

GRASSHOPPER AND LOCUST CONTROL WITH POISONED BAITS: A RENAISSANCE OF THE OLD STRATEGY?

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Key words:

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Abstract

Insecticidal baits have been used to control grasshoppers and locusts since the 1880s. After the peak in the 1940s-1950s, they were increasingly replaced by more economical dusts and sprays. Nowadays, baits are used on a regular basis in North America to control rangeland grasshoppers and Mormon crickets. A typical bait formulation consists of wheat bran impregnated with carbaryl. Although in general, bait applications produce less consistent efficacy than sprays, they have certain environmental advantages. Baits are better targeted to acridid pests, which reduces their negative impact on non-target organisms and makes them an attractive management option for ecologically sensitive areas. On a small scale, baits are applied by farmers using ground equipment to create crop protection barriers. Large-scale applications are done from aircraft equipped with bait spreaders. Further improvements of bait methodology lie in the area of using new active ingredients, increasing bait palatability by adding attractants, and optimizing spreading.

Baits at the dawn of chemical pest control: A historical overview

Locust and grasshopper control with poisoned baits was one of the earliest attempts of pest outbreak suppression by chemical insecticides. The first experiments with grasshopper baiting were done in North America in the late 1870s (U.S. Entomological Commission, 1878), and the first field applications were reported by Coquillet in 1886. Before the advent of baits, acridid pest control was largely mechanical, relying on manual labor for digging barrier trenches and egg destruction. The use of poisoned baits, containing arsenates, was a significant step forward in both efficacy and efficiency of crop protection from pests (Riegert *et al.*, 1997). In North America, where grasshopper

assemblages often include >10 species with different food preferences and feeding habits, the initial baiting trials produced mixed results due to differing bait acceptance among pest species. In an effort to increase the palatability of baits, ingredients as diverse as wheat bran, maize bran, sawdust, and horse manure were used as substrates for arsenates, and attractants such as molasses, bananas, lemons, onions, apples, salt, oranges, sugar beet pulp, and even such extravagant components as beer and vanilla extract were experimented with (Cowan, 1940; Shotwell, 1942). Poisoned baits, especially the famous "Criddle mixture" with dry horse manure as the main component, were applied on a very large scale to control the now extinct Rocky Mountain locust (*Melanoplus spretus*). This bait was widely used for grasshopper control after the locust's demise at the turn of the century. During an outbreak in 1917, over 3,000 tons of poisoned baits were applied to 0.5 million ha in Kansas alone (Lockwood, 2004).

In Russia, where control was primarily applied to populations of a single locust species, insufficient bait acceptance was not an issue. The application of baits quickly became the predominant strategy of locust control in the 1920s when these materials were applied annually to areas over one million ha (Bei-Bienko & Mistchenko, 1951). Baiting received a further impulse with the introduction of aviation. As early as 1931, the pioneering aerial spreading of baits was developed, and in 1934 it was implemented to control locusts on 100,000 ha (Bei-Bienko & Mistchenko,



Figure 1. ATV bait spreading in Wyoming against rangeland grasshoppers. Photo: S. Schell, Univ. of Wyoming, USA.

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Figure 2. “Sun bands” of the Moroccan locust (*Docostaurus maroccanus*) can be effectively treated with poisoned baits. Photo: A. Latchinsky, Univ. of Wyoming, USA. Location: Uzbekistan.

1951). In North America, aerial bait application significantly improved the efficacy and economics of grasshopper control. Aerially applied chlordane baits over rough, rugged terrain yielded 95% pest mortality (Cowen & Brown, 1948).

In South Africa, successful tests of wheat bran or maize meal baits to control nymphs of the Red locust (*Nomadacris septemfasciata*) and the Brown locust (*Locustana pardalina*) were reported by Faure and Jacot-Guillarmod (1940), Du Plessis and Nolte (1941) and Smit (1951). However, when applied to adult Brown locusts, baits yielded satisfactory results only among ovipositing females, while treatments of immature adults failed (de Wet, 1941). Gunn (1952) applied wheat bran baits to control the Desert locust (*Schistocerca gregaria*) in East Africa, and obtained more consistent results with dry bait than with bait moistened with oils. In contrast, Hynes (1953) reported the best results against the same locust using maize meal baits moistened with molasses.

