BIOMASS AND FATE OF GRAIN FOR MIGRATING AND WINTERING WATERFOWL IN TENNESSEE

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ABSTRACT

Millions of North American waterfowl migrate through and winter in the southeastern United States. Because of the widespread loss of wetlands in this region, waterfowl frequently acquire high-energy food resources in harvested agricultural fields. Recent studies in the Mississippi Alluvial Valley reported there is currently 50% less waste grain in harvested rice fields compared to the 1980s. Rapid loss of waste grain post-harvest is considered a primary cause. To date, no studies have quantified waste grain in harvested or unharvested corn, grain sorghum, and soybean fields in the Southeast. Therefore, we compared waste grain biomass in 105 harvested and 59 unharvested corn, grain sorghum and soybean fields in Tennessee from September through January 2006−2007, and quantified the fate of grain loss in designated plots. We also used our estimates in January (i.e., when peak waterfowl numbers occur in the Southeast) to calculate available duck energy-days (DED).

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Mean biomass of waste corn, soybean and grain sorghum declined 239 to 39, 118 to 26 kg/ha and 392 to 19 kg/ha, respectively, from post-harvest to January 2006−2007. Exponential decay functions explained sufficient variation in the rate of grain loss in harvested fields. Continuous rates of decline were 64%, 84% and 74% each consecutive month for corn, grain sorghum and soybean, respectively. Waste grain in corn and grain sorghum fields dropped below the waterfowl giving-up density (50 kg/ha) in 3 months; waste soybean dropped below this threshold in only 1 month post-harvest. Waste corn was lost primarily (52%) to granivory, and waste soybean and grain sorghum loss was attributed mostly to decomposition (45% and 56%, respectively). Mean DEDs per ha in harvested corn, grain sorghum and soybean fields were low (413, 90 and 27, respectively) in January, and DEDs were functionally zero in over 85% of fields. In unharvested corn, soybean and grain sorghum fields, mean DEDs per ha were high (69,000, 18,000 and 26,000, respectively), and rates of loss (8%, 12% and 45%, respectively) between drydown and January were much lower than for harvested crops. Waterfowl biologists in the Southeast should use these revised grain estimates in DED calculations, and consider providing moist-soil wetlands and unharvested food plots to meet the nutritional needs of migrating and wintering waterfowl.

INTRODUCTION

North American waterfowl populations declined to record lows in the mid-1980s due primarily to the degradation and destruction of wetlands and associated uplands used by waterfowl (U.S. Department of the Interior and Environment Canada 1986, Kelley et al. 1998, Williams et al. 1999). In response to this decline, the North American Waterfowl Management Plan (NAWMP) was enacted in 1986, with the primary goal of restoring waterfowl populations to levels existing during the 1970s (US Department of the Interior and Environment Canada 1986). The NAWMP focuses on protecting, restoring, and managing waterfowl habitat to meet this goal.

The NAWMP is enacted through regional joint ventures. Joint ventures in non-breeding areas (e.g., the Lower Mississippi Valley Joint Venture, LMVJV) typically focus on managing foraging habitat (Reinecke et al. 1989). Energy-rich foods are necessary for waterfowl in non-breeding areas to rebuild lipid reserves metabolized during southward migration, meet energy needs associated with thermoregulation and winter life-history activities (e.g., courtship), and accumulate sufficient resources for return flight to northern breeding areas (Neely and Davison 1971, Williams et al. 1999).

The Mississippi Alluvial Valley (MAV) is a major migration corridor and wintering area for millions of North American waterfowl (Reinecke et al. 1989). This area was a vast hardwood bottomland that flooded regularly and provided habitat for waterfowl (Heitmeyer 2006). By the mid-1980s, however, 79% of the MAV had been drained, deforested, and most of it converted to agricultural lands (Hefner et al. 1994). Agricultural transformation of the MAV resulted in a change in the availability of waterfowl food resources, because natural foods (e.g., acorns, moist-soil seeds, and invertebrates) became less abundant, while coverage of agricultural grains increased.

Studies in Texas and the MAV suggest that many waterfowl species have adapted to an increase in cropland coverage in migrating and wintering areas and feed commonly on agricultural grains (Baldassarre and Bolen 1984, Delnicki and Reinecke 1986, Combs and Fredrickson 1996, Heitmeyer 2006). The availability of agricultural grains can be beneficial to waterfowl. On average, agricultural grains have a greater amount of true metabolizable energy than moist-soil seeds 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 natural wetland plants (Reinecke and Kaminski 2006).

To evaluate if NAWMP goals are being met, biologists annually estimate availability of food resources and foraging carrying capacity. The standard for quantifying foraging carrying capacity is calculation of duck energy-days (DEDs, *sensu* Miller and Eadie 2006). Duck energy-days can be calculated using equation 1 published initially by Prince (1979) and modified to include an empirical food density (50 kg/ha; Reinecke et al. 1989, Rutka 2004) where waterfowl abandon feeding sites because foraging efficiency decreases:

EQUATION 1:

$$\text{DEDs/ha} = \frac{\text{TME (kcal/g)} \times (Q_F\ [\text{kg/ha}] - 50\ \text{kg/ha}) \times 1000\ \text{g/kg}}{\text{DER (kcal/bird/day)}}.$$

This equation represents the number of waterfowl that can be sustained in an area for a certain amount of time given available food resources. True metabolizable energy (TME) is the energy metabolized per gram of dry food. The daily energy requirement (DER) for a mallard-sized duck is approximately 292 kcal/day (Prince 1979, Reinecke et al. 1989), and Q_F is the amount of available food per hectare.

For over 15 years, waterfowl managers have used estimates of available grain published in Reinecke et al. (1989) to calculate DEDs in harvested agricultural lands. However, 2 recent studies in rice fields (Manley et al. 2004, Stafford et al. 2006a) suggest estimates in Reinecke et al. (1989) may be inflated. Stafford et al. (2006b) reported that available rice was 52-83% less than estimates based on studies in the 1980s. Further, Manley et al. (2004) and Stafford et al. (2006a) collectively reported that available waste rice decreased 71-99% between harvest and early winter in the MAV. Stafford et al. (2006b) attributed this trend to decomposition, germination and granivory. Although crop yields have increased since the mid-1980s (NASS 2008), improvements in harvesting technology may result in less waste grain deposited from combines, hence available for wildlife (Krapu et al. 2004, Manley et al. 2004).

Important agricultural grains for wintering waterfowl in the MAV include corn, grain sorghum, soybean and rice (Reinecke et al. 1989). In general, rice is the primary agricultural grain available for waterfowl in the lower MAV because of its extensive acreage (T. Moorman, Ducks Unlimited, personal communication). However, in the upper MAV, corn, grain sorghum and soybean are primary crops. In Tennessee, no acres of harvested rice were reported in 2005 whereas corn, grain sorghum and soybean accounted for 15.0%, 0.5% and 24.2% of cropland agriculture, respectively (NASS 2008). Further, it is assumed that harvested soybean fields provide very few food resources for waterfowl (T. Moorman, Ducks Unlimited, personal communication). This assumption is based on studies that showed soybeans in flooded fields decompose rapidly (e.g., Neely 1956, Shearer et al. 1969, Nelms and Twedt 1996). To date, no studies have examined the decomposition or disappearance rates of soybeans and grain sorghum in harvested fields that are not flooded. Baldassarre et al. (1983) reported a 92% decrease in waste corn availability in unmanipulated corn fields between harvest and late winter on the Texas Southern High Plains, although mechanisms responsible for grain loss were not investigated.

Estimates of available corn, grain sorghum and soybean currently used by most waterfowl managers in the upper MAV are based on studies conducted in Illinois, Nebraska and Texas during the 1980s (Reinecke et al. 1989). Reinecke and Kaminski (2006) provided revised grain availability estimates to the LMVJV for rice and other grains, but among harvested crops, only the estimate for waste rice was from recent research in the MAV (Stafford et al. 2006b). In unharvested fields, it often is assumed that between 15% (USFWS 2005) and 20% (Reinecke and Kaminski 2006) of the grain is lost to decomposition and granivory before waterfowl arrive, but these assumptions have not been tested. Indeed, revised estimates of available waste corn, grain sorghum and soybean are needed, because 1) some estimates are based upon untested assumptions, 2) previous estimates are outdated, 3) previous estimates are not from the southeastern United States, and 4) grain loss between harvest and early winter has not been quantified or related to microclimatic conditions.

