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Abstract: Research at the Pennsylvania State University was directed towards finding effective repellents to control damage caused by white-tailed deer (Odocoileus *virginianus)* and to develop a low-cost alternative to the traditional 2.4 m woven wire barrier fence, considered to be deer-proof, but too expensive for mgt agricultural uses. Fourteen repellents were screened and 9 were found to be more effective than the others. These 9 repellents were further investigated under semi-field conditions and only 1 repellent was found to be consistent in reducing deer feeding. A vertical electric deer fence was effective in excluding deer at field sites containing alfalfa, small grains, vegetables, orchards and young coniferous trees. This fence offers producers a low-cost alternative to the 2.4 m woven wire fence.

Introduction

The. problem of deer damage to Pennsylvania agriculture has been discussed since the Commonwealth was settled. Today, deer damage continues to be a serious problem not only for the farmer but also for the forest products industry.

Corn is the most frequently damaged crop, with fruits, vegetables and small grains also receiving heavy damage. Regeneration failures are the major problem in. Pennsylvania's forests.

Personnel from the School of Forest Resources, The Pennsylvania State University, conducted a survey of producers, game wardens, and county agricultural extension agents regarding what deer damage control methods were being used in Pennsylvania (Wingard et al. 19811. Based on the results of this survey, research was conducted on chemical repellents and fencing.

Repellent Study #1

Methods

Many repellents have been tried in various parts of the country. It is difficult to compare different repellents because tests done in the past have not been comprehensive in nature nor scientifically conducted. A major problem arises when trying to compare repellents tested in different studies because of differing combinations of repellents and dissimilar procedures. This study compares the effectiveness of 14 commonly used deer repellents under pen conditions. The repellents selected included commercial products and "home remedies" (Table 1).

The study was conducted at the Pennsylvania State University Deer Research Facility. Repellents were applied to shelled corn in concentrations suggested by manufacturers or by the literature and personal communications for "home remedy" repellents.

Table I. White-tailed deer repellents tested in **Repellents Study** #I at the Pennsylvania State Deer Research Facility.

Trade Name	Active Ingredient(%)	Application Process	Active Ingredient Applied %
Home Remedies			
Feather meal	Chicken feathers (100)	5g/500 g corn	100
Moth balls	Napthalene (100)	3 balls/500 g corn	100
Creosote	Creosote (97)	saturated 25-cm2 rag/500 g corn	97
Hot sauce	Capsaicin (2.5)	spray	0.0012
Hair	Human hair (100)	2g/500 g corn	100
Blood meal	Blood (100)	10g/500 g corn	100
Meat meal (Tankage)	Meat meal (100)	10g/500 g corn	100
Registered (EPA) Deer Repellents			
Big Game Repellent	Putrescent egg solids (37)	spray	4. 93
Magic Circle	Bone tar oil (93.8)	saturated 25-cm, 2reg/500 g corn	93.75
Spotrete-F Flowable Fungicide	Thiram (42)	spray	5.25
Hinder	Ammonium soaps of higher fatty acids (15)	spray	0.71
Gustafson 42-S	Thiram (42)	spray	2
Chaperone	Thiram (7)	spray	7
Nott Chew-Not	Thiram (20)	spray	10

The technique used for presenting a treatment (repellent) with a control to deer was a modification of a preference-testing system developed by Campbell and Bollard (1972). Pairs of parts, spaced 10.2 cm apart, were offered to deer on a manually rotated plywood wheel. Each pair consisted of a pan containing treated, shelled corn and a pan containing an equal amount of untreated, shelled corn. The corn was prepackaged in polyethylene bags that were used to line the pans to prevent cross-contamination. The positions of the pans were randomized for each presentation to assure that the treated corn appeared an equal number of times on the right and left for each deer. The operator removed a shield covering the wheel and exposed a pair of pans to the deer. After a choice (Le., feeding from a pan for 2 **sec) between the treated and untreated corn** was made, the pans were covered and the next pair rotated into position for the next offering.

