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Development of a Bait for the Oral Delivery of Pharmaceuticals to White-Tailed Deer (*Odocoileus virginianus*)

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Abstract: Solid and liquid baits were tested for the delivery of drugs to white-tailed deer. The solid bait was comprised of a mineral block paired with apple, peanut butter, or acorn extract. The liquid bait was comprised of water, apple juice, glycerine, salt, and either peanut butter or apple odor. Although both solid and liquid baits were attractive to deer, the latter may be more useful because consumption can be measured directly, ingestion by nontarget animals is minimized, and bait degradation by weathering is reduced.

Keywords: bait, deer, *Odocoileus virginianus*, odor, taste

Deer (*Odocoileus* sp.) cause more agricultural damage than any other vertebrate species in the United States (Conover and Decker 1991). In New Jersey alone, white-tailed deer (*O. virginianus*) damaged more than $20 million of various food and nonfood crops in 1990 and were involved in 8,000 collisions with automobiles (New Jersey Farm Bureau 1990). Burgeoning deer populations also pose a growing threat to human and animal health and safety because deer are important in the life cycle of *Ixodes damini*, the tick that is the primary vector for transmission of the Lyme disease spirochete (Anderson 1988).

To date, deer control activities have focused on increasing hunter access to private lands (Atwill 1991, New Jersey Agricultural Statistics Service 1990), manipulating hunting seasons (Conover and Decker 1991), erecting deer fences (Boggess 1982), and developing repellants to protect localized areas from severe browsing damage (Conover 1984 and 1987, Scott and Townsend 1985). These techniques are effective, but lethal control is not considered safe, practical, and/or politically acceptable in many suburban and urban areas. Deer herds have grown so large in many areas that repellants now have little effect (Milunas et al. 1994).

Nonlethal methods to reduce deer numbers and/or slow population growth in suburban and urban areas are being sought (Kirkpatrick and Turner 1985). Chemical sterilants and immunosterilants may become available within the next decade (Turner et al. 1990), but the problem of inoculating large numbers of deer remains. Silastic™ implants (e.g., Plotka and Seal 1989) and direct intramuscular injections (Harder and Peterle 1974) are neither economical nor efficient. Although oral vaccines would be both inexpensive and relatively easy to use, no bait formulations are currently available. The investigations described herein address this need.

Materials and Methods

Three experiments were performed during the winter of 1991 and spring of 1992. Experiment 1 evaluated the relative attractiveness of apple, acorn, sweet corn, and peanut butter extract. Experiment 2 explored the attractiveness of salt blocks, mineral blocks, molasses blocks, and molasses–mineral blocks. All block types were presented in combination with apple extract. Experiment 3 assessed whether synergisms might occur among the food extracts.

Two additional experiments were performed during the spring and summer of 1993. The first (experiment 4) compared the relative attractiveness of mineral blocks with the attractiveness of a solution comprised of water, apple juice, glycerine, and salt. Apple and peanut butter extracts were evaluated as components of both bait types. The second (experiment 5) measured the consumption of the liquid bait adulterated with fluorescein. Feces were collected to determine whether they contained fluorescent particles.

1991–92

Study Sites—Four 25-ha sites near Poughkeepsie, NY, were selected, each representing a different habitat type. The first site was an annually mowed field; the second, an old field with scattered apple trees and clumps of honeysuckle; the third, a woodlot dominated by maple (*Acer* sp.); and the fourth, a bottomland dominated by sweetgum *(Liquidambar styraciflua)* and sycamore *(Platanus occidentalis)*. Between 10 and 20 deer were regularly observed at all sites during the 4 weeks prior to the experiment. For all of the experiments below, transect grids were established within each site. Transect intersect points served as potential testing locations (see below).

Experiment 1—Apple odor extract was obtained from International Flavors and Fragrances (Union Beach, NJ). Peanut butter extract was donated by Hercules Flavor Co. (Middletown, NY). Acorn and sweet-corn odor extracts were purchased from the M & M Fur Co. (Bridgewater, SD). Each stimulus liquid was diluted in propylene glycol to produce 2-percent (mass/mass) stimulus concentrations.

We chose to examine extracts and not foods, per se, for two reasons. First, we expected that the extracts would be more durable in the field. Second, there is evidence that extracts of preferred foods are attractive to captive deer and increase ingestion even when presented "out of context." For example, food odors in solution enhance drinking (Rice and Church 1974).

