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I am submitting herewith a thesis written by Melissa Ann Foster entitled "Abundance and Losses of Agricultural Seeds for Waterfowl in Tennessee" I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Wildlife and Fisheries Science.

Matthew J. Gray, Major Professor

We have read this thesis
and recommend its acceptance:

Craig A. Harper

Richard M. Kaminski

Lisa I. Muller

Accepted for the Council:

Carolyn R. Hodges

Vice Provost and Dean of the
Graduate School

(Original signatures are on file with official student records)

ABUNDANCE AND LOSSES OF AGRICULTURAL SEEDS FOR WATERFOWL IN TENNESSEE

A Thesis
Presented for the
Master of Science
Degree
The University of Tennessee, Knoxville

Melissa Ann Foster
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DEDICATION

I dedicate this thesis to four ladies who have each taught me more about life than any collection of scientific papers ever could. To Becky Turner, for always knowing exactly what to say and when not to be well-behaved. To April Schmid, whose amazing spirit made it easy to see what things in life are truly important. To the Gibb, the best friend and purest soul I have ever known. Finally, to my mother, whose beauty and grace I have still only begun to appreciate.

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ABSTRACT

Waterfowl acquire high-energy agricultural seeds in harvested and unharvested croplands during migration and winter. Estimates of dry seed mass in agricultural fields are used by biologists and managers to calculate duck-energy days (DEDs) to estimate potential foraging carrying capacity of these fields. However, estimates for corn, grain sorghum and soybean fields do not exist or are outdated for the southeastern United States. Therefore, I estimated seed mass and DEDs in 105 harvested and 59 unharvested corn, grain sorghum and soybean fields across Tennessee, U.S.A., from September – January 2006 and 2007. I also estimated rates of seed loss to germination, decomposition, and depredation and compared seed mass loss between flooded and unflooded fields. Mean seed mass of grain sorghum, corn, and soybean in harvested fields declined 392 to 19, 239 to 39, and 118 to 26 kg ha^{-1} from post-harvest to January, respectively. Continuous monthly rates of decline were 64% for corn, 84% for soybean, and 74% for grain sorghum. Mean DEDs ha^{-1} in harvested corn, grain sorghum and soybean fields during January were low (274, 90 and 27), and DEDs were zero in > 85% of fields. In unharvested corn, soybean and grain sorghum fields, mean DEDs ha^{-1} in January were large (69,000, 18,000 and 26,000), and continuous rates of decline (3%, 7% and 18%) were much lower than for harvested croplands. Scattered corn seed was lost primarily to depredation (37−68%), whereas soybean and grain sorghum seed were lost mostly to decomposition and germination (≥35%). Loss of submersed seed in flooded fields was 40−300% greater than on dry land. I recommend that waterfowl biologists in the southeastern United

States should use estimates herein (Table II-3) for DED calculations. I also recommend managers provide unharvested food plots and natural wetlands for waterfowl because seed resources are low in winter in harvested agricultural fields. Given rapid seed loss in harvested and flooded fields, managers should delay harvesting and flooding until immediately prior to the arrival of waterfowl whenever feasible. For agencies interested in modeling fate-based seed loss on a landscape scale, rates of loss in Table III-1 could be used.

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CHAPTER I

INTRODUCTION

North American waterfowl populations declined to record lows in the mid-1980s as a result of 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 (U.S. 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 Flyway is a major migration corridor and wintering area for millions of North American waterfowl (Reid et al. 1989, Reinecke et al. 1989). Much of the landscape within this migratory flyway has been converted from forest to agricultural fields. For example, Mississippi Alluvial Valley (MAV) was a vast hardwood bottomland that flooded regularly and provided habitat for waterfowl (Heitmeyer 2006). By the mid-1980s, 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 and other geographic regions in the Mississippi Flyway 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 because of their high carbohydrate content (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 (Kross et al. 2008, NASS 2008).

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 the following equation 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:

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

This equation represents the number of waterfowl that can be energetically 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 mass of food per hectare. Reliable DED calculations are dependent on precise and unbiased estimates of food abundance.

For over 15 years, waterfowl managers have used estimates of grain abundance 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 abundance of rice in harvested fields was 52-83% less than estimates based on studies in the 1980s. Further, Manley et al. (2004) and Stafford et al. (2006a) collectively reported abundance of rice seed in harvested fields 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 seed deposited from combines, hence available for wildlife (Krapu et al. 2004, Manley et al. 2004). Further, advances in rice varieties have resulted in faster maturing plants, which allow for earlier harvest but greater time for rice seed to germinate, decompose or be depredated by other wildlife prior to the arrival of migrating waterfowl (Manley et al. 2004, Stafford et al. 2006b).

Important agricultural grains for migrating and wintering waterfowl 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 (Eadie et al. 2008). However, in other portions of the Mississippi Flyway, corn, grain sorghum and soybean are primary crops. For example, 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 quantified rates of seed loss in harvested soybean and grain sorghum fields that are not flooded. Baldassarre et al. (1983) reported a 92% decrease in corn abundance in unmanipulated corn fields between harvest and late winter on the Texas Southern High Plains, though mechanisms responsible for grain loss were not investigated.

Estimates of corn, grain sorghum and soybean abundance currently used by most waterfowl managers in the Southeast are based on studies conducted in Illinois, Nebraska and Texas during the 1980s (Reinecke et al. 1989). Reinecke and Kaminski (2006) provided revised grain abundance estimates to the LMVJV for rice and other grains, but among harvested crops, only the estimate for rice was from recent research in the Southeast (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 corn, grain sorghum and soybean abundance are needed because some estimates are based upon untested assumptions, previous estimates are outdated, and no studies have been conducted in the southeastern United States where climate and growing season differs substantially from other regions of North America. Additionally, no studies have quantified relative seed losses to germination, decomposition and depredation for these crop types.

Given these uncertainties, the objectives of my study were: (1) estimate seed mass of these crops in harvested and unharvested fields, (2) estimate the cumulative and monthly rates of seed loss to germination, decomposition and depredation in unflooded harvested fields, and (3) relate rates of loss to microclimate conditions. Objective 1 is addressed in Chapter II, and objectives 2 and 3 are addressed in Chapter III. I conducted my research from September – January 2006 and 2007 in 105 harvested and 59 unharvested corn, grain sorghum and soybean fields located across Tennessee. In 2007, I added two objectives: (1) quantify rates of seed loss between unflooded and flooded fields (addressed in Chapter IV), and (2) quantify rates of seed loss between scattered and aggregate seed heads (addressed in Chapter III). These objectives were added because waterfowl managers frequently flood agricultural fields for waterfowl and occasionally knock down or bushhog agricultural food plots on refuges, which could affect seed loss. Collectively, results from my study will aid waterfowl biologists in the Southeast and elsewhere in estimating the number of waterfowl that can be sustained by agricultural fields, and assist in determining if NAWMP goals are being met in Tennessee and elsewhere.

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CHAPTER II

AGRICULTURAL SEED ABUNDANCE FOR MIGRATING AND WINTERING WATERFOWL IN THE SOUTHEASTERN UNITED STATES

Abstract

Waterfowl frequently acquire high-energy agricultural seeds in harvested and unharvested croplands during migration and winter. Estimates of agricultural seed abundance in harvested and unharvested corn, grain sorghum and soybean fields do not exist or are outdated for the southern United States. Therefore, I estimated agricultural seed mass in 105 harvested and 59 unharvested corn, grain sorghum and soybean fields across Tennessee, U.S.A., from September through January 2006 and 2007. I also used estimates of seed abundance to calculate duck-energy days (DED) in January when migratory waterfowl abundance peaks in the southeastern United States. Mean mass of corn, soybean and grain sorghum seed in harvested fields declined 239 to 39, 118 to 26 and 392 to 19 kg ha^{-1} from post-harvest to January, respectively. Continuous monthly rates of decline were 64% for corn, 84% for soybean, and 74% for grain sorghum. Agricultural seed in harvested corn and grain sorghum fields dropped below the waterfowl giving-up density (i.e., 50 kg ha^{-1}) in 3 months; soybean dropped below this threshold 1 month post-harvest. Mean DEDs ha^{-1} in harvested corn, grain sorghum and soybean fields were low (274, 90 and 27, respectively) in January, and DEDs were zero in more than 85% of fields. In unharvested corn, soybean and grain sorghum fields, mean DEDs ha^{-1} in January were high (69,000, 18,000 and 26,000), and continuous rates of decline (3%, 7% and 18%) were much

lower than for harvested crops. Waterfowl biologists in the southeastern United States should use my mass estimates of agricultural seed abundance in DED calculations. I also recommend that biologists provide unharvested food plots and natural wetlands for waterfowl foraging because seed resources are low in harvested agricultural fields.

Introduction

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), which requires accurate estimates of available food for waterfowl (Reinecke et al. 1989).

Energy-rich foods are necessary for waterfowl in non-breeding regions to rebuild lipid reserves metabolized during migration, meet energy needs associated with thermoregulation and winter life-history activities, and accumulate sufficient reserves for spring migration to breeding areas (Neely and Davison 1971, Williams et al. 1999). 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 wetland plants (Kross et al. 2008*b*, NASS 2008).

To calculate DEDs, waterfowl managers generally have used data in Reinecke et al. (1989). However, contemporary studies conducted in rice fields suggest these earlier estimates may be inflated (Manley et al. 2004, Stafford et al. 2006, Kross et al. 2008*a*). These authors attributed decreased rice abundance to earlier harvest dates, which increase exposure time for seed loss, and advances in combine harvest efficiency (Manley et al. 2004, Stafford et al. 2006).