Available grain also may differ among private, state and federal lands. Pre-harvest yields and harvesting efficiency may be greatest on private farms because of the need to generate profits (Warner et al. 2005). In contrast, yield and efficiency are generally less important for government agencies interested in providing crops for wildlife (Yoakum et al. 1980). Moreover, federal and state agencies often are restricted on the application of pesticides, which ultimately could affect yields. Differences in planting and harvesting equipment among agencies also may influence available grain for waterfowl (Yoakum et al. 1980).

Given these uncertainties in the amount of available waste corn, grain sorghum and soybean in harvested and unharvested fields, the goal of our research was to obtain precise estimates of corn, grain sorghum and soybean available for waterfowl in harvested and unharvested fields in Tennessee. We also investigated potential factors that may influence these estimates, including microclimate, granivory, and landownership (federal, state or private). This information will be useful in determining if NAWMP goals are being met in Tennessee and elsewhere.

STUDY AREA

Federal Land

The Tennessee National Wildlife Refuge (NWR) is located along 105 km of the Tennessee River, and consists of 3 management units: Big Sandy, Duck River, and Busseltown (Figure 1). Sampling for this study occurred in the 10,820-ha Duck River Unit (35.917°N, 87.950°W) located near New Johnsonville, Tennessee. The Duck River Unit contains approximately 647 ha of sharecropped farmland planted exclusively for waterfowl (USFWS 2005). In addition, it contains 567 ha of managed moist-soil wetlands. On average, Tennessee NWR provides migrating and wintering habitat for approximately 200,000 ducks (subfamily *Anatinae*) and 10,000 Canada geese (*Branta canadensis*) each year (USFWS 2005).

We sampled 4 corn and 4 soybean fields on Tennessee NWR each year. In each corn and soybean field, alternating strips were harvested, and 0.202-ha plots were placed in 2 harvested and 2 unharvested strips per field (Figure 2), resulting in 16 plots each for corn and soybean (4 plots per field × 4 fields) per year. This strip-split-plot design was used to increase experimental replication (Montgomery 2000:583). We also sampled 4 grain sorghum fields in 2006, but these fields were not harvested because the sharecropper was not interested in selling this grain. Four sorghum fields also were planted in 2007, but drought conditions (NCDC 2008) prevented seed-head maturation.

Thus, the total number of 0.202-ha plots on Tennessee NWR equaled 68 (16 corn × 2 years + 16 soybean × 2 years + 4 grain sorghum).

State and Private Land

State and private sites were located throughout the 4 climate regions of Tennessee (U.S. Department of Commerce 1968; Figure 3). In general, temperature increases from east to west in Tennessee (Encyclopedia Brittanica 2006). Correspondingly, duration of growing season differs among regions with an average 196 and 216 d in east and west Tennessee, respectively (NRCS 2006). Precipitation tends to be greatest on the Cumberland Plateau and southern portion of middle Tennessee, whereas east Tennessee usually receives the least amount of precipitation (Encyclopedia Brittanica 2006).

Corn and soybean production occurs statewide (NASS 2008), thus we sampled 0.202-ha plots in 4 harvested fields in each region for corn and soybean each year (4 fields per grain species per region × 4 regions = 16 fields total per grain species per year). Approximately 50% of the fields per region were located on state land and 50% on private land. Grain sorghum production is primarily limited to west Tennessee (NASS 2008), and very few state wildlife management areas (WMAs) in Tennessee plant this crop (T. White, Tennessee Wildlife Resources Agency, personal communication). Therefore, sampling of harvested grain sorghum was limited to private land in west Tennessee, where 5 fields were sampled each year. In addition to harvested fields, we were able to sample 4 unharvested corn fields in 3 of the 4 climate regions (west, middle and east Tennessee) on state WMAs ($n = 12$ per year). In 2006, one unharvested corn plot was accidently bush hogged, and in 2007 one unharvested grain sorghum field was accidently disked, thus these fields were not included the analyses. Total unharvested plots on state and private land equaled 96 (16 harvested corn × 2 years + 16 harvested soybean × 2 years + 5 harvested grain sorghum in 2006 + 4 harvested grain sorghum in 2007 + 11 unharvested corn in 2006 + 12 unharvested corn in 2007).

METHODS

Experimental units consisted of 0.202-ha plots located in corn, grain sorghum and soybean fields. We only used fields that were not mechanically manipulated or replanted post-harvest. In addition, we did not use fields that were flooded, because our goal was to estimate grain availability on upland sites. Despite non-manipulated and non-flooding preconditions, we anticipated that grain availability would vary considerably among fields due to the natural variation in farming practices. Thus, we collected the following covariate information from farmers to help explain variation in waste grain availability: 1) latitude and longitude of field, 2) field history (rotation, soil disturbance), 3) planting date, 4) seeding rate, 5) row spacing, 6) seed variety, 7) fertilizer, herbicide, and pesticide application rate, date and type, 8) harvest date, 9) estimated percent moisture of grain at harvest, and 10) model, size and type of combine.

Fields were not randomly selected from all possible private, state, and federal sites in Tennessee for the following reasons. First, federal sites need to be on the Tennessee NWR as stipulated in the UT-USFWS Challenge Cost Share Agreement for the study. We assume that farming practices at Tennessee NWR are representative of other federal wildlife refuges in Tennessee. Second, randomly selecting fields from all possible private and state WMAs in Tennessee was not logistically possible. Instead, sites were selected based on: 1) availability for research (i.e., managers or landowners were willing to cooperate) and 2) geographic representation per climate region. Regarding #1, sites were chosen at random when landowners or WMAs had >1 field available for research. Regarding #2, we attempted to secure permission on sites that were geographically distributed throughout each region, while considering travel time among sites. Also, we did not use sites within 20 km of climate region demarcations (Figure 3), because of presumed similarity in microclimate near these transition zones. Given there was not a contentious effort to select fields as per the measured response variables, we assume that all sampled fields were representative of state WMAs and private sites within their respective climate region.

Waste Grain Abundance

For each 0.202-ha experimental unit, 3 subsample plots were sampled every 4 weeks from harvest to the arrival of peak waterfowl numbers. For Tennessee, peak waterfowl abundance occurs in December and January (R. Wheat, USFWS, unpublished data), thus we sampled through January. Experimental units were 88.4 × 22.85 m (L × W), with the long side orientated in the direction of planting (Figure 4a). Experimental units were 221 × 9.14 m when field dimensions prevented plots from being 22.85 m in width. This occurred in 3 unharvested corn fields on state land and for all soybean fields on federally-owned land. Plots were placed randomly in fields, at least 10 m from an edge to reduce possible edge effects, and corners marked with wire flags. Once location of the experimental unit was established, a grid containing forty-nine 40.4-m^2 plots (8.84 × 4.57 m) was overlaid, and used to determine subsample plot locations (Figure 4a). Subsample locations (1 –49) were randomly generated without replacement using

Minitab® v.14 for each field and month, and the corners marked with flagging to ensure they were not re-sampled.

The dimension of subsample plots that we used is based on sampling theory in harvested corn fields (Frederick et al. 1984). Baldassarre et al. (1983) noted that waste corn was not uniformly distributed in harvested fields. Shredded waste and individual kernels tend to be concentrated toward the middle of the combine cut; whereas, entire corn ears tend to be distributed toward the outside. Because corn ears and grain sorghum seed heads are dense aggregations of seed, the random inclusion or exclusion of one or more intact ears or seed heads could result in biased estimates of waste grain. It has been suggested that less variable and more accurate estimates of waste grain can be obtained by sampling a larger (8.84 × 4.57 m) area for entire seed heads (Frederick et al. 1984). Frederick et al. (1984) recommended that 2 nested subsample plots are measured to capture variability in waste corn kernels and whole ears (Figure 4b). Post-harvest waste corn and sorghum kernels were collected in a 0.3 × 4.57 m (1.37 m^2) subsample plot oriented with width perpendicular to the planted rows. This plot was contained within an 8.84 × 4.57 m subsample plot, where whole or partially intact corn ears or sorghum seed heads were collected (Figure 4b).

To maintain consistency in sampling design among grain types, we collected available waste soybean in 0.3 × 4.57 m subsample plots similar to harvested corn and sorghum kernels. Previous studies have estimated available waste soybeans in plots of similar area (e.g., 0.5 m^2, Warner et al. 1985). We did not look for entire or partially intact soybean seed heads in larger plots because soybean combines shred entire plant stalks, unlike corn and grain sorghum combines, hence the probability of finding an intact seed head is low compared to other grains. In addition, the seed on corn and grain sorghum plants is more aggregated than soybean, thus random inclusion or exclusion of an entire or partially intact soybean seed head would influence precision and accuracy of estimates less than the other grains. We collected all soybean seeds attached or unattached to plant parts in the 0.3 × 4.57 m subsample plot.