Likewise, we chose to examine food odors instead of semiochemical odors (e.g., urine, glandular secretions) because we wanted to promote ingestion and not merely investigation. Semiochemicals typically result in the latter but only rarely the former (R. A. Mugford and D. Passe, pers. comm.) Also, we wanted to attract both males and females, and we surmised that food odors would be superior to social odors in this respect.

A priori, we chose salt as the principal ingredient in our formulations for the following reasons. First, we infer that it is relatively simple to incorporate a variety of pharmaceutical chemicals into a salt matrix. Second, as herbivores, deer are chronically sodium deficient (Belovsky 1981), and, therefore, they avidly consume salt (Jones and Hanson 1985). Third, the use of salt provided a measure of species specificity. Unlike herbivores, carnivores and many omnivores consume diets that are sodium replete. Meat eaters rarely show strong salt preferences and often are indifferent to this tastant (Beauchamp and Mason 1991).

Testing occurred during November and December 1991. At each of the four experimental sites, eight testing locations were randomly selected, with one qualification. That qualification was that no location could be situated within 20 m of an existing deer trail (operationally defined as clear paths with deer tracks). Four of these locations were randomly assigned to the odor condition (one odor/location). The remaining locations were assigned to the control condition.

On Mondays of each of the next 4 weeks, one odor location and one control location were randomly selected (sampling without replacement) at each experimental site. At odor locations, a 1.8-kg salt block (Cargill, Inc., Minneapolis, MN) was suspended 1 m above the ground in a holder attached to a metal stake or a large tree. A metal deflector was attached to the stake above the block to shield it against precipitation. Stakes were positioned so that there was a large tree immediately behind them to block extraneous activity records (see below). Next, one of the odor stimuli was randomly selected (sampling without replacement), and 10 mL was poured into a glass scintillation vial (5 cm in length, 1 cm in diameter). The vial was attached to the stake just below the salt block. At control locations, a vial containing 10 mL of propylene glycol was attached to the stake, as described above. Braided cotton wicks were inserted through holes in the lids of the vials; half of each (1.5 cm) was exposed to the environment. These wicks controlled the escape of stimulus odors.

Infrared motion detectors (Trailmaster, Inc., St. Paul, MN) were mounted 1 m above the ground and 3–4 m from the lure block on trees at each test and control location. The units were tuned to record the time and date of visits by deer. Each unit only detected activity by moving objects at least 60 cm in diameter within 0.5 m of the salt block. Accordingly, the units were insensitive to smaller animals and to activity on either side of the trees against which the lure blocks were placed (Mason et al. 1993). In addition to visit data, the weights of the salt blocks and animal tracks within 2 m of the blocks were recorded weekly. To record weight changes of the blocks, the salt was returned to the laboratory and placed in a drying oven at 40 °C for 48 hours. The block was then weighed, and this weight was subtracted from the dry weight of the block prior to testing. Fresh oven-dried blocks were used for each 7-day test session.

Experiment 2—Salt blocks, mineral blocks, molasses–mineral blocks, and molasses blocks served as stimuli (table 1). All were presented in combination with apple extract, a generally attractive scent (see experiment 1 results, below).

Testing occurred during December 1991 and January 1992 at eight new locations that were randomly selected. The procedures followed were identical to those described for experiment 1.

Experiment 3—Mineral blocks were presented in combination with apple extract only, or paired extracts (apple–acorn, apple–peanut butter, or acorn–peanut butter). Testing occurred during January and February 1992 at eight new, randomly selected locations. The procedures followed were identical to those described for experiments 1 and 2.

Analyses—Visit data were heterogeneous (Bartlett's test, cited in von Eye 1990), and thus were transformed to their natural logs. Difference scores were created from the transformed data set by subtracting control location values from test location values. Because the baits were serially exposed, the data were evaluated in a two-way repeated measures analysis of variance (ANOVA). The within-subjects (repeated measure) was attractant. The between-subjects effect was habitat type. Tukey post-hoc tests (Winer 1962) were used to isolate significant differences among means, with the significance level set at $P < 0.05$.

Although stimulus weights were collected in all experiments, lengthy periods of severe wet weather eroded blocks and precluded accurate measurement of consumption. For this reason, these data are not reported.

