VECTOR-BORNE AND ZOONOTIC DISEASES
Volume 9, Number 4, 2009

DOI: 10.1089/vbz.2008.0200

ORIGINAL ARTICLE

The United States Department of Agriculture's Northeast Area-Wide Tick Control Project: Summary and Conclusions

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Abstract

From 1997 to 2002, the U.S. Department of Agriculture's Northeast Area-wide Tick Control Project used acaricide-treated 4-Poster Deer Treatment Bait Stations in five eastern states to control ticks feeding on white-tailed deer. The objectives of this host-targeted technology were to reduce free-living blacklegged (*Ixodes scapularis* Say) and lone star (*Amblyomma americanum* [L.]) tick populations and thereby to reduce the risk of tick-borne disease. During 2002 to 2004, treatments were suspended, and tick population recovery rates were assayed. Subsequently, the major factors that influenced variations in efficacy were extrapolated to better understand and improve this technology. Treatments resulted in significant reductions in free-living populations of nymphal blacklegged ticks at six of the seven sites, and lone star ticks were significantly reduced at all three sites where they were present. During the study, maximal significant ($p \leq 0.05$) efficacies against nymphal blacklegged and lone star ticks at individual sites ranged from 60.0 to 81.7 and 90.9 to 99.5%, respectively. The major environmental factor that reduced efficacy was the occurrence of heavy acorn masts, which provided an alternative food resource for deer. Although the 4-Poster technology requires 1 or more years to show efficacy, this host-targeted intervention was demonstrated to be an efficacious, economical, safe, and environment-friendly alternative to area-wide spraying of acaricide to control free-living populations of these tick species.

Key Words: 4-Poster—acaricide—*Amblyomma americanum*—host-targeted—*Ixodes scapularis*—Lyme disease—*Odocoileus virginianus*—tick-borne disease—tick control—white-tailed deer.

Introduction

A brief history of the development of the 4-Poster Deer Treatment Bait Station (Pound et al. 1994, 2000a, 2000b) and the protocol for establishing of the U.S. Department of Agriculture's Northeast Area-wide Tick Control Project (USDA NEATCP) are provided in Pound et al. (2009). To complement the individual research reports that are also included in this issue, this article takes a broad view of how the objectives outlined in the initial protocol were met by NEATCP participants and how changes to the study protocol may have influenced outcomes. Further, we provide a synthesis of factors only briefly addressed in the individual reports, such as costs and the impact of the acaricide treatment on the environment and targeted wildlife populations. To compare corn consumption, pesticide usage, and tick sampling results among different research locations, data for each of the treatment and nontreatment years were compared based on similar

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time periods. Consequently, sums, means, and other descriptive data presented herein may not correspond precisely to data presented in reports from individual locations.

The stated purpose of the NEATCP was to determine the efficacy of Point-Guard® (2% oily pour-on formulation of amitraz; Hoechst Roussel Vet, Warren, NJ—now Intervet, Millsboro, DE) in reducing populations of blacklegged (*Ixodes scapularis* Say) and lone star (*Amblyomma americanum* [L.]) ticks when applied by the USDA-Agricultural Research Service (ARS)–patented 4-Poster white-tailed deer (*Odocoileus virginianus* [Zimmermann]) treatment device, thereby reducing the entomological risk for human exposure to pathogens transmitted by these species. The NEATCP was intended to be a dynamic intervention, modifiable through experience, and implemented in a variety of ecological settings along the east coast of the U.S. from Maryland to Rhode Island. The NEATCP was the first attempt to deploy, maintain, and determine efficacy of 4-Poster devices in reducing blacklegged and lone star tick populations when deployed in a variety of "real world" residential and nonresidential locations.

Materials and Methods

Project locations

The seven NEATCP project sites were (1) USDA-ARS Beltsville Agricultural Research Center, Beltsville, MD (BARC); (2) Gibson Island, MD (GI); (3) Loch Raven, MD (LR); (4) Naval Weapons Station Earle, NJ (NJ); (5) Bedford, NY (NY); (6) Old Lyme, CT (CT); and (7) Narragansett, RI (RI). These locations were selected based on criteria that included a high incidence of reported Lyme disease in humans, the presence of appropriate treatment and control sites and landowner approval to access these sites, and the availability of scientific collaborators with extensive knowledge and field experience in tick biology and ecology. All seven locations had populations of white-tailed deer and blacklegged ticks, and three (BARC, GI, and NJ) had populations of lone star ticks.

While all locations contained some heavily wooded habitat, study sites at GI, LR, NY, CT, and RI also contained residential areas with varying densities of urban landscape. The Core Treatment area at BARC was predominantly agricultural, with fields planted in a variety of crops, whereas the NJ sites were heavily wooded. The BARC, LR, NY, CT, and RI study sites were unfenced and situated within larger regions of similar habitat providing an unconfined, continuous habitat for free-ranging deer. The NJ site was a secured military base surrounded by intact deer-proof fencing, while access to GI from the mainland of MD was restricted to a narrow two-lane gated causeway.

Deer in BARC, NY, and CT were considered to be the least restricted in their movements, while movements of those in GI and NJ were restricted deer between research and surrounding areas. Movements of deer in LR were somewhat restricted by a large golf course that bisected the area; similarly, deer movement in RI was somewhat restricted by a large bay that bisected the area.

Treatment schedules

As the 4-Poster protocol primarily targeted adult blacklegged ticks, two treatment schedules were initially chosen to include calendar dates when fall and spring cohorts of adult ticks would be feeding on deer. Fall treatments in NY, CT, and RI occurred from 15 September through 15 December, and spring treatments were from 15 March through 15 May. Fall treatments at the BARC and GI sites in MD and at the NJ site began 1 October, and extended through 15 December, while spring treatments began on 15 March and extended through 31 August to target all life stages of lone star ticks that feed on deer. The LR site had no appreciable lone star tick population and was treated from 1 October through 15 December and from 15 March through 15 May. Thus the NEATCP locations had three treatment schedules.

