respectively.	*Aeropedellus clavatus* *Amphitornus coloradus* *Cordillacris crenulata* *Cordallacris occipitalis* *Hesperotettix viridis* *Metator pardalinus* **Phlibostroma quadrimaculatum* *Trachyrhachys kiowa*

*These species are not likely to suffer best-case scenario levels of control.

second instars where they were incidental rather than primary target species.

Relative Susceptibility of Different Developmental Stages

Some of the GHIPM experiments provided data that allowed the comparison of the relative susceptibility of different instars of a species to bait. In general, the requirements for a meaningful test were the presence of at least four or more different stages in reasonable numbers (usually at least five individuals per instar in pretreatment sweep samples) in two or more different experiments. In those cases, the authors calculated adjusted percent control for each instar and used analyses of covariance, with instar as the covariant, to test susceptibility by instar. When covariance was significant (when percent control was affected by instar), the slope of the relationship indicated whether larger or smaller instars were most susceptible.

A total of eight species were tested, six of which were considered in table II.12–2 to be sensitive. Younger instars of three species, *A. deorum, M. packardii,* and *M. sanguinipes,* were found to be significantly more susceptible to bait than older instars. Susceptibility was not affected by instar in the cases of *A. elliotti, C. pellucida, M. infantilis, P. nebrascensis,* or *T. kiowa.*

Relative Susceptibility of Different-Aged Populations

Some of the GHIPM experiments provided data that allowed the researchers to examine the effect of age on susceptibility of populations to bait. Age was expressed as average instar, which is calculated as the sum of each instar number multiplied by the number of grasshoppers in the instar (adults are considered instar 6 for this procedure) divided by the total number of grasshoppers present. The requirements for a meaningful test were significant adjusted control observed in three or more experiments (incidences of zero control were excluded from these calculations). The relationship between average instar and percent adjusted mortality was examined by linear regression techniques.

A total of 17 species was tested, 10 of which were considered in table II.12–2 to be sensitive or vulnerable. For three of those species, *A. elliotti, A. deorum,* and *M. sanguinipes,* percent adjusted control increased significantly with average instar.

Summary and Recommendations

Grasshopper species vary considerably in their inclination to feed on wheat bran and in their susceptibility to carbaryl-treated bait. In addition, levels of control that follow bait treatments are considerably lower and much less predictable than control achieved with liquid sprays. The GHIPM Project greatly increased the knowledge base for both acknowledged pest grasshopper species (the primary target species) and for incidental (nontarget) species. Project researchers now feel that they can offer some general guidelines, based on species susceptibility (table II.12–2), for the appropriate use of carbaryl bait.

Individuals should not attempt to control nonsusceptible pest species with bait. If such species comprise a significant proportion of an infestation, a conservative manager should simply assume that bait will give no control of that proportion. Vulnerable species may or may not be markedly controlled by baits, but what regulates that degree of success remains unknown, and at this time those results cannot be predicted. Past situations have documented dramatic reductions in vulnerable species from the use of bait, as well as cases of almost total failure. In the future, managers should not use bait against vulnerable species without seriously weighing the consequences of failure. Control of the sensitive species with bait is generally reliable.

Questions about optimum timing for bait treatments remain somewhat perplexing, but it fortunately appears that timing is not of extreme importance, perhaps because of compensatory factors. Some tests support early treatments in that, at least for some species, younger instars were more susceptible than older instars. This is logical because smaller grasshoppers are killed by smaller doses of toxicant. Another advantage of early bait treatment is that natural control agents have more time to act upon surviving grasshoppers.

Other tests, however, support late treatments in that total percent control was greater for older populations than for younger populations. While these results may seem contrary, they also can be considered strong evidence that something like changes in behavioral traits (perhaps searching capabilities) or habitat characteristics (perhaps cover, litter, or bare ground) make baits more accessible as the season progresses. If such compensating factors exist, the mechanisms cannot be accurately described at the present time. Fortunately, however, for most species (14 of 17 tested), adjusted percent control was not markedly affected by population age. It therefore appears that timing of bait treatments is not of extreme importance as long as it occurs when most of the primary target grasshoppers are in third, fourth, or fifth instars.

References Cited

Connin, R. V.; Kuitert, L. C. 1952. Control of the American grasshopper with organic insecticides in Florida. Journal of Economic Entomology 45: 684–687.

Quinn, M. A.; Kepner, R. L.; Walgenbach, D. D.; Bohls, R. A.; Pooler, P. D. 1989. Immediate and 2nd-year effects of insecticide spray and bait treatments on populations of rangeland grasshoppers. Canadian Entomologist 121: 589–602.

Swain, J. L. 1986. Effect of chemical grasshopper controls on nontarget arthropods of rangeland in Chaves County, New Mexico. Master’s thesis. Las Cruces, NM: New Mexico State University. 102 p.

II.13 What, When, and Where Do Grasshoppers Eat?

Larry Jech

Some species of grasshoppers do not readily take baits. As a result, the effectiveness of grasshopper control through bait applications can be limited. Various researchers have attempted to increase bait effectiveness. These studies have focused primarily on comparing toxicants, varying applications timing, and varying the amount of toxicant on the bait applied. Carefully designed and executed experiments with alternate insecticides and time-of-day application did not lead to increases in grasshopper mortality among the species that did not feed on bait in other experiments. The Grasshopper Integrated Pest Management (GHIPM) Project conducted observation studies to improve baits through better understanding of grasshopper feeding behavior.

Findings of Direct Observations

During the summers of 1990 and 1991, GHIPM Project experiments involved direct observation of grasshoppers feeding on host plants in rangelands. The study focused on species that readily take bait and species that do not. The study sites were typical prairies in western South Dakota and North Dakota. The grasshopper densities were representative of those targeted for bait control programs (greater than 10 but less than 25 grasshoppers/m^2). Observation involved watching individual grasshoppers from daybreak to dusk and recording their behavior every 15 seconds.

Most of the behavior observed had very little to do with feeding. Grasshoppers basked in the sun, moved about their habitat, and exhibited avoidance behavior. Most observations were of third-instar (young grasshoppers) to adults.

The study included four common species that are not easily controlled by bait applications at the standard rate of 1.5 lb/acre containing 2 percent carbaryl. These species were *Amphitornus coloradus* (Thomas), *Cordillacris occipitalis* (Thomas), *Trachyrhachys kiowa* Thomas, and *Phlibostroma quadrimaculatum* (Thomas). Also, the study compared these four species' behavior with that of two species that are easily controlled with baits—*Aulocara elliotti* (Thomas) and *Ageneotettix deorum* (Scudder).

Usually grasshoppers spent the early morning basking. After the air temperature reached 81 °F, the grasshoppers began to feed. Grasshoppers allowed time for their crops to empty between feeding sessions and repeated feeding and resting cycles regularly. The insects generally groomed their antennae and eyes before feeding, but grooming apparently was not a prerequisite to feeding.

Feeding continued throughout the day if temperatures remained below 90 °F. When temperatures rose above 95 °F, the grasshoppers perched on stems or took shelter under vegetation to avoid excessive heat. While the temperature remained elevated, the grasshoppers did not actively feed; active feeding resumed when the temperature fell. In other experiments designed to determine the optimal time of bait application (including experiments during the GHIPM Project), temperatures remained below 90 °F so that timing of application was not a significant factor for most of the grasshopper population.

Very little feeding took place when winds exceeded 15 miles per hour (mi/hour) or during cool, cloudy days. The insects would remain quiet until weather conditions improved. Grasshoppers also stopped feeding when rain was imminent. After showers or rains passed and the ground warmed, grasshoppers returned to feeding.

Although grasshoppers spent one-seventh of their time moving, the movement appeared to be random. Most of the time, grasshoppers were on the soil surface and climbed the plants only to feed. The exception was *Amphitornus coloradus.* This species would enter a clump of grass and position itself so its body was nearly vertical. The upright position, combined with its cryptic body markings, gave the grasshopper maximum protection from predators. For this species, feeding behavior seemed to be balanced carefully between the need to feed and to remain hidden.

Grasshoppers were very discriminating in their food choices. They would sample a blade of grass before feeding on it and occasionally move back to a portion of the blade or another blade passed over previously. *T. kiowa,* one that does accept bran bait, often would feed on a plant, move a short distance, and then return to the same plant and resume feeding. The activity showed the grasshopper was capable of relocating a suitable host plant. Grasshoppers fed on the tips of leaf blades or would clip the tip of a blade and then feed on the tip while grasping it with their forelegs. When the latter feeding habit occurred, the grasshoppers usually ate all of the clipped portion. The other common feeding pattern was to bite a portion out of a leaf margin, leaving it notched.

Aulocara elliotti and *Ageneotettix deorum*, the two species that readily eat bran bait, often picked up bits of plant litter from the soil surface and tasted and consumed those food items in addition to feeding actively on live tissue. These two species also clipped the leaf tips but dropped the clippings to the ground and later fed on the sun-dried clippings. The four species that do not accept bran bait seldom fed on materials found on the soil surface and preferred live tissue.

Additional tests showed species that feed on live tissue and do not take baits would accept baits glued to host plants. *Cordillacris occipitalis* and *Aulocara elliotti* were caged on a host plant that is acceptable to both species. Bait particles were glued to the host at the leaf tip, midleaf, and at the leaf base. Grasshoppers were allowed to browse for 8 hours. Grasshoppers caged on untreated leaves had no mortality, while both species caged on treated leaves showed equal mortality.

Conclusions

Grasshoppers in this study spent only a small portion of their time feeding. They fed in sessions interspersed with rest or movement (see table II.13–1.) Grasshopper species that were easily controlled with baits fed on plant litter and detrital material on the ground and were therefore predisposed to feed on bran baits. Grasshoppers that did not take baits fed on living host plants.

One approach to enhancing bait effectiveness would be to treat the bait with a sticking agent as the bait is applied. Some of the treated bait would then be encountered by grasshoppers feeding on live host plants. Bait falling on the soil surface will remain available to ground-feeding species.

Attracting grasshoppers that feed on live tissue to bait and positioning bait in the known feeding locations are some areas for the next stage of research.

Table II.13–1—Summary of feeding behaviors for six species of grasshoppers

	Percent of time engaged in:			Total
Species	Basking	Moving	Feeding	hours
Ageneotettix deorum	81.8	13.9	4.4	14.9
Aulocara elliotti	69.5	17.2	13.2	25.5
Amphitornus coloradus	77.4	8.4	14.2	57.8
Cordillacris occipitalis	81.0	9.1	9.8	18.8
Phlibostroma quadrimaculatum	76.8	18.4	5.8	14.4
Trachyrhachys kiowa	36.8	31.4	31.7	14.9

II.14 Effect of Multiple Concentrations and Rates of Carbaryl–Bran Bait

Mark A. Quinn, R. Nelson Foster, and K. C. Reuter

Introduction

Insecticidal baits are a viable alternative to conventional insecticidal sprays for controlling grasshoppers (Quinn et al. 1989). Baits are particularly effective when the grasshopper community is composed largely of bran "acceptors," or those species that readily consume bran baits (see chapter II.12 on bait acceptance). Most of the recent studies involving bran baits have used concentrations in the range of 2–5 percent toxicant at rates near 1.5 lb/acre. The efficacy of higher concentrations and rates has not been studied extensively. As part of the Grasshopper Integrated Pest Management Project, a study was conducted in northwestern South Dakota to determine the effects of multiple concentrations and rates of carbaryl bran bait on grasshoppers on mixed-grass rangeland.

Multiple Concentrations and Rates of Bran Bait—A Case Study

Fifty-one 40-acre plots were treated with aerial applications of carbaryl bran bait in the following concentrations and rates: 2 percent carbaryl at 0.5, 1, 2, 5, and 10 lb/acre; 5 percent carbaryl at 0.5, 1, and 2 lb/acre; and 10 percent carbaryl at 0.5, 1, and 2 lb/acre. An additional nine plots were used as controls. The baits were applied with a Cessna Ag Truck operating at an altitude of 40–60 ft at 115 miles per hour (mi/hour) and equipped with a standard Transland 20244 spreader. Swath widths were 45 ft. Treatments were applied over a 17-day period from June 27 to July 13, 1987. Approximately 56 percent of grasshoppers were in the nymphal stage at the time of treatments (table II.14–1).

Densities of grasshoppers were estimated in the center of each plot by counting grasshoppers in 40 0.1-m^2 rings (Onsager and Henry 1977) placed approximately 16 ft apart in a 210-ft-diameter circle. Relative abundance of each grasshopper species and instar was determined by collecting grasshoppers near the circle of rings with a sweep net. Densities of individual species were estimated by multiplying their relative abundance by total grasshopper density. Grasshopper populations were monitored before treatment and 2, 4, and 7 days after treatments. Populations were monitored approximately daily from June 26 to July 20 in the control plots.

Changes in densities of total grasshoppers, bran-accepting species, and bran-rejecting species in the control plots were compared with changes in plots treated with the insecticidal baits to determine overall treatment effects. Major bran-accepting species included *Melanoplus sanguinipes*, other *Melanoplus* species, *Ageneotettix deorum, Phoetaliotes nebrascensis*, and *Aulocara elliotti*. Bran-rejecting species included *Aeropedellus clavatus, Amphitornus coloradus, Trachyrhachys kiowa*, and *Opeia obscura*. Although *O. obscura* may be vulnerable to insecticidal baits (see the bait acceptance chapter in this section), we included it in the bran-rejector category because it was not affected by the insecticidal bait in our particular study.

Mean pretreatment densities of total grasshoppers ranged from 13.1 to 22 grasshoppers/yd^2 in the treatment plots. *M. sanguinipes, A. deorum,* and *A. clavatus* constituted 32, 15, and 14 percent of all grasshopper species, respectively, during the pretreatment period (table II.14–1). Bran acceptors constituted 72 percent of all species.

All insecticidal bait treatments, except the 2 percent carbaryl at 0.5 lb/acre, caused significant reductions in total grasshopper density compared with controls (table II.14–2). The greatest mean mortalities, ranging from 72 to 86 percent, occurred in plots treated with 2 percent carbaryl bran bait at 5 and 10 lb/acre, 5 percent carbaryl bran bait at 1 lb/acre, and 10 percent carbaryl at 2 lb/acre. The more standard treatments of 2 percent carbaryl at 1 and 2 lb/acre gave intermediate results, causing average mortalities of 52 and 64 percent, respectively. Applications of bran bait at 0.5 lb/acre were least effective, killing less than 50 percent of all grasshoppers.

All treatments caused significant mortality of bran-accepting species of grasshoppers compared with controls (table II.14–2). The greatest mortality occurred in plots treated with 2 percent carbaryl at 10 lb/acre (97 percent), 5 percent carbaryl at 2 lb/acre (90 percent), 2 percent carbaryl at 5 lb/acre (90 percent), and 5 percent carbaryl at 1 lb/acre (88 percent). The commonly used treatments of 2 percent carbaryl at 1 or 2 lb/acre caused 72 and 89 percent mortalities, respectively, of bran-accepting grasshopper species. Applications of 2 and 5 percent carbaryl at 0.5 lb/acre caused 45–54 percent reductions in the bran acceptors. Densities did not change in control plots.