Table 1. Contents of stimulus blocks used in experiment 2

Type	Manufacturer	Contents
Salt	Cargill, Minneapolis, MN	Sodium chloride, white mineral oil
Mineral	Cargill, Minneapolis, MN	Sodium chloride, white mineral oil, 0.2% manganese, 0.1% iron, 0.1% magnesium, 0.05% sulfur, 0.025% copper, 0.01% cobalt, 0.008% zinc, 0.007% iodine
Molasses	Trophy Feeds, Walled Lake, MN	Corn syrup, sucrose molasses, peanuts, cracked corn, hydrogenated vegetable oil, lecithin
Molasses–mineral	PM Ag Products, San Francisco, CA	52% sodium chloride, 1.5% calcium, 0.4% phosphorus, 2.75% magnesium, 1.0% potassium, 0.0003% iodine, 0.03% iron, 0.00025% selenium, cane molasses, cottonseed meal

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Study Sites—For experiment 4, three of the four 25-ha sites (old field, woodlot, bottomland) used in experiments 1–3 were selected. Deer were regularly observed at all sites prior to the experiment.

For experiment 5, five locations were selected at the Morris Arboretum of The University of Pennsylvania. The 40.5-ha arboretum has a resident deer herd of more than 50 animals. Each of the five locations was separated from the others by at least 200 m.

Experiment 4—Two locations were randomly selected at each test site. At one, a 1.8-kg mineral block was suspended in a metal holder about 1 m above the ground, as previously described. At the other, a liquid dispenser was suspended on a metal stake at the same height. The dispenser consisted of a 1-L polyethylene bottle with a metal, 15-mm-in-diameter single-ball sipper tube attached. The bottle contained a solution of 20 percent apple juice, 18 percent glycerine, 60 percent water, and 2 percent sodium chloride. Each bottle was encased inside a section of polyvinyl chloride (PVC) pipe 32 cm high and 14 cm in diameter. A PVC end cap was permanently attached to one end. Extracts of apple or peanut butter (see below) were presented in glass scintillation vials, as previously described, and passive infrared motion detectors were used to record visits to bait locations.

A 2-week pretest period began March 1, 1993. During this period, both mineral-block and liquid baits were present, and the infrared units were used to obtain a baseline measure of activity. Eight weeks of testing immediately followed the pretest period. Testing consisted of four 2-week trials. During the first trial, the mineral blocks and liquid bait dispensers were presented in the same locations as in the pretest period. The scintillation vials contained apple extract. After 14 days, the number of visits to each location, and the amount of liquid bait consumed were recorded. An attempt was made to record consumption of the mineral block.

During the second 2-week trial, conditions were reversed. Freshly prepared liquid bait was presented at what was formerly the mineral-block location, and vice-versa. Visit and consumption data were recorded after 14 days, as described above.

The third 2-week trial immediately followed the second. Fresh solid and liquid baits were again presented in their original locations, and the only difference from the first trial was that peanut butter extract replaced apple extract in the scintillation vials. At the end of 2 weeks, fresh liquid bait was presented at what was formerly the mineral-block location, and vice-versa.

Experiment 5—Baiting locations were randomly situated (1 station/8.1-ha area) on the grounds of the Morris Arboretum. At each location, a dispenser identical to that described above was attached to a tree, approximately 1 m above the ground. Each dispenser was filled with the liquid bait, and a scintillation vial containing apple extract was taped to the PVC pipe. The bait formulation was identical to that previously described, except that it also contained 30 p/m of fluorescein. Laboratory studies had suggested that this was the minimum detectable concentration.

At each bait location, a 10-m^2 sampling plot around the bait dispenser was marked with stakes and orange spray paint. During the 12 days prior to bait presentation on June 22, 1993, each site was visited every 4 days, and all feces within the sampling plot were collected.

On day 13, 1 L of liquid bait was poured into each bait station. Over the next 3 weeks, each location was visited at 4-day intervals. Feces within sampling plots were collected, fluid losses from the bait dispensers were recorded, and the bait solution was replaced. In addition, any feces encountered as the observers walked from one bait location to the next were collected and their location was recorded.

Feces were placed in a drying oven (37.8 °C) for 72 hours. Dried feces were weighed, pulverized, and then examined under ultraviolet illumination for fluorescence. The number of fluorescein particles observed in each sample was recorded by two observers.