The era of poisoned baits continued until the 1950s, when powdered dusts and aerial sprays replaced baiting as the predominant method of insecticidal pest control. Aerial spraying with organochlorine insecticides was simpler and more economical to use, especially with the advancement of



Figure 3. Bait spreading by hand in the 1930s. Source: USDA (2002)

ultra low volume (ULV) technique (Sayer, 1959), which soon became the standard for most locust and grasshopper control programs. As a result, interest in insecticidal baits waned in the 1960s. It was not until the 1970s that trials with baits resumed, this time as a carrier for biological control agents.

Baits and biocontrol: A dead end?

The first attempts to use baits as pathogen carriers were implemented in Russia in the 1940s, when Vinokurov (1949) treated grasshopper infestations in Siberia with bran baits moistened with solution of spores of a fungal pathogen *Entomophaga grylli*. Treatments reduced egg production by 72 to 92%. However, despite the well-known ability of *E. grylli* to cause spectacular grasshopper epidemics in the temperate regions of Eurasia and North America, this method was discontinued. The mass production of the spores of *E. grylli* is impossible on artificial media and requires a passage *in vivo*, which is an insurmountable impediment for its operational use.

In North America, concerns over the ecological consequences of large-scale grasshopper control treatments using blanket coverage with organophosphates and carbamates caused the renewed interest in bait applications in the 1970s. This time the active ingredient was a protozoan pathogen, *Nosema locustae* (Canning, 1953). Although this microsporidian demonstrated grasshopper and locust specificity, thereby lowering environmental side-effects, it failed to produce consistent efficacy to warrant large-scale use at an economically viable cost. Onsager *et al.* (1981a) could only attribute a 12% grasshopper reduction to *N. locustae* alone and a 58% reduction when the pathogen was applied with carbaryl as a “stressor” in a 1:2 ratio. Few improvements were made in *N. locustae* treatments, with Johnson (1989) reporting only a 30% reduction in grasshopper densities attributable to the pathogen. Although recent, significant progress has been made in promoting biocontrol of locusts and grasshoppers using entomopathogenic fungi such as *Metarhizium anisopliae* and *Beauveria bassiana* (Lomer *et al.*, 2001), baits do not appear to be appropriate carriers for these and other fungal pathogens since fungal infection requires contact of spores with the cuticle of target pests, whereas baits require ingestion to be effective.

Baits versus sprays: 3 Es

Although baits were increasingly replaced by sprays in grasshopper and locust outbreak suppression programs since the 1950s, interest in bait methodology, particularly in North America, continues into the current century. In this section, we will address some of the pros and cons of bait application in comparison to insecticidal sprays, all of which fall under three major headings: Efficacy, Economics, and Environment.

Efficacy. Applied aerially, sprays tend to result in more uniform distributions of insecticide than baits, contributing to more consistent pest suppression (Fuller *et al.*, 1996). ULV applications typically produce higher grasshopper mortality than bait applications with the same active

ingredient (Mukerji & Ewen, 1987). Foster *et al.* (2000) reported that carbaryl spray reduced grasshopper populations at 14 days after treatment by 96 to 97% while carbaryl bait by only 35 to 85%. One of the major reasons for this discrepancy is the fact that baits must be ingested for them to work, and ingestion is dependent on palatability (Onsager *et al.*, 1981b). Mortality among bait accepting grasshopper species can be as high as 97% with no significant mortality among bait “rejectors” (Onsager *et al.*, 1996; Foster *et al.*, 1998). Young hoppers are killed more easily with bait than the older stages, with the latter requiring higher dose rates (Mukerji *et al.*, 1981); however, the same pattern is also true for sprays (Dobson, 2001).