Tractable deer were used in this experiment because of the extent of handling and training required. Nine deer of mixed ages (3 yearlings, 4 2-year-olds, 1 3-year-old, and 1 5-year-old) and both sexes (3 females, 6 males) were used. All deer were taken off feed at least 2 hours prior to testing: This feed restriction ensured that deer readily completed choices.

Each deer was used to test one repellent per day until each had bin offered ail repellents. The order of repellents was randomized for each deer as well as the daily test order of deer. Each deer was allowed to make a maximum of 20 choices per day and this constituted a trial. The trials were replicated to increase the sample site to a maximum of 40 choices per repellent per deer, for a total of approximately 360 deer choices per repellent.

Percentage of times each deer chose the repellent treatment over the untreated paired control was calculated by the formula:

$$\text{Percent choice} = \frac{\text{number of times treatment chosen} \times 100}{\text{15 total number of choices}}$$

Results and Discussion for Study #1

Deer made choices in short time intervals. In most trials (8396), deer completed 20 choices in 10 or fewer minutes. The longest trial of 20 choices lasted 37 minutes. Deer did not complete 20 choices in only 9 trials (496). These trials were ended when the operator determined that a deer would no longer readily make a choice. The longest trial lasted 39 minutes.

A chi-square analysis for heterogeneity (goodness of fit) (Zar 1974) was used to test if all choices of all deer could be pooled for each repellent. The samples of choices of feather meal and creosote were homogenous ($P < 0.05$). The percentage of choices of treated corn for these 2 repellents were based on pooled choices and distributed equally among all deer. All other percentages were determined from the number of choices of treated corn made by individual deer.

The percentage of choices for all repellents was ranked for individual deer and summed across ail deer for each repellent A Friedman 2-way layout (Hollander and Wolfe 1973) showed highly significant differences ($P < 0.001$) among sums of ranks of percentages within treatments. A Friedman multiple comparison analysis was performed; differences ($P < 0.10$) existed between 5 groups of repellents (Table 2). The most and least repellent treatments, are distinctly separate groups with the exception of Spotrete-F. The other

Table 2. Deer repellents grouped according to Friedman's multiple comparison analysis of summed total of ranks. Banked were percentages of times deer chose corn, treated with repellent, against untreated corn.

Treatment	Summed total of ranks
Meat meal	26.5 Aa
Big Game Repellent	27.5 A
Feather meal	39.0 AB
Hinder	50.5 ABC
Hot sauce	51.5 ABC
Chew-Not	55.5 ABCD
Chaperone	57.0 ABCD
Gustafson 42-S	57.5 ABCD
Spotrete-F	61.5 ABCDE
Blood meal	91.5 BCDE
Magic Circle	9'3.5 BCDE
Human hair	106.5 CDE
Moth balls	110.0 DE
Creosote	117.0 E

aTotals with same letters are not significantly different ($P > 0.10$).

treatments (mothballs, creosote, human hair, Magic Circle, and blood meal) in the least repellent group cannot possibly belong to the most repellent group, so they should not be included as promising repellents.

This study evaluated 14 white-tailed deer repellents. Five repellents (mothballs, creosote, human hair, Magic Circle, and blood meal) were not as effective as the others. The other repellents (meat meal, BGR, feather meal, Hinder, hot source, Chew-not, Chaperone, Gustafson 42-5, and Spotrete-F) showed promise as deer repellents and were further investigated. Chew-not, Chaperone. Gustafson 42-S, and Spotrete-F contain the same active ingredient (thiram) and rank similarly in this study, although applied in different concentrations (2-1096). In the second study, one thiram repellent (Spotrete-F) was selected for use as a representative of all thiram repellents.

Repellent Study #2

Methods

This study was designed to further evaluate the 9 more effective repellents under semifield conditions.

