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THE EFFECTIVENESS OF ORCO MOLE BAIT
IN CONTROLLING MOLE DAMAGE

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Dale Koval Elshoff

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Glenn R. Dudderar
Major professor

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THE EFFECTIVENESS OF ORCO MOLE BAIT IN CONTROLLING MOLE DAMAGE

By

Dale Koval Elshoff

A THESIS

Submitted to
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ABSTRACT

THE EFFECTIVENESS OF ORCO MOLE BAIT
IN CONTROLLING MOLE DAMAGE

By

Dale Koval Elshoff

The tunneling damage caused by eastern moles (Scalopus aquaticus) and starnosed moles (Condylura cristata) is widespread and persistent. Present damage control methods have a wide variety of limitations. Professional and non-professional applicators need an easily applied mole damage control method that can be used in a variety of conditions.

This study was designed to test the effectiveness of Orco Mole Bait on both mole species; sand, loam and muck soils; and irrigated and non-irrigated areas.

Information was collected on tunneling habits and social interactions of eastern and starnosed moles, and how these factors affect bait effectiveness.

Orco Mole Bait was equally effective in controlling the damage caused by both eastern and starnosed moles. The average time to control in field trials was 30.3 days. The bait was effective on all three soil types, but irrigation lessened effectiveness.

Multiple occupancy, reinvasion of abandoned tunnel systems, the use of ideal microhabitats, and the presence of other fossorial species occurred in several tunnel systems. Moles appeared to construct tunnels in response to soil condition rather than by species type. There was no relationship between weather factors and tunneling activity.

DEDICATION

This Thesis is dedicated to Mom and Keefer,

who both taught me you have to go for it when you can.

You never know when it'll all be taken away.

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I would like to thank Dr. Glenn Dudderar, Dr. Richard Hill, and Dr. Harold Prince for their time and guidance in my coursework, experimental design, and the completion of this thesis. Thanks also go to Dr. Scott Winterstein for his expert advice on the statistical analysis of my data.

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Simply giving thanks to all my friends and family for all of their encouragement, persistence, and love is grossly insufficient, but I don't know what else to say. Without Dad, Tricia, Erin, Courtney, Chip, Bean, and Tyler, the last few years, and particularly the last few months, would have been impossible. Paul Martin, Gary & Lori Brandenberg, Kitty & Paul Stuart, Ken & Ellen Krenz, Joe & Deb Herriman, and the Davis' make me forget how far away my "real" family really is. Paul Padding- thanks for everything, even the things I'm not supposed to mention!

Finally, my most sincere appreciation to my husband and best friend David Elshoff, who inadvertently funded part of this research, ventured out in all sorts of weather and hours to help collect data, and who truly went above and beyond the call of duty in the field and at home. You make me who I am, and this whole thing wouldn't have been possible without you. Now.. on to bigger and better!!

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INTRODUCTION

Professionals in lawncare, golfcourse maintenance, pest control, and turfgrass production, as well as many private landowners, are well acquainted with the damage that moles can do through their tunneling activities. This damage, from disfiguring lawns and greens to creating hazards for people and machinery, is well documented (Eadie 1954, Dudderar 1977, Marsh & Howard 1978, Henderson 1983). Over time, many techniques have been suggested to control mole damage (Hanawalt 1922, Henning 1952, Eadie 1954, Marsh & Howard 1978, Ware 1980, Dudderar 1983a, 1983b, 1985, Henderson 1983, Benjamin 1985, Corrigan 1987). The most popular of these methods include trapping, gas and smoke fumigation, and insecticide applications. These methods are subject to a wide variety of limitations and prove impractical in some situations. Trapping is considered very effective if traps are properly set. However, traps are physically difficult to set, are easily mis-set in tunnels, and can be mis-placed in systems. All of these situations severely decrease the effectiveness of trapping as a mole control tool. Traps are also conspicuous, which makes them not only unaesthetic, but also attractive to vandals, curious children and pets. The most effective fumigants are available only to certified applicators, and use areas are restricted. For instance, they can not be applied around house foundations, which are a favorite tunneling area of moles. When using fumigants it is necessary to treat the entire tunnel system, which can be very difficult if not impossible when the system travels in restricted use areas, into wooded or meadow areas, or onto uncooperative adjacent landowners' property. Insecticide applications are used as an indirect mole control method by killing the insects and other arthropods which moles feed on. While the insecticides are effective in controlling populations of these invertebrates, often only a small proportion of the mole's diet consists of these animals. Therefore, insecticide applications are generally not effective (Corrigan, 1987), particularly on clay and moist, organic soils where earthworms are abundant. In addition, there are restrictions on area and vegetation use after application.

