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*Management and Conservation Article*

# Agricultural Seed Biomass for Migrating and Wintering Waterfowl in the Southeastern United States

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**ABSTRACT** Waterfowl frequently acquire high-energy agricultural seeds in harvested and unharvested croplands during migration and winter. Estimates of agricultural seed biomass in harvested and unharvested corn, soybean, and grain sorghum fields do not exist or are outdated for the southeastern United States. Therefore, we estimated seed biomass in 105 harvested and 59 unharvested corn, soybean, and grain sorghum fields across 4 climate regions in Tennessee, USA, from September through January 2006 and 2007. We also used estimates of seed biomass to calculate duck-energy days (DEDs) in December and January when migratory waterfowl abundance peaks in the southeastern United States. Mean biomass of corn, soybean, and grain sorghum seed in harvested fields declined 239 kg/ha to 39 kg/ha, 118 kg/ha to 26 kg/ha, and 392 kg/ha to 19 kg/ha, respectively, from postharvest to January. Continuous monthly rates of decline were 64% for corn, 84% for soybean, and 74% for grain sorghum. Agricultural seed biomass in harvested corn and grain sorghum fields dropped below the waterfowl giving-up density (i.e., 50 kg/ha) in 3 months; soybean dropped below this threshold 1 month postharvest. Mean DEDs/ha in harvested corn, soybean, and grain sorghum fields were low (274, 90, and 27, respectively) in January, and DEDs were zero in >85% of fields. In unharvested corn, soybean, and grain sorghum fields, mean DEDs/ha in January were high (69,000, 18,000, and 26,000, respectively), and continuous rates of decline (3%, 7%, and 18%, respectively) were much lower than for harvested crops. Waterfowl biologists in the Southeast should use our estimates of agricultural seed biomass in DED calculations. We also recommend that biologists provide unharvested grain fields and natural wetlands for migrating and wintering waterfowl because seed resources are low in harvested agricultural fields.

**KEY WORDS** agriculture, carrying capacity, cropland, duck-use day, energy, foraging, seed, Tennessee, waste grain, waterfowl.

North American waterfowl populations declined to record lows in the mid-1980s, prompting enactment of the North American Waterfowl Management Plan (NAWMP; U.S. Department of the Interior and Environment Canada [1986]). The NAWMP functions through regional joint ventures that focus on conserving, restoring, and managing habitat to maintain waterfowl populations at levels existing during the 1970s (U.S. Department of the Interior and Environment Canada 1986). To evaluate if NAWMP goals are being met, biologists annually estimate the number of nonbreeding waterfowl that can be sustained energetically in migrating and wintering regions of North America. The standard procedure for this evaluation is calculation of duck-energy days (DEDs). Duck-energy days are equivalent to duck-use days in Reinecke and Loesch (1996) and require accurate estimates of available food for waterfowl (Reinecke et al. 1989).

Many waterfowl species have adapted to historic increases in cropland and feed commonly on agricultural seeds (Baldassarre and Bolen 1984, Delnicki and Reinecke 1986, Combs and Fredrickson 1996). Waterfowl also consume natural foods including moist-soil seeds, tubers, acorns (*Quercus* spp.), and aquatic invertebrates (Reinecke et al. 1989). Generally, agricultural seed contains greater true metabolizable energy than moist-soil seed or acorns (Petrie et al. 1998, Checkett et al. 2002, Kaminski et al. 2003). In addition, yield per unit area for agricultural crops is greater than for wetland plants (Kross et al. 2008*b*, National Agricultural Statistics Service [NASS] 2008). Thus, biologists frequently incorporate agricultural fields into management of migratory waterfowl (Reinecke et al. 1989).

To calculate DEDs in agricultural fields, waterfowl managers generally used seed biomass data in Reinecke et al. (1989). However, contemporary studies conducted in rice fields suggest these earlier estimates are greater than seed biomass that is currently available in harvested fields (Manley et al. 2004, Stafford et al. 2006, Kross et al. 2008*a*). Decreased rice biomass may be attributable to earlier harvest dates, which increase exposure time for seed loss, and to advances in combine harvest efficiency (Manley et al. 2004, Stafford et al. 2006).

Similar to rice, estimates for corn, soybean, and grain sorghum in Reinecke et al. (1989) may be greater than what is currently available. Estimates of seed biomass in harvested fields for these crops are from studies conducted in Illinois, Nebraska, or Texas, USA, during the 1980s (Reinecke et al. 1989). Two of the above studies were conducted in the northern United States, which differs in climate from the southeastern United States where most North American waterfowl spend winter. Additionally, few estimates exist for seed biomass in unharvested croplands managed for waterfowl. Biologists have assumed that 15–20% of unharvested crop is lost to decomposition and granivory

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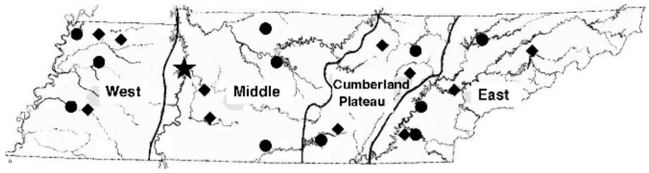


**Figure 1.** Four climate regions of Tennessee, USA (U.S. Department of Commerce 1968, Redmond and Scott 1996). Circles and diamonds indicate locations of fields sampled for agricultural seed on private and state land, respectively. The Tennessee National Wildlife Refuge (star) is where fields on federal land were located, September–January 2006 and 2007.

before waterfowl arrive (U.S. Fish and Wildlife Service [USFWS] 2005), but this assumption has not been tested.

