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Abstract White-tailed deer (*Odocoileus virginianus*) cause millions of dollars of damage to agricultural crops annually. We tested the effectiveness of propane exploders and Electronic Guards (Pocatello Supply Depot, Pocatello, Id.) for reducing deer damage in cornfields during the silking–tasseling stage of growth. Track-count indices ($F_{2,7}$=0.70, P=0.532), corn yields ($F_{2,6}$=0.14, P=0.873), and estimated damage levels ($F_{2,12}$=1.45 P=0.272) did not differ between experimental and control fields. The size ($F_{2,11}$=0.08, P=0.924), location ($F_{2,9}$=0.30, P=0.750), and percent overlap ($F_{2,9}$=0.46, P=0.644) of use-areas of radiomarked female deer in the vicinity of experimental fields did not differ among before, during, and after 18-day treatment periods. In a related study, we placed propane exploders in cornfields within use-areas of 12 radiomarked female deer. The deer did not react appreciably to the devices: the size ($F_{2,17}$=0.08, P=0.921), location ($F_{2,22}$=1.37, P =0.275), and percent overlap ($F_{2,10}$=0.47, P=0.636) of deer use-areas did not differ among before, during, and after 14-day treatment periods. We conclude that propane exploders and Electronic Guards have limited potential for reducing deer damage to corn at the silking–tasseling stage.

Key words animal damage control, Electronic Guard, frightening devices, *Odocoileus virginianus*, propane exploder, white-tailed deer, wildlife damage management

Economic loss from wildlife depredation to agricultural producers has been estimated to approach $4.5 billion annually in the United States (Conover 2002). Deer (*Odocoileus* spp.) are the species most responsible for crop damage in many areas of the United States (Conover and Decker 1991, Wywialowski and Beach 1992). In 1993 over $30 million of corn was lost to deer damage in the 10 largest corn-producing states alone (Wywialowski 1996).

Deer feed on corn from its emergence through harvest (VerCauteren and Hygnstrom 1998), but frequency of use peaks in late June to early July, during the silking–tasseling stage of growth (Hygnstrom et al. 1992). At this stage, silk-producing ears emerge from the nodes and pollen-producing tassels emerge from the meristem of the corn plant. Cornfields are highly susceptible to deer damage at the silking–tasseling stage because use by deer is high and this is the most critical period for damage that reduces yield (Eldredge 1935, Shapiro et al. 1986, Vorst 1986). Producers may be able to reduce damage and associated costs by implementing control methods, such as frightening devices, at the silking–tasseling stage.

Methods used to manage deer damage consist of lethal and nonlethal techniques. Lethal techniques in the form of sharpshooting or controlled hunting

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can be difficult to implement because of safety concerns, local ordinances, and public attitudes against the use of firearms and harvesting of animals (Jones and Witham 1995, Kuser 1995, Mayer et al. 1995, Kilpatrick et al. 1997). In many situations nonlethal techniques are the only options available. The public supports management of wildlife that is causing damage to personal property, especially when nonlethal techniques are employed (Green et al. 1997, Loker et al. 1999, Reiter et al. 1999).

Propane exploders are the most commonly used frightening devices for deer depredation (Koehler et al. 1990, Craven and Hygnstrom 1994). Belant et al. (1996) reported that periodically firing (every 8–10 minutes) propane exploders was effective in frightening deer for ≤2 days while motion-activated exploders provided protection at artificial feeding sites for 1–2 weeks. Electronic Guards (Pocatello Supply Depot, Pocatello, Id.) are frightening devices originally developed for reducing coyote (*Canis latrans*) predation on sheep (Linhart et al. 1992). Belant et al. (1998) found that Electronic Guards protected feeding sites from deer for <1 week.

Koehler et al. (1990) suggested that frightening devices should be tested in field conditions rather than at artificial feeding sites to generate more applicable results. Our objective was to determine the efficacy of propane exploders and Electronic Guards for reducing white-tailed deer (*O. virginianus*) damage to cornfields during silking–tasseling. We also evaluated the influence of propane exploders on use-areas of female white-tailed deer.