The initial treatment period in 1997 was delayed in NJ, NY, CT, and RI for 27, 21, 24, and 38 days, respectively. Administrative delays resulted in a spring 1998 initial treatments at BARC, GI, and LR on 13 May, 28 June, and 10 June, respectively.

Treatment efficiency—spring of 1997 and fall of 1998 (project—year 1)

During fall of 1997 samples from five deer anesthetized at CT (Stafford et al., 2009) showed minimal amitraz residues on the hair, so the recharging protocol was changed to increase the volume of acaricide available to deer by including an assessment of deer use of 4-Posters based on corn consumption. In fall 1998, larger rollers with greater absorptive capacity were installed and charged with a minimum of 1.75 mL of PointGuard/0.45 kg (=1 lb) of corn missing from the bin since the previous visit. The increased dose (volume applied per deer per day) was greater than that used to effectively control lone star ticks in Texas (Pound et al. 2000b). In addition, it was discovered that the PointGuard formulation contained a volatile component that made up roughly one-third of the initial volume. This compromised the volume of liquid available for transfer to deer during the 1997 fall and 1998 spring treatment periods, but the problem was rectified by the changed protocol.

4-Poster deployment

During the first year, twenty-five 4-Posters were installed and charged with acaricide at BARC, GI, LR, NJ, and NY, and 23 at CT and RI. Although most study sites maintained 25 devices/518 ha (1/21 ha) throughout most treatments, NY dropped briefly to 23 devices in spring 2001 (year 4). In CT, 22–24 devices were deployed with the exception of only 6 devices in fall 1998 because of the large acorn mast available to deer. At RI, 23 devices were deployed during the first 2 years and 25 during the latter 3 years.

Based on Core Treatment areas of 518 ha, with exception of GI, which was 376 ha, sites maintained a device density for most treatment sessions of 1/21 ha (25 devices) to 1/24 ha (22 devices). The device density at GI was estimated at 1/15 ha.

Postproject questionnaires

Before implementing the NEATCP, meetings were held with property owners, home owners associations, and governmental entities at several potential research sites in each state to explain the 4-Poster technology, observe attitudes and acceptance of the technology, and to evaluate the potential to gain permission to place and maintain units on the properties. At the end of the project a questionnaire was sent to scientists at each location, and their anecdotal responses were compiled and summarized.

Statistical analyses

Data analyses were conducted using SAS for Windows version 9.1.3 (SAS Institute, Cary, NC; rev. SE05). Analyses included comparisons of nymphal tick populations in Core Treatment versus Control areas using ANOVA (mixed model with repeated measures by location), ANCOVA (analysis of covariance), and both correlation and regression analyses.

Results and Discussion

Corn consumption

During the project a total of 602,811 kg (1,328,970 lb) of whole kernel corn was dispensed by an average of 24.13 4-Posters over 7411 total feeding days for an average of 3.4 kg of corn/4-Poster/feeding day. The total area of all Core Treatment sites was 3484 ha. Therefore, a total of 602,811 kg of corn, or approximately 173.0 kg/ha, was dispensed during 10 seasons. This equates to an average of 34.6 kg of corn/ha/treatment site/year.

PointGuard usage

Throughout the project 3640.27 L of PointGuard was dispensed onto 4-Poster application rollers; while some remained impregnated into the fiber roller covers, most was transferred to the pelage of deer. Other than limited amounts of acaricide that might have contacted nontarget species (e.g., raccoons, turkeys, and squirrels), no appreciable acaricide was released into the environment. With the total area treated being roughly 3484 ha, and discounting acaricide lost by replacing rollers, an average of 1.04 L/ha (=0.11 gal/ac [acre]) of acaricide was dispensed over the 5 treatment years. Because PointGuard is a 2% solution of the active ingredient amitraz equal to 18.0 g/L (=0.15 lb/gal), the amount of amitraz applied to deer averaged <3.8 g/ha/year (<1.5 g/ac/year).

Estimated deer populations

As indicated in the NEATCP—History and Protocol (Pound et al. 2009), information obtained from wildlife agencies in each state estimated pretrial populations of roughly 22–23 deer/259 ha (=1 mile^2) or approximately 44 deer within the 518 ha Core Treatment and Control areas at LR, NJ, NY, CT, and RI. Pretreatment estimates from independent sources for deer at BARC were 120 and 104 in the Core Treatment and Control areas, respectively, and at GI estimates were 45 and 38, respectively.

Multiple deer counts were made from helicopters at LR (two counts), NY (three), CT (two), and RI (two). While counts at LR utilized helicopter-mounted forward-looking infrared equipment, other locations used two observers who flew transects and counted deer over a background of snow. Comparisons were made between initial and subsequent counts in Core Treatment and Control areas to assess impact on deer numbers from corn provision at treatment sites. Numerically, there was a 4.2% decline in total deer estimated present in Core Treatment areas and a 7.5% increase among Control areas between initial and subsequent deer counts. Regression analyses (Fig. 1) showed a similar trend of declining deer in the Core Treatment areas but indicated deer numbers were stable or slightly decreasing among Control areas.