Contemporary estimates of available corn, soybean, and grain sorghum are needed for the southeastern United States because 1) previous estimates may be unreliable due to advances in harvesting technology and yields, 2) most published estimates are not from the Southeast, 3) estimates of seed loss in unharvested fields are based on untested assumptions, and 4) estimates of rate of seed loss in harvested fields for these crops do not exist. Given uncertainty in the amount of corn, soybean, and grain sorghum in agricultural fields available for waterfowl in the southeastern United States, our objective was to estimate biomass of these seeds in harvested and unharvested fields. We also sought to model rate of seed loss using exponential decay functions.

## STUDY AREA

We conducted our study on federal, state, and private lands across the 4 climate regions of Tennessee, USA (35°15′–36°59′N and 82°21′–90°04′W; U.S. Department of Commerce 1968; Fig. 1), from autumn through early winter 2006 and 2007. We sampled on the 10,820-ha Duck River Unit of Tennessee National Wildlife Refuge (NWR) near New Johnsonville, Tennessee. We sampled 4 corn and 4 soybean fields on Tennessee NWR in 2006 and 2007 that were harvested in a strip-split-plot design (Montgomery 2000). Each field contained 2 harvested and 2 unharvested 0.202-ha plots, totaling 16 plots each for corn and soybean per year. We also sampled 4 grain sorghum fields in 2006, but these were not harvested because the farmer decided not to sell the crop. Four sorghum fields also were planted in 2007, but drought decimated the crop (National Climactic Data Center [NCDC] 2008).

We also sampled agricultural fields on state and private lands that were not flooded, disked, or replanted postharvest. Approximately 50% of the fields per region were located on state land and 50% on private land. Corn and soybean production occurs statewide in Tennessee (NASS 2008). Thus, we sampled 4 harvested corn and soybean fields in each region and year. Grain sorghum production occurs primarily in western Tennessee (NASS 2008). Therefore, we limited sampling of harvested grain sorghum to this region and sampled 5 fields on private land each year. Additionally, we sampled 4 unharvested cornfields in 3 regions (W, middle, and E TN) on state wildlife management areas ($n = 12$/yr).

## METHODS

In each field on federal, state, and private land, we randomly located 0.202-ha plots $\geq$10 m from field edges to reduce possible bias due to edge effects. For each plot, we randomly selected and sampled 3 subplots monthly from immediately postharvest (i.e., within 3 weeks) through January 2006 and 2007. Month of harvest (Sep–Dec) varied among fields. We based dimensions of subplots on sampling protocol for harvested corn fields (Frederick et al. 1984). We collected whole or partially intact corn, soybean, and grain sorghum seeds by hand in a 0.3 $\times$ 4.57-m subplot oriented with width perpendicular to crop rows. For corn and grain sorghum fields, this subplot was contained within an 8.84 $\times$ 4.57-m subplot, where we collected seed aggregates (i.e., corn ears containing $>$10 seeds or sorghum seed heads $>$5 cm in length; Frederick et al. 1984). We did not collect soybeans in a larger subplot because the seeds are not contained in dense aggregates. We also collected corn, soybean, and grain sorghum seed from 0.3 $\times$ 4.57-m subplots in unharvested plots following plant drydown (i.e., seed $<$25% moisture; Nielsen 2005). Month of drydown (Sep–Dec) varied among fields. We removed all seed on stalks and also collected any whole or partial agricultural seed on the ground.

We threshed seed from seed heads, removed chaff, froze samples at $-20°$ C within 1 week after field collection and dried all samples to constant biomass. Drying durations and temperatures were 72 hours at 90° C for soybeans and grain sorghum and 48 hours at 103° C for corn. We weighed dried seed to the nearest 0.01 g.

### Statistical Analyses

Two experimental fields were inadvertently mowed or disked; hence, we deleted these fields from our analyses. Overall, we analyzed data from 68 plots on federal land (i.e., 16 corn $\times$ 2 yr + 16 soybean $\times$ 2 yr + 4 grain sorghum) and 96 fields on state and private land (i.e., 16 harvested corn $\times$ 2 yr + 16 harvested soybean $\times$ 2 yr + 5 harvested grain sorghum in 2006 + 4 harvested grain sorghum in 2007 + 11 unharvested corn in 2006 + 12 unharvested corn in 2007). We performed all analyses using the SAS® system (SAS Institute, Cary, NC) at $\alpha = 0.05$.

