The Effects of Tillage on Shot Concentrations in Dove Fields

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Abstract: Despite the research on lead (Pb) shot deposition and ingestion by mourning doves (*Zenaida macroura*), there has been no research to determine how management practices may be used to effectively reduce Pb shot concentrations in fields managed for dove hunting. For instance, no-till cropping systems could potentially lead to accumulation of lead shot in upper soil layers compared to conventional tillage practices. We measured shot concentrations in five publicly managed mourning dove fields in North Carolina to determine if concentration levels were significantly affected by tillage. We used a complete block design with 12 plots, each of which received a combination of the following planting and management treatments: three crops (sunflower (*Helianthus annuus*), millet (*Setaria italica* or *Brachiaria ramosa)*, or corn (*Zea mays*)) and two treatments (till or no-till). Soil samples ($n = 4{,}204$) were collected across seven sampling periods (before, during, and after dove hunting seasons) from 2007 to 2009. Data were analyzed using a generalized linear mixed model, with a negative binomial distribution, to evaluate differences in shot concentrations among crops, between tillage treatments, and between areas of high and low hunter effort. Shot concentrations differed among crops and between areas of high and low hunter effort, but did not differ between tillage treatments. Significant interactions were observed between crop and hunter effort, tillage and crop, and tillage and hunter effort. Our study results indicate that tillage does not reduce overall shot concentrations in dove fields. Managers could effectively reduce shot concentrations in the upper soil layers of dove fields and, therefore, reduce Pb exposure to doves, by limiting hunter access and/or effort or requiring nontoxic shot on managed dove fields.

Key words: lead shot, mourning dove, North Carolina, shot concentration, tillage

Lead (Pb) toxicity was first identified in wild birds in 1842, with the first documented cases of Pb poisoning in the United States in the late 1870s (Friend et al. 2009). Reports of Pb poisoning in birds, especially waterfowl, became increasingly common over the 20th Century and by the 1980s, scientists had confirmed that the accumulation of spent Pb shot in the environment, primarily from hunting activities, was the most common means of exposure to Pb by waterfowl and was a significant mortality factor in waterfowl species (Shillinger and Cottam 1937, Jordan and Bellrose 1950, Bellrose 1951, Jordan and Bellrose 1951, Coburn et al. 1951, Bellrose 1959, White and Stendell 1977, Longcore et al. 1982, Kendall and Driver 1982, Mudge 1983, Sanderson and Bellrose 1986, Anderson et al. 1987, Srebocan and Rattner 1988, Pain and Rattner 1988, Smit et al. 1988, Friend et al. 2009). Annual total mortality estimates attributed to Pb poisoning for North American waterfowl populations ranged from 1.5 to 3 million birds (Davidson 2006). As a result, the U.S. Fish and Wildlife Service issued a national prohibition on the use of Pb shot for waterfowl hunting, phased in from 1987–1991 (USFWS 1986), and Canada enacted legislation to prohibit lead shot in 1999 (Stevenson et al. 2005, Scheuhammer and Thomas 2011).

Despite the research conducted in the 1960s and 1970s on the effects of Pb shot ingestion in other birds, insufficient research existed to justify the use of nontoxic shot for hunting non-waterfowl species at that time (Friend et al. 2009). Since then, a surge of research has continued throughout the world on Pb exposure, ingestion, and toxicity in other avian species. Today, research has documented the ingestion of Pb ammunition—shot pellets, bullets and/or fragments, and prey contaminated with Pb ammunition—by over 120 avian species (Kendall et al. 1996, Tranel and Kimmel 2009). Of particular importance to the authors was the research on Pb exposure in mourning doves (*Zenaida macroura*), as mourning doves are the most harvested game species in North Carolina and second only to white-tailed deer (*Odocoileus virginianus*) in the number of hunters that pursue them (Pollock and Wen 2009).

Reported frequencies of Pb shot ingestion by mourning doves have ranged from 0.2% to 6.5%, based on manual or x-ray examination of gizzards for pellets, and 10.9% to 60.0%, based on tissue analysis of Pb levels in blood, liver, kidney, and bone (Locke and Bagley 1967, Kendall and Scanlon 1979, Best et al. 1992, Schulz et al. 2007, Franson et al. 2009, Plautz et al. 2011). The ingestion of Pb shot may cause short-term and long-term health effects, including mortality. Health effects, such as weight loss, lethargy, abnormal behavior, and decreased food intake from the chronic effects of

Pb toxicosis from low Pb doses, may result in morbidity and indirect mortality from increased predation or susceptibility to disease (Carrington and Mirarchi 1989, Castrale and Oster 1993). Alternatively, doves may ingest multiple Pb pellets and may die quickly from the effects of acute Pb toxicosis (Schulz et al. 2006). Kendall et al. (1996) reported that ingestion of spent shot was the primary means of Pb exposure for upland game birds, especially mourning doves, and that doves tend to forage in heavily hunted fields that are managed specifically to attract doves, thereby increasing their risk of Pb exposure and ingestion. High concentrations of Pb shot have been found in dove fields especially during and immediately following the hunting season when doves may be foraging in these areas (Kendall et al. 1996). Studies have reported Pb shot concentrations in the top soil layers of managed dove fields ranging from 0 pellets/ha to 107,639 pellets/ha (Anderson 1968, Lewis and Legler 1968, Castrale 1989, Schulz et al. 2002).

