EFFECTS OF FOLIAR INSECTICIDES ON SURVIVAL OF NORTHERN BOBWHITE QUAIL CHICKS

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Abstract: Reduced survival of chicks may result from exposure to insecticides and may explain declines in northern bobwhite quail (*Colinus virginianus*) populations on agricultural landscapes. To determine the risk insecticides pose to quail, we quantified exposure rates and hazard. Exposure rate depends on quail habitat use in relation to insecticide applications, whereas hazard depends on susceptibility to a toxin and the dose an individual receives. Because providing early-successional vegetation around row-crop fields is a typical habitat management recommendation, we determined rates of exposure of quail and their broods to insecticides applied to soybean fields with and without vegetated field borders. Radiocollared quail (n = 69) used soybean fields extensively (64% of telemetry locations) at the time of year insecticides were applied. Quail used soybean fields twice as often when vegetated borders surrounded crop fields (P = 0.04). Ten of 18 broods monitored by telemetry were located in soybean fields 88% of the time. In 1993, 4 of 6 broods <14 days old were in crop fields at the time insecticides were aerially applied. Mesocosm trials simulating worst-case exposure of quail chicks to insecticides resulted in no chick mortality or depression of brain cholinesterase (ChE) activity for the currently used insecticides thiodicarb and methomyl (P > 0.49). However, ChE activity was depressed (P < 0.001) and body mass was lower (P = 0.02) in chicks exposed to methyl parathion, which historically (pre-1980) received significant use in production of row crops in North Carolina. Our results, along with data on use and toxicity of other insecticides applied to row crops, collectively suggest direct affects to survival of quail chicks from use of foliar-applied insecticides does not explain reduced quail densities on agricultural landscapes.

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Northern bobwhite quail (hereafter, quail) populations have declined significantly over the past 30 years (Brennan 1991, Church et al. 1993). A potential contributing factor to reduced quail numbers on agricultural landscapes is the affect agrichemicals may have on survival of quail chicks. Mortality of quail chicks may be linked directly or indirectly to exposure to anticholinesterase insecticides (Hill and Fleming 1982, Grue et al. 1983, Palmer and Bromley 1992).

Late-summer (i.e., Jul–Sep) reproduction accounts for a significant proportion of quail productivity on modern farms (Burger et al. 1995, Puckett et al. 1995). If foliar applications of insecticides coincide with late-season brood production, effects on chick survival could reduce quail populations. However, relations between insecticide use and quail reproductive ecology are poorly documented for populations of quail on modern farms. Information is needed on probability of exposure and associated hazards posed to adult and young quail by insecticide applications.

Advances in knowledge of insecticide effects on quail chicks have been hindered by difficulties inherent to studying ecology of wild quail chicks. Small sample sizes obtainable from modern farms, difficulties recovering chicks exposed to insecticides (Balcomb 1986, White et al. 1990), and large variances in chick survival estimates (e.g., DeMaso et al. 1997) are obstacles to testing hypotheses concerning insecticide effects to quail chicks. In addition, extrapolation from laboratory studies to field situations is often tenuous (Hill 1994).

To overcome the limitations of traditional research approaches, we used a combination of field studies and mesocosm experiments (Odum 1984) to determine exposure of quail chicks to

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foliar insecticide applications and assess the risk posed by specific carbamate and organophosphorus insecticide applications. The objectives of this study were (1) determine exposure rates of wild quail to insecticide applications on farms with and without habitat enhancements, (2) determine the hazard to quail chick survival posed by modern insecticides used on soybeans, and (3) assess whether direct effects from currently used insecticides explain low quail densities on farms in eastern North Carolina.

STUDY AREA

Two study farms were located on the Alligator River National Wildlife Refuge (ARNWR), Dare County, North Carolina, in the northeastern Coastal Plain. Farm A was 500 ha and Farm B was 1,050 ha. These farms were separated by approximately 5 km over which the refuge managed moist-soil units and crop fields for waterfowl. The area surrounding the farms was uninhabited pocosin and mixed-pine–bottomland hardwood covering 80,000 ha. Originally, these farms were forested wetland, so both were drained by a system of drainage ditches and canals. Parallel drainage ditches occurred at 70–90-m intervals and averaged 0.9 km in length (range = 0.3–1.3). These ditches empty into canals that run perpendicular to the ditches. Crop fields were located between drainage ditches and averaged 6 ha (range = 4–10 ha). The primary crop grown on ARNWR during summer was soybeans planted either by broadcast spreader and disked into the soil, drilled in 17.5-cm rows, or planted in 75-cm rows; however, limited amounts of corn and milo were planted.