We used a 2-way repeated measures analysis of variance (ANOVA) with Huynh–Feldt correction to test for differences in biomass of seed in 0.202-ha plots among months and between years (PROC GLM; SAS Institute 1999). The month effect was number of months postharvest for harvested fields and number of months postdrydown for unharvested fields. We tested for differences in biomass among 0–3 months postharvest for corn and among 0–2 months postharvest for grain sorghum and soybean. For unharvested fields, we tested for differences in biomass among 0–3 months postdrydown for corn and grain sorghum and among 0–2 months postdrydown for soybean. The SAS® procedure PROC GLM requires a balanced design for repeated-measures ANOVA and deletes observations (i.e., fields) that do not have a response for all months (SAS Institute 1999). Because fields were harvested or drydown occurred during different months, 6 fields for harvested corn and soybean and one unharvested cornfield were deleted. We also removed one harvested cornfield, because distribution analyses suggested it was an influential outlier (i.e., studentized residual >3; Myers 1990). We included a month × year interaction term in the repeated-measures ANOVA and performed analyses by year when the interaction was significant. Because we did not sample unharvested grain sorghum plots in 2007, we did not include interaction and year effects in this analysis. When ANOVAs were significant, we used Tukey's Honestly Significant Difference test for pair-wise comparisons of effect levels (SAS Institute 1999). We also modeled the rate of seed loss in 0.202-ha plots among months postharvest or postdrydown using exponential decay functions (PROC NLIN; SAS Institute 1999). We used all data, except the influential outlier, for these analyses. When we detected a year effect in the repeated-measures ANOVA, we constructed separate exponential models for each year.

We calculated means and standard errors for seed biomass (kg/ha) and DEDs for December and January estimates for harvested and unharvested corn, soybean, and grain sorghum using all of our data except the influential outlier. We calculated December estimates because it represents the month when substantial numbers of waterfowl begin arriving at southern latitudes in the United States. We calculated January estimates because it is the month when waterfowl numbers generally peak in the Mississippi Alluvial Valley and conservation agencies conduct mid-winter inventories of waterfowl (Pearse et al. 2008; R. Wheat, United States Fish and Wildlife Service, unpublished data).

# RESULTS

## Available Seed Postharvest and Postdrydown

Month and year effects interacted for harvested corn ($F_{3,114} = 5.7$, $P = 0.01$). Biomass of harvested corn decreased with increasing time postharvest in 2006 and 2007 ($F_{3,51} \geq 16.6$, $P < 0.001$), but monthly patterns of decline differed between years (Table 1). We did not detect differences in corn biomass in harvested fields between years for any month postharvest ($F_{1,44} \leq 2.8$, $P \geq 0.10$). Biomass of seed in harvested soybean fields differed among months postharvest ($F_{2,80} = 69.8$, $P < 0.001$) but not between years ($F_{1,40} = 0.19$, $P = 0.66$). Soybean biomass immediately postharvest was 3–4 times greater than 1 or 2 months postharvest (Table 1). We detected a marginal difference in biomass of grain sorghum among months postharvest ($F_{2,14} = 4.9$, $P = 0.05$), but we did not detect any pair-wise differences among months (Table 1). We also did not detect differences in grain sorghum biomass in harvested fields between years ($F_{1,7} = 1.3$, $P = 0.29$).

Exponential decay functions for corn, soybean, and grain sorghum explained 46–66% of the variation in the rate of seed loss in harvested fields ($P < 0.001$; Table 2). Our models predicted a continuous rate of seed loss between 64% and 84% for corn, soybean, and grain sorghum among consecutive months postharvest. For corn and grain

**Table 1.** Biomass (kg/ha) of agricultural seed available for waterfowl in harvested and unharvested fields for increasing number of months postharvest and postdrydown, respectively, Tennessee, USA, 2006 and 2007.

| | | | | Months[a,c] | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 0 | | 1 | | 2 | | 3 | |
| Crop | Manipulation | Yr[a,b] | *n* | $\bar{x}$ | SE | $\bar{x}$ | SE | $\bar{x}$ | SE | $\bar{x}$ | SE |
| Corn | Harvested | 2006 | 18 | 298 A | 64 | 122 B | 23 | 68 B | 17 | 34 B | 17 |
| | | 2007 | 22 | 180 A | 21 | 129 AB | 20 | 67 BC | 13 | 48 C | 20 |
| Soybean | Harvested | NI | 42 | 118 A | 10 | 44 B | 6 | 30 B | 7 | NT | |
| Grain sorghum | Harvested | NI | 9 | 392 A | 139 | 208 A | 86 | 63 A | 18 | NT | |
| Corn | Unharvested | NI | 38 | 6,924 A | 566 | 6,537 A | 577 | 6,413 A | 607 | 6,083 A | 605 |
| Soybean | Unharvested | NI | 16 | 2,240 A | 501 | 2,172 A | 436 | 2,081 A | 463 | NT | |
| Grain sorghum | Unharvested | NT | 4 | 4,109 A | 259 | 3,121 A | 355 | 3,051 A | 601 | 2,243 A | 766 |

[a] NT = we did not test because of insufficient replication.
[b] NI = no interaction of yr and month effects.
[c] Means within rows followed by unlike letters are statistically different by repeated-measures analysis of variance and Tukey's Honestly Significant Difference test.