Study area

We conducted the study during the summer of 1999 at the DeSoto National Wildlife Refuge (DNWR) and the Loess Hills State Forest (LHSF). The DNWR is 30 km north of Omaha, Nebraska in the Missouri River valley. The 3,166-ha area consisted of a mosaic of forests, grasslands, wetlands, and agricultural fields. Crops were cultivated on a 3-year rotation and included: corn (239 ha), soybeans (258 ha), grain sorghum, alfalfa, and a wheat/clover mix. The average size of test fields was 9 ha (range = 4–15 ha). The density of deer at DNWR was approximately 19 deer/km^2, based on previous estimates (VerCauteren 1998) and consistent subsequent harvest rates (DNWR unpublished data). The LHSF is 80 km north of Omaha and contained 3,774 ha of forest, prairie, and agricultural fields. Crops in the area included: corn (215 ha), soybeans (161 ha), grain sorghum, and alfalfa. The average size of the test fields was 2 ha (range = 1–3 ha). Density of deer was 5–7 deer/km^2 (B. Olsen, Iowa Department of Natural Resources, personal communication).

We selected 4 groups (blocks) of 3 test fields on DNWR and 4 groups of 3 test fields on LHSF. Test fields were similar in size, shape, and location and ≥1 km apart to minimize the potential for dependence among the fields (Belant et al. 1996). Fields containing propane exploders or Electronic Guards are referred to as "experimental" while fields with no frightening device are referred to as "control." The average distance between experimental and control fields on DNWR and LHSF was 1.4 km (range = 1.0–2.5 km) and 0.8 km (range = 0.5–1.4 km), respectively. Wooded areas between the fields on DNWR dissipated acoustic intensity while test fields in the LHSF were located in valleys where ridges and dense forests attenuated the sounds from the devices greater than the level floodplains of DNWR, minimizing the potential for dependence between experimental and control fields.

Methods

Efficacy of propane exploders and Electronic Guards

Treatments tested included propane exploders and Electronic Guards. We connected each propane exploder (Thunderbird Scare Away, Reed-Joseph International, Greenville, Miss.) to a 9.1-kg bottle of propane. Propane exploders were set to discharge (130 dB output at 75 m) at 15-minute intervals throughout the night, and we manually turned them on and off at sunset and sunrise, respectively.

Each Electronic Guard consisted of a photocell, timer, flashing white strobe light (70,000 cp, flash rate = 60/minute), and a 1.4-kHz modulating siren (15–20 modulations/minute, 116-dB output at 1 m). A 12-volt lantern battery powered the unit. The photocell automatically activated and deactivated the device at sunset and sunrise, respectively. When operational, the timer randomly activated the system to sound for 7–10 seconds at 6–7-minute intervals throughout the night.

We randomly assigned treatments to each of the 3 fields in each group. We placed 2 frightening devices of the same type on opposite sides of the perimeter of each experimental field. We placed the devices on corners of fields and along forest–field edges that experienced the highest levels of damage to maximize the visual and auditory effectiveness of the device (Figure 1).

Frightening devices were applied at the first sign of silking–tasseling in the cornfields (13 July 1999 on DNWR, 25 July 1999 on LHSF) and were active for 18 days, which was sufficient time for the ears of corn to develop past silking–tasseling and become less susceptible to deer damage. We repositioned the devices on the perimeters of each field after the ninth day to minimize habituation to the devices (Koehler et al. 1990, Nolte 1999).

We used track-count indices, corn-yield data, damage assessments, and use-areas of radiomarked deer to evaluate the efficacy of the frightening devices on DNWR. We used only damage assessments on the LHSF.

We conducted track counts around the perimeters of all test fields on DNWR every 6 days. We conducted track counts before applying frightening devices, during the 18-day treatment period and after the treatment period. We used a tractor-mounted, 2-m drag to maintain a smooth dragline. We counted deer tracks that were oriented into and out of cornfields in the 1-m width of the dragline nearest the corn. A single observer counted tracks on all fields to eliminate observer bias. We recorded 1 track count before the frightening-device application, 2 during the 18-day treatment period, and 1 after the treatment.