We modified the availability of early-successional vegetation, an important component of quail nesting and brood-rearing habitat (Stoddard 1931), on both farms to determine if exposure rates of quail to insecticide applications varied with availability of nesting and brood-rearing cover on farms. We increased availability of early-successional habitat on a portion of each farm by creating 1 section with and 1 section without field borders. Field borders were approximately 2.5-m strips of vegetation that bordered both sides of drainage ditches. Field borders were planted in a mixture of legumes but had been invaded by naturally occurring vegetation including *Solidago* spp., *Eupatorium* spp., *Andropogon* spp., *Panicum* spp., and *Paspalum* spp. Farm A had a 282-ha section with field borders, and Farm B had a 640-ha section with field borders. Field borders accounted for approximately 5% of crop land.

METHODS

Field Experiments With Telemetry

Determining exposure of quail to insecticide applications on the study farms necessitated monitoring habitat use. To accomplish this, we captured quail from February to July 1993–94, using baited funnel traps on the 2 farms located on ARNWR. We fitted quail with harness-style radiotransmitters (Holohil Telemetry Systems, Woodlawn, Ontario, Canada) and released them at the capture site. This research was approved by the North Carolina State University Institutional Animal Care and Use Committee (Project 92–103).

We located each quail 3 times/week from May through September to determine use of crop fields and other habitats. We located adults with broods twice daily during the first 2 weeks posthatch and daily thereafter. We determined locations of adults and adults rearing chicks via triangulation from known points (White and Garrot 1980) or by walking to within approximately 30 m of their location. We used Telebase (Wynn and Hurst 1990) to determine coordinates of quail locations and entered coordinates into a Geographic Information System (GIS) for habitat analyses (Strategic Mapping 1993). We determined habitat use by overlaying quail locations onto a GIS habitat map. We located broods immediately prior to and after insecticide applications that occurred during August 1993. We monitored quail daily for incubation behavior. When a quail began incubation, we located the nest by triangulation and did not visit it again until incubation ended. We estimated chick survival by flushing the brood and counting the chicks once they were 28 days old (DeVos and Mueller 1993).

Production of Quail Broods for Insecticide Trials

To produce quail broods for mesocosm experiments, we obtained eggs by crossing captured wild males with captive-strain females housed at our lab. After hatching, we placed 12 1 day-old chicks with different adult quail until adoption had occurred (Stoddard 1931). After adoption, we moved the brood and adult to an outdoor rearing pen. Rearing pens consisted of a 0.75- × 0.75-m covered brooding chamber

Table 1. Description of insecticide trials in which northern bobwhite quail chicks were exposed to applications of carbamate and organophosphate insecticides.

Trial	Product	Date	Row width (cm)	Nozzle[a] type	Application[b] rate (a.i. kg/ha)	Canopy closure (%)
1	Lannate	3 Sep 1992	91	8002 f.f	0.50	74
1	Larvin	3 Sep 1992	91	8002 f.f	0.28	76
2	Lannate	27 Aug 1993	91	8002 f.f	0.50	82
3	Larvin	9 Sep 1994	20	TX6 h.c	0.45	88
3	Penncap-M	9 Sep 1994	20	TX6 h.c	1.12	91

[a] f.f. is a flat-fan nozzle, and h.c. is hollow-cone nozzle.
[b] a.i. is active ingredient of the insecticide.

connected to a triangular, 6.25-m^2 outdoor exercise area. Vegetation in the exercise portion of pens consisted of planted white clover (*Trifolium repens*) and native vegetation. Each day, we used sweep nets to collect arthropods from areas where no insecticides had been applied and released them into the rearing pens to provide chicks a greater opportunity to forage on arthropods. We provided water and a commercial food, but no heat source. Broods remained in rearing pens until we conducted insecticide trials when chicks were 7–11 days old.