Despite the research on Pb shot deposition, there has been no research to determine how management practices may be utilized to effectively reduce Pb shot concentrations and therefore potentially reduce Pb exposure in fields managed for dove hunting. Although Castrale (1989) documented how shot concentrations changed over time and the potential effects of tillage on Pb shot concentrations in dove fields, the actual effects of tillage on Pb concentrations were undeterminable because the degree of tillage was not consistent across fields, tillage was not uniformly applied as a treatment across fields, nor was tillage replicated in all crop types throughout the study. To examine the effects of tillage on Pb concentrations, we studied Pb shot concentrations in publicly managed mourning dove fields in North Carolina, in both tilled and no-till crops. Objectives of our study included: 1) measuring the concentration of shot pellets in soil samples taken from hunted dove fields in eastern North Carolina from August 2007 to August 2009; and 2) determining the effects of tillage, crop type, and hunter effort on the shot concentrations found in these fields. We hypothesized that shot concentrations would be higher in areas of high hunter effort, would not differ among crop types, and that tillage would reduce shot concentrations by burying deposited shot below the soil surface.

Study Area

Our study was conducted at Conoho Farms (CF), a segment of the Roanoke River Wetlands Game Land (RRWGL). The RRWGL is publicly owned and managed by the North Carolina Wildlife Resources Commission (NCWRC) and consists of 16,985 ha in Bertie, Halifax, Martin, and Northampton counties, North Carolina. The RRWGL is a permit-only hunt area for hunting white-tailed deer, wild turkey (*Meleagris gallopavo*), small game, dove, and waterfowl.

The NCWRC manages five fields in CF specifically for mourning dove hunting; all are located off Hwy 125 North in Williamston, North Carolina (Figure 1). These fields have been managed intensively for dove hunting since 1997 and range in size from 1.5 ha to 13.4 ha.

We selected the fields at CF for this study because they were: 1) located <1 km from each other, minimizing environmental variation due to precipitation, topography, and soil characteristics; 2) reported as having heavy hunter use, to help make treatment effects more noticeable; 3) consistently managed; 4) large enough in size to meet sample size requirements; and 5) included in the NCWRC permit hunt system, allowing for hunter effort to be quantified.

Management History

Before the NCWRC acquired CF in 1995, the fields were heavily grazed as part of an active cattle farm. In 1996, the NCWRC removed the farm buildings and fences from the property, applied several herbicide treatments to control the tall fescue (*Festuca arundinacea*), and planted buckwheat (*Fagopyrum esculentum*) in the fields. In 1997, the NCWRC began managing the fields intensively for dove hunting. The fields were planted in strips of sunflowers (*Helianthus annuus*) and millet (*Setaria italica* or *Brachiaria ramosa*) using a combination of till and no-till practices and sprayed with herbicide as needed to control other vegetation. Portions of the sunflower and millet strips were mowed, and sections of the millet strips were burned, each year <2 weeks prior to the hunting season. Sunflower and millet strips were rotated within the fields annually to increase the efficacy of herbicide applications. In the early 2000s, strips of corn (*Zea mays*), milo (*Sorghum* sp.), and native warm season grasses were added to the fields and the management regime continued in the same way, with annual crop rotations, till and no-till planting, herbicide treatments, and mowing or burning portions of each crop strips prior to the hunting season (D. Davis, NCWRC, personal communication).