**Table 2.** Exponential decay functions relating biomass (kg/ha) of seed (BMASS) for waterfowl in agricultural fields to number of months postharvest (TIME), Tennessee, USA, 2006 and 2007.

| Crop | Manipulation | Yr[a] | $n$ | Model | $F$ | $R^2$ |
|---|---|---|---|---|---|---|
| Corn | Harvested | ND | 189 | BMASS = $241.1 \times e^{(-0.637 \times \text{TIME})}$ | 95.5 | 0.51 |
| Soybean | Harvested | ND | 159 | BMASS = $116.2 \times e^{(-0.844 \times \text{TIME})}$ | 155.1 | 0.66 |
| Grain sorghum | Harvested | ND | 35 | BMASS = $369.8 \times e^{(-0.737 \times \text{TIME})}$ | 13.8 | 0.46 |
| Corn | Unharvested | 2006 | 85 | BMASS = $8{,}621.5 \times e^{(-0.003 \times \text{TIME})}$ | 323.8 | 0.89 |
| | | 2007 | 86 | BMASS = $5{,}081.8 \times e^{(-0.051 \times \text{TIME})}$ | 101.1 | 0.71 |
| Soybean | Unharvested | 2006 | 32 | BMASS = $4{,}018.8 \times e^{(-0.029 \times \text{TIME})}$ | 606.4 | 0.98 |
| | | 2007 | 24 | BMASS = $468.0 \times e^{(-0.113 \times \text{TIME})}$ | 18.8 | 0.63 |
| Grain sorghum | Unharvested | 2006 | 16 | BMASS = $4{,}034.9 \times e^{(-0.183 \times \text{TIME})}$ | 80.3 | 0.92 |

[a] ND = no difference between yr by repeated-measures analysis of variance.

sorghum, our models predict that seed biomass will drop below 50 kg/ha (i.e., food density at which waterfowl abandon feeding sites [giving-up density]; Reinecke et al. 1989, Rutka 2004) within 3 months postharvest (Fig. 2). For soybean, our models predict that seed biomass will drop below 50 kg/ha within 1 month postharvest (Fig. 2). Exponential decay functions for corn, soybean, and grain sorghum also explained variation in the rate of seed loss in unharvested fields ($R^2$ = 0.63–0.98, $P < 0.001$; Table 2). Our equations predicted a continuous rate of seed loss 0.3–18% among consecutive months postdrydown (Table 2).

Biomass of corn in unharvested fields differed among number of months postdrydown ($F_{3,108} = 4.2$, $P < 0.001$), but we did not detect any pair-wise differences between months (Table 1). Unharvested corn biomass was 2 times greater ($F_{1,36} = 15.8$, $P < 0.001$) in 2006 ($\bar{x}$ = 8,419 kg/ha, SE = 389) than in 2007 ($\bar{x}$ = 4,686 kg/ha, SE = 325). We did not detect differences in biomass of seed in unharvested soybean fields among months postdrydown ($F_{2,28} = 0.43$, $P = 0.65$; Table 1). Similar to corn, biomass of unharvested soybeans differed between years ($F_{1,14} = 462.3$, $P < 0.001$), with biomass in 2006 ($\bar{x}$ = 3,909 kg/ha, SE = 127) 9 times greater than in 2007 ($\bar{x}$ = 420 kg/ha, SE = 68). Biomass of grain in unharvested grain sorghum fields did not differ among months postdrydown ($F_{3,9} = 6.4$, $P = 0.08$; Table 1).