Repellents tested were: Hinder, Hot Sauce, Big Game Repellent, Spotrete-F (which represented 4 thiram-based repellents), Feather Meal, and Meat Meal. The first 4 are commercially-produced, registered repellents and were applied to seedlings using a backpack sprayer, according to label specifications. Concentrations of active ingredients in the solutions were the same as in the preliminary study (Harris et al. 1983). Spotrete-F was used to represent 4 repellents containing thiram as the active ingredient. Feather Meal and Meat Meal (5 g each) were placed in a 7.5- x 9-cm cloth bag, tied approximately 6 cm below the seedling terminal bud.

Flowering dogwood (*Corpus florida*) seedlings, which are highly-preferred native food for deer in Pennsylvania (Brenneman 1975), were used for testing the repellents. The 1-year-old seedlings, obtained from the Pennsylvania Game Commission's Howard Nursery, were approximately 30 cm tall.

Seedlings in 11- x 13- x 15-cm containers were treated, then tied to steel stakes placed in a 14- x 20-m grid pattern at 1-m intervals. Forty seedlings per repellent treatment plus 40 untreated seedlings (controls) were randomly assigned to grid locations. A group of 10 deer (various sexes and ages) were moved into the enclosure and allowed to browse. Periodic checks were made and when approximately 80% of the controls showed damage, we removed the deer and counted damaged seedlings. For the next trial, another set of treatments was randomly assigned to the locations and a new group of 10 different deer was placed in the enclosure; this process was repeated for a total of 4 trials.

The design used in this experiment allowed individual deer to wander through the seedling area and avoid undesirable treatments. Randomized treatment locations reduced the "row-feeding" effect of deer (Dodge et al. 1977) and lessened the potential problem of foreign deer scent at a location. Use of a group of deer was intended to reduce the effect of individual variation among animals; daily replications should also decrease this effect. Data were analyzed using distribution-free multiple comparisons based on Kruskal-Wallis rank sums (Hollander and Wolfe 1973).

Results and Discussions for Study #2

Only Big Game Repellent was consistent is reducing deer feeding (Table 3). We found day-to-day as well as between- repellent variation is deer response; a distribution-free test showed treatment differences ($P < 0.05$). Multiple comparisons were made for treatments vs. the control, and only Big Game Repellent differed ($P < 0.05$) from the controls (no treatment).

The previous study showed differing efficacies among 14 deer repellents. This study was a further evaluation of the promising ones. Only Big Game Repellent consistently reduced deer feeding, but still requires further evaluation under field conditions.

Management Implications

Even though Big Game Repellent was statistically different than the control, it did not totally prevent deer feeding. The reduced level of damage provided by repellents available at this time does not solve the economic problem of deer damage to agricultural crops in general Wildlife managers need damage control methods with greater consistency in effectiveness.

Our results do not mean that a repellent will not work in a given time and place, but they do support field reports (Strickland 1976) of the inconsistency and variable effectiveness of repellents currrently available. What works at i time is a particular place does not necessarily work again in the same or other areas.

If additional testing under field conditions supports these findings, Big Game Repellent may have limited use on speciality crops. Most repellents cannot be used on food crops. Big Game Repellent is registered for use on conifer seedlings, fruit trees, nurseries, and ornamental shrubs but only during the dormant season. These label restrictions prevent its use in most commercial agriculture.

Fencing Study

Research was conducted to develop a low-cost alternative to the traditional 2.4-m woven wire barrier fence, considered to be deer-proof but too expensive for most agricultural uses. This study evaluated the effectiveness of alternative fence designs in deer of mixed sex and age-classes at the Penn State Deer Research Facility. Fence designs included those reported to be effective (Longhurst et al. 1962) plus some new designs. These designs were; experimental vertical electric deer fence (Fig. 1); slanting or over-hanging deer fence; modified New Hampshire electric deer fence; slanting, high tensile 14-wire deer fence; and 1.Z-m stock fence, modified to exclude deer by construction of an overhang of 3 wires (Fig. Z).

Individual fences and deer interactions were observed for up to 30 days. This period included food restriction for up to 14 days, with food always available beyond the fence perimeter. Fences were subjected to several groups consisting of 10 deer, including animals which penetrated other designs. We were only interested in whether a design was penetrated during the 30 days, and did not attempt to rank fence effectiveness based upon frequency of penetration.