Analyses—Experiment 4 visit data were transformed to their natural logs. These log scores were evaluated in a three-factor (habitat, extract, bait type) ANOVA. As in 1991–92, weathering precluded measurement of solid bait consumption. For the liquid bait only, a repeated measures *t*-test was used to compare drinking in the

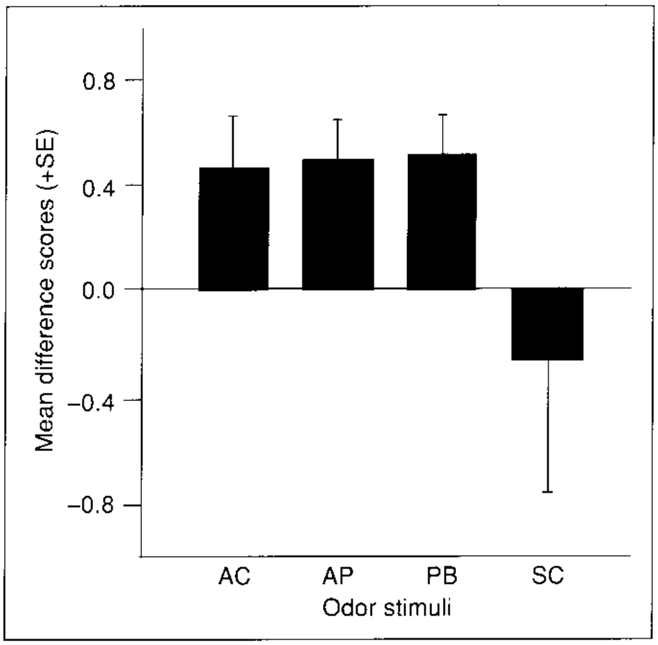

Figure 1. Mean difference scores for log visits to each odor presented in experiment 1. Capped vertical bars represent standard errors of the means. Abbreviations: AC = acorn, AP = apple, PB = peanut butter, SC = sweet corn (from Mason et al. 1993).

presence of apple extract *v.* drinking in the presence of peanut butter extract.

Experiment 5 consumption over days was evaluated in a single-factor repeated-measures ANOVA. Although the presence of fluorescein was not formally assessed, a descriptive summary of these results is presented below.

When appropriate, Tukey tests were used to isolate significant differences among means ($P < 0.05$).

Results

1991–92

Experiment 1—Deer tracks were observed at all experimental and control sites. The only other tracks observed were those of raccoons and mice.

There were significant differences among odor stimuli ($F = 3.6$; 3,72 df; $P < 0.02$), and an interaction between odor stimuli and habitat type ($F = 2.2$; 9,72 df; $P < 0.03$). Post hoc tests showed that, relative to controls, deer visited locations scented with apple, acorn, or peanut butter extract more frequently than they visited locations scented with sweet-corn extract (fig. 1).

Post hoc examination of the interaction term revealed the following pattern of effects. Apple extract had more visits than any other extract in the old-field habitat ($P < 0.05$). Peanut butter and acorn were more attractive than the other extracts in the bottomland ($P < 0.05$, fig. 2). Acorn, apple, and peanut butter were equally effective in the annually mowed field or the woodlot.

Experiment 2—Numerous deer tracks were observed at all experimental and control sites. The tracks of small birds and raccoons also were present occasionally. Other tracks were not observed.

There were significant differences among stimuli ($F = 4.9$; 3,72 df; $P < 0.004$). Post hoc tests showed that mineral blocks were significantly more attractive than salt blocks or molasses–mineral blocks ($P < 0.05$). The least attractive stimulus was molasses block (fig. 3). Otherwise, there were no significant effects.