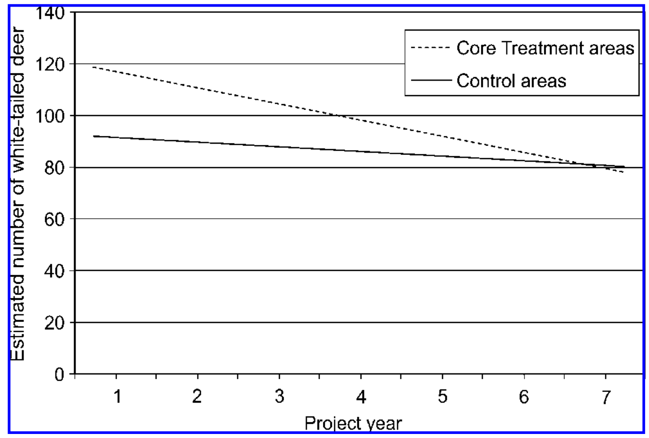

FIG. 1. Regressions showing white-tailed deer population trends of counts made from helicopters at Core Treatment and Control areas at various times during the Northeast Area-wide Tick Control Project.

Comparisons of estimated deer densities to corn consumption raised concern that the forward-looking infrared counts were providing underestimates of deer counts at LR (Carroll et al., 2009). Overall reanalysis of the data, excluding LR, showed increases in deer counts of 10.6% and 19.6% at Core Treatment and Control areas, respectively. The two data sets including or excluding LR estimates were subjected to a Henderson and Tilton's (1955) test for efficacy. With LR count data included, there was a 24.4% decrease in combined deer counts among Core Treatment areas as opposed to Control areas. Excluding the LR data also gave a similar result of a 23.8% decrease in deer. Deer count declines between treatment and control areas were 19.5%, 29.0%, and 57.6% in LR, NY, and RI, respectively. In CT there was a modest increase of 6.1% in deer counted on treatment sites relative to control sites. Therefore, while increases in deer populations in both Core Treatment and Control areas were identified by helicopter census, there was no evidence suggesting that populations of deer fed corn increased in number more so than those were not fed corn.

This observation was expected because, while corn is a good source of carbohydrate, it has a relatively low concentration of protein, averaging only about 7–9%. Therefore, while whole kernel corn is the preferred bait for deer (Kilpatrick and Stober 2002), it is not a viable alternative to high-quality pelleted supplemental or maintenance feeds that contain a minimum of 12–20% protein. During a 3-year study of the population effect of providing *ad libitum* shelled corn to deer in northern Wisconsin, Lewis and Rongstad (1998) identified a small increase in winter survival during the most severe conditions, a delayed fall migration of summer-fed deer, and a higher hunting mortality that was likely a result of the delayed migration. These findings were deemed insufficient in aiding winter survival of deer to warrant supplementary feeding of corn by governmental agencies and not detrimental enough to discourage recreational feeding.

Estimated usage of the 4-Posters by deer

Systematic spotlight counts were made at night by driving transects in the Core Treatment areas to assess the proportion of deer marked with reflective glass beads obtained at specially treated 4-Posters. During treatment periods, multiple spotlight counts were made at LR (two counts), NY (eight), CT (seven), and RI (two). Additionally, the stomach contents of hunter-killed deer at NJ were inspected for corn during three fall treatment periods. The estimated mean percentages of deer using 4-Posters at LR, NJ, NY, CT, and RI per treatment period were 65.0, 83.1, 89.6, 77.6, and 12.0, respectively, with a mean for all locations of 76.0%. Between 71% and 100% of 158 deer stomachs examined from 1999 through 2001 in NJ contained corn.

To elucidate impact that acorn mast had on reducing corn consumption, deer spotlight data were stratified by mast and nonmast treatment periods. Deer usage of devices was 61.1% during mast periods versus 79.8% during nonmast seasons. State-by-state comparisons indicated increases in the percentage of marked deer from mast to nonmast seasons from 89.6% to 90.7% (NY), 77.6% to 83.4% (CT), and 12.0% to 24.0% (RI). The low marking counts from RI were probably influenced not only by heavy mast but also by the presence of large fields of alfalfa and clover within the Core Treatment area.

To maximize the likelihood of deer contact with a 4-Posters, the protocol recommended a deployment density of one device/21 ha, which was a higher density than the single device deployed within a fenced 39 ha experimental plot used in the initial 4-Poster efficacy study (Pound et al. 2000b). During the NEATCP, Williams and DeNicola (2000) studied the spatial movements of female white-tailed deer in response to 4-Posters deployed near Old Lyme, CT, and concluded that a density of one device/50–60 ha minimized the number of bait stations while providing effective coverage of deer in the area. Movements of radio-collared deer indicated that although the core-activity areas of deer shifted closer to the bait stations, the mean size of core-activity area and home range of deer remained similar, irrespective to the presence of bait corn. Similar results were obtained from radio-collared deer tracked in Mumford Cove, CT (Kilpatrick and Stober 2002).

Efficacy of treatments against blacklegged ticks

The primary indicator of efficacy was derived by comparative sampling of nymphal *I. scapularis* ticks in Core Treatment versus Control areas because nymphs are the life-stage primarily associated with the transmission of Lyme disease, and representative sampling of adult and larval ticks is methodologically challenging (Stafford et al. 1998, Falco et al. 1999). As mentioned previously, data presented herein were selected and analyzed to reflect similar sampling effort and dates; thus, results may vary from those reported in the reports from individual sites.

Although Abbott's (1925) formula was a convenient descriptive statistic for calculating the percentage control obtained between the Core Treatment versus Control areas, modified or additional analytical procedures also were used by research teams at individual sites. Henderson and Tilton's (1955) formula provides a similar metric for measuring percentage control, but by quantifying changes in tick density between baseline and subsequent sampling times, it can be used to determine treatment effects between any two sampling periods.