Grain from unharvested plots also was collected in 0.3 × 4.57 m subsample plots. Entire plants were clipped from subsample plots and seed heads removed from stalks. We also collected any grain on the ground, because it represented available food. Seeds from non-targeted crops (e.g., volunteer plants from previous plantings) and moist-soil plants that may represent food resources were not collected, because estimating these foods was not an objective of this study.

All grain was placed in a sealable plastic bag, stored in a cool and dry location, and processed within 1 week of collection. Grain was threshed from seed heads, chaff removed, and frozen at -20C. After the field season, all samples were dried to constant mass (72 hours a 90 C for soybeans and grain sorghum 48 hours at 103 C for corn; drying duration and temperature were determined by drying trials) and weighed to the nearest 0.01 g.

Determining Seed Fate

We estimated seed fate in two 0.75 × 0.75 m plots located in the center 8.84 × 4.57 m subsample plot (Figure 4a,c) of each harvested experimental unit located off of Tennessee NWR. We did not sample at Tennessee NWR, because it is located within 25 km of the west and middle Tennessee climate zones. These plots were placed 5 m apart (Figure 4c), and all grain removed from them. One hundred grain seeds collected from outside the experimental unit were randomly scattered in each plot. One plot was randomly selected (by flipping a coin), covered by an exclosure made of hardware cloth (1 × 1 × 0.1 m; mesh size = 0.635 cm), and anchored in place with metal stakes. No exclosure was placed over the other plot. We assumed the 5-m separation was sufficient to ensure plots were experimentally independent with respect to granivory rates (i.e., that the presence of the exclosure did not draw granivores to the open plot). A HOBO® weather logger was placed in the plot with the exclosure, and microclimate assumed to be equal between plots. Temperature and humidity were recorded every 6 hours (0600, 1200, 1800 and 2400 hrs). We also acquired daily precipitation data from the nearest weather station to each field.

Once per month, the number of intact, germinated and decomposed grains in the plots were counted. Seed loss (i.e., missing seed) in the exclosures was assumed to be a result of decomposition or invertebrate depredation, while loss of seed in the uncovered plots was assumed to be a result of decomposition and invertebrate or vertebrate granivory. Thus, the difference between disappearance rates in these plots represented vertebrate granivory only. It was not possible to separate decomposition from invertebrate depredation; however, we assume invertebrate granivory was minimal.

Statistical Analyses

We used a two-way repeated measures analysis-of-variance (ANOVA) with Huynh-Feldt correction to test for differences in agricultural seed biomass among months and between years (Cody and Smith 2005). The month effect was number of months post-harvest for harvested fields and number of months post-drydown for unharvested fields. Drydown was defined as grain containing less than 25% moisture following plant maturity (Nielsen 2005), and was determined in the field. There was adequate replication to test for differences in biomass among 0 – 3 months post-harvest for corn, and among 0 – 2 months post-harvest for grain sorghum and soybean. In unharvested fields, there was sufficient replication to test differences in biomass among 0 – 3 months post-drydown for corn and grain sorghum, and among 0 – 2 months post-drydown for soybean. We included a month by year interaction term in the repeated-measures ANOVA model, and performed analyses by year when the interaction was significant. Because no unharvested grain sorghum plots were sampled in 2007, interaction and year effects were not included in this analysis. We also modeled the rate of grain loss in harvested fields using an exponential decay function (PROC NLIN, SAS Institute 2004:2371-2418).

We used a one-way ANOVA to test for differences in seed biomass among landowner categories (private, state, or federal) for each crop type. Analyses were performed immediately post-harvest for harvested fields, post-drydown for unharvested fields, and in January when waterfowl numbers peak in Tennessee. A landowner by year interaction term was included in the model, and analyses performed by year when it was significant. We performed identical tests for determining differences in seed biomass among Tennessee climate regions. Unharvested soybean and grain sorghum were not included in landowner and climate region tests, because all plots were located on 1 landowner (federal) and in 1 location (Tennessee NWR). Similarly, harvested grain sorghum was not tested because all plots were privately owned and located in west Tennessee. We also deleted 1 harvested corn field from all analyses, because it was identified as an influential outlier (studentized residual > 3), and significantly impacted analyses. All analyses were performed using the SAS® system at $\alpha = 0.05$. When

ANOVAs were significant, pairwise comparisons were made using Tukey's Honestly Significant Difference (HSD) multiple comparison test.

For use in waterfowl management, we calculated means and standard errors for agricultural seed biomass (kg/ha) and DEDs for December and January estimates for harvested and unharvested corn, soybean, and grain sorghum. December estimates were calculated, because it represents the month when significant numbers of waterfowl begin arriving in the Mississippi Alluvial Valley. January estimates are provided because it is the month when waterfowl numbers peak in Tennessee and likely in other portions of the MAV. Finally, the percent seed loss to each fate category (germination, decomposition, granivory) from post-harvest to January was summarized across the 2 field seasons.

Future analyses—Multiple linear regression models will be constructed to quantify the importance of microclimate (temperature, relative humidity and precipitation) and months post-harvest in explaining variation in decomposition, germination, and granivory rates. We will use repeated-measures ANOVA to test for differences in average percent loss among categories (i.e., germination, decomposition and granivory) through time.

RESULTS

Seed Biomass among Number of Months Post-harvest

Month and year effects interacted ($F_{3,114} = 5.66$, $P = 0.01$) for harvested corn. Biomass of harvested corn decreased with increasing time post-harvest in 2006 and 2007 ($F_{3,51} \geq 16.6$, $P < 0.001$), but the pattern of monthly differences was different between years (Table 1). No differences in corn biomass were detected between years in harvested fields ($F_{1,44} \leq 2.84$, $P \geq 0.10$). Biomass of seed in harvested soybean fields differed among months post-harvest ($F_{2,80} = 69.79$, $P < 0.001$) but not between years ($F_{1,40} = 0.19$, $P = 0.66$). Waste soybean immediately post-harvest was 2.7−4X greater than 1 or 2 months post-harvest (Table 1). Biomass of waste grain sorghum was different among months post-harvest by ANOVA ($F_{2,14} = 4.88$, $P = 0.05$), but Tukey's HSD test did not detect differences (Table 1). No differences in waste grain sorghum were detected between years ($F_{1,7} = 1.30$, $P = 0.29$).

Exponential decay functions for corn, soybean and grain sorghum explained significant variation in the rate of seed loss in harvested fields ($P < 0.001$, $R^2 = 0.46 – 0.66$; Table 2). These equations predicted a continuous rate of seed loss between 64 and 84% among consecutive months post-harvest (Table 2, Figure 5). It is predicted that on average waste corn and grain sorghum will drop below 50 kg/ha within 3 months post-harvest, and soybean within 1 month post-harvest (Figure 5).

Biomass of corn in unharvested fields differed among number of months post-drydown by ANOVA ($F_{3,108} = 4.17$, $P < 0.001$), but Tukey's HSD test did not detect differences (Table 1). Unharvested corn biomass was 1.8X greater ($F_{1,36} = 15.80$, $P < 0.001$) in 2006 (8419.12 kg/ha SE = 388.59) than in 2007 (4685.78 kg/ha, SE = 324.50). Biomass of unharvested soybean fields did not differ among months post-drydown ($F_{2,28} = 0.43$, $P = 0.65$; Table 1). Similar to corn, biomass of unharvested soybeans differed between years ($F_{1,14} = 462.31$, $P < 0.001$), with biomass in 2006 (3908.62 kg/ha, SE = 126.89) 9.3X greater than in 2007 (419.61 kg/ha, SE = 67.83). Biomass of grain in unharvested grain sorghum fields did not differ among months post-drydown ($F_{3,9} = 6.42$, $P = 0.08$; Table 1).

Seed Biomass and DED in December and January

Biomass and DEDs were low in harvested fields in December and January (Table 3). In December, the greatest seed biomass (156 kg/ha) was in harvested grain sorghum fields; waste corn and soybean biomass was <100 kg/ha. By January, there was a 49, 45, and 98% decrease in biomass of corn, soybean and grain sorghum in harvested fields, respectively (Table 3). This equated to 275.3, 90.4, and 27.2 DED/ha for corn, soybean and grain sorghum in January. Approximately, 55 and 87% of harvested cornfields in December and January, respectively, 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.