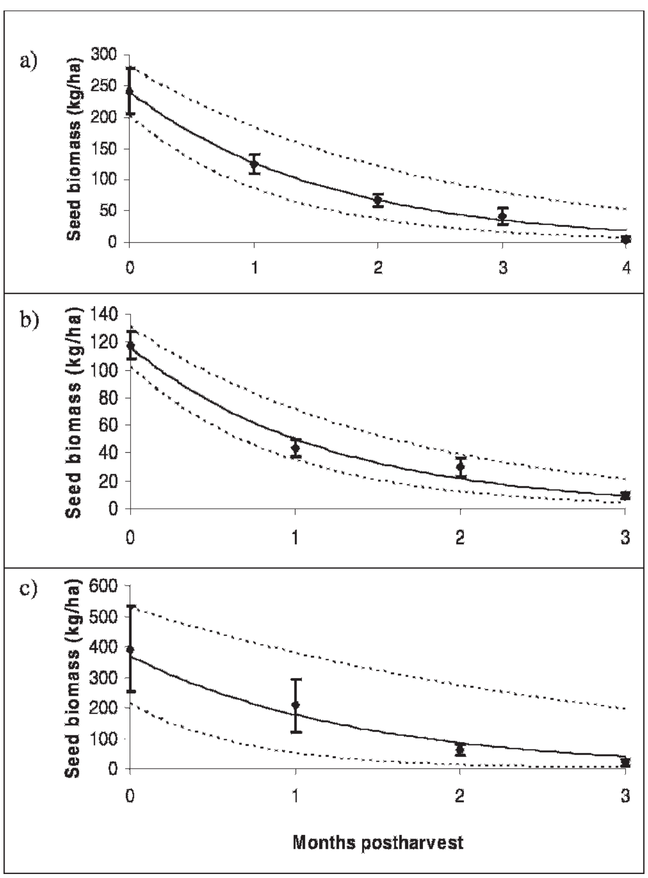


**Figure 2.** Predicted biomass of seed for waterfowl in harvested (a) corn, (b) soybean, and (c) grain sorghum fields in Tennessee, USA, 2006–2007. Error bars represent standard error about the mean, and dashed lines are upper and lower 95% confidence intervals for the model.

### Duck-Energy Days

In December 2006 and 2007, mean corn and soybean biomass was <100 kg/ha and the greatest seed biomass ($\bar{x}$ = 156 kg/ha) was in harvested grain sorghum fields (Table 3). By January, there was a 48%, 42%, and 88% decrease in biomass of corn, soybean, and grain sorghum in harvested fields, respectively. January biomasses equated to 274 DEDs/ha, 90 DEDs/ha, and 27 DEDs/ha for corn, soybean, and grain sorghum, respectively (Table 3). Approximately 55% of harvested cornfields in December and 87% in January contained <50 kg/ha of seed. Similarly, 71% of harvested soybean fields in December and 85% in January contained <50 kg/ha of seed. Finally, 33% of harvested grain sorghum fields in December and 89% of fields in January contained <50 kg/ha of seed.

Seed biomass and DEDs remained high in unharvested corn, soybean, and grain sorghum fields in December and January (Table 3). Unharvested corn, soybean, and grain sorghum fields provided 12%, 9%, and 27% fewer DEDs in January than in December, respectively (Table 3). Five and 10% of unharvested cornfields in December and January, respectively, contained <50 kg/ha of agricultural seed. Unharvested soybean and grain sorghum fields always contained >50 kg/ha of seed in December and January.

## DISCUSSION

### Available Seed Postharvest and Postdrydown

Mean biomass of corn, soybean, and grain sorghum seed immediately postharvest in Tennessee was 239 kg/ha, 118 kg/ha, and 392 kg/ha, respectively. Available seed postharvest in cornfields has decreased since the late 1970s and mid-1980s when average postharvest biomass in areas of

**Table 3.** Biomass of agricultural seeds (kg/ha) for waterfowl and duck-energy days (DEDs) in harvested and unharvested fields in December and January 2006–2007, Tennessee, USA.

| | | | Month | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Dec | | | | Jan | | | |
| | | | Biomass | | DEDs/ha | | Biomass | | DEDs/ha | |
| Crop | Manipulation | *n* | $\bar{x}$ | SE | $\bar{x}$ | SE | $\bar{x}$ | SE | $\bar{x}$ | SE |
| Corn | Harvested | 47 | 75 | 14 | 522 | 160 | 39 | 12 | 274 | 131 |
| Soybean | Harvested | 48 | 45 | 8 | 164 | 55 | 26 | 6 | 90 | 39 |
| Grain sorghum | Harvested | 9 | 156 | 83 | 1,381 | 970 | 19 | 7 | 27 | 27 |
| Corn | Unharvested | 39 | 6,260 | 591 | 78,079 | 7,416 | 5,539 | 568 | 69,056 | 7,125 |
| Soybean | Unharvested | 16 | 2,190 | 439 | 19,423 | 3,987 | 1,998 | 452 | 17,675 | 4,101 |
| Grain sorghum | Unharvested | 4 | 3,051 | 601 | 35,874 | 7,183 | 2,243 | 766 | 26,212 | 9,155 |

the Midwest and Texas ranged 312–353 kg/ha (Baldassarre et al. 1983, Warner et al. 1989, Krapu et al. 2004). Similarly, soybean biomass in harvested fields (118 kg/ha) was 30% less than estimates from Illinois in the early 1980s (i.e., 172 kg/ha; Warner et al. 1989). No past estimates of postharvest grain sorghum were available for comparison. However, Iverson et al. (1985) reported average grain sorghum biomass in harvested fields was 292 kg/ha in January, which was 15 times greater than our January estimate (19 kg/ha). Despite increased crop yields since the 1980s (NASS 2008), improvements in harvesting technology may be resulting in less grain deposited by combines, hence available for waterfowl (Krapu et al. 2004, Manley et al. 2004).

