Post-harvest Fates of Agricultural Seeds in Tennessee Croplands

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Abstract: Agricultural seed left in harvested fields is an important source of energy for migrating and wintering waterfowl. However, rates of seed loss from germination, decomposition or depredation have not been quantified for corn, soybean, or grain sorghum. Because seed loss rates directly influence habitat quality and management recommendations for waterfowl and other wildlife, we estimated rates of germination, decomposition, and depredation for scattered seed and aggregate seed heads in 98 harvested corn, soybean and grain sorghum study plots across Tennessee from September – January 2006–07 and 2007–08. Total seed loss in plots between harvest and January was more than 80%. Scattered corn seed was lost primarily (37%–68%) to depredation, whereas soybean and grain sorghum seed were lost mostly (≥35%) to decomposition. Rates of germination generally decreased and decomposition rates increased from October through January for scattered corn and grain sorghum. Rates of loss were related to ambient temperature, relative humidity, and time since harvest. Seed aggregated on seed heads (e.g., corn cobs) was lost more slowly than scattered seed. Where crops are planted for wildlife, harvest should be delayed if possible to reduce seed loss and land managers should consider planting corn instead of grain sorghum and soybean because seed of the latter species decompose rapidly.

Key words: agriculture, decomposition, germination, granivory, waterfowl.

Waterfowl consume agricultural seeds in croplands to meet energetic needs during their annual cycle but especially during the non-breeding season (Baldassarre and Bolen 1984, Delnicki and Reinecke 1986, Combs and Fredrickson 1996). In the 1980s, corn and grain sorghum seeds lost during harvest operations and deposited on the ground (i.e., waste seed) commonly exceeded 200 kg/ha (dry mass) in early winter (Iverson et al. 1985; Warner et al. 1985, 1989). However, recent studies indicate the average mass of seed in harvested agricultural fields in early winter is 52%–83% less than estimates from the 1980s (Manley et al. 2004, Stafford et al. 2006, Kross et al. 2008, Foster et al. 2010). Current decreased seed abundance may be a consequence of advances in combine efficiency that result in less waste seed deposited after harvest and earlier harvest dates, which increase exposure time for seed loss to germination, decomposition, or wildlife depredation (Manley et al. 2004, Stafford et al. 2006). Stafford et al. (2006) reported that 8%, 14%, and 58% of waste rice seed was lost to germination, decomposition, and depredation between harvest and early winter

when large numbers of waterfowl migrate to the southeastern United States. In addition to rice, important crops for wintering waterfowl in the Southeast include corn, grain sorghum, and soybean (Reinecke et al. 1989). Foster et al. (2010) documented that monthly rates of seed loss exceeded 64% in corn, soybean, and grain sorghum fields, but the fates of lost seeds were not quantified.

Rates of seed decomposition, germination, and depredation may vary among crop species because of differences in seed morphology, potential for water uptake, tannin levels, and optimum germination temperatures (McDonald 1986). These fates also may vary temporally with local microclimate and whether seed is scattered on the ground or intact in an inflorescence (hereafter aggregates), both of which can occur in harvested fields. No studies have quantified fates of waste seeds among months and related rates of loss within a season to microclimate conditions (e.g., temperature, humidity and precipitation) and seed aggregation. Cause-specific estimates of seed loss in corn, soybean, and grain sorghum fields are needed to understand variation in seed availability for wild-

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life in agricultural landscapes and to derive mitigative strategies that counteract losses. Therefore, our objectives were to 1) estimate cumulative and monthly rates of loss to germination, decomposition and depredation for scattered and aggregated seed, and 2) relate loss to microclimate conditions in harvested corn, grain sorghum and soybean fields from September – January 2006–07 and 2007–08.