Professional and non-professional applicators need an easily applied mole damage control method that can be used in a variety of physical and environmental conditions. The primary purpose of this study was to test the efficacy of Orco Mole Bait on eastern moles (Scalopus aquaticus) and starnosed moles (Condylura cristata) and compare the bait to other mole damage control methods.

The development of an effective damage control technique requires a thorough understanding of the species' physiology, population dynamics, habitat requirements, and habits. In reviewing the literature it becomes more obvious why there is not a consistently reliable mole damage control method despite numerous attempts. While there is an abundance of information concerning the population dynamics, social habits, tunneling behavior, and food preferences of moles (Slonaker 1920, Hanawalt 1922, Jackson 1922, Hamilton 1931, Arlton 1936, Eadie 1954, Eadie & Hamilton 1956, Godfrey 1957, Conaway 1959, Brown 1972, Giger 1973, Funmilayo 1976, 1977, Harvey 1976, Hartman & Gottschang 1983, Hickman 1983), much of this information is contradictory. Therefore, a second goal of this study was to collect observations on the tunneling activity and social habits of eastern and starnosed moles in mid-Michigan, and the effect that these behaviors have on bait effectiveness. Specifically, information was collected on multiple mole occupancy in tunnel systems, the use of mole tunnels by other fossorial species, tunneling habits, and habitat preferences. Relationships between summer tunneling activity and precipitation, evaporation, and average maximum and minimum ambient temperatures were investigated. Winter tunneling activity and tunnel and soil temperatures, precipitation, and average minimum and maximum ambient temperatures were also investigated.

METHODS

SITE DESCRIPTION

All studies were conducted in Meridian Township, in Ingham County, Michigan (R.1W, T.4N) (Figure 1). Topographically, the county lies on a broad glaciated plain lying 200-600 feet above Lakes Michigan, Erie, and Huron. It is characterized by smooth or gently undulating topography, though some regions are relatively hilly. Swamps and lakes are widely distributed. Originally the area was entirely forested, except the 3-4% of marshland and water (Sommers, 1977). The climate in the county is characterized by fairly cold winters and mild summers. The mean annual temperature is 46.9 degrees Fahrenheit (24.2 in winter, 68.6 in summer). The average length of frost free season is from May 3 to October 10 (160 days), but this period is shorter on muck lands. Normal annual precipitation is 31.43 inches, including melted snow. Yearly snowfall averages 47.4 inches (Michigan Weather Service, 1974).

Sites were scattered throughout the county in five areas. Halmich Sod Farm sites (S 1/2, NE 1/4, section 5) were situated on Carlisle muck (Bellefontaine, Hillsdale, Coloma, Fox soil association). Riverglen Apartment sites (S 1/2, NE 1/4, section 20) were on Granby sandy loam. Michigan State University sites (center, SE 1/4, section 19) consisted of Hillsdale sandy loam, Granby sandy