Efficacy is also dependent upon the duration of control and weather impacts. In this respect, baits tend to be superior to sprays because they generally have a longer residual and are not as dependent on meteorological (especially wind) conditions during application. Drift (or its absence) is a major problem when applying sprays, whereas baits, because of the higher particle weight, are not as influenced by these factors. Consequently, baits are less sensitive than sprays to the timing of application. While spraying is usually limited to a few hours at dawn and at sunset, application of baits can take place at any time during daylight hours (Foster & Onsager, 1996). However, a rain event soon after bait application may reduce its efficacy to a minimum, while certain liquid insecticides may withstand rain without being washed off the treated vegetation. Also, bait efficacy may be reduced by ants and other ground arthropods.

High population densities can also decrease bait, but not spray, efficacy. Still, baits may have an important advantage over sprays because their application does not need precise targeting. Instead of treating hopper bands (as in the case of contact insecticide sprays) or vegetation (as in the case of sprays with stomach poisons), baits can be applied to strategically important areas as perimeters of agricultural fields. Even if such areas are completely devoid of vegetation, which is typical for many arid regions, the



Figure 4. Such hotspots of Clearwinged grasshopper (*Camnula pellucida*) are an easy target for bait spreading by hand or from vehicle-mounted spreader. Photo: A. Latchininsky, Univ. of Wyoming, USA. Location: Wyoming.



Figure 5. The Twostriped grasshopper (*Melanoplus bivittatus*), an important economic pest in North America, is among the best bait accepting species of grasshoppers. Photo: A. Latchininsky, Univ. of Wyoming, USA. Location: Wyoming.

insecticidal “barrier” created by the bait application would ensure the protection of valuable crops. Another advantage of bait application with products like carbaryl over insecticidal sprays with slower-acting products like Insect Growth Regulators (IGRs) consists in its much faster action and rapidly visible results.

Economics. Effective bait application requires a fraction of the active ingredient as compared to sprays, thus lowering the cost of the treatment (Foster & Onsager, 1996). However, aerial application costs are higher for baits than for sprays. Furthermore, unlike standard spraying gear, fewer aircraft possess appropriate equipment for baiting. Infestation densities must be taken into consideration as well, for it may become uneconomical to apply enough bait to ensure adequate level of control when pest densities are extreme.

Logistics of bait application are typically more complex than that of spraying. Baits require 5 to 50 times more formulation to apply per unit area than ULV spraying, which results in a slower work rate. In the case of locust control, the recommended dose rates of baits range from 5 to 15 kg/ha for marching hopper bands to over 50 kg/ha for settled hoppers and adults (Dobson, 2001). Consequently, the amount of product to move and store is much higher, which adds to the cost of a control program. Preparing bait may include an arduous mixing process and bait application requires more attention to prevent bridging and ensure even dispersal. On the other hand, baits do not need water, which constitutes an important advantage over full volume spraying and makes baits as attractive as ULV for use in arid regions.

Large-scale, aerial carbaryl bait treatments to control rangeland grasshoppers are still conducted in several western states of the USA on a regular basis. Depending on the type of application (aerial or ground), their per unit area costs appears to be two to five times higher than ULV spraying (NGMB, 2006). Generally, contract costs are substantially higher for applying baits than sprays (Foster & Onsager, 1996). However, baits remain an economically viable management option for many small-scale applicators like

individual ranchers or farmers, who do not need expensive aircraft and apply baits from the ground.

Environment. Comparing environmental impacts of baits versus sprays in acridid control, it is necessary to bear in mind that most of the available data on baits come from North America. In general, baits have considerable environmental advantages over liquid insecticide applications. Baits are easier to direct toward the targets, and they affect fewer non-target organisms than sprays (Foster, 1996). For example, bees (both cultivated and wild) and other pollinators are likely to be susceptible to some liquid insecticidal sprays, but not baits (Peach *et al.*, 1994; 1995; Alston & Tepedino, 2000; McEwen *et al.*, 2000).

Extensive studies by Quinn *et al.* (1989, 1990, 1991) revealed that carbaryl bait applications affect only arthropods that consume the baits directly (such as darkling beetles, ground beetles, field crickets, and ants), but the effects are not long-term. Foster *et al.* (2001) studied the effects of grasshopper suppression programs on flea beetles (*Aphthona* spp.), used as weed biocontrol agents, finding that carbaryl bait resulted in a 17% mortality, while carbaryl spray resulted in a 60 to 82% mortality.