Study Area

Our study areas and sampling plots were located in unflooded agricultural fields throughout four regions in Tennessee (3515–3659N and 8221–9004W; U.S. Department of Commerce 1968; Figure 1). Given that corn and soybean production occur statewide in Tennessee (NASS 2008), we placed paired 0.5625-m^2 fate plots (discussed below) in four harvested corn and soybean fields per region each study year (September–January 2006–07 and 2007–08). Grain sorghum production in Tennessee is primarily restricted to the western portion of the state (NASS 2008). Therefore, we placed plots in five harvested grain sorghum fields in western Tennessee. To increase spatial replication for this crop species, we also established plots and added grain sorghum seeds to these plots in four harvested corn fields in each of the other study regions (Figure 1). Given that plot conditions were standardized (discussed below), we assumed that fate-based estimates for grain sorghum seed loss were similar between western Tennessee and the other sampling regions (Foster 2009). Overall, we analyzed data from 98 plots (i.e., [16 corn + 16 soybean + 17 grain sorghum plots] * 2 years).

Methods
Study Design

We estimated fates of seeds in two 0.75 x 0.75 m paired plots placed in harvested corn, soybean, and grain sorghum fields. We positioned paired plots 5 m apart at a randomly-generated location in each field; all plots were placed at least 20 m from the field edge. Given that agricultural fields are not harvested simultaneously across Tennessee, we established plots between September and December as fields were harvested, which created unbalanced sample sizes that increased from September–December (i.e., $n = 6 – 32$ fields per month). To standardize plots, we removed all chaff and preexisting seed by hand then scattered 100 seeds with chaff to emulate field conditions; seeds used for scattering were randomly collected from harvested areas outside the plot. For grain sorghum plots that were placed in corn fields, we used seed and chaff from harvested grain sorghum fields located in western Tennessee. Given that grain sorghum plots in corn fields were established identically to plots in grain sorghum fields, we assumed that corn fields functioned as reasonable surrogates for grain sorghum seed loss
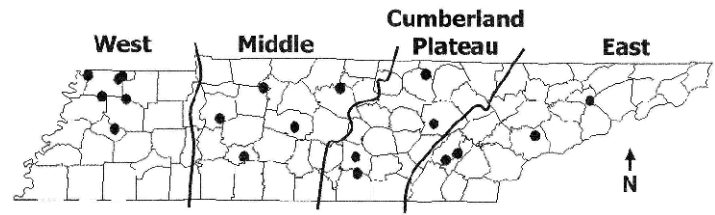
Figure 1. Four regions of Tennessee and approximate locations of agricultural fields (circles) where rates of germination, decomposition, and depredation of corn, soybean, and grain sorghum seeds were quantified. More than one field may be located near each circle.

within plots. This assumption was reasonable because preliminary analyses revealed that seed loss in western Tennessee was similar to the other regions for all crop types (Foster 2009). In 2007, we expanded the study to include corn cobs and grain sorghum aggregates. We excluded soybean because it does not form aggregated seed heads. We placed one randomly-collected seed aggregate in each paired corn and grain sorghum plot.

We randomly designated one plot of each pair as the enclosed plot, covered it with hardware cloth (0.75 x 0.75 x 0.1 m; mesh size = 0.635 cm^2) to exclude vertebrate granivores, and anchored the enclosure with metal stakes. We placed a HOBO (model H8 pro, Onset Corp, Pocasset, Massachusetts) weather logger with solar radiation shield at the enclosed plot and assumed microclimate was equivalent between plots. The logger recorded temperature and humidity daily every 6 hours (0600, 1200, 1800 and 2400). We also acquired daily precipitation data from the nearest National Oceanic and Atmospheric Administration weather station ($n = 19$ stations; 4–6 per region), which was between 2–19 km from our study fields.

Monthly, we recorded the number of intact, germinated, and decomposed seeds in all plots. No new seed was added during the experiment, but we removed seed that was mostly decomposed or germinated seed to ensure the fates of seed were not recorded multiple times. We assumed the fate of missing seeds in the enclosed plot was decomposed, while lost seeds in the open plots were due to either decomposition or vertebrate depredation. Seed loss due to flooding or sheet flow during rain events was unlikely because our fields were located at upland sites that did not flood, topography was flat which limited sheet flow velocity, and evidence of rapid water flow (e.g., scouring, deposited litter) was never observed. Thus, the difference between disappearance rates in the paired plots represented vertebrate depredation only. Given that enclosures probably did not exclude invertebrates, it is possible that some of the seed loss attributed to decomposition was from invertebrates. For grain sorghum plots in corn fields, we sampled

only enclosed plots, because we believed it was unreasonable to assume that vertebrate depredation rates for grain sorghum seed in corn fields were representative of plots in harvested grain sorghum fields given that granivores can develop search images for seed types. We sampled both open and enclosed plots within grain sorghum fields in western Tennessee to estimate depredation.