Biomass and DEDs remained high in unharvested corn, soybean and grain sorghum fields in December and January (Table 3). Unharvested grain sorghum fields provided 27% fewer DEDs in January than in December. There was a 10 and 13% decrease in DEDs for unharvested corn and soybean between December and January (Table 3). Five and 10% of unharvested cornfields in December and January contained <50 kg/ha of grain. Unharvested soybean and grain sorghum fields always contained over 50 kg/ha of seed in December and January.

Land Ownership Categories and Climate Regions

Year and owner effects interacted ($F_{3,40} = 5.39$, $P < 0.001$) for harvested corn. Biomass of harvested corn immediately post-harvest was greater in federally-owned fields compared to state and private fields in 2006 ($F_{2,21} = 5.95$, $P < 0.001$), but no differences were detected in 2007 ($F_{2,19} = 0.43$, $P = 0.65$; Table 4). Corn biomass in harvested federal fields differed between years ($F_{1,14} = 7.57$, $P = 0.02$), but no differences were detected ($F_{1,13} \leq 0.56$, $P > 0.47$) between years for state and privately-owned fields (Table 4). Biomass of soybeans immediately post-harvest differed among landowners by ANOVA ($F_{2,42} = 3.40$, $P = 0.04$), Tukey's HSD test did not detect differences. No differences were detected among landowner categories ($F_{2,41} = 2.39$, $P > 0.15$) for harvested corn and soybean in January (Table 4).

Year and owner effects interacted ($F_{2,34} \geq 8.17$, $P < 0.01$) immediately post-drydown and in January for unharvested cornfields. Biomass in federally-owned fields was greater than state-owned cornfields immediately post-drydown in 2006 ($F_{1,16} = 5.72$, $P = 0.03$), but not in 2007 ($F_{1,18} = 0.02$, $P = 0.89$; Table 4). Biomass in 2006 was greater than 2007 in federally-owned fields both immediately post-drydown and in January ($F_{1,14} \geq 91.55$, $P < 0.001$), but not in state-owned fields ($F_{1,20} \leq 3.48$, $P > 0.08$; Table 4). No differences were detected among climate regions for harvested corn, harvested soybean and unharvested corn immediately post-harvest or in January ($F \leq 1.24$ $P \geq 0.32$; Table 5).

Fate of Waste Grain

The majority (52%) of waste corn was depredated between post-harvest and January. Germination accounted for 23% of waste corn loss, 20% decomposed, and 5% remained intact (Figure 6). The majority (45%) of soybeans decomposed, 29% germinated, 8% were depredated and 18% remained intact by January. The majority (56%) of grain sorghum seeds decomposed, 29% germinated and 15% were depredated. No grain sorghum seeds remained intact by January (Figure 6).

DISCUSSION

Seed Biomass among Number of Months Post-harvest

Average biomass of corn, grain sorghum, and soybean immediately post-harvest was 239, 392, and 117 kg/ha, respectively. Initial waste grain biomass in harvested cornfields has decreased since the late 1970s and mid-1980s when average post-harvest biomass ranged from 312−353 kg/ha (Baldassarre et al. 1983, Warner et al. 1989, Krapu et al. 2004). Similarly, waste soybean biomass (117 kg/ha) was nearly 1/3 less than estimates from the early 1980s (i.e., 172 kg/ha; Warner et al. 1989). No post-harvest estimates of waste grain sorghum are available for comparison, although Iverson et al. (1985) reported an average waste grain sorghum biomass of 292 kg/ha in January, which is 15X greater than our January estimate of 19 kg/ha. Despite increased crop yields since the 1980s (NASS 2008), improvements in harvesting technology may be resulting in less waste grain deposited by combines, hence available for waterfowl (Krapu et al. 2004, Manley et al. 2004).

Our estimate of waste corn biomass immediately post-harvest in Tennessee (239 kg/ha) was comparable to post-harvest estimates from the late 1990s in Nebraska (i.e., 177 and 254 kg/ha; Krapu et al. 2004). Similarly, Frederick et al. (1984) noted that no differences existed among study locations (Texas, Nebraska and Iowa) for abundance of waste corn in the late 1970s and early 1980s. Similarity in corn biomass immediately post-harvest over a large spatial scale is likely a consequence of similar agricultural production and harvesting techniques throughout the United States. This suggests that waste grain estimates immediately post-harvest from our study and Krapu et al. (2004) may be reliable over large geographic areas.

Biomass of waste grain declined rapidly following harvest. Grain in harvested corn and grain sorghum fields was 67 and 62 kg/ha, respectively, by two months post-harvest, and dropped below 50 kg/ha in three months. Soybean biomass declined below 50 kg/ha after one month post-harvest. Recent estimates of waste corn, grain sorghum and soybean during late autumn or winter do not exist. However, waste rice in the lower Mississippi Alluvial Valley approached the waterfowl giving-up density within 4 months post-harvest, with an average of 78 kg/ha provided in December (Stafford et al. 2006b). Manley et al. (2004) reported that the majority of harvested rice fields in winter contain <50 kg/ha. Manley et al. (2004) and Stafford et al. (2006b) attribute low waste rice biomass to rapid rates of seed deterioration between harvest and December. Given high rates of seed loss documented by the aforementioned studies and us, harvested agricultural fields in the Southeast provide few food resources for migrating and wintering waterfowl (Stafford et al. 2006b).

Loss of waste grain in our fields could be characterized using an exponential decay function. The continuous monthly rate of loss was 64, 74, and 84% in harvested corn, grain sorghum and soybean fields, respectively. Thus, on average, grain biomass declined at a rate of 74% of the preceding month in harvested fields. For corn, our rates of decline were faster than those observed in more northern regions. Warner et al. (1989) reported 55% loss of corn in unmanipulated fields from late fall to early spring in Illinois. Similarly, rate of corn loss in harvested Ontario fields was 44% between fall and early spring, with 347 kg/ha remaining in spring (T. Barney, Long Point Waterfowl and Wetlands Research Fund, unpublished data). These differences in rates of seed decline may be due to climactic differences between the southeastern United States and regions farther north. Seeds rapidly deteriorate in the warm and humid climate of the Southeast (Stafford et al. 2006a, M. Foster, unpublished data). Conversely, rates of decline on the Texas Southern High Plains were similar to those that we observed. Baldassarre et al. (1983) reported a 92% decrease in waste corn availability in unmanipulated corn fields during the 6-month period from September–March. Plugging 6 months into our exponential decay equation for harvested corn, predicts a 98% loss in corn biomass in Tennessee. Although the Southern High Plains receives less precipitation than the Mississippi Alluvial Valley, temperatures are similar due to similar latitude, which facilitates earlier harvest than northern regions and increases time for seed depredation, germination and decomposition prior to the arrival of waterfowl. Warner et al. (1989) reported an 85% rate of decline for harvested soybean in Illinois, which is similar to our estimate, thus there may be differences in rates of agricultural seed loss among crops in northern regions.

Average biomass of corn, grain sorghum, and soybean immediately post-drydown in unharvested fields was 6924, 4109, and 2240 kg/ha, respectively. These values are similar to statewide average yields of 7767, 5548, and 1917 kg/ha for corn, grain sorghum and soybean, respectively, in Tennessee (NASS 2008). No differences were detected in biomass among number of months post-drydown, although there was a decreasing trend. Biomass of seed in unharvested corn and grain sorghum fields declined 12 and 44% within 3 months post-drydown, and unharvested soybean declined 8% in 2 months. Reinecke and Kaminski (2006) proposed a 20% loss in unharvested grain before waterfowl arrive due to decomposition and wildlife depredation. Biologists at Tennessee NWR assume that 85% of the commercial yield is available for waterfowl in unharvested food plots (USFWS 2005). Our study suggests that rates of seed loss in unharvested food plots depend on grain type, with high rates of loss in grain sorghum plots. Unharvested grain sorghum may experience higher rates of loss than other grains due to depredation by other wildlife. In particular, blackbirds and sparrows can significantly reduce available seed in grain sorghum fields for waterfowl (Atkeson and Givens 1952, Neely and Davison 1971).