Table II.14–1—Relative abundance of grasshopper species and instars and number of plots occupied on the pretreatment sampling dates, June 26–July 7, 1987, Harding County, SD

Species	No. of plots occupied	Percentage of grass-hoppers[1]	Percentage of individuals in each instar					
			I	II	III	IV	V	Adult
Melanoplus sanguinipes (F.)	55	32.31	0.0	0.9	13.6	17.0	32.1	36.4
Ageneotettix deorum (Scudder)	55	14.35	0.0	0.8	4.6	15.2	57.6	21.8
Aeropedellus clavatus (Thomas)	51	13.95	0.0	0.0	0.0	0.0	0.0	100.0
Melanoplus dawsonii (Scudder)	40	5.31	0.4	4.7	23.8	27.7	20.6	22.8
Melanoplus confusus Scudder	47	4.57	0.0	0.0	0.0	0.0	0.0	100.0
Amphitornus coloradus (Thomas)	50	4.55	0.0	0.0	2.7	9.5	43.1	44.6
Melanoplus infantilis Scudder	44	3.76	0.2	2.8	15.9	15.3	31.7	34.0
Trachyrhachys kiowa Thomas	48	2.50	0.0	0.6	10.5	16.8	35.0	37.1
Melanoplus spp.	38	2.32	25.0	74.6	0.0	0.0	0.4	0.0
Orphulella speciosa (Scudder)	31	2.13	0.4	2.0	11.8	34.1	29.5	22.2
Phoetaliotes nebrascensis (Thomas)	39	2.10	4.5	40.1	36.7	14.8	3.9	0.0
Aulocara elliotti Thomas	38	1.92	0.0	0.0	0.5	0.8	20.0	78.7
Melanoplus packardii (Scudder)	46	1.47	0.6	4.9	16.0	38.8	32.8	8.7
Melanoplus femurrubrum (DeGeer)	17	1.36	6.1	20.8	42.8	15.6	11.0	3.7
Melanoplus bivittatus (Say)	34	1.30	0.0	1.5	5.7	12.8	15.1	64.8
Opeia obscura (Thomas)	39	1.19	0.0	2.4	15.3	39.3	36.1	6.9
Others (26 species)	—	4.91	6.8	10.6	13.6	14.3	23.0	31.7
All species	55	100.00	1.1	4.3	10.0	13.7	27.3	43.6

[1] Based on a total of 12,063 grasshoppers collected.

Table II.14–2—Pretreatment densities and reductions in grasshopper densities 7 days after treatments with different rates and concentrations of carbaryl bran bait, Harding County, SD

Grasshopper variable	Treatment[1]	Pretreatment density[2] ($\bar{x}$ ± SEM) standard error of the means	Percent reduction[3] ($\bar{x}$ ± SEM)
Total grasshoppers	Control	13.7 ± 1.91a	8.1 ± 12.66a
	2% — 0.5	12.5 ± 2.43a	31.3 ± 10.69abcd
	2% — 1.0	13.8 ± 0.61a	51.7 ± 17.01be
	2% — 2.0	17.4 ± 2.81a	63.9 ± 2.17efgh
	2% — 5.0	17.4 ± 4.21a	75.3 ± 8.20gk
	2% — 10.0	20.1 ± 6.57a	85.9 ± 7.91k
	5% — 0.5	16.4 ± 1.40a	37.4 ± 15.58bcdf
	5% — 1.0	18.6 ± 5.53a	77.9 ± 7.54hk
	5% — 2.0	18.0 ± 4.92a	56.0 ± 8.05ceg
	10% — 0.5	12.0 ± 2.83a	49.9 ± 5.98bcdf
	10% — 1.0	13.9 ± 2.39a	58.7 ± 3.81deg
	10% — 2.0	17.3 ± 2.33a	72.3 ± 4.71ek
Bran acceptors	Control	9.4 ± 1.43a	5.7 ± 12.77a
	2% — 0.5	8.7 ± 1.42a	45.2 ± 19.72b
	2% — 1.0	8.4 ± 0.60a	60.2 ± 17.80bcd
	2% — 2.0	11.3 ± 1.40a	77.5 ± 4.85cdef
	2% — 5.0	13.6 ± 4.53a	89.6 ± 5.79fg
	2% — 10.0	17.0 ± 5.23a	97.4 ± 2.34g
	5% — 0.5	12.6 ± 1.30a	53.5 ± 11.42bc
	5% — 1.0	15.1 ± 4.45a	87.9 ± 6.98efg
	5% — 2.0	10.2 ± 2.44a	89.8 ± 1.25efg
	10% — 0.5	8.2 ± 2.22a	72.1 ± 8.67cde
	10% — 1.0	10.1 ± 1.12a	69.5 ± 4.07bcd
	10% — 2.0	13.8 ± 1.74a	80.8 ± 8.47def
Bran rejectors	Control	3.4 ± 0.63a	0.1 ± 16.62ab
	2% — 0.5	3.1 ± 0.86a	–34.6 ± 24.01b
	2% — 1.0	3.2 ± 0.54a	34.6 ± 29.41ac
	2% — 2.0	5.7 ± 1.90a	–27.0 ± 44.99ab
	2% — 5.0	2.5 ± 0.28a	37.8 ± 8.79ab
	2% — 10.0	4.6 ± 1.13a	59.6 ± 28.41c
	5% — 0.5	3.7 ± 0.44a	8.5 ± 27.83ab
	5% — 1.0	3.4 ± 1.12a	33.4 ± 13.77ab
	5% — 2.0	7.7 ± 2.47a	9.1 ± 20.79ab
	10% — 0.5	3.2 ± 0.45a	15.4 ± 20.98ab
	10% — 1.0	3.3 ± 1.33a	12.2 ± 43.52ab
	10% — 2.0	3.3 ± 1.00a	–112.0 ± 117.23b

[1] Percent of carbaryl applied—application rate in lb/acre.

[2] No./yd^2.

[3] A negative percent reduction indicates an increase in grasshoppers.

Note: Means within columns followed by the same letter are not significantly different at the 0.1 level (Fisher's protected SD).

In general, bran-rejecting species were not affected by the treatments (table II.14–2). However, the greatest reduction in bran rejectors (60 percent) occurred in plots treated with 2 percent carbaryl at 10 lb/acre. Because changes in densities in these plots were highly variable, it could not be determined if this reduction was caused by mortality or natural variation in grasshopper populations.

Conclusions

The following conclusions can be drawn from the study. First, the quantity of carbaryl bran bait applied to rangeland affects grasshopper mortality. Baits applied at 0.5 lb/acre are relatively ineffective. The highest rates (5 and 10 lb/acre) were very effective in controlling grasshoppers. These results do not suggest, however, that more bait is always better (see chapter II.15 on multiple applications of bran bait). For example, 78 percent mortality was achieved in plots treated with 5 percent carbaryl at 1 lb/acre. Also, the small increase in mortality caused by higher rates may not be economically justifiable.

Second, the concentration of carbaryl seemed less important than the rate of application. For example, 2 and 10 percent carbaryl applied at a rate of 2 lb/acre caused similar grasshopper mortalities.

Finally, high mortality of grasshoppers was achieved because the grasshopper community was composed mainly of the bran-accepting *Melanoplus* species. Insecticidal baits are less effective when there is a higher proportion of bran-rejecting species (Quinn et al. 1989, Jech et al. 1993).

References Cited

Jech, L. E.; Foster, R. N.; Colletto, D.; Walgenbach, D. D.; Roland, T. J.; Rodriguez, G. D.; Bohls, R.; Houston, R. D.; Meeks, W. K.; Queener, R. L.; Jackson, C. L.; Dines, J. L.; Puclik, M. J.; Scott, A. K. 1993. Field evaluation of diflubenzuron and carbaryl bran baits against grasshopper (Orthoptera: Acrididae) populations in South Dakota. Journal of Economic Entomology 86: 557–565.

Onsager, J. A.; Henry, J. E. 1977. A method for estimating the density of rangeland grasshoppers (Orthoptera: Acrididae) in experimental plots. Acrida 6: 231–237.

Quinn, M. A.; Kepner, R. L.; Walgenbach, D. D.; Bohls, R. A.; Pooler, P. D.; Foster, R. N.; Reuter, K. C.; Swain, J. L. 1989. Immediate and 2nd-year effects of insecticidal spray and bait treatments on populations of rangeland grasshoppers. Canadian Entomologist 121: 589–602.

II.15 Comparison of Single and Multiple Applications of Bran Bait

Mark A. Quinn, R. Nelson Foster, and K. C. Reuter

Introduction

Insecticidal baits generally kill 30 to 70 percent of all rangeland grasshoppers (Quinn et al. 1989, Ewen 1990, Jech et al. 1993). Several factors influence the overall effectiveness of insecticidal baits. These include (1) the species composition of grasshoppers in the treated area, (2) total density of grasshoppers, and (3) the amount of bait applied to an area.

For control purposes, communities of grasshoppers can be classified as "bran acceptors" or "bran rejectors" depending on whether or not they consume treated baits (see chapter II.12 on bait acceptance). The larger the proportion of bran acceptors in the community, the greater the level of control by insecticidal baits. In turn, the species composition of grasshoppers is determined partly by vegetation. For example, some mixed-grass communities dominated by grasses will harbor a greater proportion of bran-rejector species than communities with abundant forbs (Quinn et al. 1991).

The effectiveness of insecticidal baits also depends on the density of grasshoppers in an area. Because insecticidal baits generally cause less mortality than sprays, baits can be ineffective when grasshopper densities are relatively high. For example, an insecticidal bait that causes only 60-percent mortality can reduce grasshopper populations below 10 per square yard only if initial densities are less than 25 per square yard.

There is some evidence that the amount of bait applied to rangeland also can limit the effectiveness of the treatments because much of the bait disappears quickly after application. For example, Mukerji et al. (1981) found that an increase in the amount of dimethoate-treated bran bait from 3.6 to 8 lb/acre caused an increase in mortality. Henry (1975) reported that most bran is consumed within a few hours of application.

In 1989, a 20-acre section of rangeland in the North Dakota Grasshopper Integrated Pest Management Project demonstration area was treated with 2 percent carbaryl bran bait at the rate of 2 lb/acre. After treatment, populations decreased 28 percent, but densities were still quite high at 25.8 grasshoppers/yd^2. After a second treatment of the insecticidal bait, populations declined an additional 47.3 percent. These results suggest that single applications of insecticidal baits at standard dosages may not produce the maximum possible control of grasshoppers because the bait is quickly consumed or lost. Besides grasshoppers, other insects may also compete for the bait. For example, Quinn et al. (1990) found that darkling beetles (Tenebrionidae), a dominant insect group on mixed-grass rangeland, probably consume treated bran bait.

Single and Multiple Applications of Bran Bait—A Case Study

In 1990, Foster et al. (unpubl.) conducted a detailed followup study to their 1989 work to determine if greater control of grasshoppers could be achieved with the application of higher dosages or multiple applications of insecticidal baits. In this study, the investigators applied flaky wheat bran containing carbaryl at 2 percent by weight to 40-acre, mixed-grass rangeland plots in North Dakota. The baits were applied with a Cessna Ag Truck operating at an altitude of 40–60 ft at 115 miles per hour (mi/hour) and equipped with a standard Transland 20244 spreader. Swath widths were 45 ft.

Three sets of plots received a single application of the carbaryl–bran bait at either 1.5, 3, or 4.5 lb/acre. One set of plots was treated with two successive applications of 1.5 lb/acre, and another set was treated with three successive applications of 1.5 lb/acre. The repeated treatments were applied 3 days apart. A final set of plots was left untreated. The six treatments were arranged in a randomized block design with four replicates per treatment. Pretreatment densities were used as the blocking variable. When the initial applications were made June 20–22, about 80 percent of the grasshoppers were in the nymphal stage.

The test showed that high dosages of the carbaryl–bran bait (3 and 4.5 lb/acre) caused greater reductions in grasshoppers after 2 days compared with the 1.5-lb/acre dosage (fig. II.15–1). The highest dosage, 4.5 lb/acre, caused a 48-percent reduction in populations of total grasshoppers after 2 days. Mortality in the single-application plots increased by an additional 7–14 percent after 7 days, perhaps because healthy grasshoppers cannibalized infected individuals.

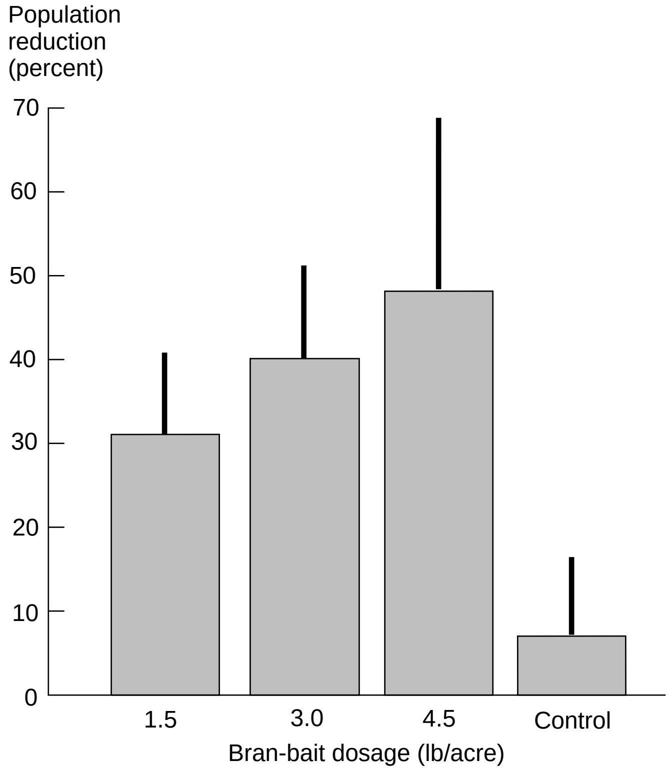


Figure II.15–1—Mean percent reduction in total grasshoppers after 2 days in plots treated with 1.5, 3, and 4.5 lb/acre of bran bait. Sample sizes for the 1.5, 3, 4.5, and control treatments were 12, 4, 4, and 4 plots, respectively. Bars indicate 1 standard error of the mean (SEM).

Successive applications of the insecticidal bait at 1.5 lb/acre caused progressive reductions in total grasshoppers (fig. II.15–2). For example, densities of grasshoppers declined by 52 percent in plots receiving the initial application of the 1.5 lb/acre treatment and declined by another 32 percent after the second application. The third application had no effect on grasshoppers.

Although repeated applications of insecticidal baits or higher dosages increased grasshopper mortality after 2 days, there was no difference in the effects of these treatments compared with a single application of 1.5 lb/acre after 7 days (fig. II.15–3). All treatments caused similar reductions after 7 days, whereas densities did not change in the control plots. Final densities of grasshoppers ranged from 6.3 to 15 per square yard in the treatment plots and were 23.8 per square yard in the control plots.