For seed aggregates, we counted numbers of seeds on corn cobs and grain sorghum spikelets prior to placement in plots. We defined a spikelet as the stalk containing seed that originated from the pedicel (Jones 2005). We counted the number of intact, germinated and decomposed seeds on cobs and spikelets each month. We assigned fates to grain sorghum spikelets, because counting numbers of seeds per grain sorghum spikelet (i.e., >600) was impractical (Kirby and Atkins 1968). When >50% of the seed on a spikelet was germinated or decomposed, we designated that fate to the entire spikelet. Similar to scattered seed, we used the difference in disappearance rates between the enclosed and open plots to calculate vertebrate depredation.

Statistical Analyses

We measured monthly and cumulative percent losses to germination, decomposition, and depredation. We calculated cumulative percent loss as the sum of individual seed or spikelets lost to each fate from harvest through January divided by the total number of seeds or spikelets originally placed when plots were established. We calculated monthly rates of loss as the sum of seed or spikelets lost to each fate during a given month divided by the total number of seeds or spikelets intact at the beginning of that month. We averaged daily measurements of temperature, relative humidity, and precipitation per month for each field prior to analysis.

We tested if cumulative percent loss for each fate differed among crop species and between years using a two-way analysis of variance (ANOVA; SAS Institute 1999). We included year as an effect to account for potential annual variation in seed or spikelet loss. Because fields were not harvested simultaneously, plots were established during different months within years. Thus, we also included month of plot establishment as a blocking variable in the two-way ANOVA model. Because seed loss of aggregates was estimated only during 2007, we used a one-way ANOVA to test for differences in cumulative percent loss between corn cobs and grain sorghum spikelets for each fate. We used two-way repeated-measures ANOVA to test for differences among months and between years in monthly rates of loss for each fate and in monthly averages for each microclimate variable (SAS Institute 1999). When ANOVAs were significant, we used Tukey's Honestly Significant Difference (HSD) multiple comparison test to determine if pairwise differences existed for effects with >2 levels (SAS Institute 1999).

Although percent loss to each fate represented compositional data, data transformation following Aitchison (1986) was unnecessary because each fate was analyzed independently. We did not test if our data followed a normal distribution because sample size was large, thus it can be assumed that the sample mean followed an approximate normal distribution as per the Central Limit Theorem (Zar 2010). We performed all analyses using PROC GLM in the SAS system (SAS Institute 1999) at $\alpha = 0.05$.