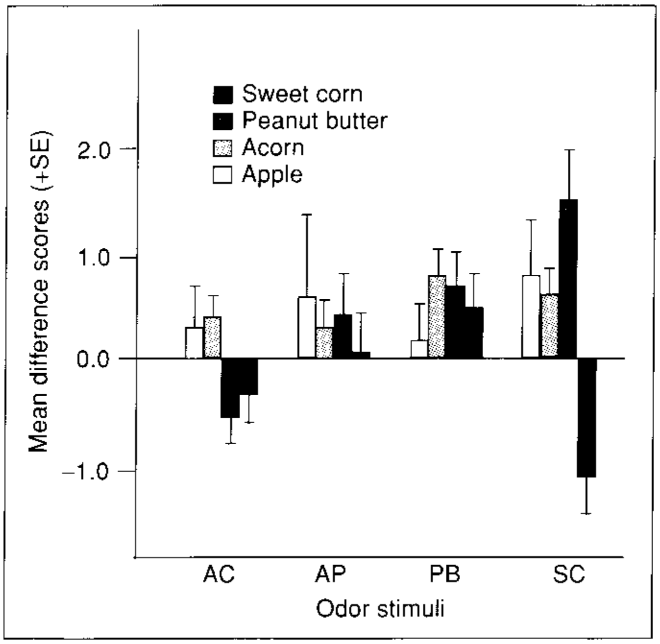

Figure 2. Mean difference scores for visits to each odor in annually mowed field (MF), old field (OF), woodlot (W), and bottomland (WET). Capped vertical bars represent standard errors of the means (from Mason et al. 1993).

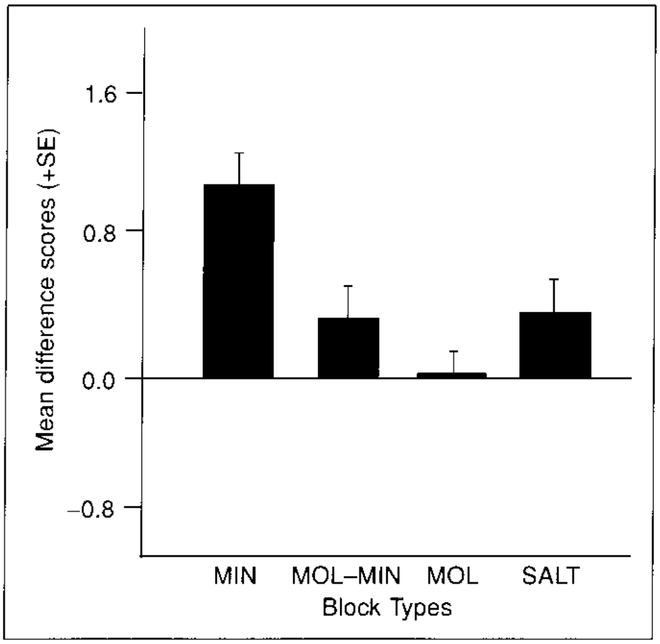

Figure 3. Mean difference scores for log visits to block stimuli presented in experiment 2. Capped vertical bars represent standard errors of the means. Abbreviations: MIN = mineral blocks, MOL–MIN = molasses–mineral blocks, MOL = molasses blocks, SALT = salt blocks (from Mason et al. 1993).

Experiment 3—Numerous deer tracks were observed at all sites. Raccoon tracks and the tracks of small birds were also occasionally present. Other tracks were not observed.

There were no significant differences among extract combinations *($P > 0.35$)* or habitat types *($P > 0.45$)* (fig. 4), and no significant interactions *($P > 0.25$)*.

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Experiment 4—There were significant differences among habitat types *($F = 12.8$; 2,3 df; $P < 0.034$)*. Deer visited old-field locations most often and wetland locations least often. Also, liquid bait locations were visited significantly more often than mineral-block bait locations *($F = 23.16$; 1,2 df; $P < 0.015$)*.

There were significant interactions between habitat type and extract *($F = 10.18$; 2,3 df; $P < 0.046$)*, and among habitat type, extract, and bait type *($F = 19.59$; 2,3 df; $P < 0.02$)*. Post hoc analyses of these interactions revealed the following pattern of effects. First, the number of visits to locations baited with apple or peanut butter extracts were equivalent at the woodlot and bottomland sites. Peanut butter was relatively more effective (i.e., attracted significantly more visits) in the old-field setting. Second, the liquid bait locations were visited more often than mineral-block locations (fig. 5). The one exception was when mineral blocks were paired with peanut butter extract in the old-field or bottomland sites. Under these circumstances, mineral blocks were visited significantly more often.

When consumption of liquid bait alone was examined, overall drinking of bait paired with apple extract (780 $\pm$ 60 mL) was significantly higher than drinking of bait paired with peanut butter extract (490 $\pm$ 80 mL). Nonetheless, preferences varied considerably from one habitat type to another (fig. 5).

Experiment 5—There were significant differences among measurement periods *($F = 6.56$; 6,24 df; $P < 0.0005$)*. Post hoc evaluation of this effect showed that liquid bait consumption increased steadily throughout the course of the experiment (fig. 6).