Field studies have shown that carbaryl bait applied at conventional rates posed little risk to birds such as killdeer, vesper sparrows, or golden eagles in the treatment areas (USDA, 2002). Adams *et al.* (1994) found no negative effects of carbaryl bait on the nestling growth and survival of vesper sparrow. Similarly, according to Krupovage *et al.* (1990), white-footed mouse and Ord's kangaroo rat were not impacted by applications of carbaryl bran baits. Gregory *et al.* (1993) found the rate of bran bait used to control grasshoppers is low enough that field populations of mice would encounter very little bait. Furthermore, mice appeared to exhibit behavioral avoidance of carbaryl bait.

Soil microorganism densities have been shown to be slightly reduced following carbaryl spray treatments, with recovery occurring within 3 weeks (Moulding, 1972). Carbaryl bait exhibits reduced soil effects relative to spray applications (USDA, 1987). Studies of carbaryl residues resulting from bran bait applications showed that they were higher than those resulting from application of liquid carbaryl; however, the residue is confined to the bran bait and is not found on vegetation or soil (USDA, 2002). Consequently, applying carbaryl in bait form greatly reduces the number of organisms exposed to this insecticide.

Figure 6. Peacock Industry's Model 20 and 62a Applicator



To summarize, bait treatments appear to be more environmentally benign than sprays. This method offers a viable alternative when grasshopper treatment is required in proximity to habitats of endangered and threatened species, water bodies, or other sensitive areas. This preference of baits over sprays is reflected in USDA programmatic documents. The Environmental Impact Statement of grasshopper suppression programs (USDA, 2002) requires a 150 m buffer around water bodies when using aerial liquid sprays, a 60 m buffer for aerial baits, and only a 15 m buffer for ground baits.

A serious disadvantage of early baits was high human exposure to dangerous toxicants. Preparation of bait formulation required mixing of extremely toxic active ingredients with carrier. Nowadays, this concern can be alleviated because most bait products are ready-to-use. Compared to sprays, baits represent lower risk for personnel during loading and offer a substantial advantage with regard to applicator safety (USDA, 2002).

Current state of the art of baiting: Have improvements been made?

At present, carbaryl remains the active ingredient of choice in bait formulations for grasshopper control in North America. Carbaryl bran baits come in 2% and 5% active ingredient concentrations, although studies showed that increased concentration of toxicant does not affect grasshopper mortality, whereas amount of formulation applied and number of applications are critical (Foster *et al.*, 1998; 1999). The most common carrier in modern baits is wheat bran. A small amount of additives may be mixed with bait to extend shelf life, increase attractiveness or assist in applying the product evenly.

Bait application technology improved over the last decades. New spreaders for baits can equal spray swath width, and adaptations to aircraft can reduce problems of formulation bridging and lumping (Foster & Roland, 1996). For increasingly popular ground application, one of the leaders in bait technology, the Canadian company Peacock Industries, offers several bait delivery models with gas-powered pneumatic devices. These efficient and affordable spreaders are mounted on pickup trucks or four-wheel all-terrain vehicles (ATV). For isolated grasshopper infestations, hatching hot spots, and roosting locusts, bait formulations can be safely applied with gloved hand.

Further improvements of bait applications are possible within the context of the Reduced Agent-Area Treatments (RAATs), a strategy for rangeland grasshopper control developed at the University of Wyoming, USA (Lockwood & Schell, 1997; Lockwood *et al.*, 2000). By applying treatments in swaths instead of blanket coverage, and utilizing attractive vegetable oils, application and insecticide costs are lowered while preserving more of the non-target and beneficial organisms. Although RAATs typically result in 5 to 15% lower control than blanket treatments, their economic and especially environmental advantages make them an attractive management alternative (USDA, 2002). Direct toxicity of carbaryl to birds, mammals, reptiles, and halictid bees (a primary pollinator of

some native plants) is unlikely in swaths treated with carbaryl under a RAATs approach (George *et al.*, 1992). Using alternating treated and untreated swaths will furthermore reduce adverse effects (USDA, 2002).