Selection of Insecticides

We tested foliar insecticides Lannate 1.8 L (methomyl), Larvin 3.2 F (thiodicarb), both carbamates, and Penncap-M 2 ME (methyl parathion), an organophosphate. Larvin and Lannate are applied to soybean fields in years when corn earworm (*Heliothis zea*) infestations reach socioeconomic thresholds, which occurs about 1 in 5 years. For instance, almost no acreage in Wilson County received an insecticide application for corn earworm during August 1993, whereas 70% received an application in August 1994 (C. Jernigan, Wilson County Cooperative Extension Service, personal communication). Penncap-M is labeled for treatment of stink bugs (Pentatomidae) but receives little use on soybeans in North Carolina for this purpose. However, methyl parathion receives significant use in other states for several pest-crop situations (U.S. Department of Agriculture 1994, Gianessi and Anderson 1995) and may provide a historical perspective of pesticide effects to quail in North Carolina since methyl parathion received significant use in North Carolina prior to 1980 (Smithson and Sanders 1978, Bacheler 1992).

Foliar Insecticide Trials

Adopted Broods.—All trials followed a "worst-case" insecticide exposure format (Table 1). We placed broods into field pens (13.7 × 4.6 × 1.0 m) constructed of plastic bird netting (1.3- × 1.3-cm mesh) attached to wooden stakes, 1 hr prior to a foliar application of an insecticide. We based rates of insecticide applications on either the recommended rate from the North Carolina Agricultural Chemicals Manual (North Carolina Cooperative Extension Service) or the highest labeled rate for each crop-pest situation. We sprayed insecticides with a Spra-Coupe applicator, with the spray boom adjusted approximately 0.5 m above the soybean canopy. Chicks remained in field pens for 2–70 hr, depending on the trial (Table 2). Termination of multiday trials was based on the lack of dead and dying arthropods remaining in the insecticide-treated portion of soybean fields. Desiccated arthropods were not consumed by quail chicks and therefore not considered a viable route of exposure.

Calibration of the Spra-Coupe was computer controlled. We measured actual volume sprayed during a water application, and it was within 2% of expected. Wind velocity ranged from 0.0–5.6 km/hr during all insecticide applications. We sprayed insecticides on a minimum of 1.4 ha surrounding pens with chicks. We placed control pens at least 300 m from insecticide-treated areas, and we sprayed control broods with water.

We conducted all trials at appropriate dates for the specific crop-pest application. Choice of soybean fields for pesticide trials was based on a pest infestation sufficient to require a pesticide application, although this was not possible in 1994. We chose sections of soybean field for use in a trial if canopy closure was similar. We

Table 2. Survival and deviation of brain cholinesterase activity (µmoles·min^{-1}·g^{-1}) from control activity levels for northern bobwhite quail chicks after exposure to insecticides applied as foliar applications to soybeans in August, 1993–94.

Trial	Product	Hours of exposure	No. broods (no. chicks)	% deviation of ChE activity from controls $\bar{x}$	SE	No. of chicks with ChE depression[a] (n)	Survival rate to 56 days (n)
1	Lannate	2	7 (44)	−1.90	3.91	0 (23)	1.00 (21)
2	Lannate	44	2 (16)	0.62	1.38	0 (8)	1.00 (8)
2	Lannate	3[b]	1 (6)	7.40		0 (5)	
1	Larvin	2	4 (24)	0.71	2.61	0 (24)	
3	Larvin	70	2 (14)	0.55	0.95	0 (5)	1.00 (6[c])
3	Penncap-M	70	2 (14)	−49.38	15.6	7 (8)	1.00 (4[d])

[a] Depression >20% from control mean and >2 SD below control mean.
[b] Human-imprinted chicks fed in treated fields 2 hr the day of spray and 1 hr the following day, prior to euthanasia (see METHODS).
[c] Three chicks escaped from the field pen.
[d] Two chicks died accidentally.

placed pens at random distances along transects paralleling soybean rows.

We assumed chicks in field pens experienced exposure through dermal (i.e, direct spray, absorption through skin), oral (i.e., preening, ingestion of poisoned arthropods), and inhalation routes similar to free-ranging chicks using soybean fields at the time of an insecticide application. However, ingestion of arthropods would be biased low, as would chick exposure to an insecticide, if the number of arthropods available to chicks in pens restricted the total consumption of poisoned arthropods over multiday trials. To design an appropriately sized pen to avoid this bias, we would have required information on feeding rates of quail chicks, density of arthropods, proportion of arthropods killed and their availability to the chicks.