Data on corn yield were available for 10 of 12 test fields on DNWR. Farmers obtained yield data from grain elevators when the corn was delivered or directly measured yield from Global Positioning System (GPS)-linked monitors on their harvesting equipment that calculated yields once every second during harvest. We compared corn yield from experimental fields and those that served as controls.

We used a variable-area-transect sampling method (Engeman and Sugihara 1998, Engeman and Sterner 2002) to assess the amount of damage caused by deer in all experimental and control fields immediately following the treatment period. We used a numbered grid to randomly locate 10 test plots in fields ≤4.0 ha ($n=12$), 20 test plots in fields 4.4–12.1 ha ($n=9$), and 30 test plots in fields >12.1 ha ($n=3$). At each test plot we inspected a row of corn, counting the total number of ears of corn including damaged and undamaged ears. When 5 deer-damaged ears were tallied, we recorded the distance traveled and the total number of ears. If 5 deer-damaged ears were not tallied in 100 m, the observer recorded the total number of ears and any deer-damaged ears observed in that 100 m. We estimated and compared the average percentage of damage/plot [damaged ears/(damaged ears + undamaged ears)] between experimental and control fields. We used a multilocation trial to test for any differences in damage assessments between DNWR and LHSF test fields.

Figure 1. Propane exploder (left) and Electronic Guard (right) on the edge of a cornfield.

We used the chronologically sequenced use-areas of radiomarked female deer associated with frightening devices as supporting data to further ascertain effectiveness of the treatments on DNWR. Use-areas were the spaces that the radiomarked deer occupied during 3 18-day study periods. We chose to use the term "use-area" rather than "home range" because of the limited time period in which we collected the data. A home range should include all normal activities—feeding, resting, mating, and rearing young (Shivik and Gese 2000). We monitored 12 radiomarked deer in the vicinity of the test fields for 18 days pretreatment ($\bar{x}$= 18 locations, range =15–20), 18 days during treatment ($\bar{x}$= 20 locations, range=18–21), and 18 days post-treatment ($\bar{x}$ = 11 locations, range=9–12). Telemetry locations were distributed equally throughout the day and night. We generated use-areas with the Spatial Ecology Analysis System (SEAS) and harmonic mean method (Dixon and Chapman 1980) using a Geographic Information System (TNTmips®, MicroImages, Lincoln, Nebr.). The use-area was defined by the 95% isopleth, 20% isopleth core area, and arithmetic center. If the core area was $\leq$1 km from an experimental field or control field, the deer was assigned to the respective treatment.

We evaluated the impact of frightening devices on radiomarked deer by comparing the: 1) size of use-areas, 2) location of the center of use-areas, and 3) percent of overlap of consecutive use-areas, among the 3 periods.

We collected data for track-count indices and use-areas in the 3 periods with a repeated-measures design. A randomized complete block design was used, and the data were analyzed using a mixed linear model (e.g., McLean et al. 1991), implemented in SAS Proc Mixed (Littell et al. 1996, SAS Institute, Inc. 2000) with means estimated as least-squares means. We used Akaike's Information Criterion (AIC) as a means of selecting the covariance structure that provided the best-fit model for the repeated measures (Littell et al. 1996), as well as the Kenward-Roger adjustment for denominator degrees of freedom.

We calculated costs of equipment and labor (at $10/hr) required to operate the 2 frightening devices.

Effect of propane exploders on radiomarked deer

We also conducted a supplemental study on DNWR (5 September 1999–16 October 1999) to determine the effect of propane exploders placed within the use-areas of radiomarked deer. We placed propane exploders on the edge of a cornfield being used by a radiomarked deer. We calculated use-areas for 12 radiomarked deer for 3 14-day periods. Fourteen-day periods were established using methods previously described. The "Before," "During," and "After" use-areas consisted of an average of 23 (range =21–24), 43 (range=42–46), and 20 locations (range =20–21), respectively, for each deer in each period. We analyzed size, location of the center, and percentage of overlap of use-areas, among periods.