Uses of Multiple Applications of Insecticidal Baits

Foster et al. (unpubl.) found that multiple applications of 1.5 lb/acre had no real advantage over a single application at 1.5, 3, or 4.5 lb/acre. However, bran baits applied at lower dosages may be quickly consumed by a subset of grasshoppers and other insects, resulting in less control of some grasshopper species. Although there is a general relationship between the amount of bait applied and grasshopper mortality (see the chapter on multiple concentrations and rates of carbaryl–bran bait in this section), more bait is not necessarily better. Lower rates can give adequate control, particularly when grasshopper densities are relatively low (less than 25 per square yard).

Summary

The rather modest degree of overall control achieved by the insecticidal bait treatments in these tests was a result of the species composition of grasshoppers (fig. II.15–3). The presence of a high proportion of bran-rejector species diluted the effect of the treatments on total densities of grasshoppers. For example, treatments had no effect on *Aeropedellus clavatus,* the second most abundant species of grasshopper in the study plots. In contrast, treatments caused up to 96-percent reductions in densities of the most abundant species, *Aulocara elliotti,* a species that is known to consume baits.

An increase in the amount of bait can increase grasshopper mortality slightly, but this added control is not likely to be economical in many situations (see section II.3, “Sprays *versus* Baits”). Under certain conditions, however, it may be useful to increase the dosage of bran bait. For example, higher dosages can be used if the goal is to obtain high levels of grasshopper mortality (greater than 80 percent) in environmentally sensitive areas where insecticidal sprays cannot be used. These sensitive areas may include riparian habitats or sites with endangered plant and animal species.

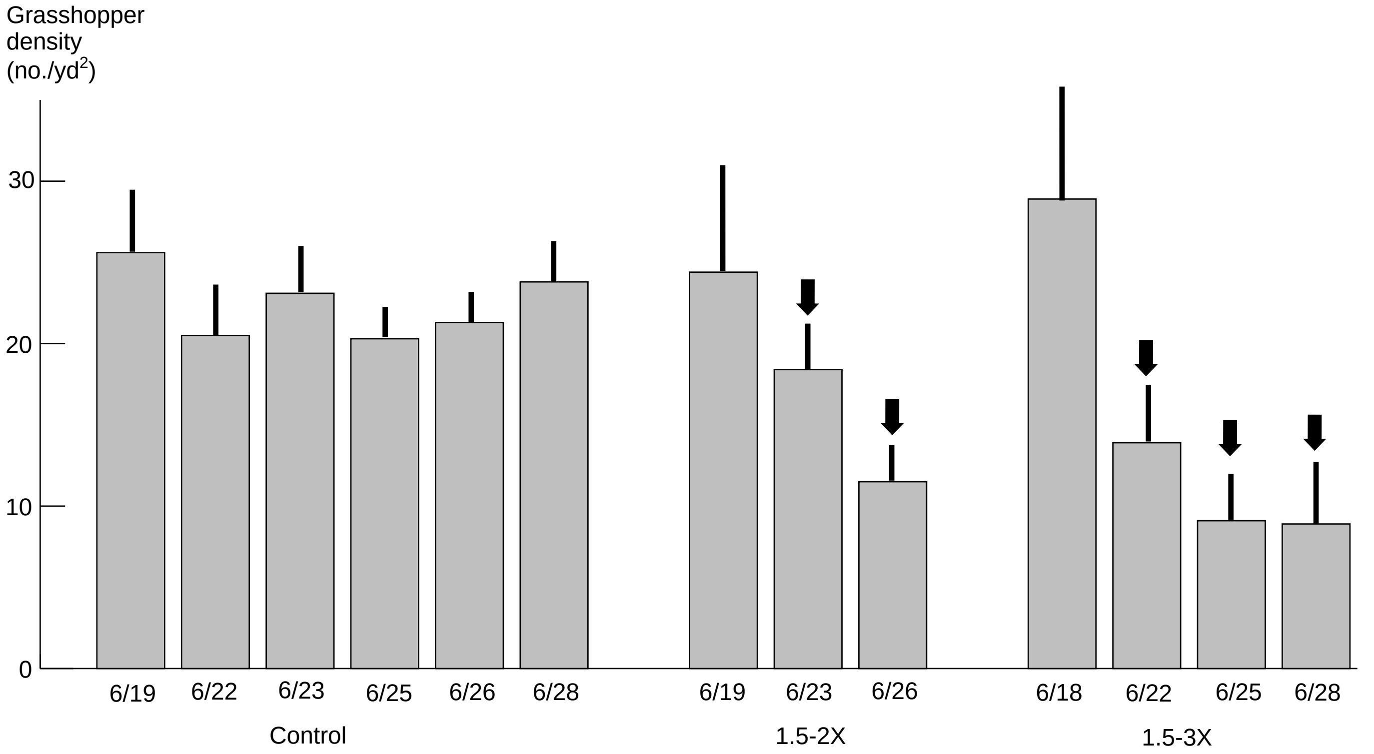


Figure II.15–2—Grasshopper densities (number/yd^2) in plots left untreated (control), treated two times with 1.5 lb/acre (1.5-2X), and treated three times with 1.5 lb/acre (1.5-3X). June 18–19 values represent pretreatment densities. Arrows indicate densities after treatments. Bars indicate 1 SEM.

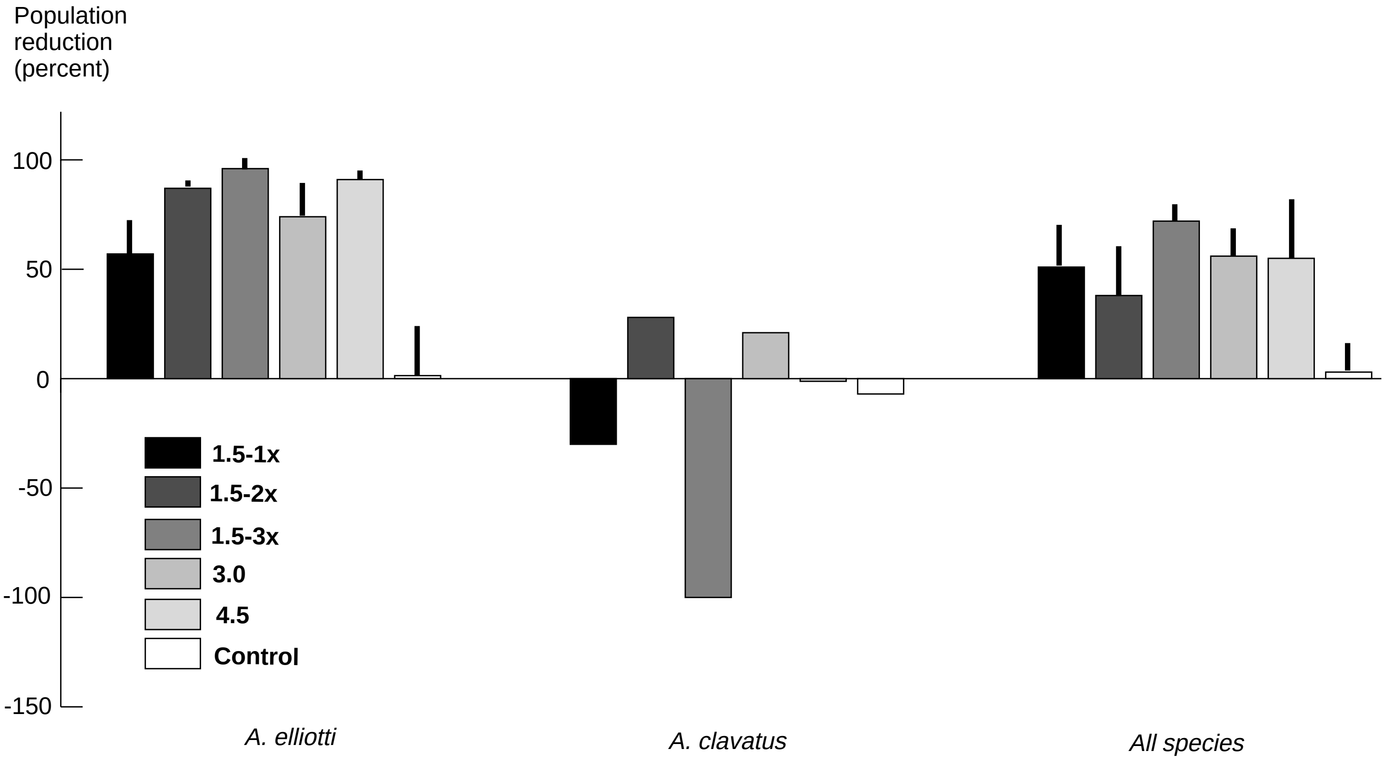


Figure II.15–3—Mean percent reduction in densities of *A. elliotti* (a bran acceptor), *A. clavatus* (a bran rejector), and all species combined, in treatment and control plots 7 days after initial treatments. A negative percent reduction indicates an increase in densities. Bars indicate 1 SEM. Standard errors for *A. clavatus* (not shown) ranged from 18.5 to 165.3.

References Cited

Ewen, A. B. 1990. A synthesis paper on the use of insecticides formulated as baits for grasshopper control in Canada and the USA. Boletin de Sanidad Vegetal (Fuera de series) 20: 83–89.

Henry, J. E. 1975. *Nosema locustae:* an alternative method of grasshopper control. In: Proceedings Advancements in Pesticides. Helena, MT: Montana Department of Health and Environmental Sciences: 16–28.

Jech, L. E.; Foster, R. N.; Colletto, D.; Walgenbach, D. D.; Roland, T. J.; Rodriquez, G. D.; Bohls, R.; Houston, R. D.; Meeks, W. K.; Queener, R. L.; Jackson, C. L.; Dines, J. L.; Puclik, J. L.; Scott, A. K. 1993. Field evaluation of diflubenzuron and carbaryl bran baits against grasshopper (Orthoptera: Acrididae) populations in South Dakota. Journal of Economic Entomology 86: 557–565.

Mukerji, M. K.; Ewen, A. B.; Craig, C. H.; Ford, R. J. 1981. Evaluation of insecticide-treated bran baits for grasshopper control in Saskatchewan (Orthoptera: Acrididae). Canadian Entomologist 113: 705–710.

Quinn, M. A.; Kepner, R. L.; Walgenbach, D. D.; Bohls, R. A.; Pooler, D.; Foster, R. N.; Reuter, K. C.; Swain, J. L. 1989. Immediate and 2nd-year effects of insecticidal spray and bait treatments on populations of rangeland grasshoppers. Canadian Entomologist 121: 589–602.

Quinn, M. A.; Kepner, R. L; Walgenbach, D. D.; Foster, R. N.; Bohls, R. A.; Pooler, P. D.; Reuter, K. C.; Swain, J. L. 1990. Effect of habitat and perturbation on populations and community structure of darkling beetles (Coleoptera: Tenebrionidae) on mixed-grass rangeland. Environmental Entomology 19: 1746–1755.

Quinn, M. A.; Kepner, R. L.; Walgenbach, D. D.; Bohls, R. A.; Pooler, P. D.; Foster, R. N.; Reuter, K. C.; Swain, J. L. 1991. Habitat characteristics and grasshopper community dynamics on mixed-grass rangeland. Canadian Entomologist 123: 89–105.

Reference Cited—Unpublished

Foster, R. N.; Quinn, M. A.; Reuter, K. C.; Jech, L. E.; Colletto, D.; Houston, R.; Puclik, M. J.; Scott, A.; Radsick, B. Comparison of single and multiple applications of carbaryl bran bait for controlling grasshoppers (Orthoptera: Acrididae) on rangeland. Crop Protection (in review).

II.16 Improving the Economics of Grasshopper Bait Application: Efficacy and Swath Comparison of an Experimental and Standard Aircraft Spreader

R. N. Foster, D. D. Walgenbach, J. A. Henderson, G. Rodriguez, L. E. Jech, D. Colletto,
W. Meeks, C. Jackson, J. Patterson, K. C. Reuter, and Mike W. Sampson

Using solid baits, particularly carbaryl–wheat bran bait, for controlling or suppressing grasshoppers on rangeland has gained renewed attention in recent years. During the 1950's, use of bait declined as use of effective small amounts of chemical sprays increased.

Renewed interest in the use of baits was a direct result of improvement in aerial application equipment and the development of calibration procedures that produced consistent results. Increasing concern for the environment and the environmental advantages inherent with baits over many chemical sprays spurred these improvements.

Grasshopper density management studies conducted in North Dakota in the mid-1980's relied on and successfully demonstrated these advances (Foster and Roland 1986). However, narrow swaths produced by the equipment used for aerial application of bait treatments in these studies demonstrated the competitive edge that was still associated with the wider swaths of aerially applied chemical sprays.

The narrow swath, while hindering the wide-scale use of baits from the air, led to the development and production of an experimental aircraft spreader with an improved swath width. Jack Henderson and the New Mexico State University designed and produced an improved spreader and incorporated further modifications during the late 1980's.

Field Studies

As part of the Grasshopper Integrated Pest Management (GHIPM) Project, we carried out field studies that looked at swath width, uniformity of bran flakes within the swath, and resulting efficacy of dispersed bait for grasshopper suppression on rangeland with the experimental spreader. During the tests, we used a Cessna Ag Husky for all flights with the modified experimental spreader. For studies with the standard spreader, a Transland 20244, a Cessna Ag Truck was equipped to prevent bridging (flow blockage) of the bran in the hopper and to promote uniform application (Foster and Roland 1986). We calibrated both spreaders according to U.S. Department of Agriculture (USDA), Animal and Plant Health Inspection Service (APHIS) guidelines for aerial contractors.

Bait was the D-Bug® Ag (Sidwell Enterprises, Inc., Parker, CO) formulation of carbaryl and wheat bran grasshopper bait containing 2 percent carbaryl by weight. Bait was applied at 1.42 lb/acre for the experimental spreader and at 1.54 lb/acre for the standard (Transland 20244) spreader.

Efficacy in the Field.—There were four treatment blocks of mixed-grass rangeland for each spreader trial. Pilots flew the blocks on July 19, 1989, northeast of Edgemont, SD. Application with the standard spreader was at 127 miles per hour (mi/hour) at an altitude of 50–75 ft with a

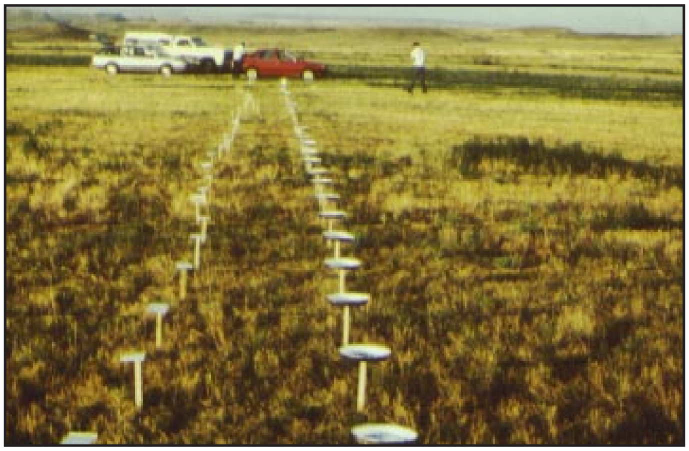


Figure II.16–1—Adhesive card and aluminum pan collection devices used to evaluate swath width and uniformity of application for the aircraft spreaders used in applying bran bait.