Biomass of unharvested corn and soybean was 1.8 and 9X greater, respectively, in 2006 compared to 2007. Seed production in unharvested grain sorghum fields was zero in 2007. The reduction in seed yield in 2007 likely was due to drought conditions in the Southeast (NCDC 2008). Rainfall deficits between May and August 2007 ranged from 23−38 cm throughout Tennessee (Fielder 2007), and the entire state was classified as experiencing extreme or exceptional drought (i.e., D3−D4, Heddinghaus 2007). It is estimated that between 30−70% of planted agricultural acres in Tennessee were lost because of drought in 2007 (Fielder 2007). Despite lower yields in unharvested fields in 2007, no differences were detected between years in waste grain remaining in harvested fields. This is likely a consequence of similar harvesting efficiency of combines whether crops have high or low yields. Thus, drought may have little impact on the amount of waste grain that remains in harvested fields.

Duck Energy-day Estimates

Seed biomass estimates were above 50 kg/ha in harvested corn and grain sorghum fields in December, and equaled 748 and 1381 DED/ha, respectively. Mean seed biomass was below 50 kg/ha for soybean in December and for all grains in January. In January, DEDs were functionally zero in over 85% of agricultural fields that we sampled.

Thus, harvested corn, grain sorghum, and soybean fields have very little food value for migratory waterfowl in Tennessee and likely elsewhere in the Southeast.

There were 78079, 35873, and 19423 DEDs/ha in unharvested corn, grain sorghum and soybean fields, respectively, in December. In January, there were 69056, 26212, and 17675 DEDs/ha in corn, grain sorghum and soybean fields. Thus, unharvested corn can energetically support the greatest number of waterfowl followed by grain sorghum.

Land Ownership Categories and Climate Regions

Biomass of corn in unharvested and harvested fields was greater on federally owned fields than on state fields in 2006. No differences were detected in 2007 or for soybeans both years. Yields in unharvested fields can be influenced by climate, planting date, seeding rate, seed variety, and fertilizer and pesticide application. However, fields on Tennessee NWR were planted similar to state and private lands, thus we are uncertain of the mechanism driving these results. Waste grain in fields can be affected by percent moisture of grain at harvest, and model, size and type of combine. Percent moisture of corn at harvest on Tennessee NWR ranged from 13−18%, which is typical during harvest. The model of combine was a 1999 Case IH 2388, which is similar to several state WMAs and private landowners. Greater biomass left behind the combine at Tennessee NWR may have been a consequence of non-optimal driving speed. Faster than normal combine speeds were observed during harvesting (M. Foster, personal observation), which can reduce harvested grain (Mayeaux et al. 1980). No differences were detected among landowners in January either year. Thus, even though more corn initially existed on federal land in 2006, these differences disappeared by the time peak waterfowl numbers occurred on Tennessee NWR. Accelerated loss of corn on Tennessee NWR may be a consequence of high granivory by various wildlife. The lack of differences in corn biomass among landowners in 2007 may have been driven by the drought, because farming practices on Tennessee NWR did not change between years.

No differences were detected among climate regions for harvested corn, harvested soybean and unharvested corn immediately post-harvest or in January. There was a trend for fields in west Tennessee to have lower biomass, and fields on the Cumberland Plateau to have higher biomass. Lack of statistical significance suggests that rates of grain loss may be independent of small-scale differences in climate. We will test this assumption when we analyze data from our fate plots, which had temperature and humidity loggers deployed. Although it is possible that climate may not play an overriding role in rates of grain disappearance across Tennessee, our waste grain estimates are likely optimistic for the MAV given that climate elsewhere in the Southeast is hotter and more humid. Thus, it is expected that rates of seed loss would be greater south of Tennessee.

Our estimates of grain biomass are for unmanipulated fields. Post-harvest treatment (e.g., grazing, tilling) can negatively affect the abundance of waste grain available for waterfowl. Grazing by cattle can reduce waste corn abundance by 84% (Baldassarre et al. 1983). Plowing can reduce was corn by over 73% (Frederick and Klaas 1982, Warner et al. 1985). Plowing soybean fields resulted in 74 – 82% reduction in abundance (Warner et al. 1985), and Iverson et al. (1985) found no grain sorghum seeds in plowed fields. Thus, our estimates likely represent a best-case scenario for seed availability harvested corn, grain sorghum and soybean fields in the Southeast.

MANAGEMENT IMPLICATIONS

Results from our study indicate that biomass of waste corn, soybean and grain sorghum declines rapidly following harvest, and harvested fields may have little nutritional value for waterfowl after 2 months post-harvest. We therefore recommend that if sharecropping occurs on WMAs or refuges that wildlife managers encourage those farmers to harvest as late as possible. Although crop maturation, grain moisture, and weather play a role when harvesting occurs, it may be feasible for sharecroppers to preferentially harvest fields later that are intended to provide waste grain for waterfowl. This strategy would help reduce waste grain loss prior to waterfowl arrival.

Inasmuch as waterfowl managers have little control over harvesting on private lands, and the majority of agricultural lands in Tennessee and the MAV are privately owned, we can expect that most corn, soybean and grain sorghum fields on the landscape will harvested by the end of November. In our study, all fields were harvested before December. Estimates of available waste grain and seed loss predictions from our exponential decay models suggest that DEDs provided by harvested corn, soybean and grain sorghum fields in Tennessee (and perhaps the MAV) are negligible. Thus, waterfowl conservation efforts should focus on providing alternate high-energy food resources on WMAs and refuges. Our research suggests that unharvested corn, soybean and grain sorghum fields can provide substantial energy for waterfowl, and very little seed is lost if crops remain standing. However, we do not recommend planting soybean food plots, because they have less energy than corn or grain sorghum, and under certain conditions esophageal impaction from soybeans can result in mortality of waterfowl (Durant 1956, Jarvis 1959). Our results also indicate that corn provides over double the seed biomass for waterfowl compared to grain sorghum. Management of natural wetlands should be provided with food plots, because waterfowl cannot be sustained on agricultural grains alone (Loesch and Kaminski 1989).

Most waterfowl cannot access standing crops unless they are flooded. Thus, for dry-land feeding, we recommend that portions of fields with standing crops are knocked down or bush-hogged throughout migration and winter. Our estimates of biomass and rates of seed decline in unharvested cropland may overestimate waterfowl carrying capacity when crops are knocked down or bush hogged for waterfowl. Our research in harvested fields indicates that grain biomass decreases rapidly when it lies on the ground. Unharvested fields that are mechanically manipulated to facilitate waterfowl feeding may lose grain at rates similar to harvested fields. Thus, we recommend that portions of fields are mechanically manipulated throughout winter. If unharvested crops are mechanically manipulated for waterfowl, hunting cannot occur over or near these areas, as it will constitute baiting.

Our estimates for available grain in harvested and unharvested fields can be used to calculate DEDs by multiplying field acreage by values provided in Table 3. We recommend that January estimates are used, because this is the month when waterfowl abundance peaks in the Southeast (Pearse 2007, R. Wheat, U.S. Fish and Wildlife Service, unpublished data). Alternatively, our exponential decay models can be used to predict site-specific DEDs using the following procedure. First, quantify available grain in fields immediately post-harvest and determine wet mass per ha (WMASS) following Frederick et al (1984). Next, convert WMASS to dry mass per ha (DMASS) using percent moisture (%MOIST) and the equation: $\text{DMASS} = \text{WMASS} \times (100 - \%\text{MOIST})$.

Estimates of %MOIST can be provided by grain elevators, and some combines have this capability. Solve for early winter biomass (BMASS) by plugging DMASS, time in months until early winter (t), and rate of decline ($r = -0.637$ for corn, -0.844 for soybean, and -0.737 for grain sorghum) into the equation BMASS = DMASS $\times e^{rt}$, where $e = 2.718$. Finally, plug BMASS in for Q_F in Equation 1 (p. 4) to calculate DEDs.

Given large between-year differences in unharvested seed biomass for corn and soybean, and the lack of yearly replication for grain sorghum due to crop failure in 2007, biologists might consider using our estimated rates of decline instead unharvested yields in Table 3. We estimated that the rate of seed loss in unharvested soybean, corn, and grain sorghum between drydown and January was 8%, 12%, or 45%, respectively. This rate of loss can be multiplied by annual commercial yields from the National Agricultural Statistics Service (www.nass.gov) or from combines that harvest adjacent fields.