Other important agricultural seeds for waterfowl include corn, soybean and grain sorghum (Reinecke et al. 1989). Estimates of seed abundance in harvested fields for these crops are from studies conducted in Illinois, Nebraska or Texas during the 1980s (Reinecke et al. 1989). Similar to rice, estimates for corn, soybean and grain sorghum in Reinecke et al. (1989) may be inflated. Two of the above studies were conducted in the northern United States, where climate differs from the southeastern United States and the majority of North American waterfowl spend winter. Additionally, few estimates exist for seed abundance in unharvested croplands managed for waterfowl. Biologists have assumed that 15–20% of the unharvested crop is lost to decomposition and granivory before waterfowl arrive (USFWS 2005), but this assumption has not been tested.

Contemporary estimates of corn, grain sorghum and soybean abundance are needed because 1) previous estimates may be unreliable due to of advances in harvesting technology and yields, 2) most published estimates are not from the southern United States, 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, grain sorghum and soybean in agricultural fields available for waterfowl in the southern United States, my objective was to estimate mass of these seeds in harvested and unharvested fields. I also modeled rate of seed loss using exponential decay functions.

Study Area

I conducted my study on federal, state and private lands across the 4 regions of Tennessee, U.S.A. (35º 15' – 36º 59' N and 82º 21' – 90º 04' W; U.S. Department of Commerce 1968; Fig. II-1), from fall through early winter 2006 and 2007. I sampled on the 10,820-ha Duck River Unit of Tennessee National Wildlife Refuge (NWR) near New Johnsonville, Tennessee. I sampled 4 corn and 4 soybean fields on Tennessee NWR in 2006 and 2007 that were harvested in a strip-split-plot design (Montgomery 2000:583). Each field contained 2 harvested and 2 unharvested 0.202-ha plots, totaling 16 plots each for corn and soybean per year. I also sampled 4 unflooded grain sorghum fields in 2006, but these were not harvested because the farmer decided not to sell the crop. Four grain sorghum fields also were planted in 2007, but drought decimated the crop (NCDC 2008). Thus, my total number of plots on Tennessee NWR was 68 (i.e., 16 corn × 2 years + 16 soybean × 2 years + 4 grain sorghum).

I also sampled agricultural fields on state and private lands, with approximately 50% of fields per region located on state land and 50% on private land. Corn and soybean production occurs statewide in Tennessee (NASS 2008). Thus, I sampled 4 harvested corn and soybean fields in each region and year. Grain sorghum production occurs primarily in western Tennessee (NASS 2008). Therefore, I limited sampling of harvested grain sorghum to this region and sampled 5 fields on private land each year. Additionally, I sampled 4 unharvested corn fields in 3 regions (west, middle and east Tennessee) on state WMAs (n = 12 per year).

Methods

In each field I randomly located 0.202-ha plots at least 10 m from field edges to reduce bias from edge effects. Fields were not flooded, disked, replanted or mowed during the study. For each plot, I randomly selected and sampled 3 subplots monthly from immediately post-harvest (i.e., within 3 weeks) through January 2006 and 2007. I based dimensions of subplots on sampling protocol for harvested corn fields (Frederick et al. 1984). I collected whole or partially intact corn, soybean and grain sorghum seeds in a 0.3 × 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 × 4.57 m subplot, where I collected seed aggregates (i.e., corn ears containing >10 seeds or grain sorghum seed heads >5 cm in length, Frederick et al. 1984). I did not collect soybeans in a larger subplot because the seeds are not contained in dense aggregates. I also collected corn, soybean and grain sorghum seed from unharvested plots in 0.3 ×

4.57 m subplots following plant drydown (i.e., seed < 25% moisture; Nielsen 2005). I removed all seed on stalks and also collected any agricultural seed on the ground.

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

<u>Statistical Analyses</u>

Two experimental fields were inadvertently mowed or disked; hence, I deleted these fields from my analyses. Overall, I analyzed data from 68 plots on federal land and 96 fields on state and private land (i.e., 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). I performed all analyses using the SAS® system (SAS Institute, Cary, NC) at $\alpha = 0.05$.

I used a two-way repeated measures analysis of variance (ANOVA) with Huynh-Feldt correction to test for differences in seed mass among months and between years (SAS Institute 1999:1560). The month effect was number of months post-harvest for harvested fields and number of months post-drydown for unharvested fields. I tested for differences in mass among 0–3 months post-harvest for corn and among 0–2 months post-harvest for grain sorghum and soybean. For unharvested fields, I tested for differences in mass among 0–3 months post-drydown for corn and grain sorghum and among 0–2 months post-drydown for soybean. I included a month by year interaction term in the repeated-measures ANOVA, and performed analyses by year when the interaction was significant. Because I did not sample unharvested grain sorghum plots in 2007, I did not include interaction and year effects in this analysis. I deleted data from one harvested corn field, because distribution analyses suggested it was an influential outlier (i.e., studentized residual > 3; Myers 1990:227). When ANOVAs were significant, I used Tukey's Honestly Significant Difference (HSD) test for pairwise comparisons of effect levels (SAS Institute 1999:1503). I also modeled the rate of seed loss in harvested fields using an exponential decay function (PROC NLIN, SAS Institute 1999:2371-2418).

I calculated means and standard errors for seed mass (kg ha^{-1}) and DEDs for December and January estimates for harvested and unharvested corn, soybean and grain sorghum. I calculated December estimates because it represents the month when significant numbers of waterfowl begin arriving at southern latitudes in the United States. I 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, U.S. Fish and Wildlife Service, unpublished data).

Results

<u>Abundance of Seed Post-harvest and Post-drydown</u>

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

Exponential decay functions for corn, soybean and grain sorghum explained significant variation in rate of seed loss in harvested fields ($R^2 = 0.46$–0.66, $P < 0.001$; Table II-2). My models predicted a continuous rate of seed loss between 64 and 84% for corn, soybean and grain sorghum among consecutive months post-harvest. For corn and grain sorghum, my models predict that seed mass will drop below 50 kg ha^{-1} (i.e., food density at which waterfowl abandon feeding sites [giving-up density]; Reinecke et al. 1989, Rutka 2004) within 3 months post-harvest (Fig. II-2). For soybean, my models predict that seed mass will drop below 50 kg ha^{-1} within 1 month post-harvest (Fig. II-2). Exponential decay functions for corn, soybean and grain sorghum also explained significant variation in the rate of seed loss in unharvested fields ($R^2 = 0.63$–0.98, $P < 0.001$; Table II-2). My equations predicted a continuous rate of seed loss 0.3–18% among consecutive months post-drydown (Table II-2).

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

Duck-Energy Days

In December 2006 and 2007, the greatest seed mass among harvested crops was in grain sorghum fields ($\bar{x}$ = 156 kg ha^{-1}); mean corn and soybean mass was less than 100 kg ha^{-1} (Table II-3). By January, there was a 49, 45, and 98% decrease in mass of corn, soybean and grain sorghum in harvested fields, respectively (Table II-3). January masses equated to 274, 90, and 27 DED ha^{-1} for corn, soybean and grain sorghum (Table II-3). Approximately, 55% of harvested cornfields in December and 87% in January contained less than 50 kg ha^{-1} of seed. Similarly, 71% of harvested soybean fields in December and 85% in January contained less than 50 kg ha^{-1} of seed. Finally, 33% of harvested grain sorghum fields in December and 89% of fields in January contained less than 50 kg ha^{-1} of seed.

Seed mass and DEDs remained high in unharvested corn, soybean and grain sorghum fields in December and January (Table II-3). Unharvested grain sorghum, soybean and corn fields provided 27, 13, and 10% fewer DEDs in January than in December, respectively (Table II-3). Five and 10% of unharvested cornfields in December and January contained less than 50 kg ha^{-1} of agricultural seed.

Unharvested soybean and grain sorghum fields always contained more than 50 kg ha^{-1} of seed in December and January.

Discussion

Abundance of Seed Post-harvest and Post-drydown

Mean mass of corn, grain sorghum and soybean seed immediately post-harvest in Tennessee was 239, 392 and 118 kg ha^{-1}, respectively. Abundance of seed post-harvest in cornfields has decreased since the late 1970s and mid-1980s when average post-harvest mass in areas of the Midwest and Texas ranged from 312–353 kg ha^{-1} (Baldassarre et al. 1983, Warner et al. 1989, Krapu et al. 2004). Similarly, soybean mass in harvested fields (117 kg ha^{-1}) was 30% less than estimates from Illinois in the early 1980s (i.e., 172 kg ha^{-1}; Warner et al. 1989). No past estimates of post-harvest grain sorghum were available for comparison. However, Iverson et al. (1985) reported average grain sorghum mass in harvested fields was 292 kg ha^{-1} in January, which was 15 times greater than my January estimate (19 kg ha^{-1}). 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).

My estimate of corn mass post-harvest in Tennessee (239 kg ha^{-1}) compared with recent post-harvest estimates from Nebraska (i.e., 177 and 254 kg ha^{-1}; Krapu et al. 2004) and Ontario (i.e., 188 kg ha^{-1}; Barney 2008). Similarly, Frederick et al. (1984) reported no differences in abundance of corn post-harvest existed among study sites in Texas, Nebraska and Iowa. Thus, grain estimates immediately post-harvest from my study, Krapu et al. (2004), and Barney (2008) seem consistent over large geographic areas.

Mass of agricultural seed declined rapidly following harvest. Seed in harvested corn and grain sorghum fields averaged 67 and 62 kg ha^{-1}, respectively, by 2 months post-harvest and dropped below 50 kg ha^{-1} in 3 months. Soybean mass declined below 50 kg ha^{-1} only 1 month post-harvest. Similarly, post-harvest rice mass in the Lower Mississippi Alluvial Valley declined from 271 to 78 kg ha^{-1} between harvest and late November – early December (Stafford et al. 2006). Given high rates of seed loss between harvest and when waterfowl abundance peaks in the southeastern United States (i.e., January; Pearse et al. 2008; R. Wheat, U.S. Fish and Wildlife Service, unpublished data), harvested agricultural fields in this region may provide limited food resources for migrating and wintering waterfowl.