Figure II.16–2—Cessna Ag Husky with experimental bran bait spreader.

Figure II.16–3—Commercial Turbine Thrush with Transland 20244 standard spreader.

working swath of 45 ft. Application with the experimental spreader was at 120 mi/h at an altitude of 70–100 ft with a working swath of 100 ft. These swath assignments were based on widths determined in earlier studies with the standard and experimental equipment. When sprays are used, these aircraft are assigned working swaths of 75–100 ft depending on the type of formulations (USDA, APHIS 1994).

We measured grasshopper densities before and after treatment using 40 0.1-m^2 rings developed by Onsager and Henry (1977). Grasshopper densities from four untreated plots were used for comparison to determine natural change in the grasshopper population during the study and for comparison to treated populations. Posttreatment population levels were compared with pretreatment levels to determine the effectiveness of the bait to reduce grasshopper populations as dispersed by both spreaders.

Comparison of Swaths.—Another set of trials compared the uniformity and widths of swaths of the standard and experimental spreaders. Adhesive cards (unfolded sticky pink bollworm traps) (Foster et al. 1977) and aluminum cake pans collected particles of bran bait dispensed during the test flights. The total number of particles collected for each card or pan was converted to particles of bait per square foot to determine the uniformity of the swath, overall swath width, and effective or working swath width. Flights for these trials occurred on July 20, 1989, at an altitude of 30 ft. This altitude was chosen because the investigators were looking for information that might also be of use if bait were used on crops in the future. Applications on cropland typically occur at lower altitudes than on rangeland. Other flights at higher altitudes were studied to determine the effect of altitude on the uniformity of bait within the swath.

Among organizations or individuals who deal with aircraft applications, there is no widely accepted specific method or criteria for assigning operational swath widths. In this study we defined “effective swath width” as the width where collection devices captured at least 73 percent of the number of bran flakes expected per square foot. Extraordinary reductions in the rate of bran deposited took place when less than 73 percent of the expected rate actually did fall to the ground.

Results.—Pretreatment grasshopper densities ranged from 11.8 to 25 per square meter and averaged 20.2 grasshoppers/m^2 in the experimental spreader plots. In the standard spreader plots, grasshoppers ranged from 18.8 to 42.5 per square meter and averaged 27. Grasshoppers in the untreated check plots ranged from 20.3 to 29 and averaged 24.5 per square meter. The grasshopper density in the untreated check plots decreased .01 percent per day during the course of the study because of natural mortality.

At 24 and 48 hours after treatment, trials with both spreaders resulted in reducing grasshoppers below the general 1989 APHIS action level in 1989 of 8 per square yard (9.6 per square meter). There was no significant difference in grasshopper mortality between the spreaders (table II.16–1).

When compared to the standard spreader at an application altitude of 30 ft, the experimental spreader provided a significantly wider swath. Both the pan and adhesive-card particle collectors showed increases in overall and effective swath width (table II.16–2).

The experimental spreader showed an increase of between 125 and 132 percent for overall swath width and between 113 and 140 percent for effective swath width. Such significant increases strongly suggest that using the experimental spreader would make the choice of bait control more cost effective.

Table II.16–1—Efficacy of 2% carbaryl bran bait on grasshoppers when aerially applied with a standard Transland spreader and an experimental spreader near Edgemont, SD, 1989 (replicated 40-acre blocks)

Spreader	Application rate	Mean percent control at indicated interval after treatment[1] 2 days	4 days
	(Lb/acre)	*(Percent)*	
Experimental	1.42	39.4a	54.7a
Standard	1.54	41.7a	57.4a

[1] Adjusted for untreated check. Means followed by the same letter in a column do not differ significantly at the 5% level of confidence (Duncan's new multiple-range test).

Table II.16–2—Mean[1] swaths (overall and visual effective) of experimental and standard dry-material aircraft spreaders with aluminum pan and adhesive card collection devices (flown at 30-ft altitude)

	Swaths			
	Overall		Effective	
Spreader	Pan	Card	Pan	Card
		(Ft)		
Standard	60b	50b	35b	39b
Experimental	135a	116a	84a	85a

[1] Means in a column followed by the same letter do not differ significantly at the 5% confidence level (Mann–Whitney test).

The standard spreader demonstrated greater uniformity of bran bait particles at 30 ft within the effective swath than did the experimental spreader. At higher altitudes, the experimental spreader showed an increase in uniformity. This increase points to the need for more study that could show additional improvements in bait economics.

Key Findings and Conclusions

- Spreaders can be built that work with swaths equal to those used for liquid applications.

- The experimental spreader produced a working swath 2.2 to 2.4 times that of the standard spreader from an application altitude of 30 ft.

- Adhesive-card particle collectors accounted for a greater number of particles per square foot than did pan collectors. Cards also are more convenient to use.

- At an application altitude of 30 ft, the standard spreader gave greater uniformity of bran bait deposited than did the experimental spreader. With minimal improvement, the experimental spreader could offer increased uniformity.

- Using the experimental spreader at higher altitudes improved uniformity of depositing bait and may increase swath widths.

- Both spreaders performed equally well in terms of rangeland grasshopper control with baits.

- The experimental spreader was efficient and was an economical improvement compared to the standard spreader.

For More Information

A detailed report on the comparison of a standard and experimental aircraft spreader for bran bait is available from the USDA, APHIS, Methods Development Center, 4125 E. Broadway Road, Phoenix, AZ 85040. The report includes data on grasshopper species composition before and after treatment, grasshopper collection procedures, and techniques for determining density, swath overlap, particle-count data, and effects of aircraft altitude on bait coverage.

Selected References

Foster, R. N.; Roland, T. J. 1986. Grasshopper suppression: techniques for ultra low volume applications of carbaryl wheat bran baits. Bismarck, ND: North Dakota Cooperative Extension Service, North Dakota Agricultural Experiment Station, North Dakota Department of Agriculture: 68–73.

Foster, R. N.; Staten. R. T.; Miller, E. 1977. Evaluation of traps for pink bollworm. Journal of Economic Entomology 70: 289–291.

Onsager, J. A.; Henry, J. H. 1977. A method for estimating the density of rangeland grasshoppers (Orthoptera: Acrididae) in experimental plots. Acrida 6: 231–277.

USDA, APHIS. 1994. Prospectus No. 73-M-APHIS-94 for aerial application.

Selected Reference—Unpublished

Foster, R. N;, Walgenbach, D. D.; Henderson, J. A.; Rodriguez, G.; Jech, L. E.; Colletto, D.; Meeks, W.; Jackson, C.; Patterson, J.; Reuter, K. C. 1990. Improving the economics of grasshopper bait application: efficacy and swath comparison of an experimental and standard aircraft spreader. In: Cooperative Grasshopper Integrated Pest Management Project, 1989 annual report. Boise, ID: U.S. Department of Agriculture, Animal and Plant Health Inspection Service: 173–183.

II.17 Efficacy of an Extended Swath With Carbaryl–Bran Bait

K. Christian Reuter, R. Nelson Foster, and Wendal J. Cushing

During 1992 and 1993, the U.S. Department of Agriculture's Animal and Plant Health Inspection Service (APHIS) conducted two separate studies each year, aerially treating separate rangeland areas with 2 percent carbaryl–bran bait at the rate of 1.5 lb/acre. In each study, a 45-ft application swath was compared to a 90-ft swath. APHIS attempted to create a 90-ft swath by increasing the aircraft's application height from 75 ft to 150 ft. Accordingly, the bait flow rate was increased to a level that maintained an application rate of 1.5 lb/acre. In theory, these adjustments would result in an increased swath (of the drifting bran bait), reducing the number of passes required by the aircraft to treat the acreage.

In 1992, APHIS applied bran bait at two sites in the Grasshopper Integrated Pest Management Project demonstration area in McKenzie County, ND. The treatment areas were approximately 1,085 acres with the 45-ft swath and 1,500 acres with the planned 90-ft swath in a location designated as the "Mead area." APHIS also treated about 1,740 acres with the 45-ft swath and about 1,753 acres with the planned 90-ft swath in a location designated as the "Crighton area." Ring counts and sweep-net samples at 10 sites in each of the treated and untreated areas were used to find grasshopper densities and species composition (see chapter II.2).

Mortalities resulting from the two swaths were not statistically different in the Mead area except at 4 days after treatment, where the 90-ft swath was superior. Results in the Crighton area showed that the 90-ft swath was statistically superior each time.

Upon examining the grasshopper species composition in the treatment areas, we noted that with the 45-ft swath in the Crighton area the dominant species was *Phlibostroma quadrimaculatum* at 24 percent of the pretreatment population. In the area treated with the 90-ft swath, this species accounted for only 9 percent of the pretreatment population. *P. quadrimaculatum* generally is a poor candidate for bran bait treatment as mortality is usually less than 25 percent (see chapter II.12 on bait acceptance). The higher proportion of a grasshopper species that does not readily eat bait in the 45-ft swath area may explain why the 90-ft swath consistently looked superior in the Crighton area.

In 1993, APHIS again applied bran bait at two sites in the demonstration area in McKenzie County. We treated 401 acres with the 45-ft swath and 408 acres with the 90-ft swath in a location designated as the "Corral Creek area." Also, we treated 422 acres and 425 acres with the 45-ft and 90-ft swaths, respectively, in a location designated as the "Wolf Coulee area."

Field personnel used ring counts and sweep-net samples at 10 sites in each of the treated and untreated areas to figure grasshopper densities and species composition. In both study areas, we found no statistical differences between the 45-ft and 90-ft swath at any time. In these studies, grasshopper species composition was very consistent between the treatment areas, containing dominant species that are susceptible to bait treatments.

These studies suggest the possibility to reduce aerial application costs with carbaryl–bran bait by increasing the application height and the bait flow rate to achieve an extended swath. It is certain that we did not get uniform coverage over the entire 90-ft swath. Visual observations in 1992 and 1993 showed the increased flight height only slightly widened the swath, and the bait did not cover the entire 90 ft. The data imply that, although the coverage was not uniform, the untreated gaps between swaths were compensated for by movement of grasshoppers to find sufficient particles of bait. Under different circumstances, gaps in bait coverage may or may not result in mortality equivalent to a uniformly covered application.

II.18 Equipment Modification, Swath Width Determination, and Calibration for Aerial Application of Bran Bait With Single-Engine Fixed-Wing Aircraft

R. N. Foster and T. J. Roland

Under certain conditions, bran bait is the best choice for controlling grasshoppers. Bait is commonly applied by ground equipment, but in many cases, rough terrain and/or extensive acreage make application by air necessary. Until recently, the acceptance of aerial application of bran bait has been hindered by the common occurrence of nonuniform application and the difficulty in calibrating the equipment accurately. Both problems are caused by uneven flow of bait from the hopper of the aircraft to the spreader.

This uneven flow usually results from what is commonly referred to as "bridging"—the formation of both a cavity in the lower portion of the bait load and an overlying bridge of bait. As bait flows from the bottom of the hopper to the spreader, the load in the hopper settles. Because the particles of bait are flat, they tend to overlap, layer, and lock together to form a bridge. That portion of the bait load that does not lock together flows to the spreader and is applied and leaves a cavity under the bridge. If the overlying bridge does not break and fall before all of the lower bait is applied, continuous flow of bait will be interrupted and nonuniform application will result.

Over several years, Foster and Roland (1986) solved these problems and demonstrated that bridging can be prevented so uniform aerial application is feasible. Nonuniform flow of bait can be detected by observation from the ground. If during application the observer watches the tips of the spreader and notices puffing or uneven flow of bran, bridging is probably occurring. This chapter will detail the required equipment modifications and procedures for establishing swath widths and consistent calibration and will identify potential problems commonly encountered during calibration and aerial application of bran baits.

Equipment Fabrication and Modification

Aerial application of bait requires the use of what are commonly called granular spreaders. These spreaders are used for aerial application of dry solid materials, such as fertilizers, herbicides, and seeds. Several different spreaders are available commercially, and some acceptable homemade types undoubtedly exist. To ensure a uniform application, each type of spreader must be evaluated with the type of aircraft on which it will be used. To date, the U.S. Department of Agriculture (USDA), Animal and Plant Health Inspection Service (APHIS) has evaluated and approved several aircraft and spreaders for aerial application of bran baits (table II.18–1).

Uniform flow of dry bait is a function of several factors, including the slope of the aircraft hopper, the physical shape (flatness) of the bait particles, the size of the opening of the gate seal assembly through which the bran is released from the hopper of the aircraft into the spreader, and the small amount of bait per acre that is usually desired for delivery. All of these factors contribute to bridging, which prevents a consistent and uniform flow of bait from the aircraft hopper to the spreader.

Three inexpensive, simple additions and modifications to the aircraft are required to ensure uniform delivery of bait. A ram air agitation system—consisting of a ram air tube, air agitation tube, and a vent tube air regulator—must be adapted to the aircraft.

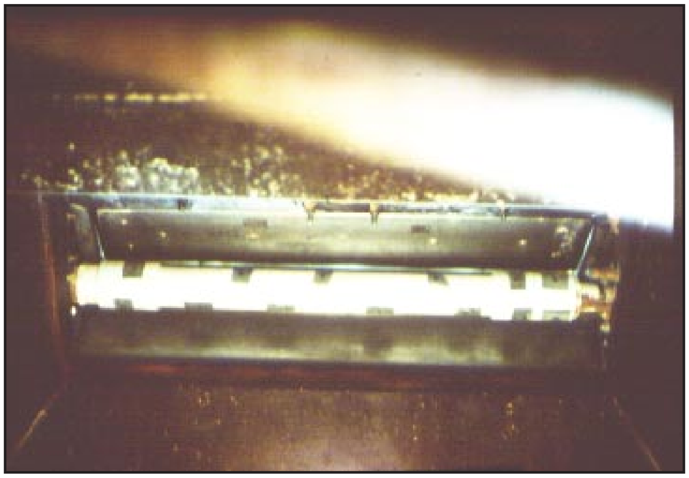
Air Agitation Tube

This tube directs air forced from the ram air tube to the inside lower area of the hopper. The moving air is forced up toward the bottom of the bait load and agitates the bait particles to prevent bridging. In addition, the air mixes with the bait particles to allow a uniform flow of material to the spreader.