Percentage control based on Abbott's (1925) formula is shown in Table 1. Year 1 (spring sampling of 1998) was considered as a baseline or pretreatment value for fall 1997 and spring 1998. Although attempts were made to select Core Treatment and Control areas with similar densities of ticks, Abbott's percentage control values ranged from −52.6% in CT to +56.0% in NJ, indicating that initially some treatment sites had higher (CT) or lower tick densities (NJ) than corresponding control sites.

Significant ($p \leq 0.05$) reductions in nymphal populations were observed initially at LR and NJ by year 2, BARC and RI by year 3, NY by year 4, and GI by year 5. During year 5, significant reductions were observed at all locations except CT. Maximal significant control levels at individual sites were 60.0% at RI (year 5), 67.0% at BARC (year 5), 72.1% at GI (year 6), 78.8% at LR (year 4), 79.0% at NJ (year 6), and 81.7% at NY (year 6).

Analyses with Henderson and Tilton's (1955) formula, using year 1 as the baseline metric, provided positive or negative

TABLE 1. PERCENTAGE CONTROL OF NYMPHAL BLACKLEGGED TICKS (ABBOTT 1925) CALCULATED FROM MEAN NUMBERS OF TICKS PER SAMPLE (NY MEANS PER 100 M) TAKEN FROM CORE TREATMENT VERSUS CONTROL SITES

	Research sites						
Sampling period	*BARC*	*GI*	*LR*	*NJ*[a]	*NY*[a]	*CT*	*RI*
Year 1 (1998)	−36.9 n/s	−45.3 n/s	26.3 n/s	56.0[b]	33.8[c]	−52.6[c]	23.8 n/s
Year 2 (1999)	23.2 n/s	−94.2 n/s	55.9[b]	59.8[b]	−10.4 n/s	24.1 n/s	33.4 n/s
Year 3 (2000)	55.4[b]	39.9 n/s	78.3[b]	64.7[b]	25.8 n/s	32.3 n/s	22.8[b]
Year 4 (2001)	58.6[b]	59.5[c]	78.8[b]	61.9[b]	67.4[b]	55.2 n/s	50.9[b]
Year 5 (2002)[d]	67.0[b]	71.0[b]	77.0[b]	77.0[b]	65.5[b]	53.9 n/s	60.0[b]
Year 6 (2003)	48.9 n/s	72.1[c]	65.8[c]	79.0[b]	81.7[b]	26.4 n/s	59.5[b]
Year 7 (2004)	−20.5 n/s	59.0 n/s	31.9 n/s	57.3[b]	−45.2	−12.9 n/s	−53.7 n/s

Negative values indicate greater numbers of ticks in Core Treatment than Control sites.
[a]Significance levels as reported in research location manuscripts.
[b]$p \leq 0.05$.
[c]$p \leq 0.10$; others not determined.
[d]Treatments were terminated at the end of spring of 2002.
BARC, U.S. Department of Agriculture–Agricultural Research Service Beltsville Agricultural Research Center, Beltsville, MD; GI, Gibson Island, MD; LR, Loch Raven, MD; NJ, Naval Weapons Station Earle, NJ; NY, Bedford, NY; CT, Old Lyme, CT; RI, Narragansett, RI; n/s, nonsignificant ($p > 0.10$).

values indicating enhanced or diminished control. BARC had a baseline Abbott's score of −36.9% and reached a maximum Henderson and Tilton's value of 75.9% control in year 5, while NJ with a baseline Abbott's of 56.0%, attained a maximum Henderson and Tilton's metric of only 52.3% effect in year 6. The preponderance of positive values in Table 2 between all comparisons of year 1 versus 4 through year 1 versus 7, with the exception of negative values at NY and RI during year 1 versus 7, indicated a trend for significant control by the forth year of treatment.

In addition to efficacy against nymphal ticks, CT (Stafford et al., 2009) and NJ (Schulze et al., 2009) reported percentage control values for larval blacklegged ticks of 71.6% during year 5 and 87.0% during year 7, respectively. Percentage control of adult ticks in RI was 65.0% during year 5 (Miller et al., 2009), and NJ reached 94.2% during spring of year 4 and 81.8% during fall of year 6.

Efficacy of treatments against lone star ticks

Only BARC, GI, and NJ had appreciable populations of lone star ticks, and as with blacklegged ticks, year 1 densities of nymphal lone star ticks served as the baseline for comparisons between Core Treatment and Control areas (Table 3). Baseline percentage control (Abbott 1925) varied from −134.4% at GI, to 84.8% at BARC, with NJ intermediate at −2.7%. Maximal control values for nymphal lone star ticks of 99.5% and 98.9% were reached by years 4 and 5 at BARC and GI, respectively, and 90.9% was obtained in NJ during year 6. While BARC began with a very high baseline control value of 84.8%, remaining years were $\geq 93.7\%$. Although, treatment sites at GI began at −134.4% baseline, 73.6% control of nymphs was achieved by year 3, and reached 92.6% by year 4 before leveling off at $\geq 95.3\%$ through year 7. Control values at NJ reached 75.1% by year 3, dropped to 58.5% during year 4, and then reached 89.4% and 90.9% during years 5 and 6, respectively, before dropping to 64.4% during year 7, the second year after stopping treatment.

As opposed to metrics derived from blacklegged ticks, all Henderson and Tilton's (1955) values for lone star ticks were positive, even after the second year after stopping treatment (Table 4). When compared to control achieved for blacklegged ticks, control of nymphal lone star populations was more rapid, of greater magnitude, and was sustained into posttreatment years.

