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Abstract: We conducted experiments with behavioral conditioning of white-tailed deer *(Odocoileus* virginianus) using verb 3-wire, electrified fencing modified with either an attractant or a repellent in order to test the idea that an attractant or repellent coupled with an electric shock, would be a more effective deterrent than a random shock or no shock at all. Exclosures measuring 6 x 6 m with 3 wires at heights of 50, 100, and 150 cm were established at 2 study sites in Tompkins County, New York. Each site contained 4 exclosures which were either nonelectrified (control), electrified, electrified with an attractant, or electrified with a deer repellent. We baited each exclosure with fresh apples to ensure visitation by deer. All exclosures were monitored daily to determine her visitation, disappearance of apples, and to measure fence voltage. Data from 116 days indicate that the electric fence with a repellent excluded deer most effectively. Deer penetrated this type of exclosure only once. Electricity and attractant ranked second, and electricity alone ranked third in effectiveness for excluding deer. The control was the least effective barrier (37 encroachments).

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Increasing human populations, urbanization of rural areas, and increasing populations of white-tailed deer cause more frequent interactions between humans and deer. This increase in interactions corresponds with an increase in deer damage incurred by fruit growers, nurserymen, and other groups (McAninch and Fargione 1987). Damage and economic losses sustained by farmers (Hyngstrom and Craven 1988), orchardists (Phillips et al. 1987, Purdy et al. 1987), nursery growers (Sayre and Decker 1990), and even gardeners and ornamental plant owners (Sayre and Decker 1990) have brought about the need for improved deer control techniques.

Little work has been done combining electric fencing with deerrepellentsorattractants. Separately, fencingandrepellents have been found to reduce damage, and perhaps together they have a synergistic effect. We hypothesize that the addition of a repellent to an electric fence would double the negative reinforcement for deer. The repellent itself may cause the deer to avoid the fence. However, if a deer does attempt to enter the fence and receives a shock, the combination of the repellent and the shock may clause the deer to recognize and avoid the fence in the future. Coupling the electric shock with an attractant, to ensure that the encroaching deer receives the shock, may also enhance fence effectiveness. Peanut butter was used as an attractant to encourage deer to touch the electric wires with sensitive parts of their bodies (i.e., their tongue or nose). This, we hypothesize, results in a sufficiently severe shock for deer, and would cause conditioned animals to avoid fenced areas in the future. The use of peanut butter has been found effective with single-wire fences exposed to light deer pressure (Kinsey 1976, Porter 1983, Hygnstrom and Craven 1988), and may therefore enhance the effectiveness of the 3-wire design. We report here on the testing of the 3-wire electric fence with attractants and with repellents to determine its effectiveness as a deer exclosure.

STUDY AREA

Two sites in the Town of Dryden, Tompkins County, New York were selected for this fencing study. Site 1 was in Varna, a rural area 4 km east of the City of Ithaca, southeast of Cayuga Lake. The exclosures were in a 16-ha field owned by Cornell University. The field was used primarily for experimental vegetable crops, and was bordered on one side by County Route 366, and by a mixed hardwood-conifer woodlot and Fall Creek on the other sides. Hunting was not allowed in the bordering woodlots.

Site 2 was in Ellis Hollow, another rural area about 5 km southeast of Ithaca and 3 km southeast of the Varna site. Exclosures were in a privately-owned 3-ha field of goldenrod (Solidago spp.) and red-osierdogwood (Cornus stolonifera). The field contained a pond, was bordered by county roads to the north and west, and a mixed hardwood-conifer woodlot to the south and east. The area immediately surrounding the field provided excellent deerr cover. Private ownership greatly limited hunting.

The density of deer in the study area is not known. The New York State Department of Environmental Conservation (DEC) uses buck-take/kmz as their primary index for population estimates. For the 250-km2 Town of Dryden, which encompasses both study sites, the average buck-take from 1985-1989 was 1.2 bucks/km2.

Although information about buck harvest at the Varna site was not available it would seem that deer numbers in this area were at least as high as the town average. In reality, deer numbers were likely higher because of the ideal mix of cover and the lack of hunting pressure. Landowner data on deer take from the Ellis Hollow site suggest that deer densities in this area (3.6 bucks/Ian 2, n = 22 years) were higher than the rest of the town. A series of pellet-count transects were conducted at Ellis Hollow during April 1990, and an average of 89.3 pellet groups/ ha (SE = 22.3, n =14 transects) were found. Deer sign (including tracks, runs, and fecal pellets) and deer sitings (during the day and at night using spotlights) indicated that deer frequented both study sites. Although actual deer numbers were not known, a combination of the population indices and personal sightings indicate that there were medium-to-high deer numbers near the exclosures.