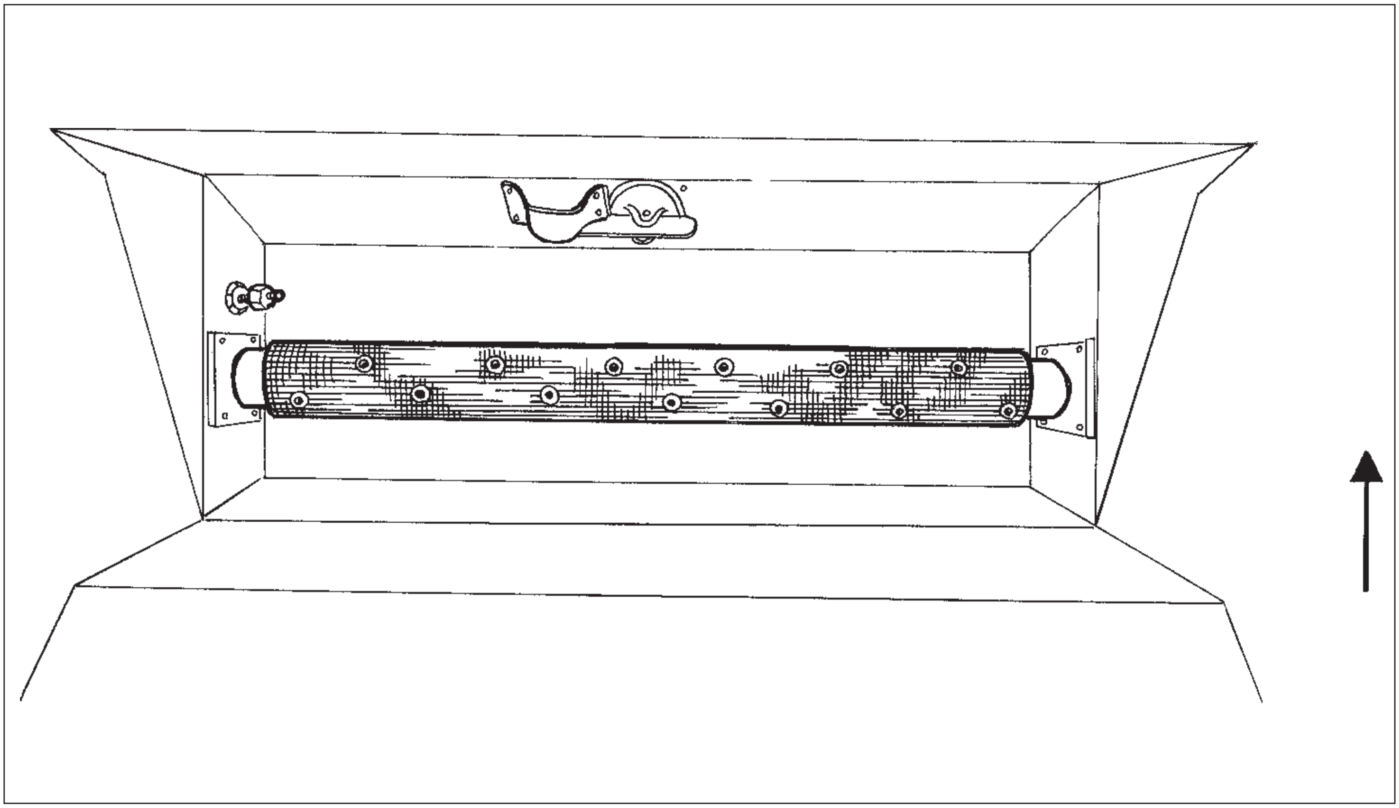
Table II.18–1—Aircraft/spreader combinations that have been certified and swath widths assigned for applying wheat bran bait

Aircraft make/model	Spreader make/model	Altitude	Swath
		(Ft)	
Cessna 188	Transland 20241/20244	50	45
Turbine Thrush	Transland 20250	50	45
Bull Thrush	Transland 22007	100	100

The air agitation tube can be built using Federal Aviation Administration-approved pipe and fittings. The pipe size shall have an inside diameter 1 to 1.5 in and shall be installed across the entire width of the hopper throat just above the gate opening (figs. II.18–1 and –2). A series of $^1/_4$-inch-diameter, equally spaced holes is drilled across the upper side of the pipe and alternately angled to direct airflow to the fore and aft lower portion of the hopper walls. The number of holes can vary, but their accumulated area must not exceed 75 percent of the pipe's inside diameter area. Therefore, a 1-inch-diameter pipe should not have more than 12 holes, and a 1.5-inch pipe should not have more than 27 holes. All $^1/_4$-inch holes are covered with window screen to prevent the entry of material into the air agitation tube.



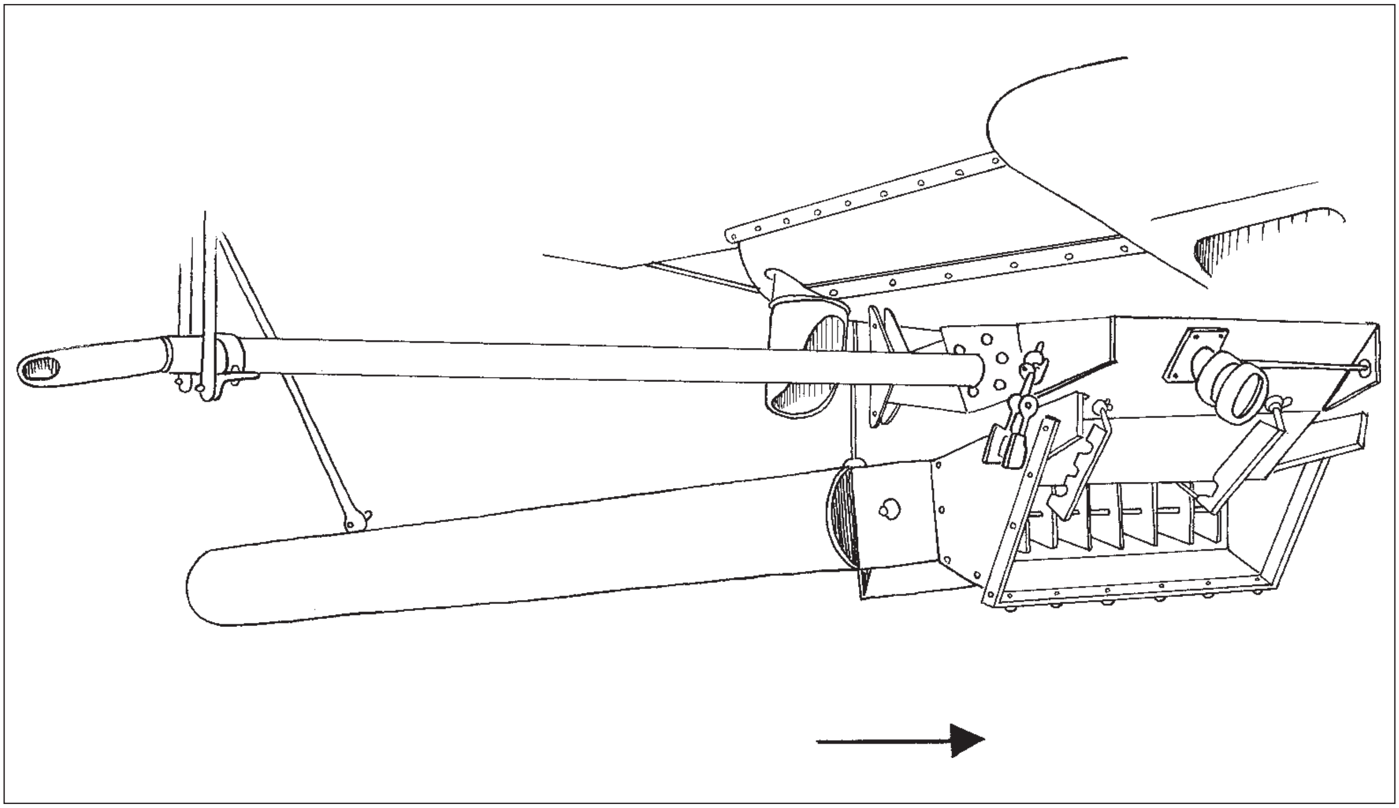
Figures II.18–1 and –2—Air agitation tube installed across entire width of the aircraft hopper throat just above the gate opening.



Ram Air Tube

This tube collects and directs forced air from outside the aircraft into the air agitation tube located in the bottom of the aircraft hopper. This supply of forced air can be provided in one of two ways.

1. Insert a pipe through the side opening of the hopper subtank with the spray valve removed and position the open end forward at approximately a 45-degree angle to the slipstream to allow for uninterrupted ram air during flight. The opposite end of the air agitation tube inside the hopper must be tightly sealed (figs. II.18–3 through –5).



Figures II.18–3 and –4—Ram air tube fastened to underside of aircraft provides forced air during flight to the air agitation tube.

2. Install a pipe tee at the proper location in the agitation tube and insert a pipe through the opening that supplies the pump for spray operations. Position the open end forward to allow for uninterrupted ram air during flight (fig. II.18–6). When this modification is used, the ends of the air agitation tube inside the hopper must be tightly sealed (fig. II.18–7).

Figure II.18–5—Ram air tube and air agitation tube before installation on aircraft.

Figure II.18–6—Front-mounted ram air tube for providing forced air to the air agitation tube during flight.

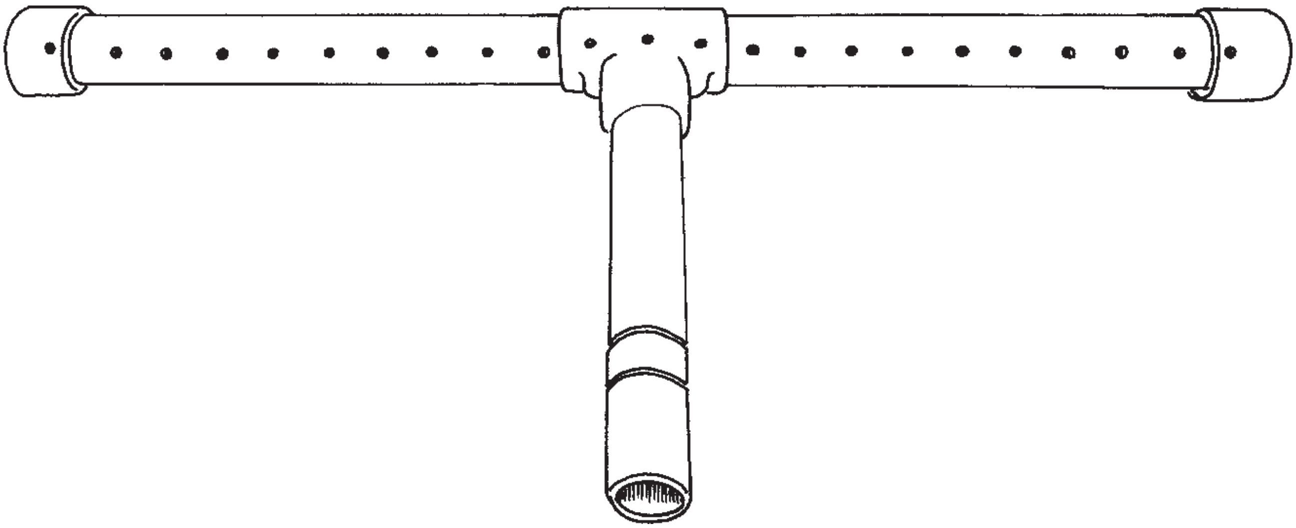


Figure II.18–7—Air agitation tube with both ends sealed when used with front-mounted ram air modification.

Vent Tube Airflow Regulator

The existing hopper vent tube can be modified easily to function as a flow regulator for the bait. The flow regulator works on the same principle as two holes in the top of an oil-can. When fluid is poured out of one hole, the opposite hole serves to prevent a vacuum from building up in the can. In the aircraft system, the hopper opening is similar to the pour hole in an oil-can. The vent tube is similar to the second hole in the oil-can. By simply restricting the amount of air that is allowed to enter the hopper vent tube, one can reduce the speed that bran is delivered through a fixed hopper-gate opening. Very minor changes in the amount of air allowed into the vent tube can cause major changes in the amount of bait delivered.

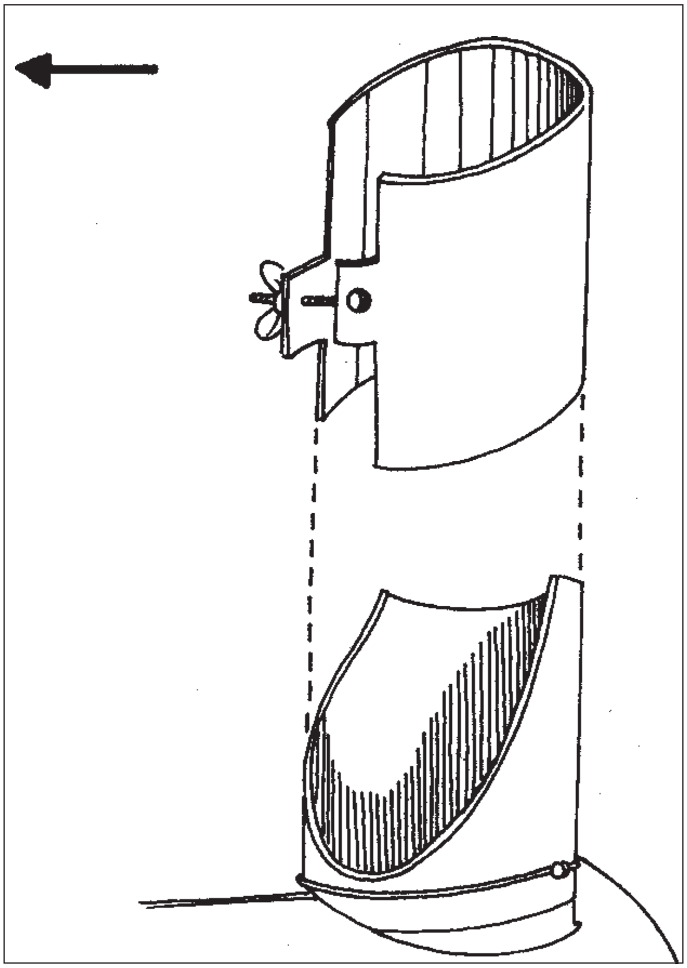


Figure II.18–8—A vent tube flow regulator fashioned from sheet metal is used to adjust the air flow through the vent tube to the aircraft hopper.

A sheet metal sleeve is fashioned and attached to the vent tube to allow adjusting the airflow through the vent tube to the aircraft hopper (fig. II.18–8). Other materials or duct tape can be used to produce similar results.

Other Requirements

The aircraft hopper-gate seal must be clean, dry (not sticky), and in good condition across its entire length to prevent an accumulation of material along the seal and edge of the gate when it is opened. An accumulation of bait on the gate seal can prevent uniform distribution into the spreader and, in some cases, can even promote bridging in the hopper. Linkage between the gate and its cockpit control handle must be in good condition or the gate may not stop in the same position each time it is opened. Gate stops are also required to ensure that the hopper gate is opened to exactly the same position each time. Screw-type stops are preferred.

Seal all openings where the ram air tube enters the subtank of the hopper. Doing this prevents leakage of bait from the aircraft and ensures a sufficient and constant amount of air entering the air agitation tube.

Remove all mechanical agitation components, nonstructured baffles, and other nonstructured obstructions from the hopper interior. Any unnecessary object can act as an anchor for the buildup of bait and thus promote bridging.

If present, the side-loader flapper valve inside the hopper should be sealed and covered to reduce protrusions. Doing that prevents dry material from entering the system when used for liquid application. Covering all protrusions reduces the chance of material buildup, which can promote bridging. The hopper interior must be thoroughly clean and dry to prevent the buildup of bait.

Determining Swath Width

The swath width for both liquid and dry bait applications will differ among types of aircraft. With baits, different types of spreaders on the same type of aircraft can produce different swath widths. Other differences among the aircraft, such as landing gear configuration, automatic flagman equipment, and weight, may also result in different swath widths.