Control of larval lone star ticks at NJ reached 79.9% by year 2, 99.2% by year 5, and declined to 67.6% by year 7. Control of adults was similar in NJ, reaching 64.0% in year 3, 96.9% in year 4, and 96.2% in year 6 before declining to 66.7% in year 7. In addition, efficacy against adults also was reported at BARC and GI (Carroll et al., 2009). Significant control ($p \leq 0.003$) of adult ticks at BARC occurred during even calendar years (1998 = 50.0%), 100% in 2000 (year 3) and 94.1% in 2002 (year 5). At GI, all contrasts of densities between even calendar years (year 1 vs. years 3 and 5) and odd calendar years (year 2 vs. years 4 and 6), with the exception of year 1 versus year 7 (2004), were significant ($p \leq 0.02$), with efficacies of −100.0%, −133.0%, 69.5%, 92.9%, 100.0%, 86.4%, and 75.0% for years 1 through 7, respectively.

Compared to blacklegged ticks, control values for all life stages of lone star ticks were higher, reached more quickly, and were sustained longer. Possible explanations for the difference in control efficacy include differences in the timing of adult feeding, host preferences for various life stages of ticks, and time required for completing life cycles.

Adult blacklegged ticks characteristically feed on deer during two periods of the year when temperatures are relatively cool (Fish 1993): from March through May and again from October through mid-December. These periods coincide with times when deer hair coats are long and thick and would retard movement of acaricide down to the skin surface where ticks are feeding, as suggested by the quantitative analyses of acaricide on hair coats of anesthetized deer (Stafford et al., 2009). By contrast, adult lone star ticks in the east feed during a single period from late March through June when the winter pelage is replaced by the shorter and less dense summer hair coat, allowing for greater coverage and skin penetration by the acaricide, thus producing greater efficacy against ticks.

Finally, although lone star ticks in MD may require 2 or perhaps 3 years to complete a life cycle (Carroll, unpublished data), a single year or less is required over most the southeastern quadrant of the U.S. In contrast, blacklegged ticks commonly require 2 or more years to complete a single cycle. This factor alone could account for differences in comparative time required to effectively control these two species by targeting acaricide to deer.

Index of prescribed treatment

To estimate and evaluate the impact of individual researcher's deviations from the initial protocol, four factors deemed most likely to influence control efficacy were investigated; (1) the proportion of prescribed treatment days on which deer were actually treated, (2) the proportion of

Table 2. Yearly Efficacy Percentages (Henderson and Tilton 1955) from Comparisons of Year 1 (1998) Versus Years 2–7 (1999–2004) of Nymphal Blacklegged Ticks Calculated from Mean Numbers of Ticks Per Sample (NY Means Per 100 m) Taken from Core Treatment Versus Control Sites

	Research sites						
Years	*BARC*	*GI*	*LR*	*NJ*	*NY*	*CT*	*RI*
1 vs. 2	43.9	−33.6	40.1	8.5	−66.7	50.3	12.5
1 vs. 3	74.7	38.2	79.8	35.1	−25.7	28.1	−74.9
1 vs. 4	69.8	72.1	71.2	13.4	50.7	70.7	35.6
1 vs. 5[a]	75.9	80.0	68.8	47.8	47.9	69.8	47.4
1 vs. 6	62.7	80.8	53.6	52.3	72.4	51.8	46.9
1 vs. 7	12.0	71.8	7.6	2.9	−119.3	26.1	−101.8

[a]Treatments were terminated at the end of spring of 2002 (year 5).

Table 3. Percentage Control (Abbott 1925) of Nymphal Lone Star Ticks Calculated from Mean Numbers of Ticks Per Sample Taken from Core Treatment Versus Control Sites

	Research sites		
Sampling period	*BARC*	*GI*	*NJ*[a]
Year 1 (1998)	84.8[b]	−134.4	−2.7[c]
Year 2 (1999)	97.5[c]	−18.8 n/s	14.7 n/s
Year 3 (2000)	99.4[c]	73.6[c]	75.1[c]
Year 4 (2001)	99.5[c]	92.6[c]	58.5[c]
Year 5 (2002)[d]	98.6[c]	98.9[c]	89.4[c]
Year 6 (2003)	97.8	98.8	90.9[c]
Year 7 (2004)	93.7	95.3	64.4[c]

Negative values indicate greater numbers of ticks in Core Treatment than Control sites.
[a]Significance levels as reported in research location manuscript.
[b]$p \leq 0.10$.
[c]$p \leq 0.05$; others not determined.
[d]Treatments were terminated at the end of spring of 2002.
n/s, nonsignificant ($p > 0.10$).

prescribed 4-Posters actually deployed, (3) the proportion of days when the ratio of applied PointGuard to corn consumption was suboptimal, and (4) the proportion of mean weight of corn consumed per day during fall and spring treatment periods in mast versus nonmast years during fall and spring treatment periods.

The “proportion of prescribed treatment days on which deer were actually treated” summed active treatment days within the prescribed interval defining the beginning and ending of treatments, and assessed the impact of variables such as inclement weather and logistical delays in deployment or service of 4-Posters that resulted in less than prescribed numbers of treatment days during individual seasons of treatment. The “proportion of prescribed 4-Posters actually deployed” evaluated the potential effects of sub-optimal density of deployed 4-Posters within Core Treatment areas. In fall 1998, the treatment protocol was adjusted to require a minimum application ratio of 1.75 mL of PointGuard/0.45 kg of corn consumed since the last servicing. Thus, the “the actual ratio of applied PointGuard to corn consumption” assessed the effects of treatment periods during which less than the minimal amount was applied. Lastly, the “the mean weight of corn consumed per day during fall and spring treatment periods in mast versus nonmast years” was calculated to assess the impact of heavy acorn mast on corn consumption.