Because this information was not available, we decided to minimize this bias by supplementing treated pens with poisoned arthropods collected from the sprayed portion of the field. We used forceps to collect poisoned arthropods from the ground and added them to pens on the second day of multiday trials, when availability of arthropods may have become low. In addition, a commercial food, which had received direct spray during the application, was placed in the pens the second day of multiday trials. Water was provided during and after application of insecticides. We assumed chicks in control pens ingested arthropods at a low rate typical of soybean fields (Palmer 1995). We provided controls with a commercial food and water throughout each trial.

We collected chicks by herding the brood into their brooding pen. We randomly selected a subsample of chicks for ChE analyses and euthanized them by CO_2 asphyxiation. Following euthanasia, we placed quail heads in liquid nitrogen or on dry ice and transported them to the laboratory where they were kept frozen at −18°C until we performed brain ChE assays. We returned the remaining chicks to their outdoor rearing pens and monitored their survival to 56 days old.

We identified and weighed the crop contents for all chicks from sprayed and control pens that were euthanized 2 hr after spraying to determine differences in food availability between treatments and also compared these data to crop contents of quail chicks feeding in other habitats (Palmer 1995).

Imprinted Quail Chicks.—In addition to adopted chicks, we used human-imprinted quail chicks in Trial 2. We walked chicks through the soybean field 1 hr after spraying and allowed them to forage in the field for 2 hr (1630–1830). The following morning, we returned the chicks to the field to feed for 1 hr (1000–1100). To determine brain ChE activity, we euthanized the chicks 2 hr after the second exposure. The purpose of this technique was to simulate a brood feeding in a treated crop field following an insecticide application and to ensure chicks had an opportunity to become satiated on arthropods.

Sample Preparation and Brain ChE Determination

We removed whole brains while still frozen and homogenized them in cold, 0.05 M tris buffer at the ratio of 100 mg/mL. We determined ChE activity (μmol· min^{-1}· g^{-1}) colorimetrically (Ellman et al. 1961, Hill and Fleming 1982) via a Bausch and Lomb Spectronic 70 connected to a chart recorder (Bausch and Lomb, Rochester, New York, USA). Each brain homogenate sample was analyzed twice, and each subsample of brain homogenate was analyzed in duplicate. Assay results for subsamples were rarely disparate (>20% difference). When this happened, we assayed 2 additional subsamples of brain homogenate. For data analysis, we then determined an overall mean ChE activity based on all subsamples.

We used the ChE activity from an independent sample of brain homogenate as an internal control for each trial. We assayed this brain homogenate periodically while assaying trial samples to ensure proper function of equipment. We assayed samples in a systematic order, choosing 1 chick from each treatment group at a time. We used a single batch of reagents for each trial.

Statistical Analyses for Foliar Trials

We averaged the ChE activity of each chick within a brood to determine a mean ChE activity for each brood. We tested normality of brood ChE activity data with a Kolmogorov-Smirnov 1-sample test, and we tested equality of variances of brood ChE activity data between treatment groups with a Box-Bartlett test (SPSS 1995). Brood ChE activity data met normality (P = 0.37) and equal variance (P = 0.35) assumptions; therefore, we conducted analysis of variance (ANOVA) with mean brood ChE activity, insecticide type, and length of exposure (SPSS 1995). We used linear contrasts to test for differences in ChE activity between individual insecticides and controls. We tested for differences in mean mass of arthropods found in crops of chicks between control and treatment broods via 1-way ANOVA (SPSS 1995). All analyses were performed at α = 0.05.

In addition to ANOVA for brood ChE activity, we compared ChE activity of chicks to ChE activity of within-trial controls. We calculated depression of ChE activity for each chick relative to the mean ChE activity of control broods for the trial. We considered an individual chick's ChE activity significantly depressed if ChE activity was below the diagnostic threshold of 2 standard deviations less than the control mean, and depression was >20% (Ludke et al.1975, Hill 1988).