Following these pen tests, the experimental vertical electric fence design (Fig. 1) was field-tested on a variety of crops at 10 sites in Pennsylvania ranging from 1.6 to 58

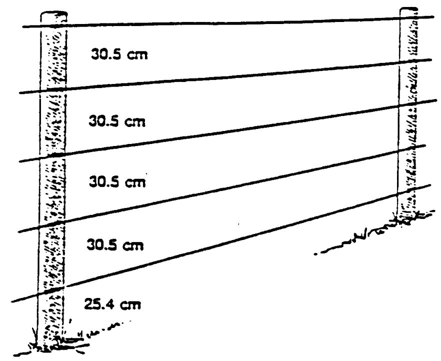

Figure 1. The Penn State Vertical Electric Deer Fence.

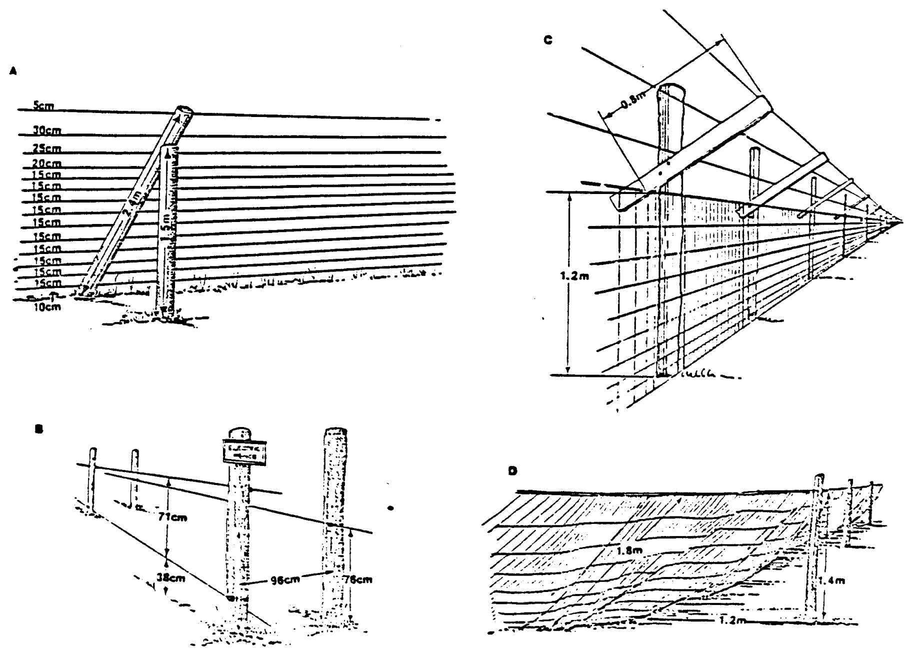

Figure 2. Other fence designs tested: A. Slanting, high-tensile, deer fence; B. Modified, New Hampshire, electric deer fence; C. Modified, stock fence; D. Slanting, or over-hanging, deer fence.

Table 3: Number of dogwood seedlings browsed by white-tailed deer in 4 trials at the Pennsylvania State University Deer Research Facility, (n=40).

	Trial 1	Trial 2	Trial 3	Trial 4
Hinder	27	33	3	2
Hot Sauce	30	33	27	26
Spotrete-F	30	28	26	21
Big Game Repellent	15	19	1	0
Feather Meal	36	26	24	23
Meat Meal	33	29	26	21
Control	31	33	32	32

Table 4. Locations and areas of crops protected by experimental deer fences in Pennsylvania, 1982.