Table 4. Percentage Control (Henderson and Tilton 1955) of Nymphal Lone Star Ticks Calculated from Mean Numbers of Ticks Per Sample Taken from Core Treatment Versus Control Sites

	Research sites		
Years	*BARC*	*GI*	*NJ*
1 vs. 2	83.7	49.3	16.9
1 vs. 3	89.1	76.8	59.1
1 vs. 4	97.0	96.9	59.6
1 vs. 5[a]	91.1	99.5	89.7
1 vs. 6	85.3	99.5	91.2
1 vs. 7	58.3	98.0	65.3

[a]Treatments were terminated at the end of spring of 2002 (Year 5).

Proportions were calculated for the four factors at each location during each of the eight treatment periods from fall 1998 through spring 2002. An index of adherence to the “optimal” prescribed treatment was defined for each location by multiplying the four ratios together for each treatment period, and a summary index was calculated by averaging the eight periodic indices (Table 5). Of note, the four research sites having summary indices of 0.8 or greater (GI, NJ, NY, and LR) had the highest corresponding maximum percentage control values (Abbott 1925) ranging from 72.1% to 81.7%. BARC, RI, and CT, had summary indices of 0.7, 0.6, and 0.5 corresponding to percentage control values of 67.0, 60.0, and 53.9, respectively. The major factor contributing to lower summary indices at BARC, RI, and CT was the occurrence of heavy acorn masts during two of the last four fall treatment periods.

A Pearson Product Moment Correlation Coefficient of 0.86 (r-value: $p \leq 0.05$) indicated a statistically significant correlation between the summary index and percent control of nymphal blacklegged ticks. Although a crude metric, the association between the summary index and achieved control suggested that adherence to study protocol and availability of alternative food resources strongly affected the major outcome of the NEATCP.

Anecdotal information summarized from postproject questionnaires

Management and servicing problems. The most common maintenance problem was clogging and clumping of corn behind the feeding port plate, primarily from the inability of operators to purchase high-quality “recleaned” or “twice cleaned corn” from local distributors. Whole kernel corn was used because it is the preferred bait for white-tailed deer, and it is considerably more resistant than cracked corn or pellets to soaking, swelling, and clumping when exposed to moisture. Broken corn kernels, cob fragments, corn dust, dirt, small seeds, and other “fines” not only reduced the free flow of corn to the feeding port, but also formed a dough-like plug at the feed port that stopped the flow of corn. Old corn commonly infested with insects, also produced dust and powdery debris. The plug supported fungal and bacterial growth, the smell of which may have repelled deer in addition to physically blocking corn flow. To reduce these problems, routine inspection must be enforced to remove blockages.

Consumption of corn by squirrels, raccoons, and turkeys presented a few problems. Squirrels feeding at the devices broke whole kernels when eating only the germ. The remainder was dropped back into the feed trough, absorbed moisture, became moldy, and clumped. Turkeys and raccoons only consumed corn that was intended for deer. Observations made using 24-h infrared, time-lapse video recordings of turkeys and squirrels feeding at 4-Posters at the Kerr Wildlife Management Area, Hunt, TX, showed essentially no contact with the pesticide application rollers (Pound and Miller, unpublished data).

Consumption of corn by large numbers of deer occasionally necessitated refilling and servicing the devices as often as three times per week. Rollers on these units also were more prone to wear. These problems can be mitigated by moving

Table 5. Comparison of Summary Indices of Prescribed Treatment Versus the Maximum Percentage Control of Nymphal Blacklegged Ticks (Abbott 1925) Observed During Either Year 5 or 6 at Each Research Location

Research site	*Summary indices of prescribed treatment*	*Maximum percentage control*
GI	0.9	72.1
NJ	0.8	79.0
NY	0.8	81.7
LR	0.8	77.0
BARC	0.7	67.0
RI	0.6	60.0
CT	0.5	53.9

less utilized devices into areas of high deer density. In addition to acorn mast, the presence of alternative food sources, such as alfalfa, can reduce deer use of the devices. However, only acorn mast would likely affect device use in suburban or predominantly residential areas sufficiently distant from agricultural fields.

Breakage of spindle supports for rollers varied among sites. The plastic spindles were designed to break if deer accidentally became entangled in them; however, breakage also could result from numerous deer feeding simultaneously or from deer kicking an empty device. Adding an additional device nearby generally alleviated this problem.

Overturned devices were minimal, with two reports from only one location and one or none reported for the other six. The suspected cause of overturned devices was intense deer activity, at a time when little corn remained in the bin. As the protocol specified, corn could be allowed to run low, but never empty. Mistimed service visits probably contributed to this problem.

Acaricide spillage was minimal. A minor spill occurred from a lose hose that was then tightened, and small leaks occasionally were reported at the hood. Drips from overcharged rollers were contained by catch pans located beneath the devices and were removed.

Cooperation and involvement of citizens. Because the majority of units were on private properties, with many in backyards of residential communities, success of the NEATCP required cooperation, understanding, and assistance not only from private citizens, but also from government and military personnel. During the approximately 6378 days (156,016 device-days) during which treated 4-Posters were deployed, there were no reports or complaints of accidental contact with acaricide-impregnated rollers by persons or pets.

Overall, the study proceeded with few problems, but consideration of the issues that arose is important for any methodology that is dependent upon community participation (see report from GI; Carroll et al., 2009). One of the greatest concerns that influenced the decision to place many devices within view of houses was the potential for vandalism. It was reasoned that devices visible from residences would be more secure and provide added safety from the attraction of curious persons than distantly placed devices. However, even within an affluent community one device was stolen and five were vandalized. Two other locations reported theft of a single device, and three units were vandalized, with one unit being beaten with rocks beyond repair. Natural accidents were rare, but in one location a device was damaged by a falling tree. Not surprisingly, the research site within the highly secure confines of Naval Weapons Station Earle (NJ) reported no vandalism.