I characterized loss of agricultural seed in my fields 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. For corn and soybean, my 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 fall to early spring (Warner et al. 1989; Barney 2008; M. H. Sherfy, U.S. Geological Survey, unpublished data). Warner et al. (1989) also reported that 85% of soybean seeds in harvested fields were lost from late fall 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 my harvested fields. Differences in rate of seed loss among these studies and ours are likely in response to climactic differences between southern and northern regions of the United States. Seeds rapidly deteriorate in the warm and humid climate of the southeastern United States (Stafford et al. 2006; Chapter III). However, seed may be significantly preserved at latitudes greater than 39° N in the eastern United States, which is the approximate boundary between major United States climate zones (i.e., zones 2 and 3; USDOE 2003). Given that Tennessee is located north of most states in the Southeast, my estimates of seed mass in harvested corn, grain sorghum, and soybeans fields probably are liberal for this region. Further, my estimates of seed mass are for harvested fields without post-harvest 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 mass of corn, grain sorghum and soybean immediately post-drydown in unharvested fields was 6,924, 4,109 and 2,240 kg ha^{-1}, respectively. My values are similar to estimates from unharvested cornfields in Illinois (5,008 kg ha^{-1}; J. Stafford, Illinois Natural History Survey, unpublished data), and statewide average yields for corn, grain sorghum and soybean in Tennessee (7,767, 5,548, and 1,917 kg ha^{-1}; NASS 2008). Conservation planners assume about a 15–20% loss of agricultural seed mass 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, my exponential decay models predict about a 5, 13 and 30% loss of seed in unharvested corn, soybean and grain sorghum fields. Thus, for my study, the 15–20% seed-loss assumption in unharvested fields under or overestimated mass 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 (Passeriformes: Icteridae) and sparrows (Passeriformes: Emberizidae) may significantly reduce available seed in grain sorghum fields (Atkeson and Givens 1952, Neely and Davison 1971).

Mass 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. The 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 23–38 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 my unharvested cornfields were exacerbated by subsequent wildlife depredation. I observed significant damage from foraging white-tailed deer (*Odocoileus virginianus*) and sandhill cranes (*Grus canadensis*), resulting in 4 unharvested cornfields containing less than 50 kg ha^{-1} in 2007. Fielder (2007) estimated between 30–70% of planted agricultural crops in Tennessee failed in 2007.

Duck-Energy Days

Seed mass estimates were above 50 kg ha^{-1} in harvested corn and grain sorghum fields in December, with fields providing an average of 748 and 1,381 DED ha^{-1}, respectively. My DED estimates in December for harvested corn and grain sorghum are 77% and 49% lower than those reported by Reinecke et al. (1989). Mean seed mass was below 50 kg ha^{-1} for soybean in December and for all crops in January. In January, DEDs were functionally zero in more than 85% of sampled agricultural fields. Thus, harvested agricultural fields in the southeastern United States probably provide limited amounts of agricultural seed to North American waterfowl.

Duck-energy days were substantial in unharvested corn, grain sorghum and soybean fields in December and January. Unharvested corn has the capability of energetically supporting the greatest number of waterfowl followed by grain sorghum (69,056 and 26,212 DED ha^{-1} in January, respectively). Unharvested soybeans provided the least amount of energy (17,675 DED ha^{-1} in January), and esophageal impaction by soybeans can cause waterfowl mortality under dry ambient conditions (Durant 1956, Jarvis 1969). Thus corn and grain sorghum may be superior to soybean as a waterfowl food source.

Management Implications

Results from my study indicate mass of corn, soybean and grain sorghum seed declines rapidly following harvest at southern latitudes and harvested fields may have little foraging value for waterfowl 2–3 months after harvest. My research suggests unharvested corn and grain sorghum food plots can provide substantial energy for waterfowl, and very little seed is lost if crops remain standing. Thus, waterfowl conservation efforts should continue to focus on providing high-energy unharvested crops plus natural (e.g., moist-soil) wetlands on public and private lands (Kross et al. 2008*a*, *b*). Additionally, wildlife biologists and landowners interested in managing for waterfowl may promote growth of moist-soil vegetation within food plots by increasing width between rows of planted corps (i.e., ca. 1 m) and limiting use of herbicide after crops are 30–60 cm in height (Kaminski and Brasher 2008). My estimates for agricultural seed abundance in harvested and unharvested fields can be used to calculate DEDs in the southeastern United States by multiplying field area by DED ha^{-1} values provided in Table II-3. I recommend using January estimates in Table II-3, because seed mass declined rapidly between December and January when waterfowl numbers peak. Given between-year differences in unharvested seed mass that I documented, biologists might consider using equations in Table II-2 to predict available mass. For more accurate estimates, yield data from combines that harvest adjacent fields or annual commercial yields from the National Agricultural Statistics Service (www.nass.gov) could be substituted for the intercept in the Table II-2 equations and solved.

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APPENDIX A:

TABLES AND FIGURES

Table II-1. Mass (kg ha^{-1}) of agricultural seed for waterfowl in harvested and unharvested fields for increasing number of months post-harvest and post-drydown, respectively, Tennessee U.S.A., 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 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 = No test performed because of insufficient replication.
Table II-1(continued).
[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 II-2. Exponential decay functions relating mass (kg ha^{-1}) of seed (MASS) in harvested fields to number of months post-harvest (TIME).

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

[a] ND = no difference between years by repeated-measures ANOVA.

Table II-3. Mass of agricultural seeds (kg ha^{-1}) and duck-energy days (DED) in harvested and unharvested fields in December and January 2006–2007, Tennessee, U.S.A.

			Month							
			December				January			
			Mass		DED ha^{-1}		Mass		DED ha^{-1}	
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

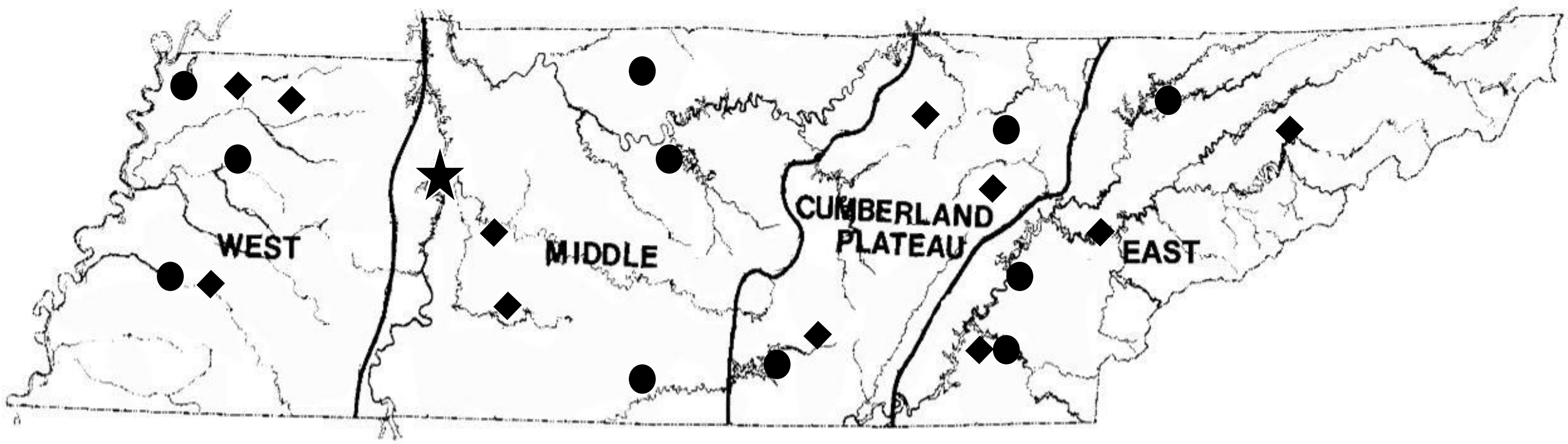

Figure II-1. Four climate regions of Tennessee, U.S.A. (U.S. Department of Commerce 1968; Redmond and Scott 1996). Circles and diamonds indicate locations of fields sampled on private and state land, respectively. The Tennessee National Wildlife Refuge (star) is where fields on federal land were located.