Results
Cumulative Percent Loss

Crop species and year effects interacted for rates of germination, decomposition and depredation for scattered seed ($F_{2,72} \geq 3.3$, $P \leq 0.04$). Germination was greatest for soybean in 2006–07 ($F_{2,36} = 8.5$, $P = 0.001$), but no differences were detected among species in 2007–08 ($F_{2,35} = 3.1$, $P = 0.06$; Figure 2a). Germination differed between years for corn and soybean ($F_{1,31} \geq 9.1$, $P \leq 0.01$), but not for grain sorghum ($F_{1,8} = 2.1$, $P = 0.19$; Figure 2a). Decomposition was 1.7–3.8 times greater in sorghum plots than in soybean or corn plots in 2006–07 ($F_{2,36} = 8.6$, $P = 0.001$; Figure 2b). Decomposition was greatest in soybean plots in 2007–08 ($F_{2,35} = 9.3$,
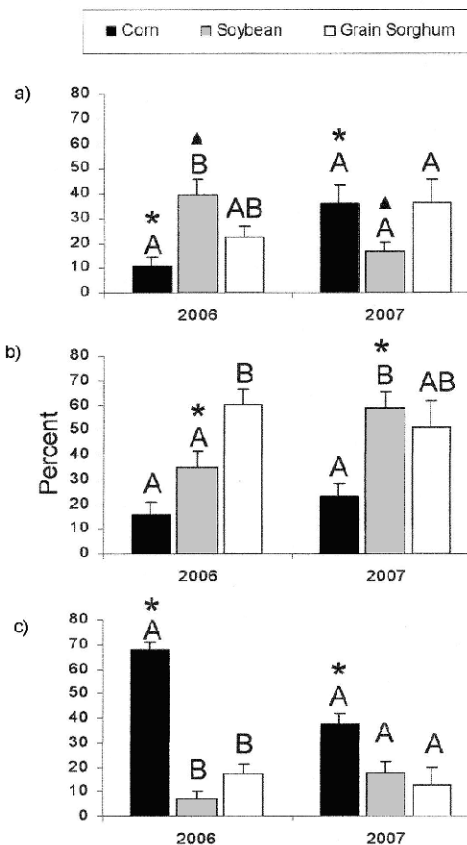
Figure 2. Cumulative seed loss (%) from (a) germination, (b) decomposition and (c) depredation for corn, soybean, and grain sorghum between harvest and January 2006–07 and 2007–08, Tennessee. Bars within years with unlike letters are statistically different by ANOVA and Tukey's HSD test. Bars between years with like symbols (asterisks [*] or triangles [▲]) are statistically different by ANOVA.

$P<0.001$; Figure 2b). Decomposition was 1.7 times greater in 2007–08 than 2006–07 for soybean ($F_{1,31}=6.7$, $P=0.01$), but did not differ between years for corn and grain sorghum ($F_{1,31}\leq0.96$, $P\geq0.33$; Figure 2b). Rates of depredation differed among species in 2006–07 and 2007–08 ($F_{2,35}\geq6.3$, $P\leq0.01$; Figure 2c). Rate of corn depredation was 3.9–9.3 times greater than grain sorghum or soybean in 2006–07, but we did not detect any pairwise differences in 2007–08. The cumulative rate of corn depredation was 1.8 times greater in 2006–07 than in 2007–08 ($F_{1,3}=7.6$, $P=0.01$; Figure 2c). Depredation rate did not differ between years for soybean and grain sorghum ($F_{1,8}\leq0.37$, $P\geq0.56$; Figure 2c).

Cumulative percent germination was 22 times greater for grain sorghum aggregate seed heads ($\bar{x}=20.0\%$, SE = 3.4) than for corn cobs ($\bar{x}=0.9\%$, SE = 0.6; $F_{1,19}=86.3$, $P<0.001$). Cumulative percent decomposition was 16 times greater for grain sorghum seed heads ($\bar{x}=66.9\%$, SE = 4.9) than corn cobs ($\bar{x}=4.3\%$, SE = 1.1; $F_{1,19}=314.8$, $P<0.001$). We did not detect a difference in depredation between corn cobs ($\bar{x}=62.6\%$, SE = 10.7) and grain sorghum seed heads ($\bar{x}=9.4\%$, SE = 5.4; $F_{1,19}=3.7$, $P=0.07$).

Monthly Losses

Germination rates decreased ($F_{3,50}=4.6$, $P<0.01$) and decomposition rates increased ($F_{3,50}=29.9$, $P<0.001$) from October through January for scattered corn seeds (Table 1). Rates of germi-

nation and decomposition also differed among months for grain sorghum ($F_{3,30}\geq7.1$, $P<0.001$), but no pairwise differences were detected. No differences were detected among months for germination or decomposition of scattered soybean seed or for depredation rates of any species ($F_{1,16}\leq5.1$, $P\geq0.08$; Table 1).