As the project progressed, a few cooperators voiced concerns over the continuing presence of the devices. At two sites, devices were removed because owners believed that the units attracted deer that were damaging ornamental plants, and similar concerns were voiced by a commercial lettuce farmer. In contrast, some owners believed that the devices reduced deer browsing on ornamentals and others enjoyed watching the deer feeding from the units. Several owners became impatient with the frequent servicing of the devices or simply became tired of viewing the devices in their backyards, and some devices were moved to more distant locations or were painted black to reduce visibility. Again, NJ reported no complaints from citizens, and deer hunters observed dramatic decreases in tick populations in the field.

Estimated cost of implementing 4-Poster tick control. Estimates of the number of hours required to service the devices, excluding travel to and from the Core Treatment areas, varied widely. The highest estimates, 35 h to service 24 units per week and 16 h to service 25 units per week, came from rural sites with large deer population, necessitating up to three visits weekly. Of the five remaining locations, two reported 8 and 6 h/week, and three reported 4–5 h/week. Service effort was not directly linked to corn consumption because the site reporting 35 h/week to service 24 units dispensed approximately the same amount of corn/feeding day from spring 1998 through fall 2002 as the site reporting 4–5 h/week. The site reporting 8 h/week dispensed approximately twice as much corn/feeding day as the site that reported 16 h/week. It was suggested that to minimize the time needed to service individual units, devices should be installed near roads or in locations otherwise accessible by vehicles.

Rough estimates of costs associated with deployment and operation of 4-Posters were made based on units of service to a single 4-Poster/week and corn consumption/deer. Obviously, location-specific costs will vary by corn price, density of the deer population, device deployment densities, travel times to deployment sites, and other factors. Excluding travel time from home-base to the first treatment site, an average service time of one-half hour/device with a labor cost of \$15.00/h resulted in a cost of \$7.50/device/week (Table 6). The additional cost of replacing rollers, posting warning signs, purchasing of gasoline, and other minor incidentals was estimated to be \$6.00/unit/week, provided an overall service cost estimate of \$13.50/device/week.

The average cost of corn reported by participants was \$6.00/22.7 kg (=50 lb) bag. Each deer was assumed to consume 0.45–0.68 kg (=1.0–1.5 lb) of corn daily, providing a corn consumption cost of \$0.12–\$0.18/deer/day or \$0.84–\$1.26/deer/week (Table 6).

To compute meaningful cost estimates for future 4-Poster deployments, changes to the available technology need to be considered. The PointGuard used by the NEATCP was issued under an Experimental Use Permit from U.S. Environmental Protection Agency and was not officially labeled for

Table 6. Estimates and Comparisons of Costs Associated with 4-Poster Versus Commercial Area-Wide Spray Treatments (Stafford 1997) to Control Blacklegged and Lone Star Ticks

Estimates of costs associated with 4-Poster treatment		
Initial 4-Poster purchase		
4-Poster	Per unit	425.00
Tickicide	Per 3.79 L (=1 gal)	175.00
Dosing gun w/hood	Per unit	110.00
Additional applicator rollers	12 each (recommended)	35.00
Additional warning signs	12 each (recommended)	35.00
	Total	\$780.00
Servicing		
Labor@\$15.00/h	$\leq$30 min/4-Poster/week	7.50
Incidentals	rollers, gasoline, etc./week	6.00
	Total	\$13.50
Consumables		
Corn@\$6.00/22.7 kg	0.45–0.68 kg/deer/day	\$0.12–\$0.18/deer/day or \$0.84–\$1.26/deer/week
'Tickicide'@\$46.17/L	0.67–1.0 mL/deer/day	\$0.031–\$0.046/deer/day or \$0.21–\$0.32/deer/week
Total consumables	1 deer/week	\$1.05–\$1.58/deer/week
	5 deer/week/4-Poster	\$5.25–\$7.90/5 deer/week
Yearly (26 week) cost estimates		
Year 1—4-Poster and dosing gun	\$425.00 + 110.00	535.00
Servicing + consumables/year	(\$13.50 + \$7.90/5 deer/week)×26	556.40
	Total	\$1,091.40
Cost estimate/ha/year	(\$1091.40/21 ha)/21	\$51.97/ha/year
Subsequent years—Servicing + consumables/year	(\$13.50 + \$7.90/5 deer/week)×26	\$556.40
Cost estimate/ha/year	(\$556.40/21 ha)/21	\$26.50/ha/year
Estimates of costs associated with area-wide spray application in CT (Stafford 1997)		
Commercial spray estimates	1 application/ha/yr	\$450.00
	2 applications/ha/yr	\$900.00
Comparison of cost estimates of 4-Poster vs. spray applications		
Savings per ha during Year 1 of 4-Poster treatment		
1 spray application vs. 4-Poster		\$450.00–\$51.97 = \$398.03
2 spray applications vs. 4-Poster		\$900.00–\$51.97 = \$848.03
Savings per ha during subsequent years of 4-Poster treatment		
1 spray application vs. 4-Poster		\$450.00–\$26.50 = \$423.50
2 spray applications vs. 4-Poster		\$900.00–\$26.50 = \$873.50

commercial use on white-tailed deer. PointGuard has since been taken off the market. In 2003, the U.S. Environmental Protection Agency granted a label for the use of a 10% oily formulation of permethrin to Y-TEX (Cody, WY). This formulation, marketed as 4-Poster "Tickicide," was labeled for exclusive use on the 4-Poster, with a treatment season from 1 September through 30 June to control blacklegged ticks (no restriction on use during deer hunting season) and a treatment season from 1 February through 1 October to control lone star ticks. Unlike the amitraz formulation used in the NEATCP, Tickicide contains no volatile components, thereby providing the full volume of applied acaricide for transfer to the deer. An oily formulation of 10% permethrin, somewhat similar to Tickicide, resulted in 91% control of nymphal blacklegged ticks (Solberg et al. 2003), as compared to the 71% control efficacy estimated by meta-analysis of data from the five NEATCP locations (Brownstein et al., 2009).