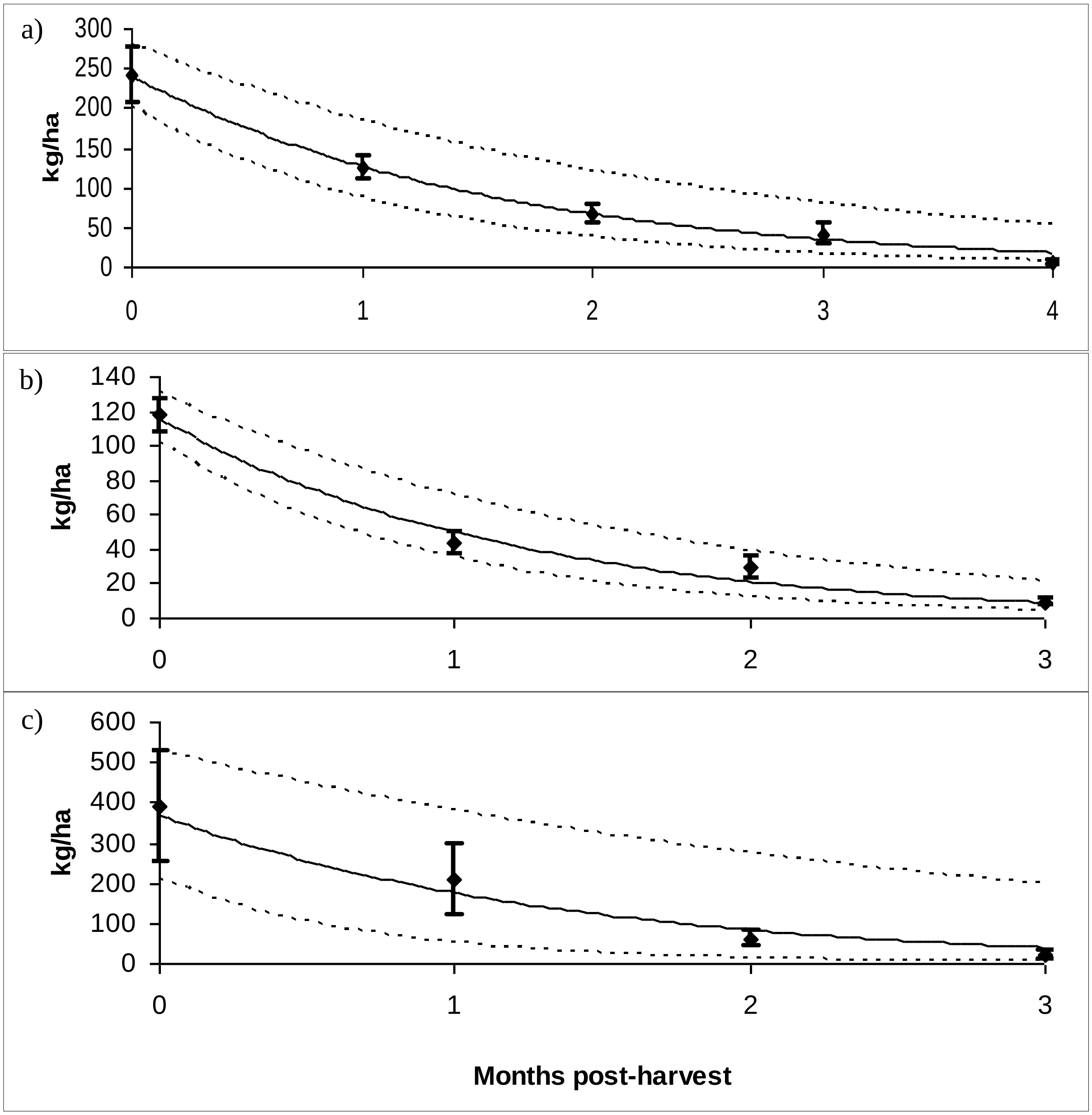

Figure II-2. Predicted mass of seed in harvested (a) corn, (b) soybean, and (c) grain sorghum fields in Tennessee, U.S.A. Error bars represent standard error about the mean, and dashed lines are upper and lower 95% confidence intervals for the model.

CHAPTER III

FATE OF AGRICULTURAL SEED IN HARVESTED FIELDS IN THE SOUTHEASTERN UNITED STATES

Abstract

Agricultural seed left in harvested fields is consumed by migrating and wintering waterfowl, yet recent studies suggest that rates of seed loss in harvested fields may be higher than historically. Seed could be lost to germination, decomposition or depredation. Rates of loss according to these possible fates have not been quantified for corn, soybean or grain sorghum. Therefore, I estimated rates of germination, decomposition and depredation for scattered seed and aggregate seed heads in 98 harvested corn, soybean and grain sorghum study plots located across Tennessee, U.S.A., from September – January 2006 and 2007. Total seed loss in plots between harvest and January was over 80%. Scattered corn seed was lost primarily (37−68%) to depredation, whereas soybean and grain sorghum seed were lost mostly (≥35%) to decomposition. Rates of germination generally decreased and decomposition rates increased from October through January for scattered corn and grain sorghum. Rates of loss were related to ambient temperature, relative humidity and post-harvest duration. Seed aggregated on seed heads (e.g., corn cobs) was lost more slowly than scattered seed. Wildlife biologists should consider planting corn instead of grain sorghum and soybean, because seed of the latter species decompose rapidly. For refuges that manipulate upland food plots for waterfowl, I recommend knocking down crops instead of mowing, which scatters seed and accelerates loss.

Introduction

Waterfowl frequently consume agricultural seed in harvested fields to meet energetic needs associated with migration, courtship, and thermoregulation (Baldassarre and Bolen 1984, Delnicki and Reinecke 1986, Combs and Fredrickson 1996). Through the 1980s, corn and grain sorghum seed in harvested fields commonly exceeded 200 kg/ha in early winter (Iverson et al. 1985, Warner et al. 1985, Warner et al. 1989). However, recent studies indicate the average mass of seed in harvested agricultural fields in early winter is 52–83% less than estimates from the 1980s (Manley et al. 2004, Stafford et al. 2006, Kross et al. 2008, Chapter II). Current decreased seed abundance may be a consequence of advances in combine efficiency and earlier harvest dates, which increase duration for seed loss to germination, decomposition or wildlife depredation (Manley et al. 2004, Stafford et al. 2006). Stafford et al. (2006) reported that 8, 14, and 58% of rice seed was lost to germination, decomposition and depredation between harvest and early winter. In addition to rice, important crops for wintering waterfowl in the southeastern United States include corn, grain sorghum and soybeans (Reinecke et al. 1989). In Chapter II, I documented monthly rates of seed mass decline were more than 64% in corn, soybean and grain sorghum fields, but I did not quantify the fate of seed loss, which is important for waterfowl biologists interested in mitigating this loss (Stafford et al. 2006).

Rates of seed decomposition, germination and depredation may vary among crop species and calendar months. These fates also may vary with local microclimate and whether seed is scattered on the ground or aggregated on a seed head. Several authors have noted that warm and humid conditions generally result in rapid seed loss (Atkeson and Givens 1952, Neely and Davison 1971, Warner et al. 1989), but none have quantified rates of loss to different fates. These rates may differ among crop species because of differences in seed morphology, potential for water uptake, and optimum germination temperatures. No studies have quantified seed fate among months or related rates of loss within a season to microclimate conditions (e.g., temperature, humidity, and precipitation). Further, a variety of resident and migratory wildlife species consume agricultural seed (Baumgras 1943, Baldassarre and Bolen 1984, Krapu et al. 2004, Pearse et al. 2008). Rates of seed depredation may differ among crop species as related to wildlife preference and food availability in the area, and among months as a result of changes in abundance of migratory species. The fate of seed on corn cobs and grain sorghum seed heads (hereafter: aggregates) may differ compared with scattered seed because much of the seed on aggregates is not in contact with the ground. Seed aggregates also may be depredated at greater rates because they are easier to detect. More information is needed to understand rates and fate of seed loss in harvested agricultural fields.

Estimates of the fate of seed loss in corn, soybean and grain sorghum fields are needed to better understand seed availability in agricultural landscapes and to derive strategies to manage waterfowl habitat more effectively. Thus, my objectives were to 1) estimate the cumulative and monthly rates of seed loss to germination, decomposition and depredation for scattered and aggregated seed, and 2) relate rates of loss to microclimate conditions.

Study Area

I conducted my study on private and state lands throughout Tennessee, U.S.A., from September – January 2006 and 2007. Study plots used to quantify fate of seed were located in unflooded agricultural fields on state and private land throughout the 4 regions of Tennessee (U.S. Department of Commerce 1968; Fig. II-1). Given that corn and soybean production occur statewide in Tennessee (NASS 2008), I placed paired 0.5625-m^2 fate plots (discussed below) in 4 harvested corn and soybean fields per region each year. Grain sorghum production in Tennessee is primarily restricted to the westernmost portion of the state (NASS 2008). Therefore, I placed plots in 5 harvested grain sorghum fields in western Tennessee. To increase spatial replication for this crop species, I also placed artificial grain sorghum plots in 4 harvested cornfields per region for the middle Tennessee, Cumberland Plateau and east Tennessee regions (Fig. II-1). Overall, I analyzed data from 98 plots (i.e., [16 corn + 16 soybean + 17 grain sorghum fields] × 2 years). These fields were located between 35º 15' – 36º 59' N and 82º 21' – 90º 04' W.

Methods

I estimated seed fate in two 0.75 × 0.75 m paired plots placed randomly in harvested agricultural fields. Given that agricultural fields across a landscape are not harvested simultaneously, plot placement occurred between September and December as fields were harvested. This created an unbalanced design, with sample size increasing from September – December (n = 6 – 32 per month). Plots were positioned exactly 5 m apart and at least 20 m from field edges to reduce potential edge effects.

To standardize plots, I removed all chaff and preexisting seed then scattered 100 randomly selected seeds and chaff to emulate field conditions. For grain sorghum plots in cornfields, I used chaff from harvested grain sorghum fields collected in western Tennessee. Given that grain sorghum plots were set up identical in corn and grain sorghum fields, I assumed that cornfields functioned as reasonable surrogates. In 2007, I expanded the study to include seed aggregates (i.e., corn cobs and grain sorghum seed heads), because loss may differ between scattered and aggregated seed, and both types can remain in a harvested field. Soybean was not included because soybean seeds are not aggregates. I placed one randomly collected seed aggregate in each paired corn and grain sorghum plot.