Soils

Six different soils occur on the study plots (USDA 1989): Norfolk loamy fine sand (NoB, NoA), Bonneau loamy sand (BoC, BoB), Lynchburg fine sandy loam (Ly), and Goldsboro fine sandy loam (GoA). The total plot area covered by these soil types ranged from 0.3% for GoA to 44.3% for NoB. Four of these soils are categorized within two soil series, NoB and NoA (in the Norfolk series) and BoC and BoB (in the Bonneau series), and thus have very similar soil characteristics. Norfolk and Bonneau soils are the dominant soils on the study plots and represent a total of 95.8% of the total plot area. They are both well drained soils with a moderate
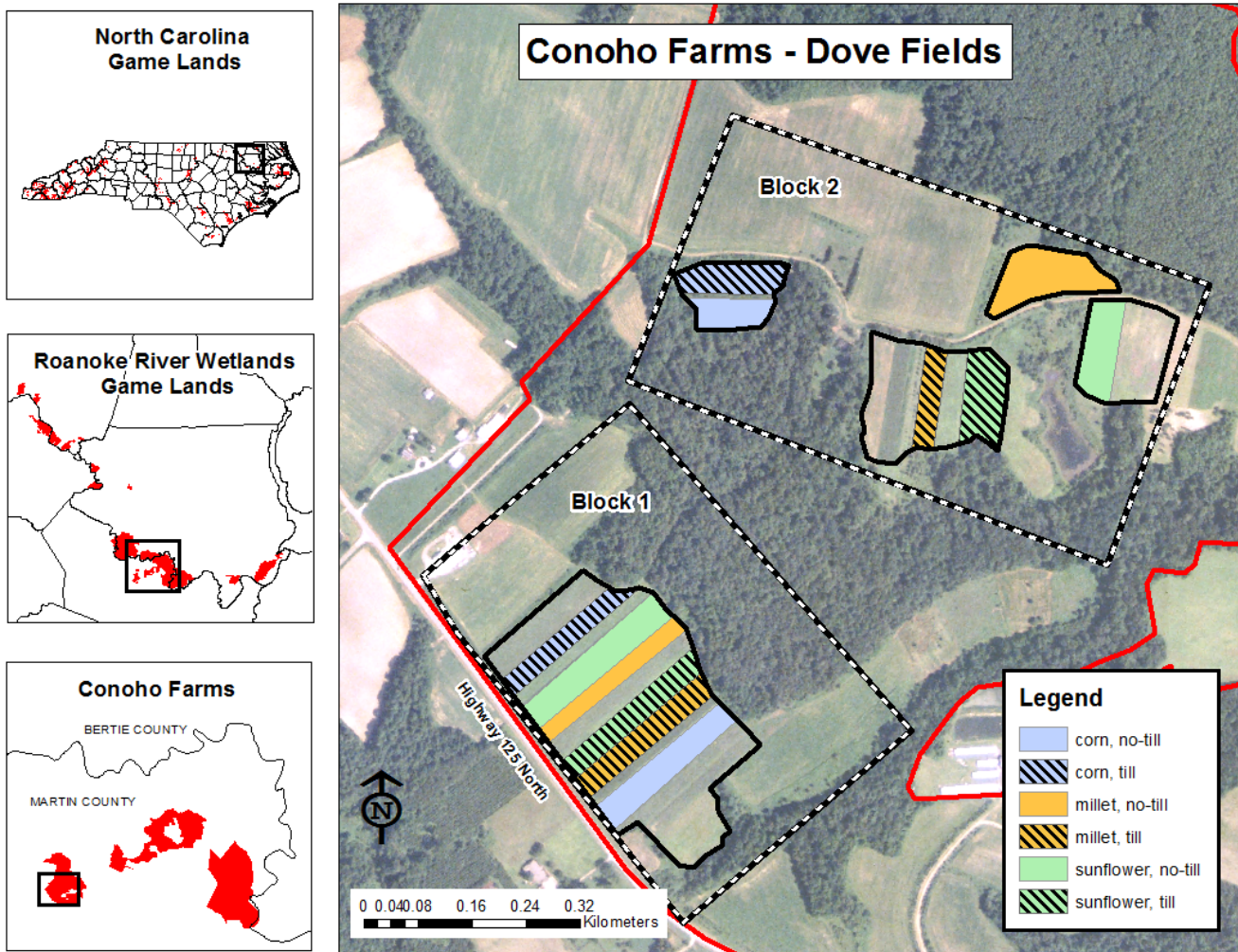
Figure 1. Twelve plots within two blocks of five publicly managed dove fields used to study shot concentrations within Conoho Farms, a segment of the Roanoke River Wetlands Game Land, Martin County, North Carolina, 1 August 2007 – 31 September 2009.

to rapid permeability, weak fine to fine granular structure, medium acidity, and are light yellowish to grayish brown in color. Although soil slope ranges from 0% to 12%, the topography of the study site is relatively flat and uniform with 90.9% of the total plot area having a soil slope of ≤6%.

Hunting Seasons

The U.S. Fish and Wildlife Service determines the federal framework for all dove hunting seasons in the United States, including the maximum number of hunt days, season date range, daily bag limit, and the number of season splits. Each state wildlife agency then establishes the dove season for their state within the federal framework. The NCWRC adopted dove hunting seasons using the maximum allowable hunting opportunity provided by the frameworks for 2007 and 2008. The season dates, daily bag limits, and

possession limits for 2007 and 2008, respectively, were: 1 September 2007–12 January 2008 (bag: 12; possession: 24) and 1 September 2008–10 January 2009 (bag: 15; possession 30). Each season had three splits, and allowed a maximum of 61 and 62 hunt days, respectively. Dove hunting is not allowed on Sundays in North Carolina.

Methods
Study Design

We used a complete block design, with 12 plots in two blocks that varied by hunter effort (Figure 1). Each block contained six plots. Each plot received a combination of the following planting and management treatments: three crops and two treatments. Crops and tillage practices were set in place before the implementation of this study but remained constant within plots over the

study period. Although crops are typically rotated each year for weed management purposes, crop rotation was suspended on the 12 plots during the course of the study to provide consistency and standardization. Each plot was planted in one of three crops: sunflower, millet, or corn. For this study, both millet species were considered one crop. These crops were chosen because they are representative of the three most common crops planted on publicly managed dove fields in North Carolina (D. Davis, NCWRC, personal communication). Each crop was planted using one of two treatments: no-till or till.