During fall 2003, the USDA-ARS–held patent for the 4-Poster was licensed to the American Lyme Disease Foundation (Somers, NY), to market devices manufactured by C.R. Daniels (Ellicott City, MD). At the latest listing from C.R. Daniels, the initial cost of a 4-Poster unit was \$425 US, a 3.79 L (=1 gal) bottle of the Tickicide was \$175, and an acaricide dosing gun with the special hood for the applicator rollers was \$110 (Table 6). The manufacturer recommended purchase of an additional dozen applicator rollers (\$35) and a dozen warning signs (\$35) for the initial setup. Therefore, the total cost of an initial setup is approximately \$780, but because the same acaricide, dosing gun, rollers, and warning signs could be used with several units, subsequent setups required only purchase of the 4-Poster unit.

According to the label, 1 mL of Tickicide is to be applied to rollers for each 0.68 kg of corn consumed from the device since the previous visit. Thus, the cost for Tickicide would be approximately \$0.031–\$0.046/deer/day or \$0.21–\$0.32/deer/week, and the cost for corn plus Tickicide would be \$1.05–\$1.58/deer/week. As reported previously, an average of 3.4 kg of corn was consumed for each 4-Poster/feeding day, suggesting that approximately five deer (taking into consideration incidental corn loss to other species) were feeding at each device/day. At \$1.58/deer/week the acaricide and corn would cost ca. \$7.90 for the five deer/week (Table 6). Adding the service cost of \$13.50/device/week, gives a total estimated cost \$21.40/device/week or \$556.40 for the 26 weeks of treatment/year.

After adding the initial cost of \$425/4-Poster device and \$110 for the applicator gun, the cost to purchase and operate a single unit during the first year was estimated at \$1091.40. Assuming a deployment density of one 4-Poster device/21 ha, property area costs were estimated to be \$51.97/ha/year for the first year and \$26.50/ha/year for subsequent years. These costs compare quite favorably to the estimated cost of \$450/ha for a single commercial application of area-wide acaricide spray on residential properties in CT (Stafford 1997). As acaricide sprays are often applied once in the spring or summer to control nymphs and again in the fall to control adults, the yearly cost of spraying can be \$900/ha/year. Also, these estimates were made in 1997 and most assuredly cost of spraying has increased since then.

Finally, it should be noted that the NEATCP protocol prescribed a density of approximately one 4-Poster/21 ha to maximize deer access to the devices. However, Williams and DeNicola (2000) and Kilpatrick and Stober (2002) have suggested, based on estimates of the home range of deer herds in CT, that one device per 50–60 ha is an adequate density that minimizes the placement of multiple devices within a herd's home range. For optimum treatment, the recommended density of devices should be based on prior knowledge of the density of deer in a specific location and the herd home range.

Conclusions

The NEATCP demonstrated that properly deployed and maintained 4-Poster Deer Treatment Bait Stations significantly reduced the numbers of free-living blacklegged ticks at six of the seven sites and lone star ticks at all three of the sites where these ticks were present. The 4-Poster technology was safe, efficacious, economical, and environment friendly.

Unlike acaricidal spraying that kills all life stages of ticks, the 4-Poster method primarily targeted adult ticks on deer. Measurable reductions in free-living nymphal blacklegged and lone star ticks densities typically occurred with a lag of 1 or 2 years after device deployments, and maximal control required 4 or more years of treatment. In addition, and in contrast to direct acaricide application technologies, the degree of efficacy achieved with the 4-Poster technology was dependent upon a variety of environmental factors, including deer densities, interference from nontargeted animals, and the timing, intensity, and duration of acorn masts. In addition to these uncontrollable vagaries of environment, the operators were required to use their experience and skill to properly implement the technology and to recognize and rapidly respond to novel situations requiring change. Although implementation of 4-Poster technology requires continuous attention throughout periods of adult tick activity, the estimated cost of 4-Poster technology is many times less than applications of area-wide sprays (Table 6). Also, as demonstrated by Solberg et al. (2003), the level of control achieved by 4-Poster deployment may be equal to that of acaricide spraying and does not leave measurable residues of acaricide in the environment.

Aknowledgments

The authors thank C.A. LeMeilleur, G.R. Earl, A.J. Siebenaler, R.W. Ryan, and the late C.M. Santos (USDA-ARS Livestock Insects Research Unit, Knipling-Bushland U.S. Livestock Insects Research Laboratory) for overseeing construction and delivery of 4-Poster devices to research locations and for manufacture and shipment of replacement and accessory parts during the project. The authors give special thanks to S. Duke (USDA-ARS Southern Plains Area), R.W. Ryan, and the late C.M. Santos for assistance in obtaining, organizing, collating, inputting, and analyzing data sets from each research location. Sincere appreciation is also expressed to Erin McHugh-Driscoll, James Vellozzi, and Theresa Boccia (The Louis Calder Center) for management and operation of the project in New York. The authors also acknowledge and thank the USDA for funding the NEATCP, Yale University, New Haven, CT, for administering and distributing funds to participants, and Intervet, Millsboro, DE, for graciously providing the PointGuard acaricide without cost to the NEATCP.

Disclosure Statement

The 4-Poster device was developed and patented as a result of research by scientists of the Agricultural Research Service, USDA. Scientists J.M. Pound and J.A. Miller are two of the three inventors listed on the patent and receive nominal royalties through the USDA as per U.S. government regulations. Other authors have no competing financial interests.

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