Any combination of aircraft, spreader, and spreader attachments that has not been previously evaluated for swath widths must be characterized. (That is, a detailed study of the uniformity of particle deposition must be made.)

The hopper interior must be completely dry before loading the bait. A proven technique for ensuring this is to fly the aircraft for several minutes with the hopper empty and the hopper gate open.

Load a sufficient amount of bran bait into the hopper to conduct swath evaluations. For determining the swath width, the rate of bait flow (application rate) is unimportant as long as bait being dispensed by the aircraft can be seen in the air by observers from the ground. The hopper gate opening should be set wide enough to make certain that bridging is not occurring. A setting that allows for a gate opening of $^1/_4$ inch or more is usually sufficient.

Conduct swath evaluations in a relatively flat area free of obstructions. Collection devices, such as pans, paper plates, or sticky cards, should be placed in a line 200 ft long perpendicular to the planned flightline. Place collection devices at 5-ft intervals along the line.

Conduct all flights to determine swath widths during no-wind conditions or by flying into a wind that does not exceed 5 miles per hour (mi/hour). The aircraft must be in level flight and at the proper operating speed and altitude for at least 1,000 ft before reaching collection devices. To ensure that bait will hit the collection devices, open the hopper gate at 500 ft before reaching the collectors and leave it open until the aircraft has passed the devices by 1,500 ft.

After each flight, inspect all collection devices and count and record the number of particles in each device. The overall swath width is the distance between the extreme collection devices that caught at least 1 particle of bait. Collection devices in the middle portion of the overall swath will contain many more particles than the devices on either end.

In many cases, the overall swath width ends abruptly on either end and is very obvious. The effective or working swath width (overall swath width minus 10 ft) is the swath width that will be used in the calculations for calibration and during the actual application. The difference between the effective swath and the overall swath is the amount of overlap that will occur during application. Where abrupt ends are not obvious, calculate the average number of particles in the heaviest portion of the swath. For the amount of material being applied on a particular test flight, the average number is the desired amount of material that should be reaching the target. Working toward the extremes of the overall swath, the points are marked at which you find about half of the average number of particles. The distance between these two points is the usable working swath width. At least three good swath-width test flights are recommended.

Calibration

Calibration is simply comparing the amount of material that was applied to a given area for a given period of time during a test flight with what is desired to be applied to that area. Make adjustments in the system until agreement is reached. The wheat bran calibration worksheet at the end of this chapter will be helpful in determining calibration.

After determining the swath width and the groundspeed of the aircraft, determine the number of acres that will be treated in a minute. To do this, multiply the groundspeed times the swath width and divide by 495 (a constant). For example, 120 mi/hour times an 80 ft-swath divided by 495 equals 19.39 acres/min (table II.18–2). By multiplying the acres per minute times the amount of bait desired per acre, you can determine the amount of bait that should be applied in 1 minute. For example, if 1.5 lb of bait per acre is desired, then from the above example, 1.5 lb times 19.39 acres/minute equals 29.09 lb of bait, the amount that should be applied in 1 minute.

For the first flight, the gate opening should be set at $^1/_4$ inch. The shank of a $^1/_4$-inch drill bit can be used as a gauge. You will need an apparatus to drain and recover wheat bran from the aircraft hopper and a scale to weigh the bait. Weigh the bait to be loaded into the aircraft. Actual weight may vary slightly from that printed on the

Table II.18–2—Matrix to determine the number of acres treated per minute

Flying speed	Working swath width (ft)								
	50	55	60	65	70	75	80	90	100
Mi/hour	*Acres/min*								
75	7.58	8.33	9.09	9.85	10.61	11.36	12.12	13.64	15.15
80	8.08	8.89	9.70	10.51	11.31	12.12	12.93	14.54	16.16
85	8.59	9.44	10.30	11.16	12.02	12.88	13.74	15.45	17.17
90	9.09	10.00	10.91	11.82	12.73	13.64	14.55	16.36	18.18
95	9.60	10.56	11.52	12.47	13.43	14.39	15.35	17.27	19.19
100	10.10	11.11	12.12	13.13	14.14	15.15	16.16	18.18	20.20
110	11.11	12.22	13.33	14.44	15.56	16.67	17.78	20.00	22.22
120	12.12	13.33	14.55	15.76	16.97	18.18	19.39	21.82	24.24
130	13.13	14.44	15.76	17.07	18.36	19.70	21.01	23.64	26.26
140	14.14	15.56	16.97	18.38	19.80	21.21	22.63	25.45	28.28
150	15.15	16.67	18.18	19.70	21.21	22.73	24.24	27.27	30.30

Note: If the above table does not list the swath width or speed, use the following formula to determine acres per minute:

$$\frac{\text{Aircraft groundspeed (mi/hour)} \times \text{Swath width (ft)}}{\text{495 (a constant)}} = \text{Acres per minute}$$

bag. Use the actual measured weight. Load the hopper with approximately 50 lb of bait plus the amount of bait to be applied in 1 minute to ensure that you will not run out of bait during the calibration flight. If there is no bait left in the hopper after a flight, overapplication was occurring; appropriate adjustments must be made, and the flight must be repeated.

Make all calibration flights crosswind and dispense bait for 1 minute. Flying upwind will increase the rate of application, and flying downwind will decrease the rate of application. Use a stopwatch to determine the exact amount of time the hopper gate is open. Timing devices attached to the application system may increase the accuracy.

After the first calibration flight, drain and weigh all bait remaining in the hopper. Make sure bait that may have fallen into the spreader during draining is included. Subtract this weight from the weight loaded. Compare the amount of bait applied to what was desired to be applied. If the application rate per minute is below the desired rate, increase the gate opening and conduct another calibration flight.

If the application rate per minute exceeded the desired rate, do not change the gate opening. Cover about half of the hopper air vent. Use the fabricated airflow regulator or duct tape. Reducing or enlarging the vent opening changes the internal pressure in the hopper, decreasing or increasing the flow rate, respectively. Make a second calibration flight.

If after the second flight the flow per minute still exceeds the desired rate, further reduce the vent opening and conduct another calibration flight. Do this until the application rate equals the desired rate. Calibration accuracy should be within 10 percent of the desired rate. A minimum of five consecutive acceptable calibration flights at the same settings will assure accurate application.

Safety and Storage

Before initiating a treatment for grasshoppers or Mormon crickets with wheat bran bait, always read the label carefully. Keep wheat bran bait dry during storage in enclosed buildings, trailers, or vans to eliminate the risk of the bait's becoming unusable. Also, keep bait in a cool location. Hot storage for long periods of time may cause the bait to become rancid and reduce its effectiveness. Dispose of empty bags or containers according to State and Federal regulations printed on the label.

Potential Problems

The following lists identify some of the problems most commonly seen to occur with calibration and application of wheat bran baits.

Equipment
- Improper or no modifications or fabrication.
- Nonstructural hopper baffles not removed.
- Airholes not covered with screen on agitation tube.
- Hopper gate seal not clean and dry.
- Side-loader flapper valve inside hopper not sealed.
- Air and agitation tube connection and alignment not proper.
- Loose gate linkage.
- Gate-setting stop not in place.
- Gate-setting screw jack moves.
- Hopper doors not covered during rain.

Material
- Lumps in bait from commercial formulation.
- Strings and/or paper in bait from the container or bag.
- Rocks, pebbles, or other objects in bait.
- Clumped bait due to moisture.
- Weight printed on bag or container inaccurate.
- Different types of bran or bran sources.
- Different formulations of bait.

Methodology
- Failure to follow guidelines.
- Failure to open hopper gate firmly and consistently.
- Inaccurate weighing during calibration and application.
- Failure to read scales accurately.
- Bait left in throat of spreader when weighing during calibration.
- Bait left in hopper when weighing during calibration.
- Calibration loads inconsistent in weight.
- Unlevel load during calibration flights.
- Calibration runs not conducted crosswind.

Weather Conditions
- Damp or wet hopper due to condensation or rain.
- Calibration may change due to large humidity changes.

Conclusion

Accurate aerial application of wheat bran bait is no more difficult than applying chemical sprays. The problems associated with accurate calibration and consistent application of bran bait by air have been identified. Solutions to the problems and procedures for implementing the solutions have been developed and refined. Both solutions and procedures are inexpensive. With experience, accurate calibration and application of bran bait by air can now be expected.

Acknowledgments

The authors wish to thank Jack Henderson, retired USDA/APHIS chief pilot, whose early work and suggestions with baits were instrumental in arriving at the final design for ram and air agitation tubes. The authors are also indebted to Tim Lockley, USDA/APHIS, for illustrations used.

References

Foster, R. N.; Roland, T. J. 1986. Grasshopper suppression: techniques for ultra low volume applications of carbaryl wheat bran baits. Bismarck, ND: North Dakota Cooperative Extension Service, North Dakota Agricultural Experiment Station, North Dakota Department of Agriculture: 68–73.

USDA, APHIS, 1994. Prospectus No. 73-M-APHIS-94 for aerial application. Phoenix Methods Development Center. Phoenix, AZ.

Wheat Bran Calibration Worksheet

Date ______________________________

Pilot ______________________________

Aircraft make/model ______________________________

Spreader make/model ______________________________

Aircraft speed (mi/hour) ______________________________

Assigned swath (ft) ______________________________

Material applied ______________________________

Desired rate per acre (lb) ______________________________

Desired rate per minute (lb) ______________________________

Acceptable range per minute (plus or minus 10 percent of desired)

Minimum _____________ lb

Maximum _____________ lb

Calibration Formula

(Speed _______ mi/hour × swath _______ ft) divided by 495 =
_______ acres per minute

Acres per minute ______ × rate per acre _____ lb =
_______ lb per minute

Calibration Worksheet, 6 replications

Load #____________________
Loaded ____________________ lb
Drained ____________________ lb
Applied ____________________ lb
Time ____________________ seconds
Rate ____________________ lb/acre
Percent ____________________ low–high
Adjustments:

Load #____________________
Loaded ____________________ lb
Drained ____________________ lb
Applied ____________________ lb
Time ____________________ seconds
Rate ____________________ lb/acre
Percent ____________________ low–high
Adjustments:

Load #____________________
Loaded ____________________ lb
Drained ____________________ lb
Applied ____________________ lb
Time ____________________ seconds
Rate ____________________ lb/acre
Percent ____________________ low–high
Adjustments:

Load #____________________
Loaded ____________________ lb
Drained ____________________ lb
Applied ____________________ lb
Time ____________________ seconds
Rate ____________________ lb/acre
Percent ____________________ low–high
Adjustments:

Load #____________________
Loaded ____________________ lb
Drained ____________________ lb
Applied ____________________ lb
Time ____________________ seconds
Rate ____________________ lb/acre
Percent ____________________ low–high
Adjustments:

Load #____________________
Loaded ____________________ lb
Drained ____________________ lb
Applied ____________________ lb
Time ____________________ seconds
Rate ____________________ lb/acre
Percent ____________________ low–high
Adjustments:

II.19 Ground Application of Bran Bait Insecticides

M. A. Boetel, B. W. Fuller, L. E. Jech, and R. N. Foster

Aerial insecticide application methods are most appropriate when extremely rough terrain and/or extensive acreages require treatment. However, smaller, isolated grasshopper outbreaks are often managed more economically using ground application equipment and techniques. A number of different application systems are available for both bran baits and conventional liquid insecticide formulations. For help selecting the appropriate insecticide formulation (liquid *v.* bait) see chapter II.3, "Sprays *versus* Baits."

In a 5-year cooperative effort 1987–91, several private and governmental agencies carried out field testing of bran bait application methods made modifications for improvement, and exposed farmers, ranchers, and Extension personnel in six States to these methods. Participants included Peacock Industries (Canada), the South Dakota Governor's Office of Economic Development, South Dakota State University, and the U.S Department of Agriculture, Animal and Plant Health Inspection Service's Plant Protection and Quarantine (USDA/APHIS/PPQ).

Bait Application Equipment

The Brie-Mar® Applicators Division of Peacock Industries (Saskatoon, SK) has developed three bran bait spreaders (models 10, 30, and 60). These spreaders are equipped with gasoline-powered pneumatic (air-driven) delivery systems that provide uniform flake distribution and can be set to deliver bran at various application rates. The spreaders have noncorrodible bran hoppers, are relatively inexpensive and easily operated, and require minimal maintenance. State and Federal cooperators in Colorado, Minnesota, Montana, North Dakota, South Dakota, and Wyoming have carried out extensive field evaluations of the units.

Model 10.—This unit is a shoulder-mounted backpack system that works well for small jobs, such as roadside ditch and yard or garden uses. It weighs 27 lb, holds 14 lb of bran, and can deliver 1.2 or 3 lb of bran per acre in 20- to 25-ft swaths with the operator walking at 3 miles per hour (mi/hour).

Model 30.—This bran spreader is designed for mounting on an all-terrain vehicle (ATV) or pickup truck, and can be used for bran applications in small and moderate-size grasshopper outbreak areas (isolated hot-spots in rangeland and pasture, roadside ditch areas, row-crop and forage field margins, large lawns, commercial vegetable gardens, and golf courses). This applicator can be used to treat outbreaks in very rough terrain where travel with a tractor or pickup truck may be difficult or impossible. Like the model 10, this system delivers bran flakes in a 20–25-ft swath. Its two-speed feed roll can deliver either 1 or 2 lb of bran per acre at 10 mi/hour, and it is capable of holding up to 45 lb of bran at a time.

Model 60.—This applicator is a larger unit that may be used for a range of different situations. It is designed for moderate-size outbreaks in areas where aerial treatment is not economically practical (roadside ditches, row-crop and forage field margins, and small to moderate acreages of pasture, rangeland, forage, and seedling row crops). Additionally, model 60 is well suited for conditions where the model 30 can be used (provided a pickup truck or tractor can traverse the terrain where applications must be made). This unit allows the operator to apply bran at 0.9, 2.1, 3, and 4 lb/acre in 40- to 45-ft swath widths at 10 mi/hour, and its hopper can hold up to 135 lb of bran flakes. In addition, bran output is turned on and off from within the pickup or tractor cab, and swath direction can easily be switched from right to left by manually moving the output tube. Using two spreaders (each applying in opposite directions) can double the swath width. This technique has been successful in the Grasshopper Integrated Pest Management Project demonstration area in North Dakota.

Bran Bait Applicator Calibration

Effective and economical insecticide applications require careful and accurate equipment calibration, and bran bait treatments are no exception. The following steps are essential for proper calibration of an applicator for broadcasting bran bait insecticide treatments.

1. Determine Swath Width.—Bran-spreader swath width should be measured before each bait application and as conditions (wind velocity and direction, terrain, or the material to be applied) change. Wind velocity is the most critical factor affecting bran-bait swath width, and neither calibration nor bait application should be conducted if winds are in excess of 5 mi/hour. If you are using a pickup- or ATV-mounted applicator

Figure II.19–1—The Brie-Mar bran spreader fits in the back of a pickup truck and will hold up to 135 lb of bran flakes. This spreader can treat up to a 45-ft swath width. (Photos courtesy of Peacock Industries; used by permission.)