After plots were placed and set up, I randomly selected one plot (hereafter: enclosed plot), covered it with a granivore exclosure made of hardware cloth ($1 \times 1 \times 0.1$ m; mesh size = 0.635 cm), and anchored the exclosure with metal stakes. No exclosure was placed over the other plot (hereafter: open plot). I assumed the 5-m separation was sufficient to ensure plots were experimentally independent with respect to depredation rates (i.e., the presence of the exclosure did not draw granivores to the open plot). A HOBO® (model H8 pro, Onset Corp, Pocasset, MA) weather logger with solar radiation shield was placed in the plot with the exclosure, and microclimate assumed to be equal between plots. The logger recorded temperature and humidity every 6 h (0600, 1200, 1800 and 2400). I also acquired daily precipitation data from the nearest weather station, which was between 2−19 km from study fields.

Once per month, I counted the number of intact, germinated and decomposed seeds in the plots. No new seed was added for the duration of the experiment, but I removed decomposed and germinated seed to ensure that no seed was counted twice. Seed loss (i.e., missing seed) in the exclosures was assumed to be a result of decomposition, while loss of seed in the open plots was assumed to be a result of decomposition and depredation by granivores. Thus, the difference between disappearance rates in these plots represented depredation only. For grain sorghum plots located in cornfields, I only sampled the enclosed plot because quantifying depredation rates for grain sorghum seed in cornfields may not have been representative of depredation rates in harvested grain sorghum fields.

For seed aggregates, I initially counted the number of seeds on corn cobs and spikelets on grain sorghum seed heads. I defined a spikelet as the stem containing seed that originated from the pedicel (Jones 2005). Number of intact, germinated and decomposed seeds on cobs and spikelets were counted each month thereafter. Fates were tallied each month for individual seeds on corn cobs but I assigned fates to spikelets for grain sorghum seed heads because the arrangement and number of seeds (i.e., >600) contained on grain sorghum seed heads made counting individual seeds impractical (Kirby and Atkins 1968). When the majority (i.e., >50%) of the seed on a spikelet was germinated or decomposed, the entire spikelet was designated this fate. Similar to scattered seed, the difference in disappearance rates between the enclosed and open plots was used to calculate depredation.

Statistical Analyses

I measured monthly and cumulative percent losses to germination, decomposition and depredation. I calculated cumulative percent loss as the sum of seed (or spikelets for grain sorghum aggregates) lost to each fate from harvest through

January divided by the total number of seeds or spikelets when plots were established. I calculated monthly rates of loss as the sum of seed or spikelets lost to each fate during a given month divided by the total number of seeds or spikelets intact at the beginning of that month. I averaged daily measurements of temperature, relative humidity, and precipitation among days for each sampling month and field prior to analysis.

I tested if cumulative percent loss for each fate was different among crop species and between years using a 2-way analysis of variance (ANOVA; SAS Institute 1999:2116). I included year as an effect to account for potential annual variation in seed loss. Because fields were not harvested simultaneously, plots were established during different months within years. Thus, I also included the month of plot establishment as a blocking variable in the 2-way ANOVA model. Because seed loss on aggregates was estimated only during 2007, I used a one-way ANOVA to test for differences in cumulative percent loss between corn cobs and grain sorghum seed heads for each fate. I used 2-way repeated-measures ANOVA to test for differences among months and between years in monthly rates of loss for each fate and in monthly averages for each microclimate variable (SAS Institute 1999:2133-2145). When ANOVAs were significant, I used Tukey's Honestly Significant Difference (HSD) multiple comparison test to determine if pairwise differences existed for effects with >2 levels (SAS Institute 1999:1503). I performed all analyses using the SAS® system (SAS Institute, Cary, NC) at $\alpha = 0.05$.

Results

<u>Cumulative Percent Loss</u>

Species and year effects interacted for rates of germination, decomposition and depredation for scattered seed ($F_{2,72} \geq 3.3$, $P \leq 0.04$). Germination was greatest for soybean and grain sorghum in 2006 ($F_{2,36} = 8.5$, $P = 0.001$), but no differences were detected among species in 2007 ($F_{2,35} = 3.1$, $P = 0.06$; Fig. III-1a). Germination differed between years for corn and soybean ($F_{1,31} \geq 9.1$, $P \leq 0.01$), but not for grain sorghum ($F_{1,8} = 2.1$, $P = 0.19$; Fig. III-1a). Decomposition was greatest in sorghum fields in 2006 ($F_{2,36} = 8.6$, $P = 0.001$) and soybean and grain sorghum fields in 2007 ($F_{2,35} = 9.3$, $P < 0.001$; Fig. III-1b). Decomposition was greater in 2007 for soybean ($F_{1,31} = 6.7$, $P = 0.01$), but did not differ between years for corn and grain sorghum ($F_{1,31} \leq 0.96$, $P \geq 0.33$; Fig. III-1b). Rates of depredation differed among species in 2006 and 2007 ($F_{2,35} \geq 6.3$, $P \leq 0.01$; Fig. III-1c). Rate of corn depredation was greatest among species both years, but Tukey's HSD test did not detect pairwise differences in 2007. The cumulative rate of corn depredation was greater in 2006 than in 2007 ($F_{1,3} = 7.6$, $P = 0.01$). Depredation rate did not differ between years for soybean and grain sorghum ($F_{1,8} \leq 0.37$, $P \geq 0.56$; Fig. III-1c).

Cumulative percent germination was greater for grain sorghum aggregate seed heads ($\bar{x}$ = 20.0%, SE = 3.4) than for corn cobs ($\bar{x}$ = 0.9%, SE = 0.6; $F_{1,19} = 86.31$, $P < 0.001$). Cumulative percent decomposition also was greater for grain sorghum ($\bar{x}$ = 66.9%, SE = 4.9) than corn aggregates ($\bar{x}$ = 4.3%, SE = 1.1; $F_{1,19} = 314.8$, $P < 0.001$). I did not detect a difference in depredation between corn ($\bar{x}$ = 62.6%, SE = 10.7) and grain sorghum aggregates ($\bar{x}$ = 9.4%, SE = 5.4; $F_{1,19} = 3.7$, $P = 0.07$).

Monthly Losses

Germination rates decreased ($F_{3,50} \geq 4.6$, $P \leq 0.01$) and decomposition rates increased ($F_{3,50} = 29.9$, $P < 0.001$) from October through January for scattered corn seeds (Table III-1). Rates of germination and decomposition also differed among months for grain sorghum ($F_{3,30} \geq 7.1$, $P < 0.001$), but no pairwise differences were detected. No differences were detected among months for germination or decomposition of scattered soybean seed or for depredation rates of any species ($F_{1,16} \leq 5.1$, $P \geq 0.08$; Table III-1).

Decomposition of grain sorghum seed aggregates increased from November through January ($F_{2,29} = 25.2$, $P < 0.001$), whereas rates of germination decreased ($F_{2,29} = 10.5$, $P < 0.001$; Table III-1). Decomposition rate of corn cobs differed among months ($F_{3,35} = 5.2$, $P = 0.01$), but pairwise differences were not detected. Differences were not detected in germination or depredation rates for corn cobs or depredation rates for grain sorghum seed heads among months ($F_{3,28} < 2.6$, $P > 0.07$; Table III-1).

Changes in Microclimate

Month and year effects interacted for temperature ($F_{3,114} = 21.1$, $P < 0.001$). Temperature at plots decreased from October – January in 2006 and 2007 ($F_{3,49} \geq 120.4$, $P < 0.001$), but monthly patterns of decline differed between years (Fig. III-2). Relative humidity at plots increased from October – January ($F_{3,114} = 17.3$, $P < 0.001$), and was not different between years ($F_{1,71} = 1.7$, $P = 0.20$). Precipitation at weather stations near fields was greatest in November and January ($F_{3,114} = 15.9$, $P < 0.001$; Fig. III-2), and did not differ between years ($F_{1,71} = 2.6$, $P = 0.11$).

Discussion

An average of 82%, 80% and 98% of corn, soybean and grain sorghum seed in my plots was lost between harvest and January. These results mirror seed declines in harvested fields that I reported in Chapter II. Corn, soybean and grain sorghum mass declined an average of 84%, 78% and 95% between harvest and January in 105 agricultural fields in Tennessee (Chapter II). Similarly, 66−99% of rice seed was lost between harvest and early winter in the lower Mississippi Alluvial Valley (Manley et al. 2004, Stafford et al. 2006, Kross et al. 2008). Thus, seed loss dynamics in my fate plots likely is representative of harvested corn, grain sorghum and soybean fields in the region.

Similar to rice (Stafford et al. 2006), corn seed was lost primarily (37−68%) to depredation, whereas rates of soybean and grain sorghum depredation were low (≤17%). Low soybean depredation may be a result of rapid decomposition, which occurred at a rate of about 40% per month. In Chapter II, I documented that mean duck-energy days (DED) in soybean fields declined from 1,000 to 0 DED ha^{-1} after 1 month post-harvest. Similar to soybean, lower depredation rates of grain sorghum could be attributed to decomposition, which occurred at a rate of about 68% per month. In comparison, corn decomposed at a rate of about 30% per month. Low depredation rates for grain sorghum also may reflect regional preference of granivores, which could be related to the low prevalence of grain sorghum fields on the landscape (i.e., <1% cropland acreage in Tennessee; NASS 2008). Grain sorghum is readily consumed by white-fronted (*Anser albifrons*) and Canada geese (*Branta canadensis*) and a host of other wildlife (e.g., blackbirds [Passeriformes: Icteridae], sparrows

[Passeriformes: Emberizidae]) in regions where it is dominant on the landscape (Atkeson and Givens 1952, Neely and Davison 1971, Ballard and Tacha 1995). Coverage of cornfields is extensive in Tennessee (i.e., >25% of row-crop acreage; NASS 2008). It has been shown that corn is consumed by a variety of wildlife species, and may comprise >90% of the diet of some waterfowl species by volume (Atkeson and Givens 1952, Moore 1980, Krapu 2004). Thus, corn may be a valuable post-harvest agricultural food for wildlife, particularly in regions where rice or grain sorghum is not grown.