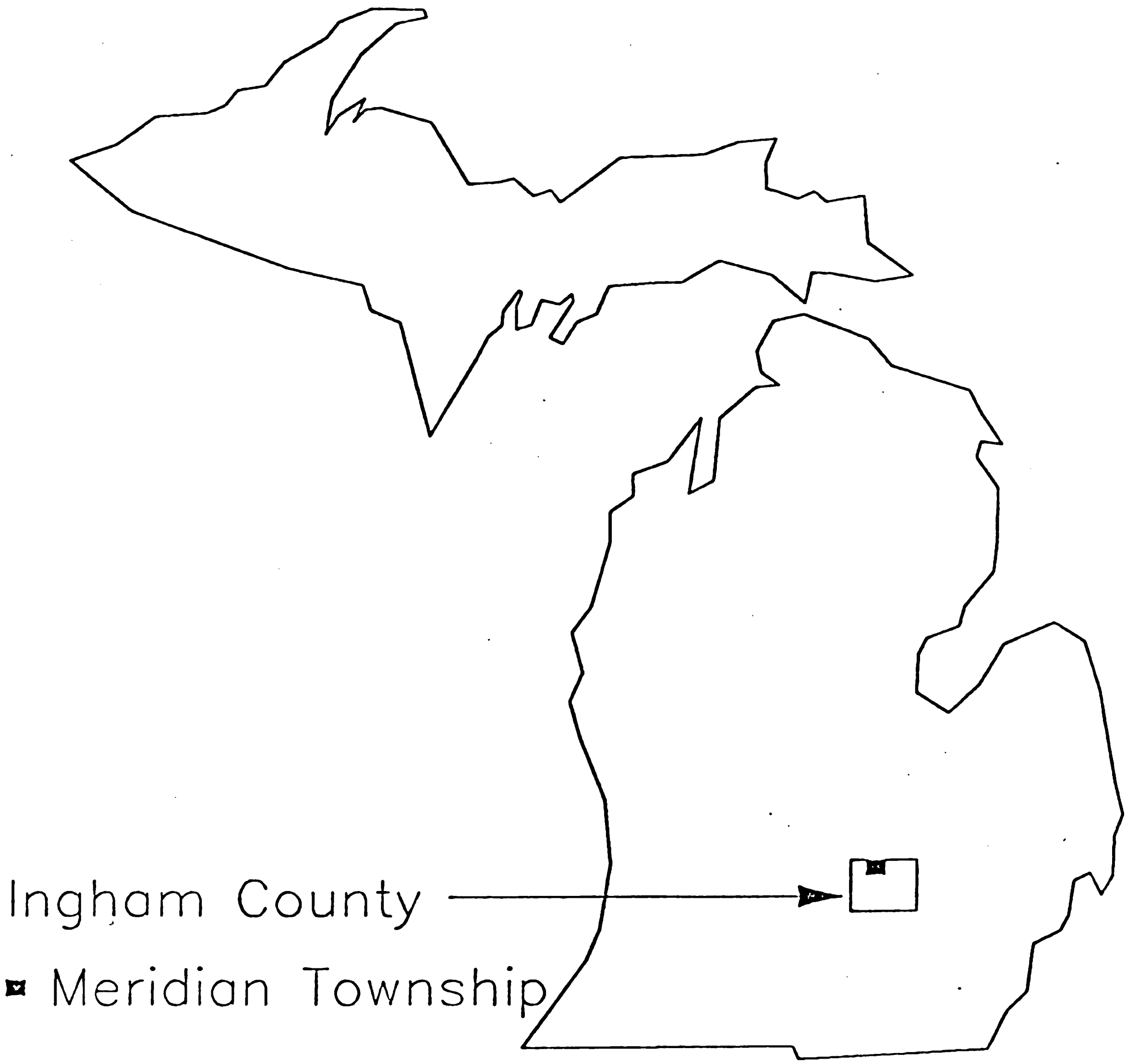

Figure 1. The location of Meridian Township in Ingham County, Michigan

loam, and Berrien loamy sand. East End Condominium sites (N 1/2, SE 1/4, section 8) were on Walkill loam and Bellefontaine loamy sand soils (Hillsdale, Miami, Conover association). Woodhill Condominium sites (N 1/2, SE 1/4, section 9) were on Bellefontaine sandy loam, Walkill loam, and Hillsdale sandy loam (Veatch et al., 1941). Soil types at some East End and Woodhill sites varied from historic soil maps because of backfill soils used in building construction. These backfill soils were sands and were treated as such in analysis.

BAIT EFFICACY

United States Environmental Protection Agency testing procedure 96-8 Mole Toxicants was followed in designing this study. Twenty study sites were identified: ten eastern systems and ten starnosed systems. Pretreatment live trapping to verify species was not carried out because of a limited number of available study sites and the lack of a dependable live trapping method. The sites were numbered geographically, with adjacent sites receiving adjacent numbers. Those sites assigned odd numbers were labeled treatment sites, and even numbered sites were designated control areas. One control site was removed from the study shortly after research began because a foreign toxic bait product was found in the system.

The bait efficacy study was originally designed to test for treatment and species effects. However, after several weeks of data collection, it became apparent that soil type and/or presence of irrigation may have been affecting bait effectiveness. Therefore, these two factors were added to final data analysis.

Sites classified as "irrigated" all had built-in irrigation systems which were operated at similar rates and schedules.

Orco Mole Bait (active ingredient: chlorophacinone) is a hard pellet bait manufactured by Oregon Rodent Control Outfitters (P.O. Box 361, Eugene Oregon). Efficacy testing of the bait was conducted July 10 to September 16, 1986 and February 10 to March 15, 1987, but sporadic mole activity during the second phase made testing impossible.

Only tunnels currently active were used for study. Mole activity was determined by creating "activity assessment points" every 10 to 15 ft along all visible tunnels. The method by which the activity assessment points were created depended on the characteristics of the damage on a particular site. In shallow systems (designated eastern mole systems as described by Dudderar (1985)) the mole tunnels just below the surface of the ground, leaving raised ridges on the turf. These tunnels were marked by depressing short sections of tunnel or by poking a 1" hole in the top of the tunnel. In deep systems (identified as starnosed mole systems) the moles tunnel 4 to 20 inches below the ground surface, pushing the excavated earth up to the surface through vertical shafts. This results in large, cone-shaped mounds on the surface of the turf. Deep systems were marked only by poking holes in the top of the tunnel, either directly in the middle of one mound or between two mounds. Activity assessment points were marked with spray paint for easy identification on subsequent visits. A tunnel was declared "active" if the moles repaired activity assessment points on that tunnel by raising the depressed section of tunnel or patching the hole with soil from within the tunnel 3 times in 5 days.