(fig. II.19–1), measure swath width while the spreader is actually mounted on the vehicle and preferably under the same conditions that you will experience during bait applications. Swath width measurement and actual bait applications should be done by traveling directly into or against the prevailing wind.

The usual measurement consists of placing collection devices (paper plates work well) at even distances apart (5 ft apart is adequate for ground-operated units) in a grid pattern over a large block (see table II.19–1). The block should be several feet larger than the maximum range specified for the particular applicator model you are using (if using a Brie-Mar unit, refer to the "Bait Application Equipment" segment of this chapter for respective maximum swath width specifications of the different spreader models) to account for wind effects on the swath. If slight breezes exist during swath width assessment, drive a nail through the center of each paper plate and fasten it to the ground. After collection devices are in place, carry out two or three test runs to determine where bran bait distribution drops off (the drop-off point will be fairly abrupt under calm wind conditions). Count and record the bran flakes that land on plates after each test run. These counts will establish the effective bran swath width.

Table II.19–1—Distribution collection devices (paper plates) for bran spreader swath width determination

Row	Plate number									
no.	1	2	3	4	5	6	7	8	9	10
	Number of bran flakes collected									
1	3	5	4	10	8	7	8	4	3	0
2	5	7	11	11	12	6	6	5	5	1
3	4	10	8	9	11	10	7	5	4	1
4	6	9	11	7	7	9	5	6	3	0
5	4	4	12	4	8	10	7	4	4	1
Total	22	35	46	41	46	42	33	24	19	3

Note: Data in the table represent the number of bran flakes collected on individual paper plates (1–10) within rows (1–5). In practice, the spreader should move perpendicular to the direction of the rows.

In this trial run, bran flakes were distributed well between and including plates #1 and #9. Since there is a total of eight 5-ft increments between these plates, the effective swath width of this bran spreader is 8 × 5 = 40 ft.

2. Measure Applicator Delivery Rate.—This process consists of running the applicator in a timed interval at the rate that will be used in the field, collecting bran output, and determining its weight as a function of time. If you are using a Brie-Mar unit, the usual practice involves filling the hopper to about 50 percent full, running the engine at full throttle, turning on the output auger, attaching one nylon pantyhose leg to the bran output tube, and collecting bran output in at least 1-minute intervals. Repeat this step several times to obtain an accurate estimate of output. Weigh samples individually to measure bran output as weight per unit time (an example of output determination appears in table II.19–2).

Table II.19–2—Weight data from five timed (1-minute) samples for estimating bran applicator output per unit time

Sample	Weight (lb)
1	0.682
2	0.655
3	0.590
4	0.724
5	0.671
Total	3.322
Average	3.322 lb/min × 5 = 0.6644

3. Determine Vehicle Speed.—Precise determination of vehicle speed may sound much easier than it is in practice. When traversing rough terrain, most vehicle speedometer needles will bounce a lot and give inaccurate readings. Under such conditions, it may be necessary to install a digital tachometer, travel in a low gear, and establish a tachometer reading to go by rather than the speedometer needle. The appropriate tachometer reading used during bait application should be established in the actual area requiring treatment. First, measure a practice path of a given distance (minimum of 100 ft) for the vehicle to pass. Then, calculate the desired time to cover the practice path. Let’s say that you are trying to apply bran bait at a rate of 1.5 lb/acre. The following calculations will use the 0.6644 lb/min applicator delivery rate derived from the example in step 2 (your delivery rate will be slightly different). The following calculation will tell you how much time it should take to cover 1 acre at the 1.5-lb application rate:

$$\frac{1.5\text{ lb}}{1\text{ acre}} \times \frac{1\text{ minute}}{0.6644\text{ lb}} = \textbf{2.258 minutes}\text{ to cover 1 acre at 1.5 lb bran per acre}$$

The next step involves dividing the area in 1 acre (43,560 ft^2) by the bran applicator's swath width derived from step 1 (40 ft in our illustration). This calculation will provide you with the number of linear feet that you should travel in the time it takes to cover 1 acre (2.258 minutes in our example) while applying bran bait at the desired application rate (1.5 lb/acre in this exercise).

$$\frac{43{,}560\text{ ft}^2}{40\text{ ft}} = \textbf{1,089 linear feet}\text{ should be traveled in 2.258 minutes}$$

Convert the time in minutes to seconds:

$$2.258\text{ minutes} \times \frac{60\text{ seconds}}{1\text{ minute}} = \textbf{135.48 seconds}\text{ to travel 1,089 linear ft}$$

The target time to traverse your 100-ft test path is then calculated using cross-multiplication as follows:

$$\frac{1{,}089\text{ ft}}{135.48\text{ seconds}} = \frac{100\text{ ft}}{X\text{ seconds}}\text{ or, } X = (135.48\text{ seconds} \times 100\text{ ft}) \div 1{,}089\text{ ft}$$

therefore, X = **12.44 seconds** to travel 100 ft

The vehicle speed to target for traveling 100 ft in 12.44 seconds is determined using the following calculation:

$$\frac{100\text{ ft}}{12.44\text{ seconds}} \times \frac{60\text{ seconds}}{1\text{ minute}} = \textbf{482.32 feet per minute}$$

Vehicle speed in ft/minute should be converted to mi/hour, which will provide a rough estimate for a speedometer reading to target when making test runs. A useful conversion factor is that for each 1 mi/hour, a vehicle travels 88 ft/minute. The target speedometer reading is calculated using cross-multiplication:

$$\frac{88\text{ ft/minute}}{1\text{ mi/hour}} = \frac{482.32\text{ ft/minute}}{X\text{ mi/hour}}\text{ or, } X = (482.32\text{ ft/minute} \times 1\text{ mi/hour}) \div 88\text{ ft/minute}$$

therefore, X = **5.48 mi/hour** as a target speedometer reading.

After the targeted time to travel the practice path and target speedometer reading have been calculated, use a stopwatch to time trial passes of the vehicle covering the test path and make adjustments until the desired speed and associated tachometer reading are established. Once these final steps are completed, you are ready to carry out a properly calibrated bran bait insecticide treatment using ground application equipment.

II.20 Alaska's Cooperative Bait Program

Wayne Vandre and Don Quarberg

Situation

Recent agricultural land development in Delta Junction, AK, has created conditions favorable for epidemic outbreaks of grasshoppers where there were few outbreaks before. Cooperative Federal grasshopper control programs in these agricultural areas have not been possible because of a 10-mile no-spray buffer zone around peregrine falcon habitat. In addition, the lack of Environmental Protection Agency (EPA) registration for use of carbaryl on barley, a major cereal crop in the area, hampered individual control efforts.

With the help of the University of Alaska Cooperative Extension Service, agricultural producers in the Delta Junction area turned to integrated pest management (IPM) techniques to control grasshopper outbreaks. Using readily available materials, small-batch mixing equipment, and spreading equipment, farmer cooperatives demonstrated the success of a local IPM philosophy.

Baiting hatching beds with carbaryl-treated wheat bran has been an effective means of controlling grasshopper populations in other States. Wheat is not a common crop grown in Alaska other than for personal use, so wheat bran is not readily available for use in baits. The farmers' cooperative successfully demonstrated that locally grown barley could successfully be substituted for wheat bran as a bait. The owner of the Sevin® registration label, Rhone–Poulenc, has stated (personal communication) that coarse barley millings can be substituted for wheat bran in formulating the carbaryl bait. Thus, the use of locally grown barley allows Alaskan farmers to formulate an effective carbaryl bait economically.

Alaska conducted a cooperatively developed grasshopper baiting trial with the U.S. Department of Agriculture (USDA), Animal and Plant Health Inspection Service (APHIS) and USDA's Agricultural Research Service (ARS), Rhone–Poulenc (carbaryl manufacturer), and the University of Alaska–Fairbanks Cooperative Extension Service. The trial used locally grown cereal grains (dry rolled barley and oats) as bait substrates. USDA/ARS laboratory bait-acceptance trials indicated that Alaskan grasshopper species would eat the barley bait.

A producer cooperative can be especially important in areas of widespread grasshopper infestation where the demand for bait application may exceed capabilities for bait formulation, distribution, and application. The cooperative can play an important role in:

- obtaining carbaryl insecticides and bait substrate material;
- providing equipment for formulating, transporting and applying bait;
- deciding on areas to which the bait is applied; and
- maintaining communication among users, the public, and regulatory agencies.

Producer cooperatives already exist in many rural communities. A board of directors elected from the producer membership governs these coops. The Alaska Farmers Cooperative of Delta Junction is such an organization and served as the bait cooperative in this trial program.

Bait Production

ARS' Rangeland Insects Lab in Bozeman, MT, tested local Alaskan barley and also oat products and found them suitable as a bait substrate. Rhone–Poulenc granted temporary permission to use Alaskan-grown barley as a bait substrate for the trial.

The cooperative obtained a $^1/_4$-yd^3 cement mixer to mix and formulate the bait. Bait batch ingredients included 100 lb of dry rolled barley, mixed with 2 qt each of carbaryl (Sevin 4-Oil®) and diesel oil. This combination produced a 2 percent carbaryl bait formulation. While the cement mixer rotated at approximately 50 revolutions per minute, a 50:50 mix of carbaryl and diesel oil was sprayed into the mixer with a portable sprayer. Using an 80-degree flat fan nozzle operated at approximately 30 lb/in^2, spray operators adjusted the sprayer pressure as high as possible with minimal overspray and misting. A cardboard cover installed over the cement mixer opening reduced spray drift.

A preliminary trial using rolled barley and water colored with red food dye determined mixing time requirements. It took nearly 30 seconds to add the liquid. Three minutes of agitation thoroughly mixed the bait and carbaryl material.

The cooperative mixed bait on an as-needed basis, with surplus bait stored in a cool, dry, signed, and locked storage facility. No bait was stored longer than 48 hours before application. The cooperative rebagged formulated bait in plastic woven sacks, each containing approximately 50 lb. All bags were sewn shut and labeled as "CARBARYL BAIT—CAUTION" with copies of the carbaryl label attached.

The cooperative used Wilmar 500 fertilizer spin-spreaders calibrated with water-treated rolled barley, to decide application rates. A bait application rate of 36 lb/acre, or 0.7 lb/acre of carbaryl, achieved a distribution density of 40 particles/ft^2 of soil surface area. This rate is within the limits specified on the carbaryl label.

Barley particle size and density are variable depending on the adjustment of the roller mill, which processes the bait substrate. Procedures for calibrating spreaders are available at Alaska's Cooperative Extension Service offices and through the State at State Office Fairbanks, Cooperative Extension Service, University of Alaska Fairbanks, Fairbanks, AK 99775-5200, (907) 474-6357.

Training and Certification Program

The Cooperative Extension Service developed a training course for carbaryl bait applicators somewhat similar to the pesticide certification training dministered by the APHIS Plant Protection and Quarantine unit. The 3-hour course addressed the topics of grasshopper life cycles; preferred food and egg-laying site conditions; scouting techniques; deciding economic thresholds; alternative controls; understanding the carbaryl label; personal and environmental safety; formulating, mixing, calibrating, and applying baits; timing and biological conditions affecting the success of baits; and evaluating the effectiveness of the bait.

An exam followed the course. Only those who successfully passed the exam could participate in the baiting program. Agricultural producers and interested participants from the public could take the course.

Evaluation and Results

All persons applying baits submitted information for recordkeeping. A survey questioned bait users about their opinions on weather conditions when the bait was used, length of time the bait remained available and effective, growth stage of treated grasshoppers, effects on nontarget species (other insects and birds), any personal health effects, and if they would use bait again.

According to survey responses, the bait was effective. Grasshoppers readily ate the bait, and the larger bait particles remained effective even after a rainfall. Only one applicator mentioned effects on nontarget species (a decline in ground beetles following bait application). Another reported the successful raising of three robin clutches that fed on treated grasshoppers. There were no reports or observations of adverse effects on human health.

Conclusion and Discussion

The results of this grasshopper control project show that early and effective reductions in grasshopper populations are possible using a formulated carbaryl–barley bait. The reduction or elimination of pesticide spray drift, the selectivity toward pest species, and the relative safety to human and environmental health all support the approval and recommendation of this bait as an effective IPM tool.

Crop damage from grasshoppers is expected in the Delta agricultural area in the future. Federal and State agencies should authorize and encourage further development of bait-application programs. An acceptable plan must be in place well before potential outbreak periods. If not in place, the long delay in organizing the program could result in the return to more conventional pesticide controls, such as aerial spray operations over large tracts of land.

The experience gained through this trial project and input from participants shows that there are certain conditions and/or alternatives for continued use and future success:

- Barley should be included as an approved bait substrate on the label for carbaryl. This substrate is effective and does not incorporate any significant changes when compared to wheat. Local availability and cost are positive factors toward adoption by farmer–applicators in Alaska.

- The manufacturer(s) of carbaryl could request a waiver or deletion of the label requirement for direct supervision by a government official. A category-specific training and certification program approved by EPA and the State regulatory agency, such as Alaska's Department of Environmental Conservation (DEC), could substitute for direct supervision. This training program would ensure that all applicators would become knowledgeable in bait formulation, calibration, and application procedures, and all health and safety issues.

- Another alternative to the direct supervision requirement would be to have the Alaska DEC or other State regulatory agency assume this role through the State-approved certification program. The built-in safety and reduced risk of this baiting program compared to other pesticide spray procedures calls for this procedural change.

- A primary component of all future activities is education. The pesticide applicator training and certification program developed and maintained by the Alaska DEC and the Cooperative Extension Service has proven to be effective in developing applicator competence and reducing or preventing pesticide incidents. The successful start of such a certification and training component in this project would be reviewed and improved to meet all education and regulatory objectives.

Public awareness of pesticide use and misuse in the environment continues to grow. This awareness has resulted in the adoption and use of IPM philosophy and procedures when pest problems arise. The successful development and results of the grasshopper baiting program in the Delta agricultural area have shown that it is possible to develop an effective, low-cost pest management program that reduces health risks to humans and wildlife and is environmentally safe.

II.21 Bran Bait or Liquid Insecticide Treatments for Managing Grasshoppers on Croplands Adjacent to Rangeland or Conservation Reserve Program Acreages

B. W. Fuller, M. A. Catangui, M. A. Boetel, R. N. Foster, T. Wang, D. D. Walgenbach, and A. W. Walz

The principal emphasis of rangeland grasshopper intergrated pest management (IPM) is to protect forage for domesticated animals and wildlife. Row crops (corn, soybeans, small grains) occur intermixed with rangeland in the northern Great Plains. The undisturbed rangeland soils provide highly suitable habitat for grasshoppers to lay eggs, potentially leading to outbreaks of grasshoppers at levels sufficient to cause devastating damage to the rangeland ecosystem. At these times, nearby row-crops may be severely damaged by grasshopper invasion from infested rangelands.

Even in locations that are predominantly dedicated to row-crop farming, grasshopper outbreaks are not uncommon. Grasshopper sources in row-crop areas typically are roadsides, grassed waterways, fencelines, and other field margin areas where soil containing grasshopper egg pods remain undisturbed. Additionally, parks, wildlife refuges, Native American reservations, and Conservation Reserve Program (CRP) acreages can be potential sources of grasshopper hot-spots.