Decomposition of grain sorghum seed aggregates increased from November through January ($F_{2,29}=25.2$, $P<0.001$), whereas rates of germination decreased ($F_{2,29}=10.5$, $P<0.001$; Table 1). Decomposition rate of corn cobs differed among months ($F_{3,35}=5.2$, $P=0.01$), but no pairwise differences were detected. Differences were not detected in germination or depredation rates for corn cobs or depredation rates for grain sorghum seed heads among months ($F_{3,28}<2.6$, $P>0.07$; Table 1).

Changes in Microclimate

Month and year effects interacted for temperature ($F_{3,114}=21.1$, $P<0.001$). Temperature at plots decreased from October – January in 2006–07 and 2007–08 ($F_{3,49}\geq120.4$, $P<0.001$), but monthly patterns of decline differed slightly between years (Figure 3). Relative humidity at plots increased monthly from October – January ($F_{3,114}=17.3$, $P<0.001$) and did not differ between years ($F_{1,71}=1.7$, $P=0.20$). Precipitation at weather stations near experimental plots was greatest in November and January ($F_{3,114}=15.9$, $P<0.001$; Figure 3), and did not differ between years ($F_{1,71}=2.6$, $P=0.11$).

Table 1. Percentage germination (G), decomposition (D) and depredation (P) among months for scattered (S) and aggregated (A) agricultural seed in 0.56-m² plots in harvested fields, October–January 2006–07 and 2007–08, Tennessee.

Species	Aggregation	Fate	Month[a]
			\multicolumn{3}{c}{October}	\multicolumn{3}{c}{November}	\multicolumn{3}{c}{December}	\multicolumn{3}{c}{January}
			n	$\bar{x}$[b,c]	SE	n	$\bar{x}$	SE	n	$\bar{x}$	SE	n	$\bar{x}$	SE
Corn	S	G	9	34.0 A	11.1	26	26.7 A	4.8	27	17.8 AB	3.9	26	6.1 B	3.9
	S	D	9	7.3 A	6.0	26	23.4 AB	5.7	27	35.7 BC	6.1	26	57.4 C	6.7
	S	P	9	29.7 A	10.7	26	20.7 A	5.9	26	35.8 A	7.1	22	46.1 A	8.8
	A	G	6	1.5 A	1.5	16	0.1 A	0.1	16	0.8 A	0.6	16	0.2 A	0.1
	A	D	6	0.6 A	0.4	16	2.2 A	1.4	16	3.3 A	1.2	16	5.8 A	1.4
	A	P	6	0.0 A	0.0	16	37.6 A	11.6	13	27.1 A	11.3	2	37.9 A	13.4
Soybean	S	G	\multicolumn{2}{c}{NT}		12	13.0 A	4.5	26	16.4 A	3.3	32	19.4 A	4.3
	S	D	\multicolumn{2}{c}{NT}		12	41.6 A	6.9	26	37.1 A	5.9	32	42.2 A	5.1
	S	P	\multicolumn{2}{c}{NT}		12	8.9 A	4.9	26	6.2 A	2.9	30	4.7 A	6.9
Sorghum	S	G	\multicolumn{2}{c}{NT}		24	31.3 A	4.9	28	17.8 A	3.7	15	1.6 A	1.4
	S	D	\multicolumn{2}{c}{NT}		24	49.6 A	4.3	28	74.7 A	4.6	15	80.2 A	7.1
	S	P	\multicolumn{2}{c}{NT}		6	18.3 A	8.3	7	7.0 A	3.7	3	13.9 A	2.4
	A	G	\multicolumn{2}{c}{NT}		15	8.2 A	2.0	17	3.9 B	1.0	16	0.0 B	0.0
	A	D	\multicolumn{2}{c}{NT}		15	17.2 A	2.5	17	40.7 B	5.4	16	53.6 B	6.7
	A	P	\multicolumn{2}{c}{NT}		4	2.0 A	2.0	4	11.1 A	11.1	2	39.3 A	39.3