A pilot study was conducted in July 2007 to determine sample size requirements for the study. Ten samples were collected from each plot ($n = 120$) and sieved for shot pellets, using the methods listed below. The mean number of pellets per sample, including standard deviation, was calculated. Based on the means per plot from Block 1 (plots 1–6), where $\alpha = 0.05$ and $r = 0.2$ with a Poisson distribution, we determined that we needed to collect 43 samples per plot to see a treatment effect. To ensure enough usable samples, we attempted to collect 50 samples per plot per sampling period.

Plots were not assigned randomly to each block because each plot had already been planted and treated prior to the commencement of this study. Sample sizes within plots were unequal across sampling periods but exceeded the required sample size. Sample locations were randomized within each plot using ESRI Geographic Information System software (Redlands, California). Samples were located on the ground using a Trimble 5800 RTK Global Positioning System (Sunnyvale, California) survey unit with sub-centimeter accuracy. Previous sample locations were excluded from the list of possible sample locations for remaining sampling periods within a year to avoid sample bias (i.e., each 30.5 cm × 30.5 cm sample location within a plot was used only once within one calendar year).

Treatments

Tilled plots were disked annually in April or May in 2008 and 2009 to a depth of 10.16–15.24 cm. Each tilled plot was disked twice at the time of treatment. Tilled corn plots were planted with Roundup Ready corn around mid-April and sprayed post-emergent with glyphosate (Roundup WeatherMAX) at a rate of 1.6 L/ha around mid- to late-May to control weeds but were not sprayed with herbicide prior to planting. Tilled sunflower plots were sprayed pre-emergent with Prowl H2O at a rate of 2.3 L/ha around the last week in April, planted with Clearfield sunflower seeds early- to mid-May, and sprayed post-emergent with Beyond at a rate of 0.3 L/ha in late-May to control weeds. Tilled sunflower plots were also not sprayed with herbicide prior to planting. Tilled millet plots

were, however, sprayed with glyphosate (Roundup WeatherMAX) at a rate of 1.6 L/ha in mid-April each year prior to planting and were planted in mid-to late-May but were not sprayed with a post-emergent herbicide.

No-till plots were not disked or tilled in any manner during the study period. Because tillage was not allowed, the no-till plots had more weedy growth than the tilled plots at the time of planting; therefore, all no-till plots were sprayed with a pre-emergent herbicide to kill the existing vegetation and help facilitate planting. The no-till corn plots were sprayed before planting with glyphosate (Roundup WeatherMAX) at a rate of 1.6 L/ha around the second week in April each year. As with the tilled corn plots, the no-till corn plots were planted with Roundup Ready corn around mid-April and sprayed post-emergent with glyphosate (Roundup WeatherMAX) at a rate of 1.6 L/ha around mid- to late-May to control weeds. The no-till sunflower plots were also sprayed before planting with glyphosate (Roundup WeatherMAX) at a rate of 1.6 L/ha around the second week in April each year. As with the tilled sunflower plots, the no-till sunflower plots were sprayed pre-emergent with Prowl H2O at a rate of 2.3 L/ha around the last week in April, planted with Clearfield sunflower seeds early- to mid-May, and sprayed post-emergent with Beyond at a rate of 0.3 L/ha in late-May to control weeds. Identical to the tilled millet plots, the no-till millet plots were sprayed with glyphosate (Roundup WeatherMAX) at a rate of 1.6 L/ha in mid-April each year prior to planting and were planted in mid-to late-May but were not sprayed with a post-emergent herbicide.

Herbicides and/or fertilizers were applied consistently on each plot throughout the study to control weeds and maintain dominant crops. Although the timing of herbicide treatments and planting were weather dependent, the management activities varied only slightly from year to year. Although herbicides do not appear to directly affect soil properties, they can reduce weedy biomass and increase organic matter content in no-till agricultural systems (Ismail et al. 1992, Reddy et al. 2003). However, any differences in soil properties that might occur from herbicide and tillage use in this study are most likely uniform across plots because all crop species and tillage practices within these fields have been rotated annually for more than 15 years.

Sampling Periods

Soil samples were collected for two consecutive years surrounding the 2007 and 2008 dove hunting seasons in North Carolina and included one base-line sampling event [22–24 August 2007 and 29–31 August 2007]. Samples were collected from each plot during the following periods: 1) pre-hunt: prior to the opening of the dove

season and after treatments were applied [25–27 August 2008 and 31 August 2009–2 September 2009]; 2) mid-hunt: between the first and second splits [29–31 October 2007 and 3–5 November 2008]; and 3) post-hunt: after the close of the dove season and prior to treatments being applied [3–5 March 2008 and 23–25 February 2009]. During each sampling period, samples were collected within a three-day window to minimize environmental variation (e.g., precipitation). In addition, each sampling event was held within one week of the date that the sampling event occurred in the previous year, despite the length of time that occurred between seasons and treatments, to provide consistency.