County	Area Surrounded (ha)	Crops
Wayne	2.4	Alfalfa
Adams	53.0	Fruit trees, tomatoes, corn
Tioga	1.6	Young coniferous trees
Wyoming	4.0	Vegetables, fruit tree nursery
Schuylkill	2.0	Legumes, cabbage, oats
Centre	48.0	Small grain, corn, forages, vegetables
Centre	20.0	Alfalfa, corn
McKean	10.0	Black cherry seedling orchard
Mifflin	1.6	Fruit trees
Centre	1.6	Vegetables

hectares (Table 4). Agricultural extension agents, familiar with crop production, assisted in choosing the sites, all of which had a history of severe deer damage. Fences were constructed in 1980 and monitored through June 1982 to determine effectiveness in changing deer behavior and protecting against crop losses. These observations were made during ail months of the year by cooperating growers. The growers' opinions are important because they had to be satisfied if the fence was to be used. Project personnel made periodic visits to confirm grower opinions. Direct observations, including spotlighting during the summer months and track counts in the winter, were made at fence sites. The most intensive deer observations, totaling 1,150 person- hours, were made at the 48-ha Centre County site.

Results and Discussion of Fencing Study

Deer Behavior

In the pen tests, captive deer penetrated all fences except the vertical electric design. Deer usually go under or through a fence rather than jump it When deer attempted to penetrate the vertical electric fence, the tensioned wire and high voltage insured good shocking power. Following the initial shock, deer kept approximately 1 m away from wires and never tried to jump the fence.

Field experience and observations of woven-wire and brush fences have indicated that deer will normally jump over these obstacles to enter a crop field. The experimental vertical electric fence, therefore, should never be located directly adjacent to old woven-wire fences, woody fence rows, or brushy cover. Field observations indicated that a 2- to 3-m open strip should be left outside the perimeter of fences; this insures that deer will be walking as they approach, which again lessens the likelihood of jumping. The strip also provides a pathway around the fence.

Design

The specifications for wire spacing and configuration of the experimental vertical electric fence must be followed, and materials used should be equivalent to specifications, to prevent the deer from crawling beneath or going through the fence. The bottom wire must be approximately 25 cm from the ground while the remaining wires are spaced at 30.5 cm intervals, making the fence 147 cm high. Electric fences with wider wire spacing proved ineffective in excluding deer. This design was named the Penn State Vertical Electric Deer Fence to differentiate it from other deer fences.

Layout and Construction

Laying out lines for construction of electric deer fences is important and should take advantage of level land wherever possible. Removing underbrush and debris along the line and grading off humps eliminates many construction problems and results in a fence that is straighter and easier to maintain.

Each straight length of fence begins or ends at an end post, corner post, or gate post which is larger in diameter, longer in length, and set deeper into the soil than other posts. Construction of brace assemblies at these points is probably the most important aspect of a high-tensile fence because these strong points support the tension on the wires.

Line posts can be smaller and spaced 15-18 m apart on level terrain where minimal lateral, upward, or downward forces are expected In curves, and on uneven terrain with dips and rises, more posts are needed to maintain the 25-cm bottom-wire spacing. Some of these posts may have to be larger and driven deeper to withstand the added tension stresses created.

Once the fence has been constructed and a proper energizer installed, the only potential problem to consider is the possible failure of the fence to deliver sufficient shock. This could only occur because of improper grounding. In order for electricity to flow, there must be a completed circuit. For adequate grounding, the fence must have approximately 7 m of rod or pipe in the soil

Components

High-tensile fences, which are relatively new is the United States, are based on technology developed in New Zealand and Australia for controlling sheep, cattle, and horses (U.S. Steel 1980). The key materials are: high-tensile, smooth steel wire (200,000 psi, 12 1/Z gauge); special accessories to maintain 114 kg wire tension (Fig. 3); and high-voltage, low impedance energizers.

Gates were not electrified, but did not have openings large enough to allow deer to crawl through or under. The experimental vertical electric fences are equipped with galvanized steel farm gates. Materials costs, excluding labor, are listed in Table 6.