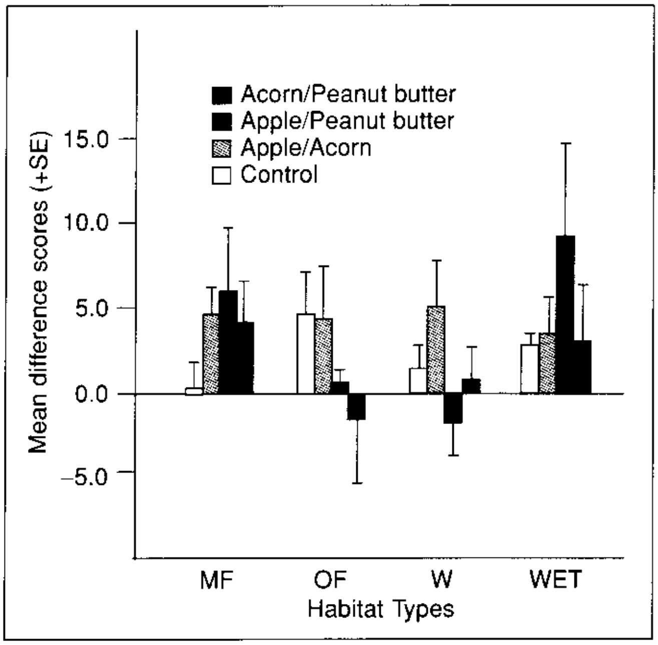

Figure 4. Mean differences scores for visits to odor pairs presented in combination with mineral block in experiment 3. Capped vertical bars represent standard errors of the means. Abbreviations: MF = annually mowed field, OF = old field, W = woodlot, WET = bottomland (from Mason et al. 1993).

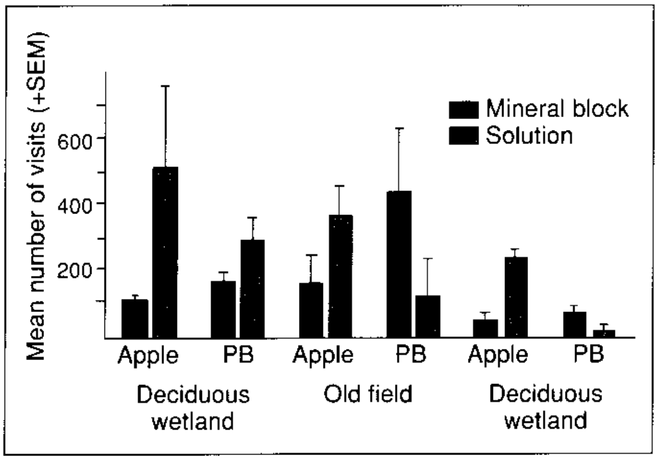

Figure 5. Mean number of visits to solid and liquid baits in experiment 4. *Bottom:* Mean consumption of liquid bait paired with either apple or peanut butter odors. Capped vertical bars represent standard errors of the means. Abbreviation: PB = peanut butter odor.

Deer droppings were found at baiting locations throughout the pretest period. Not surprisingly, no fluorescein was detected in these droppings. However, fluorescein was observed as soon as the dispensers were filled with liquid bait. Overall, fluorescent particles were observed in 75 percent of the deer droppings collected during the test period. The dye was also detected in two of the three samples of rabbit droppings collected during the experiment. All rabbit feces were collected outside of the 10-m^2 sampling grids. No fluorescence was detected in the droppings of other vertebrates (raccoon, five samples; fox, three samples).

Discussion

With the exception of sweet-corn, all food extracts evaluated in experiment 1 enhanced the attractiveness of salt blocks relative to blocks paired with propylene glycol. Attractiveness appeared to be habitat specific, however, and the reasons for this are unclear. Recent feeding histories, novelty, or differences in odor dispersion in different habitat types are all plausible explanations. There may also have been concentration differences in volatiles emanating from the stimuli. Although better documented for taste stimuli (e.g., Sclafani 1991), such stimuli undoubtedly influence the attractiveness of odors as well.

In experiment 2, mineral blocks were the most attractive stimuli and molasses blocks, the least attractive. Salt blocks and molasses–mineral blocks were moderately attractive. Habitat differences appeared to be unimportant. These data suggest that molasses may not be attractive to deer and that the presence of molasses in a formulation could decrease its attractiveness.