Sample Collection

Soil sampling methods were similar to those described by Castrale (1989). Standing vegetation on the sample was cut off at ground level and heavy vegetative debris on the soil surface was removed. Each sample was collected using a 30.5 cm × 30.5 cm × 1.3 cm box made of plywood and angle iron. To collect the sample, the box was set upside down on the soil, pressed down into the soil completely so that the plywood was level with the soil surface, and was dug out and inverted using a flat head, steel shovel made by NCWRC staff. Once the steel shovel was driven completely under the sample, the shovel and sample were lifted from the ground, inverted together, and the sample box (right side up) was slid from beneath the shovel. Excess soil was scraped off the top of the sample, level with the edges of the collection box, so a uniform volume of soil was collected. Soil was transferred from the sample box to a bucket and then to a plastic bag. Sample bags were labeled with the plot number, sample number, and date collected, and then washed through three sieves (4.0-mm, 2.0-mm, and 1.0-mm mesh screens) and visually inspected for shot pellets prior to disposal. Shot pellets were collected directly from the sieves and transferred to 7.62 cm × 5.08 cm plastic bags; all pellets were dried before cataloguing and storage. Pellets were tested for their magnetic nature to determine ferrous composition (i.e., Pb or nontoxic shot).

Hunter Effort

Hunter effort was calculated as part of a previous study on hunter use of CF (Douglass et al. 2013). In brief, hunter effort data were standardized by area and categorized (high/low) by block based on the results of a hunter survey we conducted during the 2007 and 2008 dove hunting seasons on CF. Hunter effort, measured in shots fired and hours hunted, was very dichotomous in nature throughout the study, meaning hunters either spent many hours and fired many shots or spent very few hours and fired fewer shots when dove hunting; therefore, for the purposes of this analy-

sis, hunter effort was categorized as high if ≥2,180 shots fired and ≥223.25 hours hunted while hunter effort was categorized as low if ≤865 shots fired and ≤146.5 hours hunted. All reported hunter effort measurements fell within these two categories.

Statistical Analysis

All statistical analyses were completed using SAS software (SAS Institute, 2008). We pooled shot pellets collected from all samples within each plot for each sampling period to account for pseudoreplication within plots. We analyzed plot sums using a generalized linear mixed model (PROC GLIMMIX), with a negative binomial distribution, with crop, tillage, hunter effort, and all interactions as fixed effects where $\alpha = 0.05$. We used a negative binomial distribution because it more closely approximated the underlying probability distribution of finding pellets. The model also included sampling period as a random effect to account for repeated sampling of each plot across time and to focus on the impacts of tillage. Given limited replication within the study and the focused scope of the project, we did not use multiple model comparisons.

Results

We collected and sieved a total of 4,204 samples from CF during the study period. The mean number of samples collected per plot per sampling period was 50.05 (SE 0.02), with a range of 44–55 samples/plot. The mean number of samples collected per sampling period was 600.57 (SE 0.30), with a range of 600–602 samples/sampling period. We found a total of 2,654 pellets, with 38.0% of samples containing ≥1 pellet. The mean number of pellets per sample was 0.63 (SE 0.02), with a range of 0-7 pellets/sample. The overall estimated shot concentration on CF, over time and across all crops and treatments, as based on the mean number of pellets per sample in the top 1.3 cm of soil, was approximately 67,813 pellets/ha. Thirteen (0.5%) of the pellets were magnetic, and therefore made of ferrous material (i.e., not composed of Pb).

Shot concentrations differed between areas of high and low hunter effort ($F = 645.75$, df = 1, 66; $P \leq 0.01$) with the highest concentrations occurring in the areas that received high hunting pressure (Figure 2). Shot concentrations also differed among crops ($F = 24.83$, df = 2, 66; $P \leq 0.01$), with concentrations in millet and sunflower being twice those found in corn (Figure 3). In addition, the impacts of hunter effort on shot concentrations varied by crops, with corn, millet, and sunflower plots containing 21, 7, and 4 times higher shot concentrations, respectively, in areas of high hunter effort compared to areas of low hunter effort (crop*effort: $F = 25.90$, df = 2, 66; $P \leq 0.01$; Figure 4).

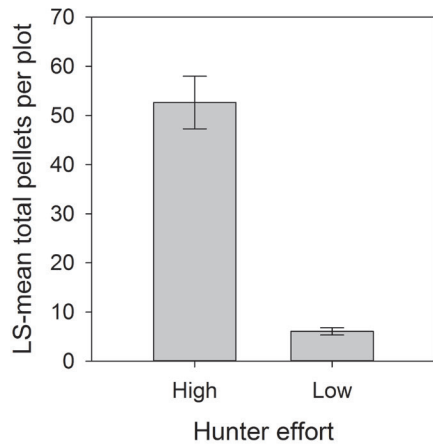Shot concentrations did not differ between till and no-till plots