a. Sample size differed among months because fields were not harvested simultaneously and 100% of seed was lost prior to January for some plots.
b. NT = no test performed due to insufficient replication (i.e., n <2 fields).
c. Means within rows followed by unlike letters are statistically different by repeated-measures ANOVA and Tukey's HSD test.
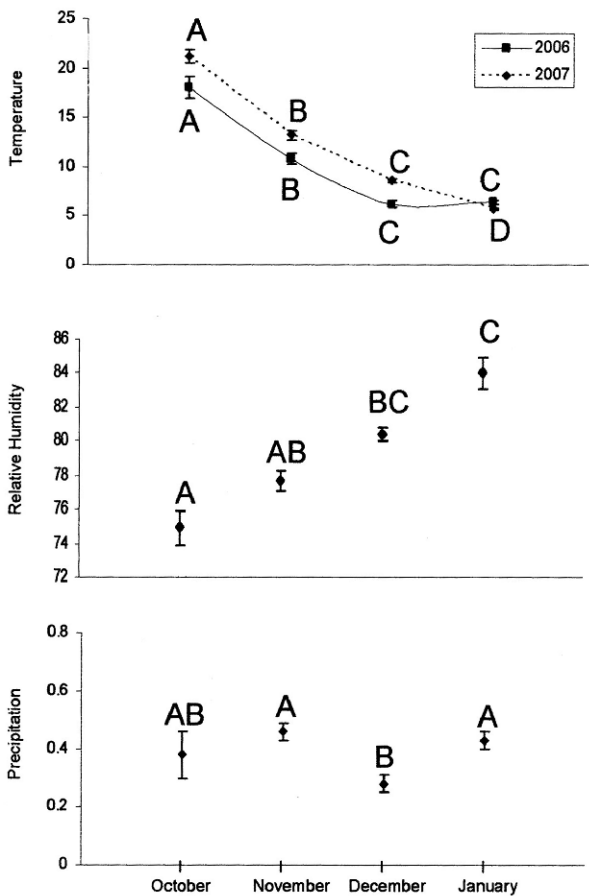
Figure 3. Mean temperature (C), relative humidity (%) and precipitation (cm) among months at study plots, October–January 2006–07 and 2007–08, Tennessee. Temperature was separated by year due to an interaction with month effects. Months with unlike letters are statistically different by ANOVA and Tukey's HSD test.

Discussion

An average of 82%, 80% and 98%, respectively, of corn, soybean, and grain sorghum seed in our study plots was lost between harvest and January. These results mirror seed declines in 105 harvested agricultural fields in Tennessee where corn, soybean, and grain sorghum mass declined an average of 84%, 78%, and 95%, respectively, between harvest and January (Foster et al. 2010). Similarly, 66%–99% of rice seed was lost between harvest and early winter in the Mississippi Alluvial Valley (MAV; Manley et al. 2004, Stafford et al. 2006, Kross et al. 2008). Thus, seed loss in our study plots was representative of waste corn, grain sorghum, and soybean in Tennessee, and perhaps elsewhere in the Southeast.

Corn seed was lost primarily (37%–68%) to depredation, whereas rates of soybean and grain sorghum depredation were low (≤17%). Low soybean depredation may be a result of rapid decomposition, which occurred at a rate of about 40% per month.

Foster et al. (2010) documented mean duck-energy days (DED) in soybean fields declined from 1,000 to 0 DED/ha only one month post-harvest. Similar to soybean, lower depredation rates of grain sorghum could be attributed to high decomposition, which occurred at a rate of about 68% per month. In comparison, corn decomposed at a rate of about 30% per month. Low depredation rates for grain sorghum may reflect regional preference of granivores, which could be related to low occurrence of grain sorghum fields on the Tennessee landscape (i.e., <1% cropland acreage; NASS 2008). Grain sorghum is readily consumed by white-fronted geese (*Anser albifrons*), Canada geese (*Branta canadensis*), and a host of other wildlife (e.g., blackbirds [Passeriformes: Icteridae] and sparrows [Passeriformes: Emberizidae]) in regions where it is dominant on the landscape (Atkeson and Givens 1952, Neely and Davison 1971, Ballard and Tacha 1995). Coverage of corn fields was extensive in Tennessee (i.e., >25% of row-crop acreage; NASS 2008). Corn is consumed by a variety of wildlife species and may comprise >90% of the diet of some waterfowl species by volume (Atkeson and Givens 1952, Moore 1980, Krapu et al. 2004). Thus, corn is a valuable post-harvest agricultural food for wildlife, particularly in regions where rice or grain sorghum is not grown.