Bait application varied with the species of mole creating damage. In eastern mole systems, a small hole was poked in the top of the tunnel with a blunt probe. A teaspoonful of bait was put into the tunnel, and the hole plugged with a clod of dirt or a wad of grass. Care was taken to keep the bait free of human scent and soil during application and hole plugging so the attractiveness of the bait was not reduced. Bait was applied in this manner every 10 to 15 ft in all active tunnels. Starnosed mole tunnels were treated by driving the blunt probe through the soil between two mounds until the tunnel was located. A length of rubber tubing was then inserted into the tunnel and the bait was fed into the tunnel through the tubing. The tube was removed and the hole blocked in the same manner as eastern mole systems.

The same process was followed on control sites of both species, but no bait was applied before the holes were plugged.

Activity was monitored on all sites every 2 to 4 days after initial bait application. New damage was baited as soon as regular activity was confirmed via activity assessment points. Bait was reapplied to the entire treatment site if activity did not stop within 10 days. If activity did cease, activity points were monitored as usual for the remainder of the study.

Bait acceptance was tested on three captured moles after acclimating them to lab conditions for 5 days. Moles were captured by quickly scooping them from surface tunnels with a shovel when their presence was detected by movements in the turf. Moles were kept in 20 x 12 x 10 inch glass aquariums with approximately 4 inches of soil, and given water and earthworms ad libitum. Bait was added on the fifth day to provide a free choice between the bait and earthworms.

Necropsy examinations were performed on all moles found dead in the field and in the lab. Any mole that had not died from internal hemorrhage due to bait ingestion was submitted to the Michigan State University Animal Health Diagnostic Laboratory for further examination.

When the presence of other fossorial species was suspected because of uncharacteristic holes in the tops of tunnels, Sherman live traps baited with oatmeal and peanut butter were placed near the openings of the holes and checked twice a day.

WEATHER-ACTIVITY CORRELATION

Data to test for correlation between mole activity and average maximum and minimum ambient temperature, evaporation, and precipitation were collected July 1 to September 15, 1986. Data were also collected February 10 to March 20, 1987 to test for relationships between winter activity and average maximum and minimum ambient temperature, precipitation, and soil and tunnel temperature. Control sites from the bait efficacy study were used to test for correlation during the summer months. Six systems were identified at Halmich Sod Farm (muck), Woodhill Condominiums (sand), and M.S.U. (loam) for winter weather correlations. These sites were not categorized by species for two reasons. 1)

Only mounded systems were found during the winter, and 2) summer studies showed species could not be accurately determined from tunneling characteristics. Activity was measured by using deep activity assessment points as described in the BAIT EFFICACY section. The daily level of tunneling activity was measured as a proportion of assessment points used per day to the total number of assessment points per site. Ambient temperatures, evaporation, and precipitation data were obtained from the East Lansing post of the National Weather Service.

Soil and tunnel temperatures were taken with T-type copper constantan thermocouples. These thermocouples were constructed by attaching subminiature male connectors to one end of polyvinyl covered copper constantan wire, and melting exposed wires together at the female end. The female end was then covered with epoxy for protection.

Three thermocouples were placed in various parts of each tunnel system, so that the female end of the thermocouple just penetrated the tunnel. About one foot from the tunnel, a fourth thermocouple was placed in the soil at the same depth as the tunnel thermocouples to measure corresponding soil temperature. The male ends of the thermocouples were covered with plastic test tubes, corked with rubber stoppers, and secured on short posts for protection from the elements. Temperature readings were taken with an Omega Engineering Copper Constantan Portable Thermometer twice a day; once in the morning between 9 and 10 a.m., and once in the afternoon between 4 and 5 p.m. When a Paired T-Test showed no significant difference between morning and evening temperatures, readings were taken only one time each day.

DATA ANALYSIS

Fisher's exact probability was used to test for differences between treatments and species type. Differences in the number of days to zero damage on irrigated and non-irrigated soils were tested with the Mann-Whitney U test. Multiple regression analysis was used to test for relationships between weather factors and level of activity. Analysis of variance was conducted to test for temperature differences within tunnel systems, and Fisher's Least Significant Difference method was used to detect where differences occurred when the F statistic was significant. Paired T-Tests were conducted to test for differences between soil temperature and tunnel temperatures. An Alpha level of .05 was used to test for significance in all cases.