Figure 2. Shot concentrations by areas of high and low hunting pressure within Conoho Farms, a segment of the Roanoke River Wetlands Game Land, Martin County, North Carolina, 1 August 2007 – 31 September 2009.
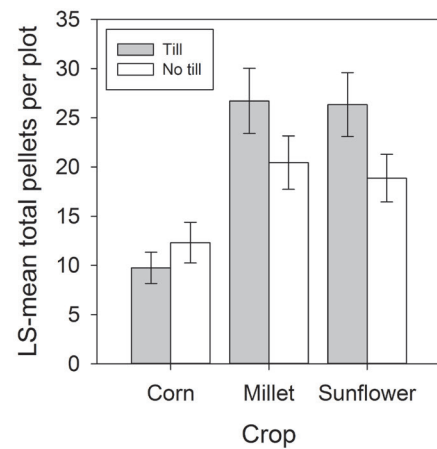

Figure 5. Shot concentrations among crops by treatment within Conoho Farms, a segment of the Roanoke River Wetlands Game Land, Martin County, North Carolina, 1 August 2007 – 31 September 2009.
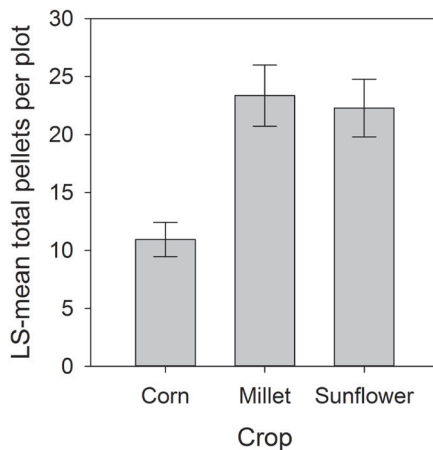

Figure 3. Shot concentrations among crops within Conoho Farms, a segment of the Roanoke River Wetlands Game Land, Martin County, North Carolina, 1 August 2007 – 31 September 2009.
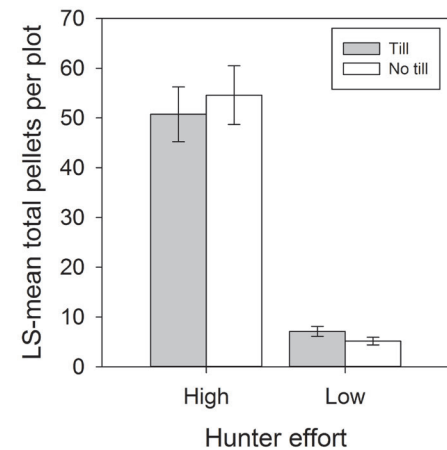

Figure 6. Shot concentrations by treatment by hunter effort within Conoho Farms, a segment of the Roanoke River Wetlands Game Land, Martin County, North Carolina, 1 August 2007 – 31 September 2009.

Figure 4. Shot concentrations among crops by hunter effort within Conoho Farms, a segment of the Roanoke River Wetlands Game Land, Martin County, North Carolina, 1 August 2007 – 31 September 2009.
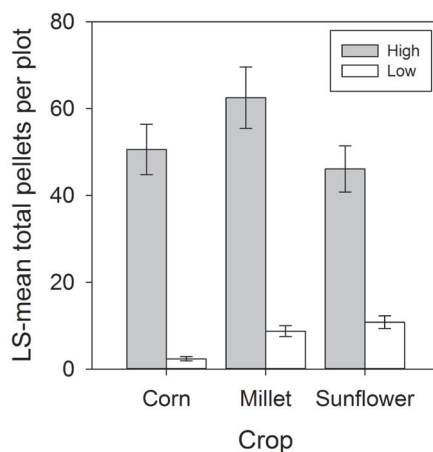
($F = 2.10$, df = 1, 66; $P = 0.15$); however, tillage increased shot concentrations in millet and sunflower by 30.7% and 39.6%, respectively, but reduced concentrations in corn by 26.2% (crop*tillage: $F = 3.36$, df = 2, 66; $P = 0.04$; Figure 5). In addition, tillage had little effect on shot concentrations in areas of high hunter effort (7.0% reduction), but increased shot concentrations in areas of low hunter effort by 37.6% (tillage*effort: $F = 5.33$, df = 1, 66; $P = 0.02$; Figure 6), although the magnitude of this effect was small. We also found no three-way interaction between crop, tillage, and effort (crop*tillage*effort: $F = 2.28$, df = 2, 66; $P = 0.11$). Least square means and standard errors associated with all other parameter estimates in the model are included in Table 1.

Table 1. Least square means, standard errors, and beta values associated with all parameter estimates used in the model to compare the effects of crop, tillage, and hunter effort (and all interactions) on shot concentrations in five publicly managed dove fields within Conoho Farms, a segment of the Roanoke River Wetlands Game Land, Martin County, North Carolina, 1 August 2007 – 31 September 2009.