All procedures involving animals were approved by the University of Nebraska-Lincoln Institutional Animal Care and Use Committee (IACUC # 99-03-014) and the United States Department of Agriculture/Animal and Plant Heath Inspection Service/ Wildlife Services/National Wildlife Research Center Institutional Animal Care and Use Committee (QA-726).

Results

Efficacy of propane exploders and Electronic Guards

Use of cornfields by deer increased similarly in all experimental and control fields across the time periods (Figure 2). We found no differences in track-count indices among treatment effects ($F_{2,7}$=0.70, P =0.532) and treatment-by-time interaction ($F_{6,8}$=

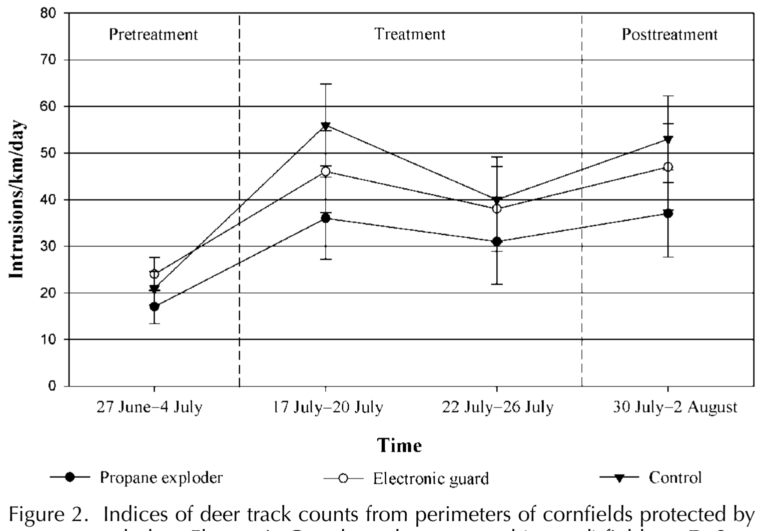

Figure 2. Indices of deer track counts from perimeters of cornfields protected by propane exploders, Electronic Guards, and unprotected (control) fields on DeSoto National Wildlife Refuge, Missouri Valley, Iowa 1999.

0.84, $P=0.575$). However, we detected differences among time periods ($F_{3,7}=20.48, P \leq 0.001$).

The mean yields of corn (kg/ha) for fields with Electronic Guards ($\bar{x}=7{,}511$, SE = 1,371, $n=3$), propane exploders ($\bar{x}=6{,}930$, SE = 1,218, $n=4$), and control fields ($\bar{x}=7{,}915$, SE = 1,390, $n=3$) did not differ ($F_{2,6}=0.14$, $P=0.873$). The field size (ha) was not a factor in corn yield/ha ($F_{1,6}=0.01$, $P=0.911$).

Damage rates between DNWR and LHSF fields did not differ ($F_{2,12}=0.59$, $P=0.571$); therefore, we pooled data from the 2 locations. We found no differences in the percentage of damage/plot among fields protected by Electronic Guards ($\bar{x}=19\%$, SE = 3, $n=8$), propane exploders ($\bar{x}=16\%$, SE = 3, $n=8$), and control fields ($\bar{x}=15\%$, SE = 3, $n=8$) ($F_{2,12}=1.45$ $P=0.272$).

Frightening devices had no effect on the use-areas of radiomarked deer (Table 1). Mean size of use-areas of radiomarked deer exposed to the treatments did not differ throughout the study. Size of use-areas was not influenced by treatment ($F_{2,11}=0.08$, $P=0.924$), time ($F_{2,12}=0.69$, $P=0.521$) or the treatment-by-time interaction ($F_{4,13}=0.86$, $P=0.513$). Mean location of centers of the use-areas of radiomarked deer did not differ throughout the study. Treatment ($F_{2,9}=0.30$, $P=0.750$), time ($F_{2,8}=1.10$, $P=0.379$), and the treatment-by-time interaction ($F_{4,9}=0.97$, $P=0.471$) did not differ among periods. Spatial information from radiomarked deer indicated that deer continued to use cornfields whether protected by frightening devices or unprotected. Regarding use-areas of the "Before to During" period, of the 5 deer exposed to propane exploders, 4 shifted their use-areas closer to experimental fields. Use-areas of the 2 deer exposed to Electronic Guards also moved closer to the experimental fields. "During to After" use-area shifts revealed that deer once again moved closer to the cornfields. The mean overlap of chronologically sequenced use-areas of radiomarked deer exposed to the different treatments did not differ throughout the study. Overlap of use-areas were not influenced by treatment ($F_{2,9}=0.46$, $P=0.644$), time ($F_{2,8}=3.00$, $P=0.107$), and treatment-by-time interaction ($F_{4,9}=1.86$, $P=0.203$). Overlap of use-areas was high, indicating that radiomarked deer did not alter their choice of habitat and continued to use cornfields that contained frightening devices.