RESULTS

BAIT EFFICACY

Data analysis shows that Orco Mole Bait was effective ($p = 0.01751$). An average of 30.3 days was required to achieve zero damage on treatment sites ($n = 10$, $s^2 = 160.45$), whereas it took an average of 47.44 days to achieve zero damage on control sites ($n = 9$, $s^2 = 27.44$) (Table 1).

The average number of days to control on different soil types and watering regimes are presented in Table 2.

Mann-Whitney U analysis showed that irrigation significantly increased the number of days to zero damage on treatment sites ($p = 0.019$).

Species of mole treated was removed from overall data analysis for two reasons. First, there was no significant difference in time to control or percent activity between designated eastern and starnosed moles systems ($p = 1.556$). Secondly, the study showed that in Mid-Michigan one cannot correctly identify the species of mole in a tunnel system by the physical characteristics of that system as was previously thought (Dudderar, 1985). On three occasions an eastern mole was collected from a designated starnosed system, and once a starnosed mole was captured in a designated eastern system.

Table 1. Average Number of Days to Zero Damage Following Application of Orco Mole Bait, With Respect to Irrigation

	TREATMENT	CONTROL
DRY	21.0 n=5 s^2=4.00	* n=5 s^2=0.00
IRRIGATED	39.6 n=5 s^2=140.80	44.25 n=4 s^2=48.25

*zero damage not achieved within 50 day observation period
n=number of sites
s^2=variance

Table 2. Average Number of Days to Zero Damage Following Application of Orco Mole Bait, With Respect to Irrigation Within Soil Type

		TREATMENT			CONTROL		
		Muck	Loam	Sand	Muck	Loam	Sand
DRY	#Days	20	24	20.5	*	*	*
	n	2	1	2	2	2	1
	s^2	0.00	-	4.50	0.00	0.00	-
IRR.	#Days	34	32	*	36	*	41
	n	1	2	2	1	2	1
	s^2	-	200.00	0.00	-	0.00	-

*zero damage not achieved within 50 day observation period
n = number of sites
s^2 = variance

Multiple mole occupancy or extremely rapid reinvasion of tunnels occurred and confounded bait effectiveness. In three systems activity persisted the day after moles were physically removed from the systems. On two of the sites eastern moles were removed (one caught with shovel, one found dead) and activity continued at all activity points. At another site a starnosed mole was removed, and 2 days later an eastern mole was removed from the same site, approximately 20 ft from the point of the first capture. Following the removal of this second mole the system remained active but a consistent subset of points was not used again for 14 days.

The presence of fossorial species other than moles was confirmed on several active and evacuated mole tunnel systems. Thirteen lined ground squirrels (Citellus tridecimlineatus), meadow voles (Microtus pennsylvanicus), short-tailed shrews (Blarina brevicauda), white footed mice (Peromyscus leucopus) and deer mice (Peromyscus maniculatus) were live-trapped in either deep or shallow mole systems during this study. The presence of these other fossorial species confounded bait effectiveness.

Observations showed that moles easily adapt and seem to be somewhat attracted to human alterations of the environment. Moles used "ideal" microhabitats on 17 of 19 sites included in this study. These ideal microhabitats are protected areas with higher moisture content and less compaction than surrounding areas. Ideal microhabitats are created by natural features such as the areas under trees, bushes, and rocks, and man-made features such as gardens and mulched areas, beneath decks and fences, under wood piles, and along building foundations and driveways. The degree of ideal microhabitat use in tunnel system varied. Some tunnel systems were 100% included within ideal microhabitat, while others systems were comprised of lengthy and extensive travel tunnels leading from one ideal microhabitat to another. Of the two sites that did not include ideal microhabitats, one individual migrated to a vacated system that included ideal microhabitats, and the other succumbed to treatment within 4 days.

Only one dead mole was recovered from field studies. This 120 g male was found above ground at a control plot. Damage at this site did not cease when the animal was found. Necropsy showed the mole was in good condition with no external lesions or evidence of hemorrhage. There was a bright pink granular material in the stomach, so stomach contents were analyzed for other toxicants. No toxic compounds were detected by GC/MS screening. Problems identified in the mole included parasitic hepatitis, most likely caused by a Schistosoma-type of parasite. A focal granulomatous enteritis caused by a foreign body, probably derived from plant material, was also found.

One mole was capture with a shovel in a treatment area two days after bait application. Internal examination showed signs of hemorrhage, and there were small pieces of bait in the stomach along with earthworm remains.

All three captive moles readily accepted the bait. All died within 24 hours after consuming the bait, and all showed evidence of internal hemorrhage.