Differences in rates of seed fate differed among months and crop species. Rates of germination generally decreased, decomposition rates increased, and depredation remained constant from October through January for scattered corn and grain sorghum. Decreasing germination and increasing decomposition may have been driven by a decrease in ambient temperature and an increase in relative humidity, respectively. Optimum temperatures for germination for corn and grain sorghum range from 23–30 C, and germination potential for each species declines with decreasing temperature (Kanemasu et al. 1975, Tyagi and Tripathi 1983, Elmore et al. 2006). Temperatures were close to optimum during September 2006 and 2007, but decreased 4-fold at my study plots by January. Conversely, relative humidity was 10% lower in September compared to January. Water uptake by seeds may occur regardless of temperature (Elmore et al. 2006), thus high humidity may facilitate germination at high temperatures and decomposition at low temperatures. Increased rates of decomposition between October and January also may have been a consequence of exposure duration, which increases the likelihood of microbe colonization necessary for decomposition (Nelms and Twedt 1996). Rates of each fate were relatively constant among months for soybean, with decomposition greatest during all months. High rates of soybean decomposition have been noted by others (Atkeson and Givens 1952, Neely and Davison 1971), and may be a consequence of its relatively soft seed coat that readily absorbs water and facilitates microbe colonization.

Occasionally, I documented differences in decomposition, germination, and depredation rates between years. Cumulative rates of germination and decomposition were greater for corn and soybean, respectively, in 2007 compared to 2006. In 2007, drought conditions occurred throughout Tennessee. Rainfall deficits between May and August 2007 ranged from 23–38 cm throughout the state (Fielder 2007), which resulted in fields harvested earlier (NASS 2008). Consequently, plots were placed in the field earlier and for longer duration in 2007 than in 2006. Earlier harvest and longer duration likely contributed to these seed fates. Interestingly, less scattered corn seed was depredated in 2007, because a greater amount germinated. Thus, harvesting fields earlier may lead to more corn seed lost to germination and less available for wildlife consumption.

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

Management Implications

My results suggest that scattered corn seed in harvested fields is depredated more by wildlife than grain sorghum and soybean. Seeds of these latter species decomposed and germinated at relatively high rates. Thus, when given the opportunity, wildlife biologists should consider planting corn instead of grain sorghum or soybean in areas intended for wildlife use. My results also indicated that when cornfields are harvested early, a large percentage of seed will germinate. Thus, biologists should delay harvesting corn until wildlife use is intended. I also found rates of seed loss on aggregated seed heads (e.g., corn cob) are slower than scattered seed, thus on areas where hunting does not occur, biologists should consider knocking down food plots instead of mowing, which scatters seeds. For some wildlife (e.g., dabbling ducks), manipulating food plots may be necessary to facilitate use (Reinecke and Kaminski 1989). For agencies interested in modeling fate-based seed loss on a landscape scale, rates of loss in Table III-1 could be used. I recommend that future research inspect rates of agricultural seed loss to decomposition, germination and depredation for regions outside of the southeastern United States.

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APPENDIX B:

TABLES AND FIGURES

Table III-1. Percentage germination (G), decomposition (D) and depredation (P) among months for scattered (S) and aggregated (A) agricultural seed in randomly located in 0.56-m^2 plots in harvested fields, October – January 2006 and 2007, Tennessee U.S.A.

			Month[a]											
			October			November			December			January		
Species	Aggregation	Fate	*n*	$\bar{x}$ [b,c]	SE	*N*	$\bar{x}$	SE	*n*	$\bar{x}$	SE	*n*	$\bar{x}$	SE
Corn	S	G	9	34.0 A	11.1	26	26.7A	4.8	27	17.8 AB	3.9	26	6.1 B	3.9
	S	D	9	7.3 A	6.0	26	23.4 AB	5.7	27	35.7 BC	6.1	26	57.4 C	6.7
	S	P	9	29.7 A	10.7	26	20.7 A	5.9	26	35.8 A	7.1	22	46.1 A	8.8
	A	G	6	1.5 A	1.5	16	0.1 A	0.1	16	0.8 A	0.6	16	0.2 A	0.1
	A	D	6	0.6 A	0.4	16	2.2 A	1.4	16	3.3 A	1.2	16	5.8 A	1.4
	A	P	6	0.0 A	0.0	16	37.6 A	11.6	13	27.1 A	11.3	2	37.9 A	13.4
Soybean	S	G		NT		12	13.0 A	4.5	26	16.4 A	3.3	32	19.4 A	4.3
	S	D		NT		12	41.6 A	6.9	26	37.1 A	5.9	32	42.2 A	5.1
	S	P		NT		12	8.9 A	4.9	26	6.2 A	2.9	30	4.7 A	6.9

Table III-1. (Continued).

Sorghum	S	G	NT	24	31.3 A	4.9	28	17.8 A	3.7	15	1.6 A	1.4
	S	D	NT	24	49.6 A	4.3	28	74.7 A	4.6	15	80.2 A	7.1
	S	P	NT	6	18.3 A	8.3	7	7.0 A	3.7	3	13.9 A	2.4
	A	G	NT	15	8.2 A	2.0	17	3.9 B	1.0	16	0.0 B	0.0
	A	D	NT	15	17.2 A	2.5	17	40.7 B	5.4	16	53.6 B	6.7
	A	P	NT	4	2.0 A	2.0	4	11.1 A	11.1	2	39.3 A	39.3

[a]Sample size differed among months because fields were not harvested simultaneously and 100% of seed was lost prior to January for some plots.
[b]NT = no test performed due to insufficient replication (i.e., $n < 2$ fields).
[c]Means within rows followed by unlike letters are statistically different by repeated-measures ANOVA and Tukey's HSD test.

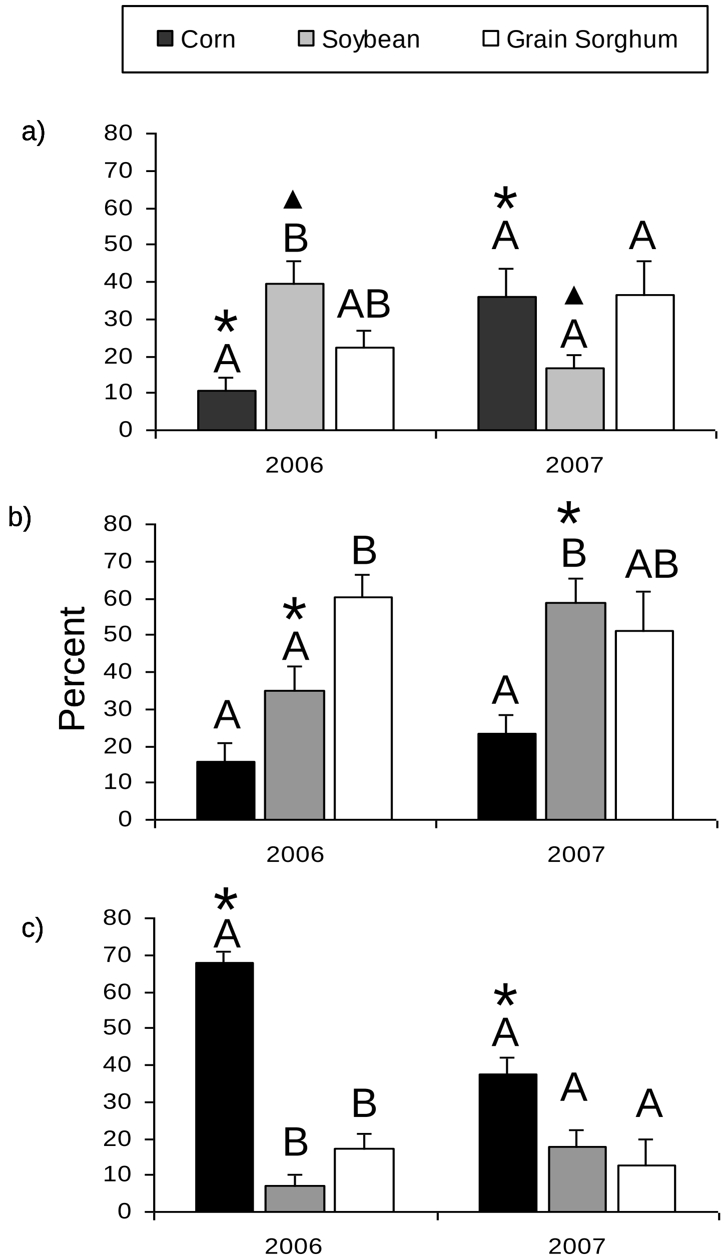

Figure III-1. Cumulative seed loss (%) from (a) germination, (b) decomposition and (c) depredation for corn, soybean and grain sorghum between harvest and January 2006 and 2007, Tennessee U.S.A. Bars within years with unlike letters are statistically different by ANOVA and Tukey's HSD test. Bars between years with like symbols (asterisks [*] or triangles [▲]) are statistically different by ANOVA.