The propane exploders we used cost \$310 apiece, and each consumed about 4.5 kg of fuel (\$6) during the 18-day period. About 1 hour was required to recondition and calibrate each exploder to fire at 15-minute intervals, and each had to be turned on and off each day. It cost about \$20/day to purchase and operate each propane exploder during the 18-day test period.

The Electronic Guards we used cost about \$260 apiece, including the Electronic Guard (\$250), a 12-volt lantern battery (\$13), and a piece of re-bar to suspend the device. About 0.5 hours was required to install each device in the field. It cost about \$15/day to purchase and operate each Electronic Guard during the 18-day test period. Electronic Guards required no labor after being placed in fields because they were activated by photoelectric sensors.

Effect of propane exploders on radiomarked deer

Radiomarked deer in the supplemental study were not deterred from using cornfields protected by propane exploders. Mean size of use-areas did not differ for 12 radiomarked female deer ($F_{2,17}=0.08$, $P=0.921$). Mean size of the "Before" use-area was 42 ha (SE = 11, $n=12$), "During" was 38 ha (SE = 5, $n=12$), and "After" was 38 ha (SE = 6, $n=12$). Mean locations of centers of use-areas of the 12 radiomarked deer exposed to propane exploders did not differ among periods ($F_{2,22}=1.37$, $P=0.275$). The mean center shift of the "Before to During" period was 95 m (SE = 20, $n=12$), "During to After" was 108 m (SE = 20, $n=$

Table 1. Use-areas of radiomarked female deer exposed to propane exploders and Electronic Guards on DeSoto National Wildlife Refuge, Missouri Valley, Iowa 1999.

		$\bar{x}$ size (ha)			$\bar{x}$ center shift (m)[a]			$\bar{x}$ % overlap[b]		
Treatment	n[c]	Before[d]	During[e]	After[f]	B–D	D–A	B–A	B–D	D–A	B–A
E. Guard	2	11	42	31	195	174	164	27	76	32
P. exploder	5	24	21	63	71	198	225	78	47	47
Control	5	33	37	30	135	100	177	51	82	55

[a] B–D = "Before to During" shift, D–A = "During to After" shift, B–A = "Before to After" shift.
[b] B–D = "Before to During" overlap, D–A = "During to After" overlap, B–A = "Before to After" overlap.
[c] Number of deer exposed to corresponding frightening device or control.
[d] Before = 24 June 1999–11 July 1999.
[e] During = 12 July 1999–30 July 1999.
[f] After = 31 July 1999–17 August 1999.

12), and "Before to After" was 130 m (SE=20, n=12). Six of the 12 deer shifted their use-areas closer to the fields with propane exploders. Four of the 12 deer moved away from the propane exploders. Two of the 12 deer moved neither away nor toward the fields with the propane exploder but shifted their use-area only slightly and parallel to the field with the propane exploder. Mean overlap of use-areas for radiomarked deer did not differ among periods ($F_{2,10}$=0.47, P=0.636). Mean overlap of the "Before to During" period was 72% (SE=5, n=12), "During to After" was 76% (SE=8, n=12), and "Before to After" was 70% (SE=7, n=12).