WEATHER-ACTIVITY CORRELATION

Regression analysis showed no relationship between precipitation, average minimum and maximum ambient temperatures, or evaporation and level of tunneling activity on 7 of 9 sites. A correlation between minimum average temperature ($Pr>F = 0.000$, $r^2 = 0.7147$) and negative correlation between maximum average temperature ($Pr>F = 0.000$, $r^2 = 0.6918$) and activity occurred on one irrigated sand site, and between evaporation and activity on an irrigated muck site ($Pr>F = 0.001$, $r^2 = 0.6489$). However, because of the insufficient sample size these results are questionable, and type II errors are assumed in these cases.

Statistical analysis was impossible on winter activity-weather correlations because of small sample size, short duration of observation time, and insufficient variance of independent weather variables (particularly temperature). However, in reviewing the data, no obvious relationship between these factors and winter activity on a short term basis is apparent.

On only one site was there a significant difference among temperatures within a tunnel system ($Pr>F=0.002$).

DISCUSSION

BAIT EFFICACY

While the bait was effective on all soil types, differences between soil types may have been confounded by geographical location.

While analysis showed that irrigation lessened the effectiveness of the bait across soil types, small sample sizes within irrigation and soil type made statistical analysis of irrigation effects within soil types meaningless. However, the data suggest that irrigation increases the number of days to zero damage within each soil type. An increase in number of days to zero damage due to high soil moisture might occur for two reasons. First, more earthworms and other natural food items would be present at the depth where foraging moles cause detectable soil disturbance. While limited laboratory bait acceptance tests showed that moles ingested lethal quantities of bait even when given free choice between the bait and earthworms, their behavior under natural conditions is unknown. The moles may not consume as much bait as they would when natural food items are less abundant. A second reason that excessive soil moisture may increase the length of time to reach control is that under these conditions the bait may become less palatable and therefore not be consumed. When bait was placed in a container of soil and left outside in an unprotected area for ten days, it was still intact but quite mushy. When using Orco Mole bait on irrigated soils it may be necessary to retreat the system if satisfactory results are not obtained within seven days. Stopping or decreasing irrigation during treatment may decrease the number of days until control is reached, but more research regarding irrigation and bait efficacy is needed before firm recommendations can be made.

Although there was no difference in the number of days to zero damage on shallow or deep systems, this study showed that the physical characteristics of damage are not a viable indicator of the species of mole occupying a system in Mid-Michigan as previously believed (Dudderar, 1985). On two occasions eastern moles were captured in designated starnosed or deep systems, and once a starnosed mole was captured in a categorized eastern mole system. There are two possible explanations for this phenomenon. 1) These systems were originally constructed by the designated species then reinvaded by the "opposite" species, or 2) these moles constructed tunnels in response to soil type or soil condition, rather than to species type. Slonaker (1920) and Harvey (1976) found that Scalopus made both ridged tunnels and mounds, and Hamilton (1931) documents Condylura creating both shallow and deep tunnels as well. Both reinvasion of abandoned tunnels and creating alternative tunnel types would be beneficial from an energy use perspective. Hisaw (1923), Arlton (1936), and Giger (1973) refer to the tremendous amounts of energy that moles expend. Any energy conservation would be to the mole's advantage. It would require less energy to invade a vacated system than to construct a new one. Maintaining surface tunnels where the soil surface is regularly compacted by mowing, rolling, or freezing would be extremely energy intensive. When such conditions are present it would seem more energy efficient to construct a deep tunnel system one time rather than rebuild surface tunnels every 2-3 days. Future research on energy requirements of foraging and tunnel construction would be very helpful in determining when and why moles exhibit different tunneling behaviors.

Four factors observed during the study confounded evaluation of bait effectiveness: multiple mole occupancy, reinvasion of evacuated systems, the presence of other fossorial species, and the use of ideal microhabitats.

Multiple occupancy of mole tunnel systems was confirmed on several study sites. On three separate occasions damage continued in an entire system after one or more moles were removed from system. This suggests that either more than one mole was concurrently using all parts of the tunnel system, or extremely rapid reinvasion occurred. Rapid reinvasion is an unlikely explanation for this situation. While reinvasion of vacated tunnels was documented on 4 treatment sites (supporting Hartman & Gottschang's (1983) findings), no site in this study was clearly reinvaded for at least 10 days after the system was vacated. In several instances a few sporadic activity points would be used after a system was evacuated. These intermittent, low levels of activity appear to be exploratory actions to determine the possibility of reinvasion. If these low levels of activity appeared within seven days after tunnel evacuation, activity would cease without treatment. If these low levels of activity occurred 10 or more days after tunnel evacuation, activity levels would dramatically increase, indicating that a successful reinvasion of the system had occurred. This concurs with Leftwich's (1972) findings of exploratory diggings from translocated moles. Leftwich speculates that moles use some type of chemical marking to identify their tunnels, which may explain why no systems were reinvaded for at least 10 days after evacuation. Since damage remained at a constant level after individuals were removed from the system on the three sites in this study, I believe multiple occupancy, not reinvasion, was occurring.