An alternative management strategy not addressed in our study is increasing acreage of moist-soil wetlands on WMAs and refuges to meet energy needs. Recent estimates from the Lower MAV suggest that moist-soil wetlands provide 1,883 DED/ha (Kross et al. 2008), and decomposition of moist-soil seeds is much slower compared with agricultural seeds (Neely 1956, Shearer et al. 1969). Moist-soil seeds and aquatic invertebrates in moist-soil wetlands provide waterfowl with essential nutrients that are not available in grain-exclusive diets (Loesch and Kaminski 1989, Gray et al. 1999). Moist-soil wetlands also are important resting areas, and used when breeding pair bonds are established. Despite the multiple benefits of moist-soil wetlands, extensive acreage of natural wetlands may be necessary to meet the energy needs of North American waterfowl populations. Unharvested agricultural crops can provide far more DEDs per unit area than moist-soil wetlands. Thus, the supplementary use of unharvested agricultural crops on WMAs and refuges may be essential to meet the energy needs of migrating and wintering waterfowl, especially when managing extensive acreage of moist-soil wetlands is impossible or impractical.

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Table 1. Biomass (kg/ha) of agricultural seed available for waterfowl in harvested and unharvested fields for increasing number of months post-harvest and post-drydown, respectively, Tennessee, 2006 and 2007.

				Months[a]							
				0		1		2		3	
Crop	Manipulation	Year[a,b]	*n*	$\bar{x}$[c]	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
Corn	Harvested	2006	18	298.3 A	64.0	121.9 B	22.6	67.5 B	16.6	34.4 B	17.4
		2007	22	180.5 A	21.3	128.5 AB	19.6	66.6 BC	12.6	47.7 C	20.3
Soybean	Harvested	NI	42	117.5 A	9.8	43.8 B	6.5	29.7 B	6.9	NT	
Grain Sorghum	Harvested	NI	9	391.7 A	139.5	208.5 A	86.4	62.6 A	18.4	NT	
Corn	Unharvested	NI	38	6924.5 A	566.0	6537.5 A	577.5	6413.1 A	606.9	6083.4 A	604.8
Soybean	Unharvested	NI	16	2239.7 A	501.3	2171.5 A	435.8	2081.1 A	462.8	NT	
Grain Sorghum	Unharvested	NT	4	4109.4 A	259.5	3120.8 A	354.8	3051.5 A	601.0	2243.1 A	766.0

[a] NT = No test performed because of insufficient replication.
[b] NI = No interaction of year and month effects.
[c] Means within rows followed by unlike letters are statistically different by repeated-measures ANOVA and Tukey's Honestly Significant Difference test.

Table 2. Exponential decay functions relating biomass (kg/ha) of seed (BMASS) in harvested fields to number of months post-harvest (TIME).

Crop	*n*	Model	*F*	R^2
Corn	189	$\text{BMASS} = 241.1 \times e^{(-0.637 \times \text{TIME})}$	95.47	0.51
Soybean	159	$\text{BMASS} = 116.2 \times e^{(-0.844 \times \text{TIME})}$	155.08	0.66
Grain sorghum	35	$\text{BMASS} = 369.8 \times e^{(-0.737 \times \text{TIME})}$	13.81	0.46

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

			Month							
			December				January			
			Biomass		DED/ha		Biomass		DED/ha	
Crop	Manipulation	*n*	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
Corn	Harvested	47	74.7	14.2	521.6	160.2	38.7	12.1	273.6	130.8
Soybean	Harvested	48	45.4	7.9	163.9	55.4	25.5	6.3	90.4	39.1
Grain Sorghum	Harvested	9	156.0	83.1	1381.5	969.9	19.3	7.2	27.0	27.0
Corn	Unharvested	39	6260.1	590.7	78079.0	7416.2	5539.2	568.2	69056.0	7125.0
Soybean	Unharvested	16	2190.2	439.3	19422.6	3986.8	1997.6	451.9	17675.3	4101.5
Grain Sorghum	Unharvested	4	3051.5	601.0	35873.6	7182.9	2243.1	766.0	26212.5	9154.9

Table 4. Biomass of agricultural seed (kg/ha) available for waterfowl immediately post-harvest (post-drydown for unharvested corn) and in January among land ownership categories, Tennesseee, 2006 and 2007.

				Land Owner[a]					
				Private		State		Federal	
Food Resource	Sampling Period	Year[b]	*n*	$\bar{x}$[c]	SE	$\bar{x}$	SE	$\bar{x}$	SE
Harvested Corn	Post-harvest	2006	24	156.3 A	37.4	179.4 A	59.0	559.2 B *	144.6
		2007	24	198.4 A	42.6	286.1 A	100.1	153.6 A *	28.6
	January	NI	48	58.3 A	27.6	61.0 A	38.0	32.2 A	19.6
Harvested Soybean	Post-harvest	2006	24	83.1 A *	21.5	155.9 A	32.4	125.2 A	17.6
		2007	24	143.9 A *	13.0	99.5 A	28.5	104.6 A	31.7
	January	NI	48	14.1 A	4.8	44.9 A	17.2	25.3 A	11.9
Unharvested Corn	Post-drydown	2006	15	NT		7746.6 A	1161.5	11000.9 B	428.7
		2007	16	NT		5084.1 A	922.8	4914.8 A	438.8
	January	2006	15	NT		6641.8 A	1079.4	8888.4 B	304.9
		2007	16	NT		3584.5 A	1193.7	3963.4 A	414.7

[a] NT = No test performed because of insufficient replication.
[b] NI = No interaction of month and year effects.
[c] Means within rows followed by unlike letters are statistically different by repeated-measures ANOVA and Tukey's Honestly Significant Difference test; * = yearly means within columns are statistically different.

Table 5. Biomass of agricultural seed available for waterfowl immediately post-harvest (post-drydown for unharvested corn) and in January among the 4 climate regions of Tennessee (TN), 2006 and 2007.

		Climate Region[a]							
		East TN		Plateau		Middle TN		West TN	
Food Resource	Sampling Period	$\bar{x}$ [b,c]	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
Harvested Corn	Post-harvest	158.4 A	26.5	407.1 A	108.0	192.2 A	21.9	88.7 A	18.3
	January	37.3 A	33.3	169.9 A	76.8	22.0 A	7.6	9.4 A	4.6
Harvested Soybean	Post-harvest	91.7 A	20.2	131.1 A	19.2	141.5 A	29.4	111.1 A	26.3
	January	10.8 A	5.4	26.5 A	9.7	52.2 A	25.4	13.1 A	7.2
Unharvested Corn	Post-drydown	7080.0 A	865.9	NT		5537.0 A	1593.6	6374.1 A	1462.7
	January	5042.7 A	1399.9	NT		3999.7 A	1433.4	6019.2 A	1768.0

[a] NT = No test performed because of insufficient replication.

[b] For each climate region-food resource combination, $n = 8$ except harvested corn in the Plateau region where $n = 7$.

[c] Means within rows followed by unlike letters are statistically different by repeated-measures ANOVA and Tukey's Honestly Significant Difference test.