Another area of bait improvement is connected with carrier optimization. New carriers such as EcoBran[®] by Peacock Industries, Apple Pumice Crumbles by Wilbur-Ellis, and Taste-E-Bait[®] by Advanced Organics appear to expand the palatability of baits to more acridid species. Recent trials by R.N. Foster *et al.* show all of the above to produce equal mortality, and a faster and higher mortality than sprays during a fall treatment of overwintering species (NGMB, 2005). Additional attractants on baits possibly result in greater acceptance. Peacock Industries claims an added polymer on EcoBran[®], which extends the residual effects of carbaryl, acts as an attractant, luring susceptible species up to 15 m. Bomar and Lockwood (1994) found that linoleic and linolenic acids, which constitute the major fraction of the volatile compounds emitted by grasshopper cadavers, improved bait acceptance of some bait-rejecting species.

Niche of Baits: Where is the place for bait today and tomorrow?

Bait applications at registered rates are currently unrestricted in North America, and can be applied even while livestock are grazing (Marsh *et al.*, 1951). Livestock poisoning by carbaryl baits is beyond the realm of probability in the context of normal application practices using labeled rates. In moderate grasshopper infestations, application can be effective at 1 lb of 2% carbaryl bran bait per acre (1.125 kg/ha of formulation, or 22.5 g of a.i./ha), which is equivalent to just 5 flakes in the area of a palm. Farmers can effectively apply baits to grassland borders and roadsides adjacent to susceptible crops using vehicle-mounted spreaders or simply by gloved hand, without any special protective gear other than a simple face mask. Village brigades in impoverished regions of the world can safely apply baits in the morning hours around roosting locusts. Bait (hand, aerial and ground) applications can be made in ecologically sensitive habitats.

Bait applications in North America became the treatment of choice against such important agricultural pest as the Mormon cricket (*Anabrus simplex*), which is a flightless katydid (Family Tettigoniidae). These orthopterans march in dense bands covering up to several km/day, and can seriously damage crops. Applications of carbaryl bran baits in front of a moving band or as protective barriers around crops usually result in a quick reduction of the pest densities below the economic levels (NGMB, 2006). Taking into account striking behavioral similarities, it is possible that treatment parameters of highly mobile nymphal bands of different locust species could be modeled after the control of the Mormon cricket bands using poisoned baits.

For treatments of immature grasshoppers, IGRs, specifically diflubenzuron, offer an environmentally superior alternative to broad-spectrum insecticides (USDA, 2002). Acting mostly by ingestion, the IGRs constitute a potentially promising treatment option if applied in the bait form. An application of wheat bran bait impregnated with

diflubenzuron using an ATV-mounted spreader resulted in 50 to 65% grasshopper mortality under adverse conditions and moderately high (20-35/ m²) densities (Lockwood *et al.*, 2002). Other active ingredients such as fipronil appear to have potential for use in a bait form, especially in a RAATs context.

Increasing environmental concerns over large-scale anti-locust treatments with broad-spectrum insecticides resulted in renewed interest to baiting in South Africa. A pyrethroid insecticide, silafluofen, applied in wheat bran bait, produced an average of 91% (range 67-100%) mortality of the Brown locust nymphs 5 h after application (Price & Brown, 1997).

Conclusions: To bait or not to bait?

The main limitations of baits for grasshopper and locust control have been their inconsistent efficacy and increased application cost when compared to sprays. Baits, however, have a distinct advantage in that they have a reduced impact on the environment and can be applied safely. In critical habitats for non-target arthropods and wildlife, baits are the only clear choice (USDA, 2002). In crop borderlands and roadside areas, baits offer an economic method of grasshopper control and can be applied by the landowner with a vehicle-mounted spreader. The advent of new chemicals, carriers, and attractants could increase the efficacy of bait applications (Lockwood *et al.*, 2001).

Baiting represents a type of preventive strategy within the framework of IPM. Under the ever-increasing pressure of environmental concerns, the renaissance of baits offers a sound alternative to broad-spectrum insecticidal sprays and finds its place in certain niches of acridid pest management. By gaining target specificity with baits, one is plausibly engaged in a form of conservation biological control in which the predators and parasites of grasshoppers are effectively protected via the insecticide formulation.

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