In experiment 3, combinations of extracts were no more effective than apple extract alone. This result was surprising because we had expected some synergy in the stimulus combinations. One possible explanation for this lack of effect is that the deer had considerable experience with each of the odor types at lure stations. Conceivably, naive deer would respond differently.

In experiment 4, the liquid bait was significantly more attractive (i.e., was associated with significantly more visits) than the mineral block–apple extract bait. As expected on the basis of experiment 1, apple and peanut butter extracts appeared to be equally effective stimuli. Although mean consumption was relatively higher in the presence of the former, presentations of the extracts were confounded with time. As such, visits might have continued to increase regardless of the extract presented. This possibility is consistent with the steady increases in drinking observed in experiment 5.

Although deer were the principal bait consumers in experiment 5, fluorescent particles were present in two of the three samples of rabbit droppings collected during the experiment. We speculate that one explanation for this observation may be that the rabbits consumed spillage under the liquid dispensers. In pilot testing, small amounts of spillage (15 mL/dispenser over 4 days) were observed. An alternative explanation is that rabbits may have eaten deer pellets containing fluorescein. Evidence indicates that rabbits will ingest the fecal pellets of conspecifics as well as those of other herbivores, including deer (Hill 1964). In this regard, it may be important that the contami-

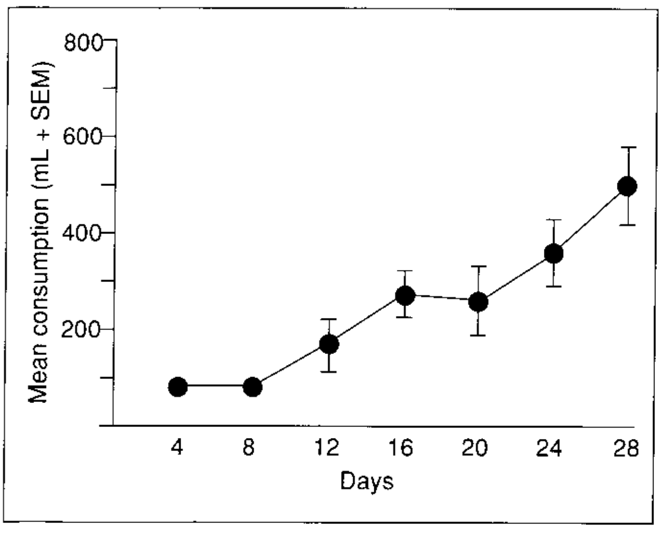

Figure 6. Mean consumption of liquid bait over measurement sessions in experiment 5. Capped bars represent standard errors of the means.

nated feces were collected between baiting locations and outside the sampling grids. Whatever the explanation, the presence of fluorescein in rabbit droppings is evidence that nontarget exposures to pharmaceutical substances presented in a liquid bait can occur. Of course, solid baits (and possibly, even injected substances) present the same likelihood of nontarget exposure via coprophagia or consumption of spillage. Experiments are needed to address this issue.

Management Implications

We are cautious about extrapolating from a series of small field experiments. Nevertheless, our results have testable, practical implications. Foremost among these is the possibility that mineral blocks paired with apple, acorn, or peanut butter extracts, or liquid bait (water, apple juice, glycerine, salt) paired with apple or peanut butter extracts could provide effective, economical, and relatively selective baits for the delivery of contraceptives or other chemicals (e.g., vaccines against Lyme disease) to white-tailed deer.

A number of important research issues remain. First, we still do not know how many different deer actually contact baits, nor do we know the frequency of contacts by individual deer. Second, we suspect that the number of deer in an area could affect lure effectiveness. Finally, it would not be surprising if the attractiveness of lures was seasonally and/or geographically variable (Schultz and Johnson 1992). Although experiments 4 and 5 suggest that the liquid bait is as effective in summer as it is in late winter and early spring, there is evidence that deer are more likely to use mineral licks during the spring and early summer than during the winter (Weeks and Kirkpatrick 1976, Weeks 1978, Jones and Hanson 1985). This seasonal effect may be more pronounced in southern latitudes (e.g., Louisiana) than in the north (Schultz and Johnson 1992).

At present, liquid baits appear to be more useful than solid baits for several reasons. First, the addition of pharmaceutical substances to the formulation appears to be simpler. Second, problems with the direct ingestion of the bait by nontarget animals are reduced (though secondary nontarget hazards may still exist). Third, bait degradation by weathering is minimized, and the measurement of bait consumption is enhanced.

Acknowledgments

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