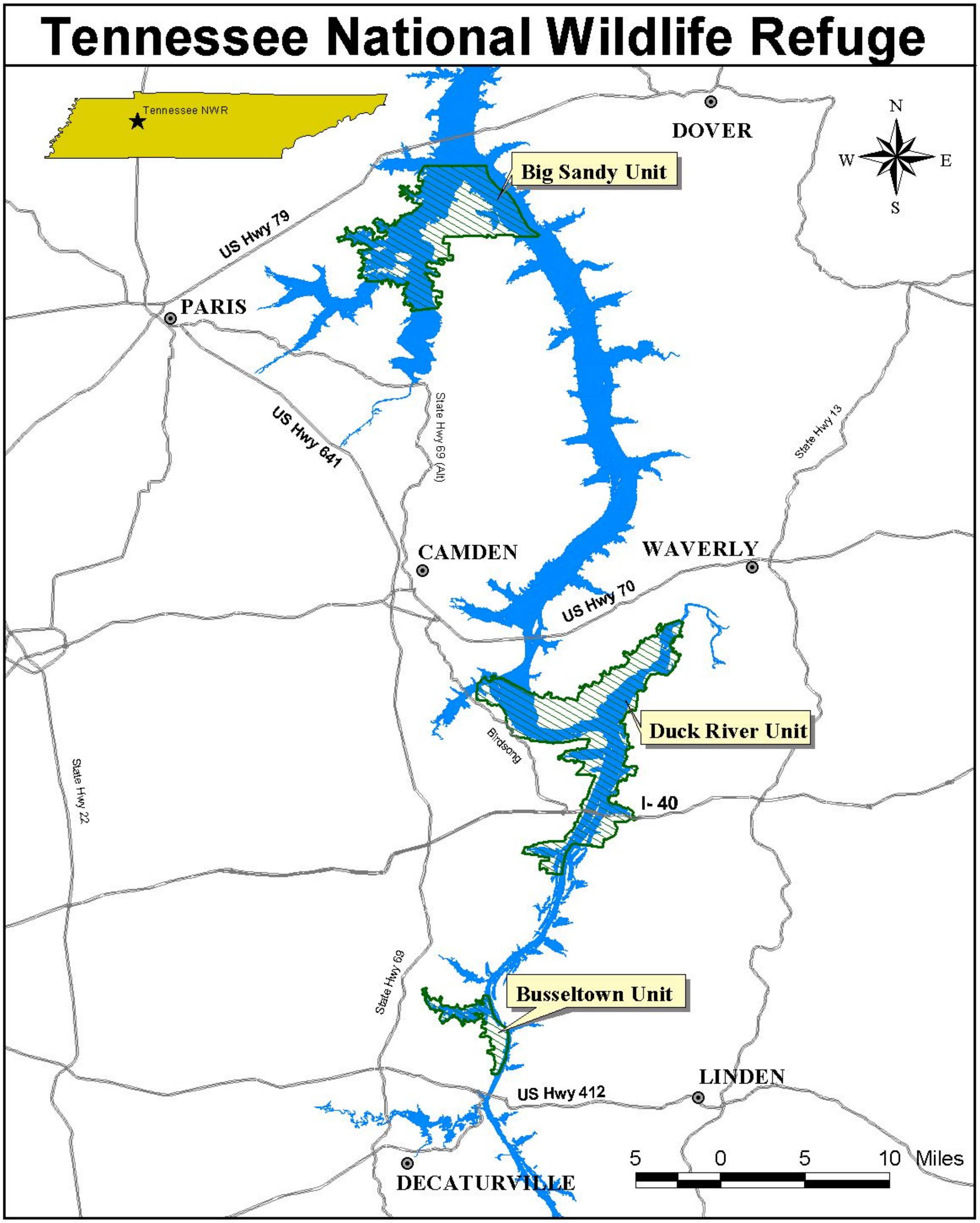

Figure 1. Vicinity map and management units at Tennessee National Wildlife Refuge (USFWS 2005).

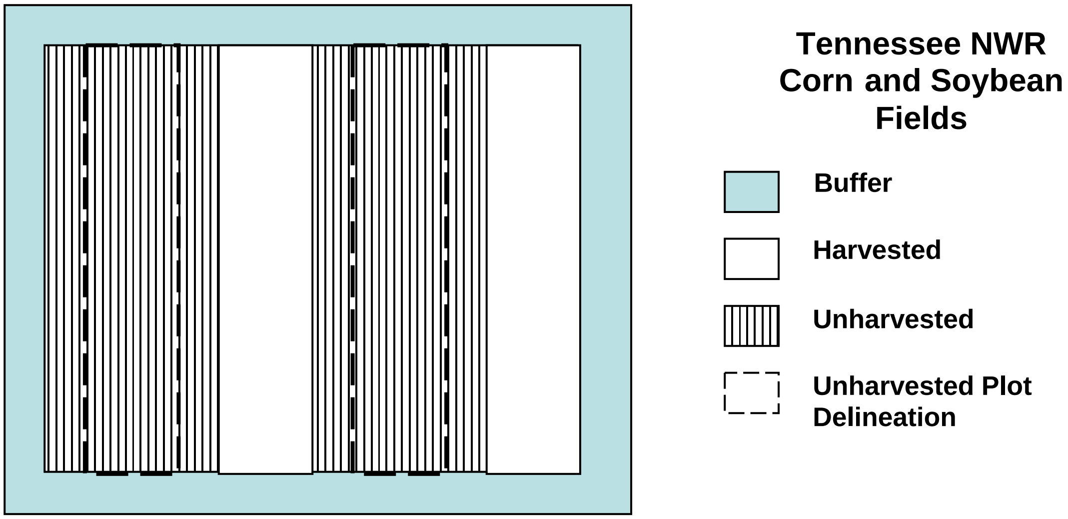

Figure 2. Strip-split-plot design of harvested and unharvested corn and soybean plots (0.202 ha) on Tennessee NWR.

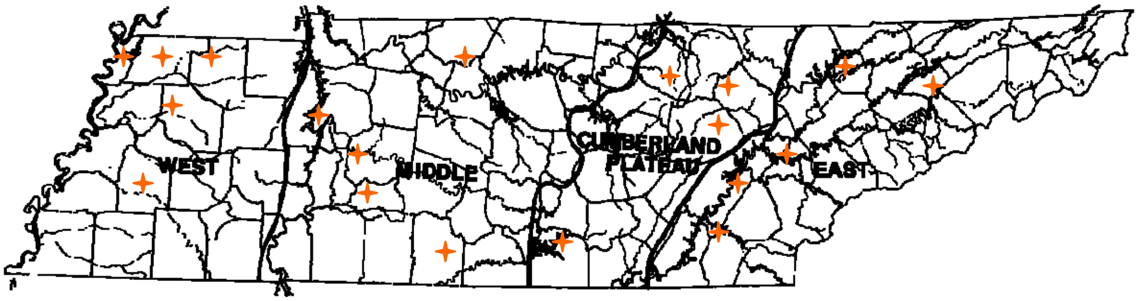

Figure 3. Four climate regions of Tennessee (US Department of Commerce 1968).

Crosses indicate locations of study sites on private and state land in each climate region.

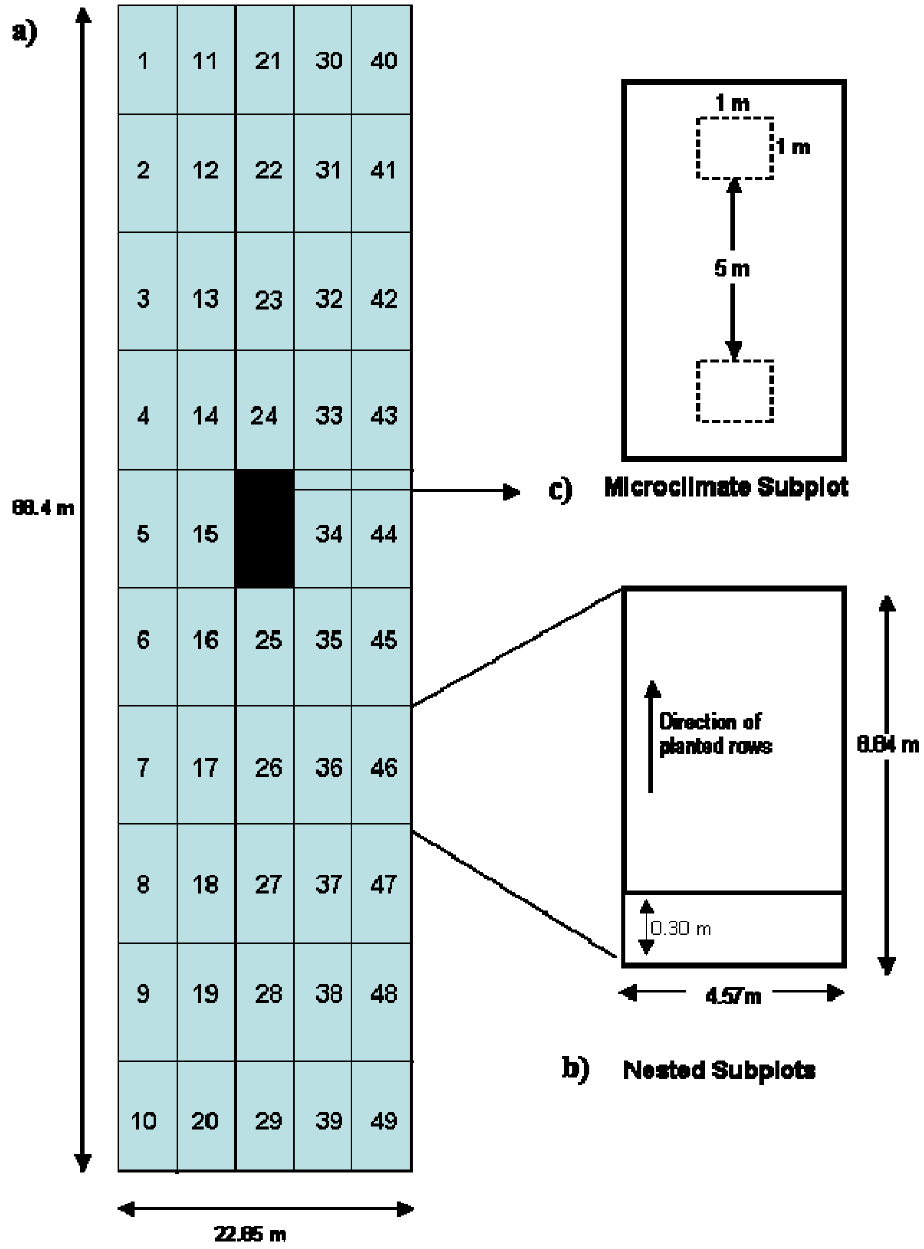

Figure 4. Experimental units (0.202 ha plots) with a grid overlaid for random generation of subsampling locations (a), nested design of subsampling plots (b), and location and design of microclimate plot (c).