While there is no argument that starnosed moles are gregarious (Hamilton 1931, Eadie and Hamilton 1956), there are conflicting reports on conspecific interactions among eastern moles. Schwartz and Schwartz (1959) and Leftwich (1972) claim that eastern moles are solitary, while Henning (1957) and Harvey (1976) support the belief that multiple occupancy occurs among this species.

In one instance during this study a starnosed mole was removed from a system by a dog, and two days later an eastern mole was removed from the same tunnel approximately 20 feet from where the first mole was taken. Damage remained constant after removal of the first mole, and when the second mole was removed activity stopped in a subset of points in the system for 14 days. This suggests that the second mole may have had an established territory within the larger tunnel system, similar to Giger's (1973) findings with Scapanus. However, this is the first report of two different mole species occupying the same tunnel system, which rules out the possibility of multiple occupancy due to family grouping and/or early pairing for the breeding season.

When either multiple mole occupancy or reinvasion is occurring in a system being treated with Orco Mole Bait, several applications of bait may be required before all individuals occupying or reinvading the system are affected.

Other fossorial species' use of mole tunnels occurred on at least three treatment sites. Hickman (1987) caught Microtus in Condylura systems, but this was the only reference to other species' use of mole tunnels found in the literature. Just as it would be less energy intensive for a mole to invade an existing mole tunnel rather than construct a new one, it would be easier for a ground squirrel, shrew, mouse, or chipmunk to use existing subterranean corridors than to construct new ones.

When moles and other species were concurrently using the tunnel systems, it was difficult to detect the other species' presence and categorize damage by species. Only upon closer inspection of root damage and the length of time that activity occurred was there any indication of additional species' damage. After several bait applications the nature of the damage changed slightly, indicating that moles were eradicated from the system but non-target species were not. Where shrews were co-occupying mole systems (2 sites), tunnels got smaller, more shallow, with more small (<1") holes in the tops of tunnels, and had more concentrated foraging areas which remained in mulched and garden areas rather than expanding onto turf areas. Where ground squirrels remained in previous mole tunnels (2 sites), the tunnel diameters increased slightly and deep travel tunnels were very well maintained without the mounding typical of mole maintenance.

There is some question why these non-target species were not eradicated during treatment. Non-target species may not find the bait attractive or palatable and therefore not ingest it. They may consume some bait, but not get a lethal dose either because there is an ample supply of preferred natural food items, because they cache the bait, or because they require a higher dose of bait than is applied for mole control. Shrews are colonial, and population levels may be high enough that while some individuals die, damage continues due to the remainder of the population. Rapid reinvasion of non-target species may occur. Field and laboratory research regarding the response of these other fossorial species to Orco Mole Bait is required to determine exactly what occurs when moles and these other species are co-occupying tunnel systems. This study showed that the bait controlled mole damage with no apparent effect on non-target organisms utilizing treated tunnel systems. However, it is important to identify all species using these tunnel systems when treating damage, and damage control methods for these other species may need to be applied simultaneously or in succession to mole damage control with Orco Mole Bait.

It is widely accepted that moles prefer wooded, shady, moist areas (Arlton 1936, Godfrey 1957, Funmilayo 1977, Henderson 1983). In addition, several authors noted that stumps, logs, rocks, and fence rows are often incorporated in mole systems (Hamilton 1931, Arlton 1936, Henderson 1983, Corrigan 1987). These above ground features are attractive because they create ideal microhabitats for moles because they have a higher soil moisture content and lower soil compaction than surrounding areas, and also provide protective nesting cover. The combination of high soil moisture and low compaction not only offers little resistance to tunneling efforts, but is also conducive to earthworm populations, creating a concentrated forage area. Both of these situations result in opportunities to tunnel and forage with minimal energy expenditures.

Humans, in their attempts to create aesthetically pleasing lawn and yard environments, create prime mole habitat by creating ideal microhabitats under tree and shrub plantings, in garden and mulched areas, and under woodpiles and decks. Travel tunnels were often constructed next to house foundations and driveways. Moles were attracted to the ground beneath birdfeeders (six sites) and fruit trees (two sites). Under the fruit trees they were probably foraging on invertebrates that were attracted to rotting fruit on the ground. Moles were observed on several occasions foraging under birdfeeders and eating the seed that had fallen to the ground. When surveying mole damage, it is important to identify ideal microhabitats and recognize them as attractants. In some cases alteration of these habitats can be useful in controlling damage, such as picking fruit up off the ground under trees, or moving or removing birdfeeders. When treating systems with Orco Mole Bait, bait should be applied close to, and on all possible sides of ideal microhabitats.