RESULTS

Whole-Farm Experiment

Use of Crop Fields by Adult Quail.—During August 1993, we monitored 33 adult quail, and we monitored 36 adult quail in August 1994. Quail selected field border sections of the farms. Only 21% (1993) and 33% (1994) of quail monitored during August used nonfield border areas more than field border areas. Further, most nests were located on field border areas (83%; n = 53).

Adult quail used soybean fields extensively during August. In 1993, 267 locations (65%) were in soybean fields. We located 24 quail ≥8 times each in August ($\bar{x}$ = 15 locations, SD = 6.7), 17 of which were located in soybean fields 84% of the time and in field borders 13% of the time. Seven quail used other habitats more than soybean fields; however, 18% of their locations were in soybean fields.

Quail use of soybean fields during August followed a similar pattern in 1994. Of 308 locations, 64% were in soybean fields. We located 22 quail ≥8 times each in August ($\bar{x}$ = 12 locations, SD = 2.3), of which 16 were found in soybean fields 82% of the time and in field borders 3.5% of the time. Six quail used other habitats more than they used soybean fields, but they were located in soybeans fields 26% of the time.

In 1993, the percentage of locations in soybeans fields for each quail on areas without field borders averaged 36% (SE = 22.2) versus 70%

(SE = 6.5) for quail on areas with field borders. Similarly, in 1994, the percentage of locations in soybean fields for each quail on areas without field borders averaged 58% (SE = 10.0) versus 71% (SE = 8.2) for quail on areas with field borders. Increased use of soybean fields by quail when field borders were present was significant ($F_{1,42}$ = 4.63, P = 0.04).

Use of Crop Fields for Nesting.—Quail nested extensively in soybean fields after soybeans developed a closed canopy in early July. Of all nests initiated after 14 July (n = 23), 56% were located in soybean fields, and an additional 18% were located on the edges of soybean fields. Median date of initial incubation of nests in soybean fields was 6 August (range = 14 Jul–1 Sep). Prior to 14 July, most nests were located outside cropland habitats (97% of 30 nests), usually fallow land, field borders, or road edges.

Nest success (i.e., ≥1 eggs hatched) improved in all habitats after quail began using soybean fields. Success of early nests (<15 Jul) was only 19.4%, but nesting success increased to 54.5% following soybean growth (t_{50} = 2.66, P = 0.01). Success of nests located in soybean fields was high (53.8%).

Use of Crop Fields by Quail with Chicks.—Eighteen broods were produced by radiocollared quail, and 56% (n = 10) used soybean fields to some extent. Of the 10 broods that used soybean fields, 7 broods were monitored 7–28 days (10–31 locations/brood), and an average of 88% (range = 73–100%) of these brood locations were in soybean fields. Locations outside soybean fields were usually in field borders or road edges bordering soybean fields. Other habitats selected by broods hatched after 14 July included milo fields (n = 1), fallow fields (n = 3), road edge (n =1), and woods (n =1).

Quail Habitat Use and Insecticide Sprays.—On 27–29 August 1993, soybeans on Farm A and part of Farm B were aerially sprayed with Larvin 3.2 F at a rate of 0.175 kg active ingredient/ha. Four broods were sprayed directly while in soybean fields when chicks were 6–10 days old. Therefore, 4 of 6 broods (67%) produced after 14 July by radiocollared quail were exposed to a "worst-case scenario" insecticide application. Broods remained within their prespray home range following the application. Survival of chicks to 28 days old was determined for 2 broods exposed to Larvin and was 80% (n = 10 chicks) for 1 brood and 100% (n = 6 chicks) for the other.

In 1994, few broods were produced (n = 3) by radiocollared quail. Of 2 broods using soybean fields, 1 hatched on September, 2 weeks following insecticide applications, and the other hatched during early summer and was 7 weeks old when pesticides were applied. Therefore, telemetry data for broods were not relevant to insecticide applications during August 1994.

Mesocosm Tests of Foliar Insecticides

Adoption of Chicks.—Twenty-nine broods were produced for pesticide trials. Adoption rate of quail chicks by adults varied between trials and was 19–53%. Survival of chicks following adoption until pesticide trials was high: for instance, chick survival was 0.98 for 45 chicks from Trial 1. Following the trials, all chicks (n = 47) returned to their outdoor pens survived to 56 days old. Chicks were brooded by parents during cool weather, at night, and during rain events. Chicks and adults spent most of their time in the outdoor exercise area and roosted in the outdoor exercise pen.