Rates of germination generally decreased, decomposition rates increased, and depredation remained constant from October through January for scattered corn and grain sorghum in unflooded harvested fields. Decreasing germination and increasing decomposition may have been driven by a decrease in ambient temperature and an increase in relative humidity, respectively. Optimum temperatures for corn and grain sorghum germination range from 23–30 C, and the germination potential for each species declines with decreasing temperature (Kanemasu et al. 1975, Tyagi and Tripathi 1983, Elmore et al. 2006). Temperatures were close to optimum for germination during September 2006 and 2007, but decreased four-fold at our study plots by January. Conversely, relative humidity was 10% lower in September compared to January. Water uptake by seeds may occur regardless of temperature (Elmore et al. 2006), thus high humidity may facilitate germination at high temperatures and decomposition at low temperatures. Increased rates of decomposition between October and January also may have been a consequence of exposure duration, which increases the likelihood of microbe colonization necessary for decomposition (Nelms and Twedt 1996). Rates of each fate were relatively constant among months for soybean, with decomposition greater than germination or depredation during all months. High rates of soybean decomposition have been noted by others (Atkeson and Givens 1952, Neely and Davison 1971), and may be a consequence of its relatively soft seed coat that readily absorbs water and facilitates microbe colonization.

Cumulative rates of germination and decomposition were greater for corn and soybean, respectively, in 2007 than in 2006. In 2007, drought conditions occurred throughout Tennessee, which resulted in fields harvested earlier (i.e., 10%–16% ahead of the five-year average; Heddinghaus 2007, NASS 2008). Consequently, plots were placed in the field earlier and for longer duration in 2007 than in 2006. Earlier harvest and longer duration likely contributed to the observed yearly trends in seed fates. Interestingly, less scattered corn seed was depredated in 2007, because germination rates were greater earlier, hence less seed was available for wildlife consumption during autumn and winter. Thus, harvesting fields earlier likely leads to increased corn seed loss to germination and less available for wildlife consumption.

Average monthly rates of loss to germination and decomposition were lower for aggregated corn and grain sorghum (4% and 41%) than for scattered seed (52% and 85%, respectively). We hypothesize that germination and decomposition were lower for seed heads, because much of the seed on aggregates is not in contact with the soil, where moisture content and microbe densities are likely greater. Despite lower monthly rates of loss, cumulative decomposition (67%), germination (20%), and depredation (9%) for grain sorghum in January were similar between seed heads and scattered seed. Thus, even though rates of loss are slower on sorghum seed heads, few intact seeds remain by January. Given lower rates of loss on corn cobs compared to scattered seed or grain sorghum seed heads, corn cobs that remain after harvest may be an important food resource for resident and migratory wildlife.

Our results suggest that land managers in the Southeast should plant corn instead of grain sorghum or soybean in areas that receive extensive wildlife use because of higher decomposition and germination rates for the latter two crops. Our results also indicated when corn fields are harvested early, a large percentage of seeds germinate. Thus, harvest should be delayed as appropriate to reduce seed loss to germination. We found rates of seed loss on aggregated seed heads (e.g., corn cob) were slower than scattered seed. Thus, on areas where providing food resources for waterfowl is a priority and hunting does not occur, we recommend that land managers consider knocking down food plots instead of mowing or silage chopping them, which scatters seed and increases non-depredation losses. Wildlife managers should also consider providing natural wetlands for waterfowl use. Native seeds decompose more slowly than agricultural seeds and provide essential nutrients for waterfowl (Loesch and Kaminski 1989, Nelms and Twedt 1996). For agencies interested in modeling fate-based seed loss on a landscape scale, rates of loss in Table 1 could be used.

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