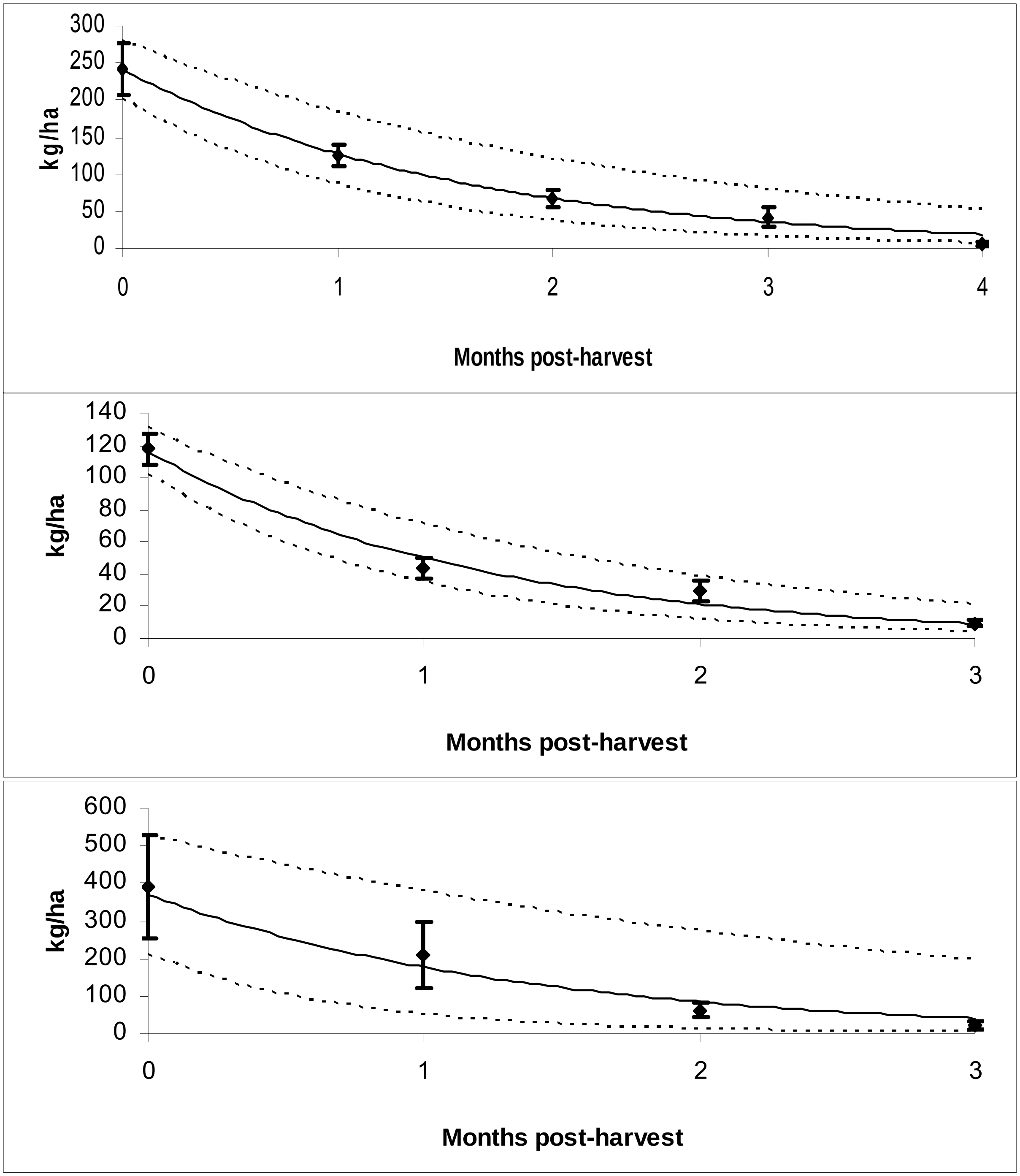

Figure 5. Predicted biomass of seed in harvested corn (a), soybean (b) and grain sorghum (c) fields in Tennessee. Error bars represent standard error about the mean, and dashed lines are upper and lower 95% confidence intervals for the model.

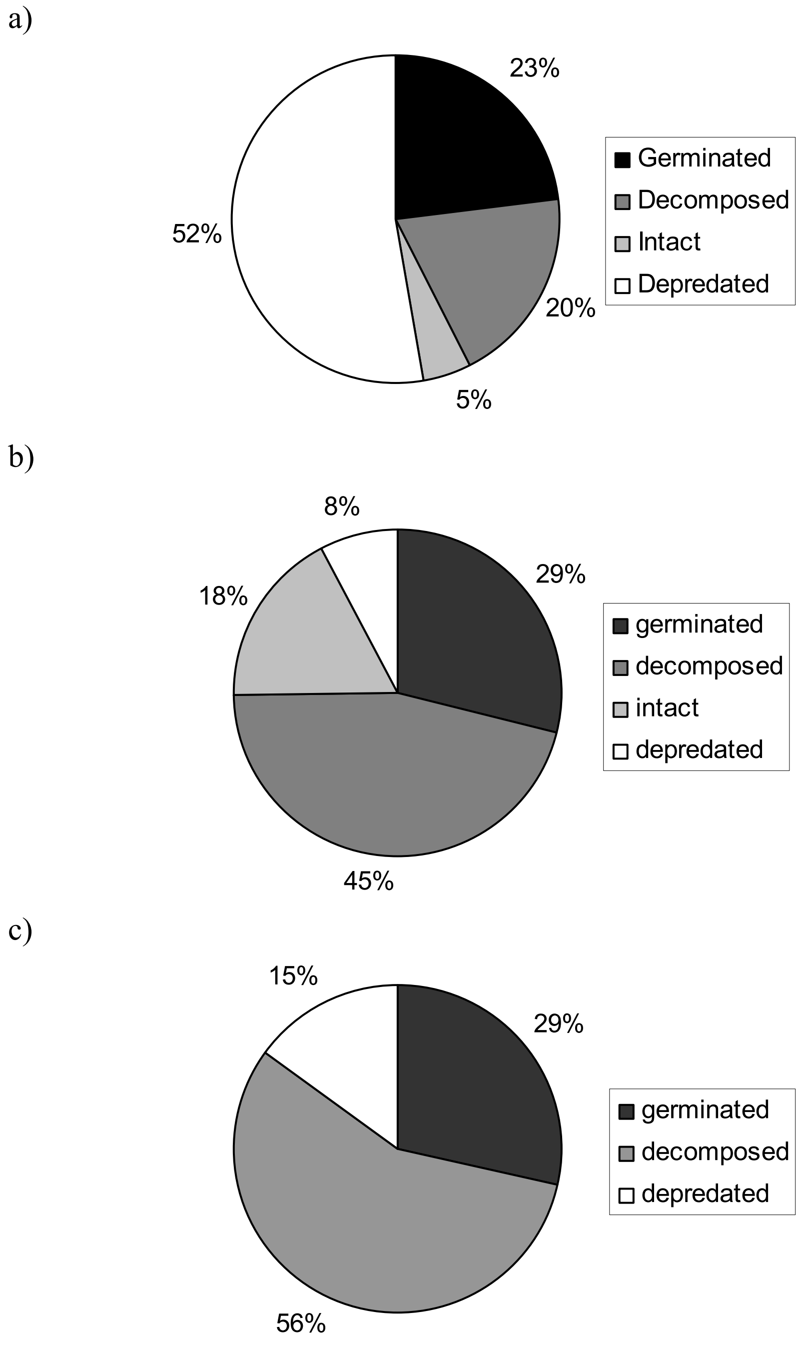

Figure 6. Percent seed loss to germination, decomposition, depredation in harvested corn (a), soybean (b), and grain sorghum (c) fields, Tennessee, 2006 – 2007.