Effect	Crop	Tillage	Effort	Estimate ± SE	df	t-value	P	Mean ± SE
Crop	Corn	–	–	2.39 ± 0.13	66	13.45	<.0001	10.95 ± 1.48
Crop	Millet	–	–	3.15 ± 0.11	66	19.25	<.0001	23.37 ± 2.64
Crop	Sunflower	–	–	3.10 ± 0.11	66	19.10	<.0001	22.29 ± 2.49
Tillage	–	No-till	–	2.82 ± 0.11	66	17.23	<.0001	16.80 ± 1.91
Tillage	–	Till	–	2.94 ± 0.11	66	18.14	<.0001	19.00 ± 2.11
Crop*Tillage	Corn	No-till	–	2.51 ± 0.17	66	12.38	<.0001	12.31 ± 2.06
Crop*Tillage	Corn	Till	–	2.28 ± 0.16	66	11.43	<.0001	9.75 ± 1.59
Crop*Tillage	Millet	No-till	–	3.02 ± 0.13	66	17.03	<.0001	20.44 ± 2.71
Crop*Tillage	Millet	Till	–	3.29 ± 0.12	66	19.16	<.0001	26.71 ± 3.32
Crop*Tillage	Sunflower	No-till	–	2.94 ± 0.13	66	16.90	<.0001	18.86 ± 2.42
Crop*Tillage	Sunflower	Till	–	3.27 ± 0.12	66	19.17	<.0001	26.34 ± 3.25
Effort	–	–	Hi	3.96 ± 0.10	66	25.26	<.0001	52.62 ± 5.37
Effort	–	–	Low	1.80 ± 0.12	66	10.72	<.0001	6.07 ± 0.74
Crop*Effort	Corn	–	Hi	3.92 ± 0.11	66	23.78	<.0001	50.57 ± 5.81
Crop*Effort	Corn	–	Low	0.86 ± 0.20	66	3.83	0.0003	2.37 ± 0.48
Crop*Effort	Millet	–	Hi	4.14 ± 0.11	66	25.12	<.0001	62.51 ± 7.10
Crop*Effort	Millet	–	Low	2.17 ± 0.14	66	11.86	<.0001	8.74 ± 1.24
Crop*Effort	Sunflower	–	Hi	3.83 ± 0.12	66	23.16	<.0001	46.09 ± 5.32
Crop*Effort	Sunflower	–	Low	2.38 ± 0.14	66	13.31	<.0001	10.78 ± 1.46
Tillage*Effort	–	No-till	Hi	4.00 ± 0.11	66	24.87	<.0001	54.58 ± 5.91
Tillage*Effort	–	No-till	Low	1.64 ± 0.15	66	8.82	<.0001	5.17 ± 0.76
Tillage*Effort	–	Till	Hi	3.93 ± 0.11	66	24.37	<.0001	50.73 ± 5.51
Tillage*Effort	–	Till	Low	1.96 ± 0.14	66	10.82	<.0001	7.12 ± 1.00
Crop*Tillage*Effort	Corn	No-till	Hi	4.21 ± 0.13	66	24.16	<.0001	67.68 ± 8.71
Crop*Tillage*Effort	Corn	No-till	Low	0.81 ± 0.28	66	2.80	0.0066	2.24 ± 0.62
Crop*Tillage*Effort	Corn	Till	Hi	3.63 ± 0.14	66	20.32	<.0001	37.79 ± 5.10
Crop*Tillage*Effort	Corn	Till	Low	0.92 ± 0.26	66	3.31	0.0015	2.52 ± 0.67
Crop*Tillage*Effort	Millet	No-till	Hi	4.14 ± 0.13	66	23.60	<.0001	62.62 ± 8.10
Crop*Tillage*Effort	Millet	No-till	Low	1.90 ± 0.19	66	8.67	<.0001	6.67 ± 1.26
Crop*Tillage*Effort	Millet	Till	Hi	4.13 ± 0.13	66	23.53	<.0001	62.4 ± 8.07
Crop*Tillage*Effort	Millet	Till	Low	2.44 ± 0.16	66	12.20	<.0001	11.44 ± 1.87
Crop*Tillage*Effort	Sunflower	No-till	Hi	3.65 ± 0.13	66	20.41	<.0001	38.36 ± 5.17
Crop*Tillage*Effort	Sunflower	No-till	Low	2.23 ± 0.17	66	10.80	<.0001	9.27 ± 1.60
Crop*Tillage*Effort	Sunflower	Till	Hi	4.01 ± 0.13	66	22.82	<.0001	55.37 ± 7.22
Crop*Tillage*Effort	Sunflower	Till	Low	2.53 ± 0.16	66	12.80	<.0001	12.53 ± 2.01
Sampling Period (Random)	–	–	–	0.063 ± 0.04	–	–	–	–

Discussion

Overall, our estimate of lead shot concentrations on CF from this study was 67,813 pellets/ha, which is similar to concentrations reported by Anderson (1986), Lewis and Legler (1968), Castrale (1989), and Schulz et al. (2002). Data from our concurrent hunter use survey indicated a potential deposition of 105,502 pellets/ha in and around the fields at CF over a two-year period (Douglass et al. 2013). Although we found 35.7% (37,689 pellets/ha) fewer pellets in the fields than what hunters reported firing, we feel this is a fairly low difference and that our results adequately characterized shot deposition during the study period. The difference between the two estimated concentrations is most likely driven by the placement of shots being fired by hunters using CF—hunters

were asked to record the exact number of shells they discharged in a specific field but were not asked to report where the pellets fell (Douglass et al. 2013). Therefore, depending on shot trajectory and placement, pellets could have easily fallen outside of the fields (i.e., along the field edge or in adjacent woods), which may account for the 35.7% difference. Another possible factor that could explain the difference in estimates could be pellets settling below the top 1.3 cm of soil we sampled or being washed to other areas of the field, although we feel this is an unlikely factor because we collected soil samples shortly after the majority of pellets were deposited in these fields. Another possible explanation of the differences in estimates could be the accuracy of the hunter surveys (i.e., if hunters inaccuracy reported the number of shells they discharged) which may have caused our estimated shot deposition to be inaccurate. We also feel this is an unlikely factor because hunters appeared to report the exact number of shots fired (e.g., 23 or 17) instead of an estimated number of discharged shells (e.g., 10 or 25) (Douglass et al. 2013).