Our estimate of corn biomass immediately postharvest in Tennessee (239 kg/ha) was comparable to recent postharvest estimates from Nebraska (i.e., 177 kg/ha and 254 kg/ha; Krapu et al. [2004]) and Ontario, Canada (i.e., 188 kg/ha; Barney 2008). Additionally, Frederick et al. (1984) reported no differences in abundance of corn postharvest existed among study sites in Texas, Nebraska, and Iowa, USA. Thus, grain estimates immediately postharvest from our study, Krapu et al. (2004), and Barney (2008) seem consistent over large geographic areas.

Biomass of agricultural seed declined rapidly following harvest. Seed in harvested corn and grain sorghum fields averaged 68 kg/ha and 63 kg/ha, respectively, by 2 months postharvest and dropped below 50 kg/ha in 3 months. Soybean biomass declined below 50 kg/ha only 1 month postharvest. Similarly, postharvest rice biomass in the Lower Mississippi Alluvial Valley declined from 271 kg/ha to 78 kg/ha between harvest and late November–early December (Stafford et al. 2006). Given high rates of seed loss following harvest and peak waterfowl abundance in January (Pearse et al. 2008; R. Wheat, unpublished data), our results suggest that harvested agricultural fields in the southeastern United States provide limited food resources for migrating and wintering waterfowl.

We characterized loss of agricultural seed in our fields using an exponential decay function. For corn and soybean, our rates of decline were faster than those documented farther north. Studies in Illinois, Nebraska, and Ontario reported that 55–67% of corn in harvested fields was lost from late autumn to early spring (Warner et al. 1989; Barney 2008; M. H. Sherfy, United States Geological Survey, unpublished data). Warner et al. (1989) also reported that 85% of soybean seeds in harvested fields were lost from late autumn to early spring in Illinois. These results correspond to continuous monthly loss rates of 19–22% for corn and 38% for soybean, which is 2–3 times slower than seed loss in our harvested fields. Differences in rate of seed loss among these studies and ours likely are due to climatic differences between southern and northern regions of the United States. Seeds rapidly deteriorate in the subtropical climate of the southeastern United States (Stafford et al. 2006, Foster 2009). Given that Tennessee is located north of most states in the Southeast, our estimates of seed mass in harvested corn, soybean, and grain sorghum fields probably are liberal for this region. Further, our estimates of seed mass are for harvested fields without postharvest treatment (e.g., grazing, tilling), which can reduce seed abundance in harvested fields by 73–100% (Frederick and Klaas 1982, Baldassarre et al. 1983, Iverson et al. 1985, Warner et al. 1985).

Average biomass of corn, soybean, and grain sorghum immediately postdrydown in unharvested fields was 6,924 kg/ha, 2,240 kg/ha, and 4,109 kg/ha, respectively. Our values are similar to estimates from unharvested cornfields in Illinois (5,008 kg/ha; J. Stafford, Illinois Natural History Survey, unpublished data), and statewide average yields for corn, soybean, and grain sorghum in Tennessee (7,767 kg/ha, 1,917 kg/ha, and 5,548 kg/ha, respectively; NASS 2008). Conservation planners assume about a 15–20% loss of agricultural seed biomass in unharvested fields before the arrival of waterfowl (USFWS 2005). Assuming an average duration of 2 months between crop drydown and the arrival of waterfowl, our exponential decay models predict about a 5%, 13%, and 30% loss of seed in unharvested corn, soybean, and grain sorghum fields. Thus, for our study, the 15–20% seed-loss assumption in unharvested fields under- or overestimated biomass depending on crop type, with the greatest loss rates in grain sorghum fields. Unharvested grain sorghum may experience greater loss than other crops because of depredation by other wildlife. In particular, blackbirds (*Agelaius* spp., *Euphagus* spp.) and sparrows (Passeriformes: Emberizidae) may substantially reduce available seed in grain sorghum fields (Atkeson and Givens 1952, Neely and Davison 1971).

Biomass of unharvested corn and soybean was 2 and 9 times greater, respectively, in 2006 compared to 2007. Seed production in unharvested grain sorghum fields was zero in 2007. Reduction in seed yield in 2007 was likely a result of drought conditions in the southeastern United States (NCDC 2008). Rainfall deficits between May and August 2007 ranged from 23 cm to 38 cm throughout Tennessee (Fielder 2007), and the entire state was classified as experiencing extreme or exceptional drought (i.e., D3–D4; Heddinghaus 2007). Decreased yields in some of our unharvested cornfields were exacerbated by subsequent wildlife depredation. We observed substantial damage due to foraging by white-tailed deer (*Odocoileus virginianus*) and sandhill cranes (*Grus canadensis*), such that 4 unharvested cornfields contained <50 kg/ha in 2007. Fielder (2007) estimated that 30–70% of planted agricultural crops in Tennessee failed in 2007.

### Duck-Energy Days

Seed biomass estimates were >50 kg/ha in harvested corn and grain sorghum fields in December, with fields providing an average of 522 DEDs/ha and 1,381 DEDs/ha, respectively. Our DED estimates in December for harvested corn and grain sorghum were 85% and 52% lower, respectively, than those reported by Reinecke et al. (1989). Mean seed biomass was <50 kg/ha for soybean in December and for all crops in January. In January, DEDs were functionally zero in >85% of our agricultural fields. Thus, harvested agricultural fields in the southeastern United States provide limited amounts of food to North American waterfowl.