Discussion

We found no differences among the effects of frightening devices in our analysis of the 4 response variables. Although no significant differences were observed, we feel that some trends in our data merit discussion. Track counts increased from the pretreatment to the treatment periods, decreased during the treatment period, while the devices were active, and increased from the treatment to the post-treatment periods (Figure 2). The initial increase in deer use from pretreatment to treatment likely was due to the appearance of new ears of corn, which was a preferred food source and an attractant of deer to cornfields. Track indices in cornfields with frightening devices increased at a lower rate than control fields, which may suggest that the frightening devices were initially effective at reducing deer intrusions, but not to a significant degree. Deer intrusions decreased throughout the treatment period, which may have been due to the growth of the ears of corn beyond the preferred size and stage of development. At the end of the treatment period, most ears of corn exceeded 20 cm in length and were less palatable.

Shelter provided by the corn plants may be a factor responsible for the tendency of deer use of cornfields to increase throughout the study period. Mature cornfields may offer protection from predators and environmental conditions. Deer may not feed on mature corn as much as during the silking–tasseling period, but may use the cornfields for cover throughout the day rather than returning to forest cover.

On average, control fields produced 7,946 kg/ha of corn, which was 1,051 kg/ha and 419 kg/ha more than fields containing propane exploders and Electronic Guards, respectively. If propane exploders and Electronic Guards were effective in reducing deer damage, experimental fields would have had higher yields of corn than control fields. Deer that used cornfields before the devices were activated may have caused damage in the fields before frightening devices were installed. We observed deer damage to corn plants before the silking–tasseling stage. Damage in some cases was sufficient to prevent plants from producing ears.

Variability in damage levels among fields may be the result of several factors. Feeding patterns of deer are difficult to change once they are established (Koehler et al. 1990, Nolte 1999, DeNicola et al. 2000). Thus, deer that fed on cornfields before the frightening devices were deployed may not have been deterred from the fields. Another possibility is that the frightening devices protected only 2 sides of the test fields. Deer may have not been frightened from the acoustic stimuli if they could not see the propane exploder or the flashing strobe of the Electronic Guard. Finally, habituation to the devices may have allowed deer to quickly disregard the stimuli and continue feeding in the cornfields. Motion-activated propane exploders are available and may be more cost-effective (Belant et al. 1996).

Density of deer was approximately 3 times lower on LHSF than on DNWR; however, damage rates were similar. A possible explanation for this trend could be that fields on LHSF were smaller than fields on DNWR. The perimeter:area ratio is greater on smaller fields, and damage by deer tends to be most severe on the perimeters of cornfields. Therefore, damage per unit of area may be greater on smaller fields.

Interestingly, the field that sustained the least damage (<1%) had ears that were about 1.4 m aboveground, as opposed to other fields in which ears were about 1 m above ground. Soil type and fertility were most likely responsible for the difference in corn height because the producer used the same variety of corn in many fields. However, development of a hybrid in which the ears form higher on the stalk may help reduce deer damage because the ears are less accessible to the deer.

When selecting a home range estimator, researchers should consider the behavior of subject animals, landscape of the study area, and statistical capabilities of the estimator since there is no single "best" estimator for all circumstances (Worton 1995, Shivik and Gese 2000). An optimal sample size for the number of locations to estimate a home range is about 50 locations per animal but may vary from as few as 20 to as many as 200 locations, depending on the home-range estimator used (Kernohan et al.

2001, Leban et al. 2001). In our study, we evaluated use-areas over 18-day periods and were concerned with spatial relationships rather than comparing estimator accuracy for inliers and outliers. We used the harmonic mean home-range estimator because it is less sensitive to small sample sizes than are other estimators. The harmonic mean is a special case of the kernel methods (Larkin and Halkin 1994). We believe we selected the most applicable estimator to achieve our objectives.

Management implications

Electronic Guards and systematic propane exploders used in this study were sonic frightening devices that lacked negative reinforcement, which probably allowed deer to rapidly habituate to the stimuli (Belant et al. 1996, Belant et al. 1998). Belant et al. (1996) recommended motion-activated propane exploders rather than systematic exploders because of reduced habituation to the devices. Belant et al. (1998) also reported that the Electronic Guard was effective for <1 week in reducing use of preferred feeding sites. Our data similarly suggests that systematic propane exploders and Electronic Guards are relatively ineffective in reducing damage to agricultural fields.

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