Ingestion of Poisoned Arthropods.—During Trial 1, chicks from treatment pens were brooding 2 hr after spraying, whereas control pen chicks were calling. Chicks fed at higher rates in treatment than control pens ($F_{2,9}$ = 10.5, P = 0.004). Wet mass (g) of arthropods in crops of chicks was 0.83 ± 0.12 ($\bar{x}$ ± SE) from Lannate, 1.01 ± 0.10 from Larvin, and 0.04 ± 0.018 from control pens. No crops from treatment chicks were empty, while most crops (61%) of control chicks were empty. Most of the arthropods ingested were caterpillars (87%, n = 245), primarily *Heliothis zea* and *Pseudoplusia includens*. Similarly, human-imprinted chicks walked through soybean fields following insecticide applications (Trial 2), ingested arthropods at a high rate, were satiated by 37 min, and then began preening, dusting, and brooding behaviors.

Cholinesterase Activity and Chick Survival.—The ANOVA on ChE activity for chicks exposed to foliar applications of insecticides was significant for product ($F_{3,16}$ = 11.3, P < 0.001); however, no differences were found for length of exposure ($F_{1,16}$ = 0.65, P = 0.431). Observed power was 0.995 for insecticide type and 0.145 for length of exposure. Cholinesterase activity for broods exposed to Lannate and Larvin were not different from controls (t_{16} = 0.04–0.69, P > 0.49); however, methyl parathion (Penncap-

Table 3. Mean and standard deviation of brain cholinesterase activity (μmoles·min⁻¹·g⁻¹) for northern bobwhite quail chicks used as controls and for determining ChE depression for chicks exposed to insecticides.

Trial number	No. broods (no. chicks)	Brain ChE activity $\bar{x}$	Brain ChE activity SD	No. chicks with ChE depression[a]
1	4 (29)	15.22	2.19	0
2	3 (10)	13.59	1.82	0
3	2 (5)	16.36	0.46	0

[a] Chicks with ChE depression >20% and ChE ≥2 SD from control mean.

M) did cause ChE depression (t_{16} = 5.4, $P <$ 0.001).

Deviation of ChE activity from control ChE activity averaged zero for all broods exposed to Lannate or Larvin and ranged from 7% above to 10% below control brood ChE activity (Table 3). Deviation of ChE activity from controls was significant for chicks exposed to Penncap-M. Cholinesterase activity was depressed 65% (range = 62–68%) for Brood 1 and 34% (range = 18–54%) for Brood 2. Further, 7 of 8 chicks exposed to Penncap-M had significant depression of ChE activity. No chick mortality occurred from exposure to foliar applications of Larvin, Lannate, or Penncap-M.

DISCUSSION

While quail use of soybean fields was relatively high, amount of use was strongly influenced by presence of field borders. In June, hens on farms with field borders had smaller home ranges and smaller movements from the location where they were trapped in spring to their first nesting sites (Puckett et al. 1995). This difference in movements of hens was a result of hens selecting field borders and crop fields for nesting areas versus searching for nesting habitat on farms lacking cover. By August, when insecticides are most often applied to soybean fields, quail on farms with field borders were twice as likely to be located in soybean fields than quail on farms without borders.

We found that quail nesting success increased nearly 3-fold after quail began nesting in soybean fields versus nesting along edges. The result of this temporal variation in nesting success was that approximately 60% of quail production occurred after July. Therefore, based on observed schedules of reproductive effort, nesting success, and the patterns of habitat use of adults and broods, recruitment would be significantly reduced if exposure to insecticides reduced chick survival.

Insecticide applications to soybeans temporarily increased the availability of arthropods to quail chicks. Chicks in pens sprayed with insecticides ingested at least 23 times more biomass of insects than control chicks. The propensity of quail chicks to feed on poisoned arthropods increased the opportunity for significant exposure to insecticides. While pen size potentially had a disproportionate effect on control chicks, which may have found more food if free to move about, data from a companion study indicated this bias was not significant. Specifically, feeding rates of human-imprinted chicks foraging in conventionally planted soybean fields (n = 14 fields) had crop contents of arthropods (0.06 ± 0.008 g; $\bar{x}$ ± SE) comparable to those from control chicks in this study (0.04 ± 0.18 g of arthropods; Palmer 1995). Hence, conventionally planted soybean fields apparently provide marginal foraging habitat for broods and more likely serve as cover. However, field borders increased the suitability of soybean fields as brood habitat by increasing the amount of insects available to the chicks (Potts 1986).