We found higher shot concentrations in areas of high hunter effort and lower concentrations in areas of low hunter effort, as hypothesized, which is most likely a function of the number of hours hunted or shots fired by hunters (Douglass et al. 2013). Plots in Block 2 (Figure 1) were separated geographically by patches of trees and paths, whereas Block 1 was located within a single field. Field configuration, location, access, and size could have affected the degree of hunter effort in each block (Douglass et al. 2013), which may have resulted in the differences in shot concentrations we documented in each block.

Contrary to our hypothesis, shot concentrations varied among crop types. Shot concentrations were higher in millet than sunflower or corn, suggesting that perhaps hunters preferred hunting over millet than sunflower or corn. However, the configuration of the crop strips within each field effectively prevented hunters from selecting a single crop over which to hunt. Even if a hunter was hunting within a millet strip, shot trajectory dictates that most of the shots fired by that hunter would be distributed over multiple crop strips (e.g., sunflower, corn, milo) and not within the narrow millet strip from which they hunted. Therefore, the higher shot concentrations observed in millet and sunflower over corn suggests the root structure of millet may be more effective at retaining pellets within the upper layers of soil (i.e., within the 1.3 cm layer we collected) or that wildlife may be foraging more often in corn over millet or sunflower, given the density of weedy biomass, general plant structure, or density of crop stems, and ingesting pellets, making them unavailable for sampling. However, the differences in shot concentration we observed among crops were only evident in areas of low hunter effort (Figure 4), suggesting that heavy shot

deposition in areas of high hunter effort eclipse these patterns. Another possible explanation of the differences in concentrations could be related to soil composition; however, the Norfolk and Bonneau soils, representing a total of 95.8% of the total plot area, are very similar in drainage, composition, and slope, and therefore most likely did not impact pellet retention substantially among crop types.

Contrary to our hypothesis, we found no overall effect of tillage on shot concentrations (i.e., shot concentrations were not significantly different between till and no-till plots). However, crop-specific treatment effects suggest that tillage could be used as a management tool to reduce shot concentrations in corn, although not in sunflower or millet where tillage increases concentrations (Figure 6). While it is difficult in this study to determine what factors drive differences in crop response to tillage, some examples may include hunter bias of a particular crop which is often managed with a specific technique, vegetation structure of or the debris produced by a crop and the management technique used to discard that debris, or weedy growth in a crop and herbicide use to control competition.

Although we did not see an overall effect of tillage on shot concentrations, we did find an interaction between tillage and hunter effort, where tillage increased concentrations in areas of low hunter effort and had no effect in areas of high hunter effort (Figure 6). Although the mechanisms driving this interaction may be difficult to distinguish in this study, we believe these results are due to a saturation effect. For example, tillage in areas of high hunter effort may be homogenizing shot concentrations because concentrations are artificially high. Whereas in areas of low hunter effort the practice of tillage might be turning over residual pellets previously buried in lower soil columns, effectively increasing shot concentrations in the upper soil layer. Shot pellets can remain near the soil surface for many years (Flint 1998, Flint and Schamber 2010, Mudge 1984, Pain 1991, Wycoff et al. 1974), which could, in effect, create a store of pellets that could be rotated up to the soil surface by tillage. However, we feel it is important to note that the magnitude of this result is very small in areas of low hunter effort—only a difference of two pellets per plot on average. Having more fields with varying degrees of hunter effort is needed to elucidate a stronger relationship between tillage and hunter effort.

Management Implications

Based on the results of this study, tillage may not be an effective means of reducing shot concentrations in publicly managed mourning dove fields. Managers could effectively reduce shot concentrations in the upper soil layers of dove fields and therefore reduce Pb exposure to doves by limiting hunter access and/or effort

or requiring nontoxic shot on managed dove fields. Given the importance of this research and its potential implications, we suggest similar research be conducted in a controlled environment using non-hunted fields upon which a known quantity of shot pellets have been randomly distributed to test the direct effects, without compounding factors, of tillage on reducing shot concentrations. Studies examining differences in pellet retention among crops, factors affecting Pb shot movement in the upper soil layers, differences in the timing of management treatments in relation to pellet deposition, varying degrees of hunter effort, and differences in management treatments or planting techniques such as prescribed burning, ploughing, harrowing, cultipacking, zone tillage, or rotational tillage, should also be considered.

Acknowledgments

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