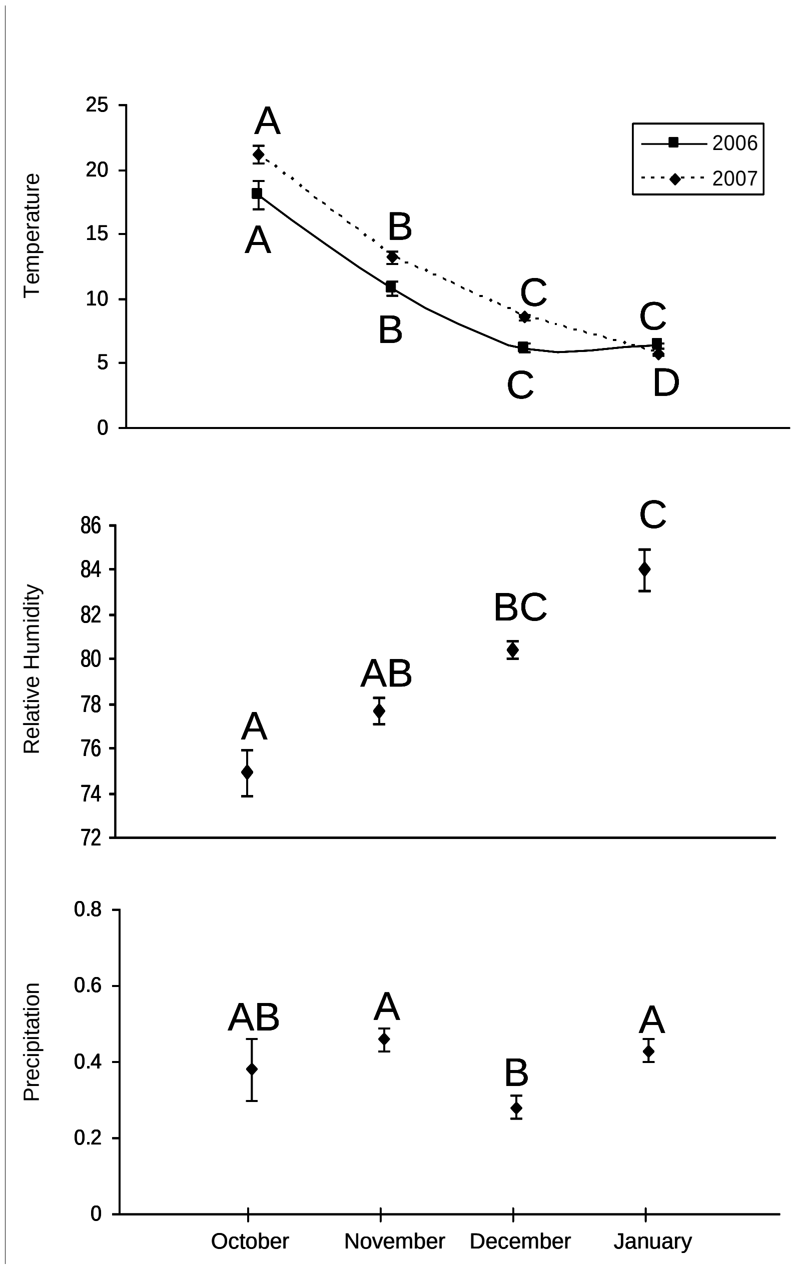

Figure III-2. Mean temperature (C), relative humidity (%) and precipitation (cm) among months at study plots, October–January 2006 and 2007, Tennessee, U.S.A. Temperature was separated by year due to an interaction with month effects. Months with unlike letters are statistically different by ANOVA and Tukey's HSD test.

CHAPTER IV

IMPACTS OF FLOODING ON AGRICULTURAL SEED LOSS

Abstract

Agricultural fields managed for waterfowl are typically flooded prior to the opening of hunting season, which could influence seed loss. Thus, I compared rates of loss between seed contained in 90 wire mesh bags placed in an unflooded field or submersed in a flooded field on the Tennessee National Wildlife Refuge. Agricultural seed mass declined 40−300% more rapidly underwater than on dry land. Mass of corn, soybean and grain sorghum seed declined 42%, 87% and 46%, respectively, after 12 weeks of submersion. These rates of decline were similar to previous studies. However, the rate of seed mass loss in unflooded seed bags (22%, 63%, and 14% for corn, soybean and grain sorghum) was lower than seed loss observed in harvested fields in Chapter II (79%, 81%, and 97%, respectively). I hypothesize this difference in decline was an artifact of the mesh bags that contained the seed. My results suggest that biologists should delay flooding harvested agricultural fields for waterfowl until immediately prior to their arrival, and be aware that absolute estimates of seed loss from studies that use mesh bags may be biased negatively.

Introduction

Waterfowl managers frequently flood agricultural fields to provide hunting opportunities. Research suggests that agricultural seed loss in flooded fields is rapid. Rates of corn and grain sorghum seed loss underwater in South Carolina and

Mississippi were around 50% for corn and 42% for grain sorghum after 90 d (Neely 1956, Nelms and Twedt 1996). However, these rates of loss are lower than what that I found in Chapter II in unflooded fields between harvest and January for corn (84%) and grain sorghum (95%). For soybean, seed loss in my unflooded fields (78%) was lower than submersed seed (>86%) over similar duration (Neely 1956, Nelms and Twedt 1996). Given that seed loss in flooded and unflooded fields has never been quantified simultaneously, it remains unclear whether seed loss is greater underwater or on dry land. Therefore, my objective was to compare rates of loss between seed in an unflooded field and submersed in a flooded field.

Study Area and Methods

I conducted my study on the federally-owned Tennessee National Wildlife Refuge Duck River Unit (NWR; 35º 58' 23" N, 87º 57' 46" W) from October 2007 – January 2008. Rates of seed loss were quantified in flooded and unflooded zones of a cornfield. I used a cornfield because it was the only crop type that was flooded on the refuge, hence available for sampling. I assumed rates of seed loss would be similar in flooded grain sorghum and soybean fields. My sampling methods followed the general procedures of Shearer et al. (1969). Specifically, I prepared 40 wire mesh bags (12.7 × 20.3 cm) each for corn, soybean and grain sorghum, and placed 100 randomly selected seeds acquired from agricultural fields on the refuge in each bag. For each species, 10 seed bags were taken to the lab and used to generate estimates of initial dry weight. I did not dry and weigh seed bags that were placed in the field because drying may have affected rates of loss. I placed 15 bags per species in flooded and unflooded zones of the cornfield on 16 October 2007. The flooded zone was unharvested for waterfowl management and the unflooded zone was harvested. Therefore, I cut and removed corn stalks in a 15-m radius surrounding the seed bags to simulate conditions in a flooded harvested field. Submersed bags were placed at common depth (ca. 45 cm). Unflooded bags were placed on the ground in the harvested field approximately 100 m upslope of the flooded bags. Bags were strung 10−15 cm apart along 12-gauge wire and attached to metal posts so they could be relocated. I removed 5 submersed and unflooded bags every 4 weeks thereafter, and ended the study at 12 weeks. Within 24 h of removal from the field, I dried seed to constant mass in a drying oven (72 h at 90 C for soybeans and grain sorghum, and 48 h at 103 C for corn; Chapter II) and weighed seed to the nearest 0.01 g. I weighed remaining seed only, because counting seeds became impossible as deterioration progressed.

Statistical Analyses

I used 2-way ANOVA to test for differences in mass between treatments (submersed and unflooded) and among 4 post-placement durations (0, 4, 8, and 12 weeks) for seed bags on Tennessee NWR (SAS Institute 1999:1504). When ANOVAs were significant, I used Tukey's Honestly Significant Difference (HSD) multiple comparison test to determine if pairwise differences existed for effects with more than 2 levels (SAS Institute 1999:1503). I performed all analyses using the SAS® system (SAS Institute, Cary, NC) with $\alpha = 0.05$.

Results

Mass of corn seed remaining in unflooded ($\bar{x}$ = 84%, SE = 2.5%) bags was greater than in submersed bags ($\bar{x}$ = 68.5%, SE = 5.4%; $F_{1,39}$ = 32.9, P < 0.001), and decreased with post-placement duration ($F_{2,39}$ = 17.3, P < 0.001; Fig. IV-1a). Treatment and duration effects interacted for soybean and grain sorghum ($F_{2,39} \geq 8.8$, P < 0.001). Except for initial mass, soybean and grain sorghum seed mass remaining in submersed bags was lower than in unflooded bags for each duration ($F_{1,9} \geq 24.7$, $P \leq 0.001$; Fig. IV-1b,c). Mass in bags decreased with increasing duration post-placement for submersed and unflooded soybean and grain sorghum seed ($F_{2,14} \geq 13.5$, P < 0.001), but the pattern of decline differed between flooding treatments (Fig. IV-1b,c).

Discussion

Mass of corn, soybean and grain sorghum seed declined 42%, 87% and 46%, respectively, after 12 weeks of submersion. These rates of decline were similar to rates reported from the 1950s in South Carolina and 1990s in Mississippi for similar duration (i.e., 39−50% for corn, 86−91% for soybean, and 42% for grain sorghum; Neely 1956, Nelms and Twedt 1996). Therefore, rates of underwater seed decline may be fairly consistent across flooded agricultural fields in the southeastern United States.

Percent decline in seed mass underwater (42% for corn, 87% for soybean, and 46% for grain sorghum) was greater than on dry land (22% for corn, 63% for soybean and 14% for grain sorghum). Dry seed generally has high water potential that enables rapid water uptake to facilitate germination (Leubner 2000). Thus, when seeds are submersed in water, they often swell and soften which compromises the seed coat and can promote colonization by microbes. Further, aquatic environments are excellent reservoirs of microbes that contribute to decomposition (Mitsch and Gosselink 2000:206). Thus, I hypothesize that the differences in rates of loss between submersed and unflooded seed was a combination of greater rates of imbibition, seed coat deterioration, and microbe colonization in the aquatic environment.

Interestingly, the rate of seed mass decline in unflooded seed bags was lower than cumulative rates of decomposition and germination measured in harvested fields in Chapter II (i.e., 79% for corn, 81% for soybean and 97% for grain sorghum), and inconsistent with field observations by others that agricultural seed tends to decompose rapidly in wet conditions (Atkeson and Givens 1952). I hypothesize that lower rates of seed decline are an artifact of the bags that contained the seed, which might limit surface area contact between the seed, substrate and microbes. Given it is common procedure to estimate seed loss using mesh bags (Neely 1956, Shearer et al. 1969, Nelms and Twedt 1996), researchers should recognize these estimates may be biased negatively. The bags I used were identical between flooding treatments, thus I assume they did not confound relative seed loss results.