METHODS

Fencing efforts began in the summer of 1990. Four 6 x 6 m exclosures were established at each of the 2 study sites. Exclosttres were randomly selected to receive 1 of 4 treatments: (1) no electricity (control), (2) electricity, (3) electricity and an

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attractant. or (4) electricitv and a repellent. The exclousers wer r

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Vegetation inside and 1 m around each plot was cut with a law re

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and plastic comer insulators, 3 wires were connected to th posts at y

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lower wires were added to the fences at heights of 10 and 25c to m

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wires provided little physical barrier to the deer, but we necessary to re

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A 1 x 1 m area was dug in the center of each plot, and to soil was s

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3 top wires on all 4 sides of each exclosure. These strip provided a d

used as an attractant, and an experimental deer repellent call s

"Jersev" (Savre and Richmond 1991).was used as a repellent

All wires of the electric fences were powered with 6-vol t
solar-powered fence chargers. Fence-line voltage was mea re

sured daily with a hand-held Voltmeter. Twelve apples we placed in the center of each plot. No lag time was permit
between presentation of bait and electrification of the fence prevent t°

December of 1990, and from early May to mid-August of 1991 the exclosures were visited daily to record the number o missing or damaged apples, and to note evidence of encroach ment by deer or small mammals (i.e., tracks, scat, hair, fenc

damage, apple damage, sightings, etc.). The study period encompassed 116 days of baited plot exposure (any day i which apples were available to deer). All missing or damage(apples were replaced daily, and plot centers were raked to cle away old tracks and keep the soil friable.

Vegetation was trimmed periodically using a lawn mower and weed whip. Fresh peanut butter and Jersey were placed on the cloth every 3-4 weeks to ensure that they continued to act as attractants or repellents.

RESULTS

The electric fence with the repellentJersey most effectively excluded deer, as this design was only penetrated once (0.9% of total exposure days, Table 1). The electric fence with the peanut butter attractant was second most effective, experiencing only 9 (7.8% of total exposure days) encroachments. The electric fence alone ranked third most effective, as deer penetrated this design 13 times (11 % of total exposure days). As expected, the least effective fence was the nonelectrified control. Deer penetrated the 2 control plots approximately 32% of the days. More than 300 apples were removed by deer during the 37 known instances of deer encroachment.

Table 1. Deer encroachment by fence design at study sites near Ithaca, New York, 1990-91.

Fence Design	Days of Plots	Exposure	Instances of Deer Damage	Apples taken by Deer
Control	2	116	37`	328
Electric	2	116	13	79
Attractant & Electric	2	116	9	59
Repellent & Electric	2	116	1°	8

'P<0.O1,X1=32.27,3df.

Deer entered the control exclosures more frequently than expected (JCS = 32.27, 3 df, P < 0.01), and deer penetrated the electric fences with Jersey less frequently than expected (X1= 13.07, 3 df, P < 0.01). Deer penetrated the electric fence alone or the fence with peanut butter as often as expected.

The addition of 2 lower electrified wires kept out some small mammals, but were not an absolute barrier. The nonelectrified fence had little effect, as 560 apples (20.1 % of all apples placed in both exclosures) were removed or damaged by small mammals. The 3 electrified fence designs reduced encroachment by small mammals. Only 385 (13.8%) apples were damaged or removed from exclosures treated with elec tricity and peanut butter, 330 (11.9%) from exclosures with electric fences without attractant or repellent, and 210 (7.5%) vfrom exclosures with electricitv and Jersev.

f DISCUSSION

Fencing has been one of the most effective controls fordeer e damage. Previously, most fencing efforts focused on conven tional nonelectrified, woven-wire designs (Ellingwood et al. n 1985). The most effective fence has been the 2.4-m vertical, woven-wire design (Caslick and Decker 1979, McAninch and Winchcombe 1981, Craven 1983). Although this design pro

vides a formidable barrier to deer, the predominant objection to conventional fencing techniques has been high construction costs (Table 2). According to Ellingwood and McAninch (1984), construction of an 2.4-m woven-wire fence costs $15.88 per linear meter (adjusted to 1991 prices). Consequently, conventional fences in areas of intensive agriculture, such as orchards or private gardens, have been limited (Harder 1968, Craven 1983). Furthermore, its large size and great visual impact makes an 2.4 m fence impractical for homeowners and gardeners.