The bait was ineffective on irrigated sandy soils. It is unclear whether this is due to inherent factors of this soil type and watering regime or because of various circumstances at the two irrigated sandy sites studied. Sandy soils have lower earthworm populations than loams or mucks, so one may argue that the moles on these areas are eating alternative food sources such as grubs and other insects, and for some reason are not consuming the bait. If this is the case, insecticide applications may be more effective than Orco Mole Bait. However, this same argument should be true on dry sandy soils. Control was achieved with the bait on dry sandy soils in this study, so the alternative food argument is invalid. One would expect even fewer earthworms on dry sandy soils. Both irrigated sandy sites had abundant ideal microhabitats, including mulched garden areas, a fruit tree, a birdfeeder, and wooded areas. On one of the sites shrews were also using the system. On the other site, multiple occupancy was suspected. Perhaps the combination of all these confounding factors (irrigation, other fossorial species, multiple occupancy, and ideal microhabitats) on each site decreased bait effectiveness enough that no control was observed within the 50 day observation period. Additional research with larger sample sizes is needed to determine whether the bait is truly ineffective on irrigated sands, or other confounding factors are playing a large part in decreasing bait effectiveness on this soil/water type.

Two cells in the Control portion of Table 1 show that damage ceased, despite the fact that no bait was applied to these systems. The site represented in the irrigated sand cell (1 repetition) was a relatively small system (< 30 ft.) that worked from the root area of a large tree to the sprinkler area of a yard. While the system was near a wooded area, the woods were not incorporated into the tunneling area. Other than the large tree there were no ideal microhabitats. Based on the soil type and lack of ideal microhabitats, this is relatively poor mole habitat. The homeowner at this site said the system had been active for 3-4 years, so natural mortality is suspected. The low quality of the site was reaffirmed by the fact that this site was never reinvaded, despite the nearby woods which could serve as a recruitment area.

Damage also ceased prematurely on the irrigated muck control site (1 repetition). The individual from this site emigrated to a nearby site which had been evacuated due to treatment. This "new" site had more ideal microhabitat area in the form of trees, as well as less standing water than the "old" site, making it more suitable for tunneling and foraging.

Emigration and reinvasion of an evacuated site was documented on one other occasion, after bait efficacy observations were completed. Again, an individual emigrated from a site with low soil moisture and no ideal microhabitats to a successfully treated site with irrigation and a large number of ideal microhabitats. These migrations to areas with ample ideal microhabitats illustrates and confirms the attractive value of ideal microhabitats.

WEATHER-ACTIVITY CORRELATIONS

Although Arlton (1936) and Harvey (1967) state that rain apparently stimulates tunneling activity, this study does not confirm that rain or any other of the other weather factors investigated encourage mole activity. It is suspected that this lack of significant correlation between weather factors and activity is due to insufficient sample size and insufficient duration of observation. This analysis measured for activity responses to short term weather fluctuations. Further study is required to determine fluctuations in activity levels due to long term weather changes. Soil moisture should be included as an independent factor in future studies.

Winter observations of tunneling activity showed that no new tunnels were constructed. Short lengths (10-30 ft.) were maintained, and when activity did occur all parts of the visible system were active. In no case was only a part of the visible system active, as happened frequently during summer months.

In the one case where a significant difference was detected among temperatures within a tunnel system, the tunnel system worked the turf area from the shady, north side of a building to the sunny, west side of the building. The temperature points on the sunny side of the building were consistently warmer than the three on the shady side of the building. There was no difference in activity levels between the warmer sites and the cooler sites, which shows that tunnel temperature in this range (0-10 degrees C) does not affect activity.

SUMMARY AND CONCLUSIONS

This study showed that Orco Mole Bait is a highly effective, easily applied mole control technique. Bait effectiveness was confounded by wet soil conditions, multiple mole occupancy, reinvasion, and the presence of other fossorial species. Moles were found to be attracted to natural and man-made microhabitats with high soil moisture and low soil compaction. A disadvantage of using Orco Mole Bait is that several applications may be required, particularly when one or more confounding factors is acting. In addition, it is a toxicant which is hazardous if consumed by children or pets. On the other hand, the bait is inconspicuous and therefore more aesthetic and tamper resistant than traps. Unlike fumigants and insecticides, there are no restrictions on use areas and it appears to pose minimal hazard to non-target species, and treatment of only a part of a system is sufficient.

No direct relationship between weather factors and winter or summer tunneling activity on a short term basis was found, but relationships between long term weather fluctuations and soil conditions are suspected to affect tunneling activity and should be examined in future research projects.

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