Unharvested corn, soybean, and grain sorghum fields can provide substantial seed biomass (>2,000 kg/ha). Unharvested corn has the capability of energetically supporting the greatest number of waterfowl followed by grain sorghum (69,056 DEDs/ha and 26,212 DEDs/ha in Jan, respectively). We do not recommend planting soybeans for waterfowl because unharvested soybeans provided the least amount of energy (17,675 DEDs/ha in Jan), and esophageal impaction by soybeans can cause waterfowl mortality under dry ambient conditions (Durant 1956, Jarvis 1969).

Our estimates for available agricultural seed in harvested and unharvested fields can be used to calculate DEDs in the southeastern United States by multiplying field area by our DEDs/ha values (Table 3). Given that we sampled 164 fields across 4 climate and several physiographic regions in Tennessee spanning approximately 450 longitudinal miles, our estimates of seed mass likely are robust for the southeastern United States. Our estimates are probably most representative for southeastern states at the same latitude as Tennessee. For states south of Tennessee, our estimates may be liberal because moisture and temperature typically are greater closer to the Gulf of Mexico, which can accelerate seed loss (Foster 2009).

## MANAGEMENT IMPLICATIONS

Waterfowl conservation efforts should continue to focus on providing high-energy unharvested crops in addition to natural (e.g., moist-soil) wetlands on public and private lands (Kross et al. 2008*a*, *b*). We recommend that biologists in the Southeast use our January biomass and DED estimates (Table 3), because seed biomass declined rapidly between December and January when waterfowl numbers peak. Given between-year differences in unharvested seed biomass that we documented, biologists might consider using our equations (Table 2) to predict available biomass. For more accurate estimates, yield data from combines that harvest adjacent fields or annual commercial yields from the NASS could be substituted for our intercepts (Table 2) and the equations solved.

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## LITERATURE CITED

Atkeson, T. Z., and L. S. Givens. 1952. Upland farming as a method of supplementing the natural waterfowl food supply in the southeast. Journal of Wildlife Management 16:442–446.

Baldassarre, G. A., and E. G. Bolen. 1984. Field-feeding ecology of waterfowl wintering on the Southern High Plains of Texas. Journal of Wildlife Management 48:63–71.

Baldassarre, G. A., R. J. Whyte, E. E. Quinlan, and E. G. Bolen. 1983. Dynamics and quality of waste corn available to postbreeding waterfowl in Texas. Wildlife Society Bulletin 11:25–31.

Barney, E. S. 2008. Change in availability and nutritional quality of postharvest waste corn on waterfowl staging areas near Long Point, Ontario. Thesis, University of Western Ontario, London, Canada.

Checkett, J. M., R. D. Drobney, M. J. Petrie, and D. A. Graber. 2002. True metabolizable energy of moist-soil seeds. Wildlife Society Bulletin 30:1113–1119.

Combs, D. L., and L. H. Fredrickson. 1996. Foods used by male mallards wintering in southeastern Missouri. Journal of Wildlife Management 60:603–610.

Delnicki, D., and K. J. Reinecke. 1986. Mid-winter food use and body weights of mallards and wood ducks in Mississippi. Journal of Wildlife Management 50:43–51.

Durant, A. J. 1956. Impaction and pressure necrosis in Canada geese due to eating dry hulled soybeans. Journal of Wildlife Management 20: 399–404.

Fielder, N. 2007. Tennessee Department of Environment and Conservation Drought 2007 Task Force: situation report #4. <http://www.tnema.org/