Under worst-case scenario conditions, significant effects to brain ChE activity or chick survival for the commonly used insecticides Larvin and Lannate were not observed. Broods from mesocosm experiments and wild broods did not have depressed ChE activity (captive chicks) or lower survival (both captive and wild) as a result of insecticide applications. We did not detect depression of ChE activity following Lannate and Larvin application either because (1) quail chicks were not exposed to a sufficiently toxic dose, (2) brain ChE activity was not measured at the appropriate time (Fleming and Bradbury 1981), or (3) reactivation of samples occurred prior to analysis (Thompson et al. 1991). We conclude that exposure of chicks to Lannate or Larvin was not great enough to cause depression of brain ChE activity or mortality. While we did not measure behavior directly, behaviors characteristic of severe depression of brain ChE activity (Hill and Fleming 1982) were not observed. Therefore, we believe it unlikely that levels of sublethal exposure occurring in this study would have subsequently affected chick survival.

Most quail chicks (88%) exposed to Penncap-M had depression of ChE activity after 70 hr in treated crop fields. Smithson and Sanders (1978) collected adult quail around cotton fields receiving weekly applications of methyl parathion (1.13 kg/ha) and toxaphene and found depression of brain ChE activity. It may be significant that the only chicks (n = 2) accidentally stepped on during collection were those exposed to Penncap-M. These chicks hid rather than follow their parent, and both had activity of brain ChE depressed >50%. Also, mass of chicks exposed to Penncap-M was slightly less than control chicks or chicks exposed to Larvin (P = 0.02). Penncap-M or other formulations of methyl parathion typically are not used on soybeans, cotton, corn, or peanuts in North Carolina, but are used in other states on cotton and soybeans (i.e., Louisiana, Mississippi, Texas, Arkansas; U.S. Department of Agriculture 1994, Gianessi and Anderson 1995). Historic use of methyl parathion in North Carolina (i.e., weekly applications to cotton) likely significantly reduced survivorship of quail and quail chicks using habitats in or around cotton fields (Tipton et al. 1980).

By beginning research with a "worst-case scenario" exposure regime, decisions as to further work are simplified. For instance, if few physiological or behavioral effects resulted from worst-case scenario exposure to an insecticide, then lower rates of exposure were assumed nonthreatening. If significant effects were found, then decisions to investigate further depend on exposure probabilities. Since Penncap-M does not receive significant use on major field crops in North Carolina and was included in the study for a historical perspective of insecticide effects, future testing on quail is not warranted. However, if significant exposure to quail was likely, then more detailed temporal examinations of brain ChE activity and mortality under different exposure regimes would be warranted.

MANAGEMENT IMPLICATIONS

Despite the substantial reduction in toxicity, amount applied, and number of applications of foliar insecticides applied to major field crops in North Carolina (National Resource Council 1989, U.S. Department of Agriculture 1994, Gianessi and Anderson 1995), quail populations have declined. Further, the decline in quail numbers on farm landscapes has occurred across farming systems (i.e., crops planted) and pesticides associated with those systems (Gianessi and Anderson 1995). If highly toxic chemicals applied to field crops were largely responsible for past quail declines on agricultural areas, then recovery of quail numbers on agricultural areas following reduced hazard from modern insecticides should have occurred. In our study, quail numbers and reproductive effort and success were greater on farms with early-successional field borders surrounding crop fields (Puckett et al. 1995), despite the increased exposure to insecticides. This outcome supports the hypothesis that loss of habitat for nesting and brood rearing is largely responsible for quail declines on farms in North Carolina. Similar conclusions were reached by Potts (1986) and Sotherton et al. (1993) for game birds inhabiting farmed landscapes in the United Kingdom. However, managers should be cognizant of our result that providing early-successional habitat along edges of crop fields will substantially increase exposure of quail to agricultural chemicals.

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