These components eliminate many of the problems associated with the maintenance of conventional soft-wire electric fences. High-tensile wire absorbs the impact of the deer, trees or limbs, and farm equipment without stretching or breaking. A single indicator spring is used to determine the proper tension of the wire. In-line wire strainers are used to tighten and maintain tension on the wire. To maintain the full breaking strength of the wire, the experimental 5-wire fence has no wire ties or knots, but instead crimping sleeves are used to splice the wire or fasten it at ends or gates. Tube insulators are used to insulate the wire from line posts. Advantages include low cost, strength (because most of the staple length is in the post) and allowance for wire to "slip°" through during tensioning, temperature changes, or impacts on the fence. Wrap-around insulators are used to fasten wires at ends and for continuous wire stringing outside of posts at corners or curves.

A "New Zealand-style" energizer is essential to power high- tensile wire fences (1982 costs, $190-$300). These chargers are available for AC or battery power. They are capable of producing the high voltage needed to turn deer, and the low impedance which helps prevent shorting-out in high leakage situations, such as vegetation on the wires. At 1 test site, a solar panel was installed to trickle-charge the battery, thus eliminating battery replacement. A low-maintenance feature is a solid safe module, which is easily replaced when an energizer needs to be repaired (1982 costs, $38.00).

Although not an essential component, round, pressure-treated softwood posts were used in the experimental fences. They have a high strength-to-weight ratio, and their natural taper facilitates driving them into the ground. Driven posts have greater pull-out resistance, an important factor on uneven terrain where fence tension creates pull. This type of wooded post has a life expectancy of 35-40 years, making this high- tensile fence a long-lived, low maintenance, and, therefore, low- cost structure.

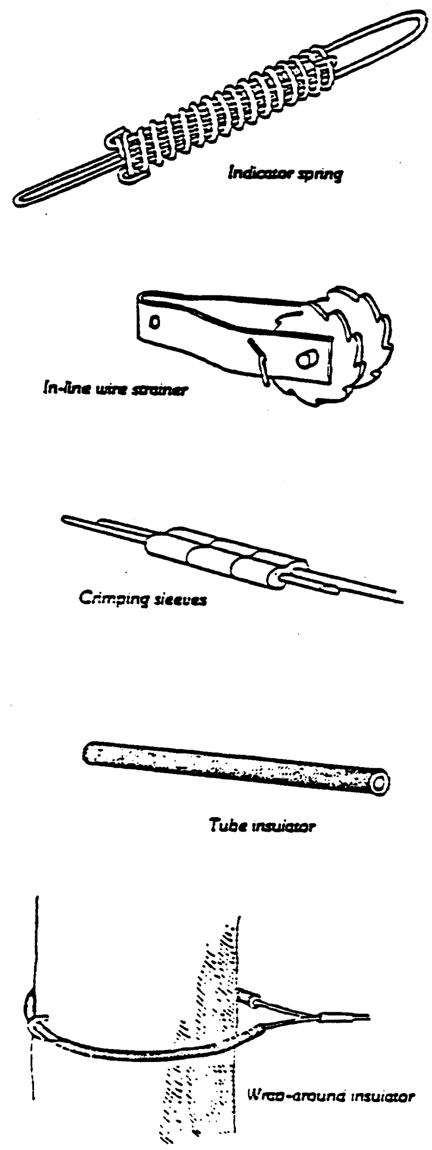

Figure 3. Components for the Penn State Vertical Electrical Deer Fence.

Maintenance

Electric fences require inspection and maintenance, especially if a battery-powered energizer is used. The safety module intended to protect the energizer should be checked after lightning storms and replaced if the storm has caused its failure. Electric fences are not effective when short circuited by heavy vegetation or deep snow. Even with high-voltage, low- impedance energizers, vegetative loads cannot be ignored. These modern energizers can power a fence with a weed load in dry weather, but during wet weather the same weed load can drain enough voltage to reduce the fence's effectiveness. Because top voltage is required to turn deer, a weed control program is necessary. Snow can have the same effect; when it covers the bottom wires, the current to those wires should be disconnected.

Conclusions

The Penn State Vertical Electric Deer Fence was effective in excluding deer at field sites containing alfalfa, small grains, corn, vegetables, orchards, and young coniferous trees. Cost: benefit ratios were favorable for the various crops protected. This fence offers farmers a low-cost alternative to the 2.44-m woven-wire fence.

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