PDF%20Files/Drought%20Task%20Force/DROUGHT%20SITREP%204.pdf>. Accessed 9 Jul 2008.
Foster, M. A. 2009. Abundance and losses of agricultural seeds for waterfowl in Tennessee. Thesis, University of Tennessee, Knoxville, USA.
Frederick, R. B., and E. E. Klaas. 1982. Resource use and behavior of migrating snow geese. Journal of Wildlife Management 46:601–614.
Frederick, R. B., E. E. Klaas, G. A. Baldassarre, and K. J. Reinecke. 1984. A method for sampling waste corn. Journal of Wildlife Management 48:298–303.
Heddinghaus, T. 2007. Tennessee: August 28, 2007. U.S. Drought Monitor, Lincoln, Nebraska, USA. <http://drought.unl.edu/dm/archive/20070828/pdfs/tn_dm_070828.pdf>. Accessed 20 Jul 2008.
Iverson, G. C., P. A. Vohs, and T. C. Tacha. 1985. Habitat use by sandhill cranes wintering in western Texas. Journal of Wildlife Management 49:1074–1083.
Jarvis, R. L. 1969. Ecological and physiological aspects of soybean impaction in Canada geese. Dissertation, Southern Illinois University, Carbondale, USA.
Kaminski, R. M., J. B. Davis, H. W. Essig, P. D. Gerard, and K. J. Reinecke. 2003. True metabolizable energy for wood ducks from acorns compared to other waterfowl foods. Journal of Wildlife Management 67:542–550.
Krapu, G. L., D. A. Brandt, and R. R. Cox. 2004. Less waste corn, more land in soybeans, and the switch to genetically modified crops: trends with important implications for wildlife management. Wildlife Society Bulletin 32:127–136.
Kross, J. P., R. M. Kaminski, K. J. Reinecke, and A. T. Pearse. 2008*a*. Conserving waste rice for wintering waterfowl in the Mississippi Alluvial Valley. Journal of Wildlife Management 72:1383–1387.
Kross, J., R. M. Kaminski, K. J. Reinecke, E. J. Penny, and A. T. Pearse. 2008*b*. Moist-soil seed abundance in managed wetlands in the Mississippi Alluvial Valley. Journal of Wildlife Management 72:707–714.
Manley, S. W., R. M. Kaminski, K. J. Reinecke, and P. D. Gerard. 2004. Waterbird foods in winter-managed rice-fields in Mississippi. Journal of Wildlife Management 68:74–83.
Montgomery, D. C. 2000. Design and analysis of experiments. Fifth edition. John Wiley and Sons, New York, New York, USA.
Myers, R. H. 1990. Classical and modern regression with applications. Second edition. PWS-Kent, Boston, Massachusetts, USA.
National Agriculture Statistics Service [NASS]. 2008. Quick stats. <http://www.nass.usda.gov/QuickStats/Create_Federal_Indv.jsp>. Accessed 30 Jun 2008.
National Climatic Data Center [NCDC]. 2008. Climate of 2007 annual review: U.S. drought. <http://www.ncdc.noaa.gov/oa/climate/research/2007/ann/drought-summary.html>. Accessed 9 Jul 2008.
Neely, W. W., and V. E. Davison. 1971. Wild ducks on farmlands in the south. U.S. Department of Agriculture Farmers' Bulletin 2218, Washington, D.C., USA.
Nielsen, R. L. 2005. Field drydown of mature corn grain. Purdue University Corny News Network. <http://www.kingcorn.org/news/articles.05/GrainDrying-0815.html>. Accessed 9 Jul 2006.
Pearse, A. T., S. J. Dinsmore, R. M. Kaminski, and K. J. Reinecke. 2008. Evaluation of an aerial survey to estimate abundance of wintering ducks in Mississippi. Journal of Wildlife Management 72:1413–1419.
Petrie, M. J., R. D. Drobney, and D. A. Graber. 1998. True metabolizable energy estimates of Canada goose foods. Journal of Wildlife Management 62:1147–1152.
Redmond, W. H., and A. F. Scott. 1996. Atlas of amphibians in Tennessee. The Center for Field Biology, Austin Peay State University. <http://www.apsu.edu/amatlas/>. Accessed 7 Jul 2006.
Reinecke, K. J., R. M. Kaminski, D. J. Moorhead, J. D. Hodges, and J. R. Nassar. 1989. Mississippi Alluvial Valley. Pages 203–247 *in* L. M. Smith, R. L. Pederson, and R. M. Kaminski, editors. Habitat management for migrating and wintering waterfowl in North America. Texas Tech University Press, Lubbock, USA.
Reinecke, K. J., and C. R. Loesch. 1996. Integrating research and management to conserve wildfowl (*Anatidae*) in the Mississippi Alluvial Valley, U.S.A. Gibier Faune Sauvage, Game and Wildlife 13:927–940.
Rutka, D. M. 2004. Waste rice depletion by waterfowl wintering in the Mississippi Alluvial Valley. Thesis, Southern Illinois University, Carbondale, USA.
SAS Institute. 1999. SAS/STAT® user's guide, version 8. Volume 2. SAS Institute, Cary, North Carolina, USA.
Stafford, J. D., R. M. Kaminski, K. J. Reinecke, and S. W. Manley. 2006. Waste rice for waterfowl in the Mississippi Alluvial Valley. Journal of Wildlife Management 70:61–69.
U.S. Department of Commerce. 1968. Climatic atlas of the United States. U.S. Government Printing Office, Washington, D.C., USA.
U.S. Department of the Interior and Environment Canada. 1986. North American Waterfowl Management Plan. U.S. Department of the Interior, Washington, D.C., USA.
U.S. Fish and Wildlife Service [USFWS]. 2005. Biological review for the Tennessee National Wildlife Refuge. U.S. Fish and Wildlife Service, Paris, Tennessee, USA.
Warner, R. E., S. P. Havera, and L. M. David. 1985. Effects of autumn tillage systems on corn and soybean harvest residues in Illinois. Journal of Wildlife Management 49:185–190.
Warner, R. E., S. P. Havera, L. M. David, and R. J. Siemers. 1989. Seasonal abundance of waste corn and soybeans in Illinois. Journal of Wildlife Management 53:142–148.

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