Table 2. Prices and cost-effectiveness of basic deer fencing designs compared to the vertical 3-wire electric fence.'

Design	Cost'ninear m	Level of deer pressure at which fence is cost-effective
2.4-m woven-wire nonelectric	$15.88	High
7-Strand slanted electric fence	6.30	Moderate-high
Vertical s-wire electric fence	3.25	Moderate-high
Vertical 3-wire electric fence	2.59	?

' Costs from Ellingwood and McAninch (1984), adjusted to 1991 prices.

Recent developments in fencing technology, including high-tensile wire and powerful, dependable fence chargers, have increased the popularity of electric fences. This, coupled with improved designs, has increased the efficacy of electrical fencing and provided the public with a variety of control options. One such design, the 7-strand slanted fence (Ellingwood et al. 1985), successfully excludes deer at high deer pressure (McAninch 1980, McAninch and Winchcombe 1981). With a construction cost of $6.30 per linear meter (Table 2), this fence is much less expensive than the 2.4-m woven-wire fence. However, its spacious and complex design are impractical for homes and gardens. The vertical 5-wire fence (Ellingwood et a1.1985), also known as the Penn State electric fence, has been an effective deer exclosure (Palmer et al. 1983, Palmer et al. 1985, Kochel and Brenneman 1987). Low cost of $3.25 per linear meter (Table 1) and easy construction have increased the popularity of the 5-wire fence with homeowners. In spite of recent improvements in design and materials, fencing costs must be further reduced for practical use by the nursery owner, home gardener, and commercial vegetable grower.

The vertical, 3-wire electric fence at $2.59 per linear meter (Table 2) is less expensive than the 5-wire fence. Its simple structure is practical for use by ornamental plant owners and gardeners. At mediumtohighdeerpressures,the3-wiredesign with attractants or repellents appeared to provide an effective deer exclosure.

The nonelectric fence was the least effective deer exclo Deer either crawled under, went through, or jumped over it little difficulty. The addition of electricity clearly increased effectiveness of the design. A possible drawback of electric alone is that many times deer going through the fence contact the wire with insensitive parts of their body (i.e., n back, or chest), resulting in a shock too mild to deter the an (McKillop and Sibly 1988). In addition, deer that recently electrical shocks to random parts of their body may not ate the pain with the fence, and as a result, may experience li aversive conditioning.

The number of deer encroachments into the electric' alone fences and electricity-plus-peanut-butter fences were statistically different in this study. However, the addition of peanut butter may create an association between the pain the shock and the fence, causing deer to avoid the fence in fu encounters. The fact that 9 instances of encroachment occur, suggests that some deer did not investigate the peanut butter and simply entered the fence. Another possible explain nation is that some deer that did receive a shock by investigation the peanut butter associated that pain only with the peanut butter and penetrated the fence in the future avoiding the peanut butter.

The electric fence with the repellent Jersey was the most effective and was encroached upon less frequently. Because w do not have observations of deer encountering any of these fences, we can only speculate as to how they work. If deer avoid the fenced area altogether because of the odor from the repellent, then this reduces the possibility of random crossings of the fence.

The combinationofelectricityandrepellentmaybeeffective because the presence of the electricity provides a second level deterrent. Without electricity, a deer that ignores the repellent would have little trouble crossing the fence. However, a deer that initially ignores the repellent and then receives a shock while trying to enter the fence may avoid the fence in the future because of the dual aversive conditioning.

Deer appeared to exhibit a conditioned avoidance of the fences equipped with the peanut butter and Jersey. McKillop and Sibly (1988) state that most animals can learn an immediate and long-lasting avoidance of objects associated with unpleasant experiences. It would be useful to continue studies of learned behavior in both captive and free-ranging deer, and attempt to take advantage of this conditioned avoidance phenomenon. Studies of multiple-cueing, or simply the identification of key signals that warn deer (i.e., flagging, unusually-shaped objects, odor-based repellents, etc.) may prove quite fruitful in a search for new deer management strategies.

MANAGEMENT IMPLICATIONS

The vertical, 3-wire electrified fence modified with the addition of a deer repellent provided an effective barrier to deer encroachment at medium-to-high deer densities. With its small

visual impact, simple design, and relatively-low construction costs, the 3-wire fence could be further developed as an inexpensive and viable control of damage in many situations, especially those faced by homeowners and gardeners. Although the use of electrified fencing may be inappropriate in areas frequented by humans, particularly children, further investigationintothedurationofconditioned-fence-avoidancebehavior by deer may reduce the amount of time necessary to keep the fence electrified.

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