Farmers are advised to treat immature (third-instar) grasshoppers at or near their hatching sites prior to further movements into the perimeter rows of cropland.
Doing so can often alleviate the need to treat an entire row-crop field. Not only does this preventive effort save considerable money over the cost of whole-field treatment, it can greatly reduce potential negative impacts on nontarget organisms (beneficial insects and endangered species).

Choosing the proper treatment and application method are critical considerations to successful grasshopper IPM. For example, in environmentally sensitive areas (wilderness preserves, endangered species habitats, wetlands, and lands adjacent to bodies of water), treatment options may be limited.

Grasshopper IPM Project research has found both benefits and weaknesses associated with ground-applied liquid insecticides and bran bait treatments for control of grasshoppers on row crops near rangeland. Bran bait offers increased environmental benefits compared to conventional liquid treatments. For example, carbaryl–bran bait with 2 percent active ingredient (AI) by weight applied at 2 lb/acre offers 92 to 97 percent less active ingredient compared to conventional liquid formulations of carbaryl (0.5 to 1.5 lb AI per acre). Additionally, baits offer reduced cost for application, improved applicator safety, and minimized risk to many nontarget organisms.

Typically, liquid formulations provide quick broad-spectrum activity, uniform coverage, cost competitiveness, effective control, and residual activity. Liquid sprays also receive wide acceptance among farmers and ranchers. While many of these characteristics may appear favorable for grasshopper control, they may produce undesirable effects on beneficial insects and other nontarget species. Liquid application may pose added concerns for handling and applicator safety when compared to the safety of bran treatments. In addition, aerially applied liquid chemicals are far more prone to wind-related drift problems. Using liquid sprays is questionable where spray sites border or approach environmentally sensitive areas.

To choose the most suitable treatment, carefully review conditions (terrain, density of vegetation, wind direction and speed, temperature, and grasshopper species composition). The Grasshopper IPM (GHIPM) Project has attempted to identify treatments or application methods that can provide acceptable levels of grasshopper suppression in association with short- and long-term environmental factors. To further these efforts, research on grasshoppers at South Dakota State University and within the Project has addressed the use of bran bait and liquid applications in several related studies: row-crop and forage protection, optimizing the level of active ingredient in bran baits, and grasshopper suppression in CRP acreage.

Row Crop and Forage Protection

As mentioned earlier, controlling grasshoppers before their movement from hatching sites into nearby row crops is highly desirable. Studies of the use of bran baits on roadside areas were conducted in Colorado, Minnesota, Montana, North Dakota, South Dakota, and Wyoming. Little definable control was found in North Dakota and Montana with plot integrity questioned.

Problems with control were noted in Wyoming; however, in larger areas, treatment with carbaryl bait provided effective grasshopper population reductions (Lockwood and DeBrey 1990). Failure of bran bait applications to control grasshoppers satisfactorily was far more evident in eastern parts of South Dakota, where roadside areas had a much denser canopy (height of more than 0.75 m) and ground cover (at least 90 percent plants). This scenario contrasts the good to excellent control that bran baits have provided in several separate studies on large tracts of western South Dakota rangeland (Jech et al. 1993, Quinn et al. 1989, Wang and Fuller 1990 unpubl). These erratic results do not warrant a strong endorsement of roadside application for bran baits. As noted earlier, plot integrity may have played a significant role in the less-than-desirable levels of control.

Grasshopper behavior (preference for open canopy over shaded areas or reduced natural ability to search for food associated with the settling of bran flakes) may be important considerations in control efforts. Grasshoppers hatching several days following a bran application are not likely to suffer negative impact because baits lack residual control.

Despite these negative factors, bran baits remain a strong option when other methods are impossible to use. Even though populations are not always reduced to subeconomic levels at the site of a bran treatment, partial control may be sufficient to reduce further movement into adjacent row-crop areas.

Seedling corn (about 3 inches in height) was treated with chlorpyrifos–bran bait to control *Melanoplus bivittatus* immature (second-instar) grasshoppers with reductions of 40 to 50 percent that resulted in subeconomic pest densities (Boetel et al. 1990a). Under a more controlled setting, screen cages (1 by 1 by 0.5 m) were placed over seedling corn and artificially infested with 20 third-instar *M. sanguinipes.* One hundred percent control was achieved after a 24-hour period with several toxicant treatments on bran bait (Wang et al. 1991). Applications directly to seedling crop foliage throughout the field would appear to be a more suitable treatment method than bran applications that were limited to field margins.

Unlike most row-crop annuals, alfalfa does not require seedbed preparation or cultivation after its initial establishment. This lack of cultivation contributes to high grasshopper survival across alfalfa fields. Field borders surrounding alfalfa are potentially even more suitable for grasshopper egg laying because of their vegetative diversity (Pooler 1989 unpubl.) and the long-term absence of soil disruption by cultivation practices. Thus, even though grasshoppers are likely to be found throughout an alfalfa field, the highest densities may still exist in perimeter areas.

Bran bait, carbaryl 2 percent AI at 2 lb/acre, was compared to a liquid application of carbaryl (Sevin® XLR, 4E) at 1 lb/acre on alfalfa plots (400 by 800 m) to control grasshoppers. Numbers of fourth- and fifth-instar grasshoppers were 20 and 18 per square meter, respectively, in pretreatment density estimates. Counts 4 days after bran bait treatment were almost unchanged (20). Conversely, a 99.5-percent reduction in grasshopper density was observed in plots that received liquid applications of carbaryl. Dead grasshoppers were observed on the ground in bran-bait-treated plots. Invasion from perimeter areas was obvious, but bran baits were offering little or no residual control. While initially effective, bran baits proved a poor choice in alfalfa because of the lack of residual control.

Optimizing the Level of Active Ingredient in Bran Baits

The percent of active ingredient placed onto bran flakes played only a minor role in grasshopper mortality in several field and laboratory studies. Significant differences were not detected among 2- and 5-percent carbaryl-treated bran baits. Likewise, 1- and 3-percent chlorpyrifos treatment provided similar grasshopper control (Boetel et al. 1990b). These results suggest that the lower dose bran baits contain sufficient toxicants to control grasshoppers. Laboratory trials provided evidence that 0.0007 g of bran flake treated with 2-percent carbaryl was adequate to cause death. Thus, bran-accepting grasshopper species will not require feeding on multiple flakes or high percentages of toxicant to receive a lethal dose.

Grasshopper Suppression in CRP Acreage

The stable environment of CRP lands is similar to rangeland in that grasshopper populations can build up in this habitat and threaten nearby croplands. Failure of bran baits to control grasshoppers effectively in roadside studies resulted in efforts to use liquid applications. Liquid applications can be cost prohibitive on CRP lands, where little economic return is expected. Thus, studies using lower rates of several insecticides (carbaryl, chlorpyrifos, dimethoate, esfenvalerate, diflubenzuron) have been undertaken.

Primary emphasis was placed on the need for residual activity in the presence of constant invasion potential. Carbaryl at 0.5, 0.75, and 1 lb AI per acre offered excellent control up to 10 weeks after treatment. Using the lowest rate would offer a farmer-acceptable control with significant economic savings. Other compounds tested offered similar results; however, several years of data support the carbaryl findings.

References Cited

Boetel, M. A.; Fuller, B. W.; Bergland, D. R.; Walgenbach, D. D. 1990a. Comparative efficacy of grasshopper bran baits in corn and ditch borders, 1989. Insecticide and Acaricide Tests 15: 184.

Boetel, M. A.; Fuller, B. W.; Bergland, D. R.; Walgenbach, D. D. 1990b. Bran bait efficacy for control of grasshoppers in South Dakota, 1989. Insecticide and Acaricide Tests 15: 180.

Jech, L. E.; Foster, R. N.; Colletto, D.; Walgenbach, D. D.; Roland, T. J.; Rodriguez, G. D.; Bohls, R.; Houston, R. D.; Meeks, W. K.; Queener, R. L.; Jackson, C. L; Dines, J. L.; Puclik, M. J.; Scott, A. K. 1993. Field evaluation of diflubenzuron and carbaryl bran baits against grasshopper (Orthoptera: Acrididae) populations in South Dakota. Journal of Economic Entomology 86: 557–565.

Lockwood, J. A.; DeBrey, L. D. 1990. Rangeland grasshopper control with baits, 1989. Insecticide and Acaricide Tests 15: 271.

Quinn M. A.; Kepner, R. L.; Walgenbach, D. D.; Bohls, R. A.; Pooler, P. D.; Foster, R. N.; Reuter, K. C.; Swain, J. L. 1989. Immediate and 2nd-year effects of insecticidal spray and bait treatments on populations of rangeland grasshoppers. Canadian Entomologist 121: 589–602.

Wang, T.; Boetel, M. A.; Fuller, B. W.; Chambers, W. W.; Jenson, J. M. 1991. Efficacy of bran baits in controlling grasshoppers in South Dakota, 1990. Insecticide and Acaricide Tests 16: 177.

References Cited—Unpublished

Fuller, B. W.; Wang, T. 1990. Grasshopper bait methodology investigations in eastern South Dakota. In: Cooperative Grasshopper Integrated Pest Management Project, 1990 annual report. Boise, ID: U.S. Department of Agriculture, Animal and Plant Health Inspection Service: 182–186.

Pooler, P. D. 1989. Factors influencing grasshopper oviposition site selection on South Dakota rangelands. M.S. thesis. Brookings, SD: South Dakota State University. 50 p.

Wang, T.; Fuller, B. W. 1990. Field evaluation of grasshopper bran baits in western South Dakota. In: Cooperative Grasshopper Integrated Pest Management Project, 1990 annual report. Boise, ID: U.S. Department of Agriculture, Animal and Plant Health Inspection Service: 187–191.

II.22 Aircraft Guidance for Grasshopper Control on Rangelands

Gil Rodriguez and T. J. Roland

Guidance methods and systems for aerial application have evolved throughout the years from the most rudimentary to the most sophisticated. The purpose was to provide aircraft guidance for the proper distribution of agricultural chemicals to field crops. In order to achieve this, pilots had to develop a method of guiding the aircraft over the ground.

Initially the pilot attempted to fly evenly spaced passes over the field by free-flying—visually estimating the distance between passes. This procedure was not accurate, and better methods were developed as time went by. Free flying is still in use, but only on smaller fields, where it is easier for the pilot to estimate the distance between passes and keep track of the number of passes. The following is a list of guidance methods/systems in the approximate chronological order that they were developed and a brief description of each.

Flaggers

Ground personnel waving flags guide the aircraft. The flagger indicates to the pilot the starting point for each pass. When the aircraft is properly lined up, the flagger steps off the required distance to get in position for the next pass. There may be one or two flaggers—one flagger at one end of the field, or one at each end. Long runs may require multiple flaggers. Flags are easy to see because of their waving motion, and this method is more accurate than free flying. Multiple flaggers may vary distance and introduce error when stepping off the spacing between passes and cause skips.

Kytoons

Ground personnel holding kytoons (tethered balloons) guide the aircraft much the same way flaggers do. This method is useful when there are visual obstructions, such as trees, buildings, or terrain, and where long runs are required. Some disadvantages of this method are that kytoons tend to get out of control under certain meteorological conditions that cause the balloons to dive into or have their tethers get tangled in trees. There are also safety hazards involved, such as collisions with the aircraft and contact with electrical power-lines.

Mirrors

Ground personnel using mirrors to flash reflected sunlight at the pilot guide the aircraft. The pilot flies toward the flashing light. This method is especially effective on long passes over flat terrain with few or no landmarks since the flashes are visible over long distances. Two disadvantages of using mirrors are that they are difficult to aim when there is a large angle between the sun and the aircraft, and they won't work if clouds block the sun. An alternate backup guidance method would be required during these conditions.

Automatic Flagman

This system consists of a mechanical device attached to the upper inboard area of the aircraft wing. The equipment is loaded with paper flags or streamers that the pilot releases at the end of each pass to assist in establishing the next pass. This system is used independently or to supplement other guidance methods.

Smoker

In this guidance system, the pilot releases a puff of smoke into the airstream by injecting a small amount of paraffin oil into the aircraft exhaust system. This procedure enables the pilot to mark the last pass momentarily in order to set up for the next one, much as with the Automatic Flagman. The Smoker also assists the pilot in determining wind direction and drift. This system supplements other methods of guidance but is not useful when winds displace the smoke while the pilot makes the turn for the next pass.

LORAN-C

LORAN (an acronym for LOng RAnge Navigation) is a radio navigation system that uses time-synchronized pulsed signals from ground transmitting stations spaced several hundred miles apart. The stations are configured in chains of three to five that transmit with the same time-synchronized signals. Within each chain, one station is designated as the master, and the remainder are secondaries.

An aircraft-mounted LORAN-C receiver converts the "time difference" between the arrival of radio signals from the master and the secondaries into latitude/longitude coordinates. Navigational values such as distance and bearing to the treatment area are computed from the aircraft's present latitude/longitude (geographic location).

A computer software program called GRIDNAV provides aircraft guidance to the pilot during aerial application. The pilot enters the geographic coordinates for the first pass plus the desired swath width into the program before leaving on the mission. The GRIDNAV software automatically provides directional and spacing guidance for each pass and keeps track of the number of passes during the aerial application operation.

This system eliminates the need for ground personnel. Mountainous terrain, mineral deposits, and position of the aircraft with relation to the stations can affect the precision of the system. LORAN-C is unsuitable for applications that require swath widths of less than 60 ft. The system is especially useful for releasing sterile insects where swath width is much wider and accuracy less critical.

Global Positioning System (GPS)

GPS is a location system based on a constellation of satellites orbiting the Earth at high altitude. The Department of Defense developed GPS for military operations, and the system proved itself during the Gulf War in 1992. GPS presently is the most accurate navigational system in the world.

Geographic position is developed in much the same way as with LORAN-C. One difference is that GPS operates in three dimensions because the transmitting stations are satellites and are not located on the surface of the Earth. The distance between several satellites and the aircraft-mounted GPS receiver is measured by highly sophisticated equipment and converted to geographic coordinates.

Although GPS is still in a developmental stage for agricultural use, it is capable of providing aircraft guidance for aerial application in the same manner as LORAN-C. This system also eliminates ground personnel and is not affected by the physical conditions that affect LORAN-C. However, it must maintain line-of-sight contact with the satellites being used. A position error of 60–100 ft can be expected under normal conditions and can be reduced to 3–6 ft or less with differential correction. Differential correction is accomplished by placing a GPS receiver base unit at a known location and using it to determine exactly what errors the satellite data contain. The base unit then transmits an error correction to the GPS receiver in use, which can use that information to correct its position. A disadvantage of this system is that it requires an additional stationary receiver placed at a known location in order to achieve maximum accuracy.

GPS will expand its use for agricultural applications and already has proven its accuracy and use in rangeland grasshopper and cotton boll weevil control programs in the United States.

Conclusions

Aircraft guidance for aerial application has made significant progress through the years. The trend has been toward greater accuracy and the elimination of ground personnel. Eliminating the need for ground personnel also reduces the exposure of humans to pesticides. Accuracy is very important in reducing damage to the environment and to threatened and endangered plant and animal species.