Management Implications

Agricultural seed mass declined 40−300% more rapidly underwater than on dry land. Thus, biologists should delay flooding harvested agricultural fields for waterfowl until immediately prior to their arrival. Conversely, shallow flooding of unharvested food plots prior to the arrival of waterfowl should not result in increased seed loss if ears are not submersed. Moist-soil management impoundments flooded for waterfowl may be superior to flooded harvested agricultural fields because natural wetland seeds decompose more slowly than agricultural seeds (Neely 1956, Shearer et al. 1969, Nelms and Twedt 1996). Finally, biologists should be aware that absolute values of seed loss from studies that use mesh bags for estimates may be biased negatively.

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APPENDIX C:

TABLES AND FIGURES

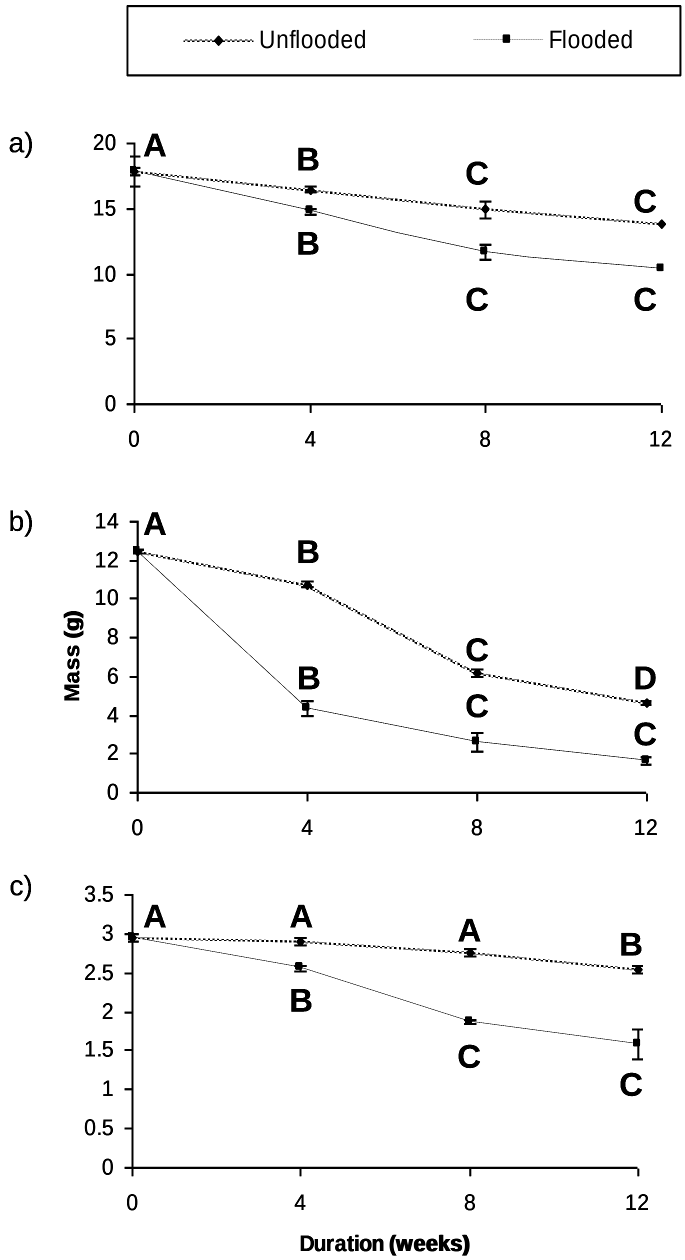

Figure IV-1. Corn (a), soybean (b) and grain sorghum (c) mass between flooding treatments and among weeks post-placement of seed bags, Tennessee National Wildlife Refuge, October−January 2007. Means within treatments with unlike letters are statistically different by ANOVA and Tukey's HSD. Except for duration = 0, flooding treatments always were different.

CHAPTER V

CONCLUSIONS AND MANAGEMENT RECOMMENDATIONS

Waterfowl frequently consume agricultural seed during fall and winter to meet energetic needs associated with migration, courtship and thermoregulation (Baldassarre and Bolen 1984, Delnicki and Reinecke 1986, Combs and Fredrickson 1996). Biologists estimate waterfowl carrying capacity on the landscape (i.e., duck-energy days [DEDs]; Prince 1979) in migrating and wintering areas each year to determine if sufficient food resources exist to support continental populations. Reliable estimates of DEDs require accurate estimates of food abundance for waterfowl (Reinecke et al. 1989). Estimates of agricultural seed mass in harvested and unharvested corn, grain sorghum and soybean fields do not exist or are outdated for the southeastern United States. Therefore, I estimated agricultural seed mass in 105 harvested and 59 unharvested corn, grain sorghum and soybean fields across Tennessee, U.S.A., from September through January 2006 and 2007. I used estimates of seed abundance to calculate DEDs in January, which is when migratory waterfowl abundance peaks in the southeastern United States (Pearse et al. 2008; R. Wheat, U.S. Fish and Wildlife Service, unpublished data). To better understand mechanisms driving seed loss in harvested agricultural fields, I estimated rates of germination, decomposition and depredation between harvest and January for scattered and aggregate seed in 98 harvested corn, soybean and grain sorghum fields. Finally, agricultural fields managed for waterfowl are commonly flooded prior to the opening of hunting season, but it remains unclear whether seed loss is greater underwater or on dry land. Therefore, I compared seed loss between flooded and unflooded fields.

My results indicated mean mass of corn, grain sorghum and soybean (239, 392 and 118 kg ha^{-1}, respectively) immediately post-harvest has decreased since the late 1970s and mid-1980s, likely due to improvements in harvesting technology (Baldassarre et al. 1983, Iverson et al. 1985, Warner et al. 1989, Krapu et al. 2004). Seed mass declined rapidly following harvest. Continuous monthly rates of decline were 64% for corn, 84% for soybean, and 74% for grain sorghum (Table II-2). Seed in harvested corn and grain sorghum fields dropped below 50 kg ha^{-1} in 3 months, and soybean dropped below this threshold within 1 month post-harvest. The 50 kg ha^{-1} threshold is referred to as the “giving-up” density, which is believed to be the food density when waterfowl abandon sites because it becomes no longer energetically profitable to continue foraging (Reinecke et al. 1989, Rutka 2004). By January, mean mass of corn, soybean and grain sorghum were 39, 26 and 19 kg ha^{-1}, respectively. Thus, harvested corn, soybean and grain sorghum fields in the southeastern United States likely provide few food resources for migrating and wintering waterfowl.

Mean DEDs ha^{-1} in harvested corn, grain sorghum and soybean fields during January were low (274, 90 and 27, respectively), and DEDs were zero in more than 85% of fields on the landscape. My estimates for abundance of agricultural seed in harvested and unharvested fields can be used to calculate DEDs in the southeastern United States by multiplying field acreage by DED ha^{-1} values provided in Table II-3. I recommend using the January estimates because seed mass declined rapidly between December and January, and waterfowl numbers generally peak in January in the

Southeast. My seed mass and DED estimates likely represent a best-case scenario for harvested corn, grain sorghum and soybean fields in the southeastern United States, because: 1) rates of seed loss are related with temperature (Chapter III), thus loss is likely greater south of Tennessee, and 2) post-harvest treatment (e.g., grazing, tilling) can drastically reduce (>70%) seed abundance (Frederick and Klaas 1982, Baldassarre et al. 1983, Iverson et al. 1985, Warner et al. 1985). Therefore, it is unlikely that harvested agricultural fields in the southeastern United States contribute substantially to sustaining North American waterfowl populations.

In contrast mean DEDs ha^{-1} in unharvested corn, soybean and grain sorghum fields in January were large (69,000, 18,000 and 26,000), and continuous rates of decline (3%, 7% and 18%) were much lower than for harvested crops. Given unharvested food plots can provide substantial energy for waterfowl, and very little seed is lost if crops remain standing, waterfowl conservation efforts should continue to focus on providing high-energy unharvested agricultural food plots. Producers also might consider leaving a portion of crops standing given that waterfowl hunting leases can be lucrative. Hunting waterfowl over standing crops requires flooding, but several conservation programs exist (e.g., Ducks Unlimited Partners Project) that provide cost-share incentives to landowner's to develop flooding infrastructure on private lands. Unharvested soybeans provided the least amount of energy, and esophageal impaction of soybeans can cause waterfowl mortality under certain conditions (Durant 1956, Jarvis 1969). Thus, I do not recommend planting soybean food plots for waterfowl.

Agricultural grains can provide substantial energy but cannot sustain waterfowl alone, because they lack essential nutrients (Loesch and Kaminski 1989). Unharvested agricultural crops should be used in combination with natural wetlands to meet the energy needs of migrating and wintering waterfowl (Kross et al. 2008*a*, *b*). Additionally, managers may promote growth of moist-soil vegetation within croplands by increasing width between rows of planted corps (i.e., ca. 1 m) and limiting use of herbicide after crops are 30–60 cm in height (Kaminski and Brasher 2008).

Rates of germination, decomposition and depredation were different among crop types, between scattered and aggregate seed, and whether seed was flooded. Scattered corn seed was lost primarily (37−68%) to depredation, whereas soybean and grain sorghum seed were lost mostly (≥35%) to decomposition and germination. Thus, I recommend that wildlife biologists plant corn instead of grain sorghum and soybean when possible, because of the high percentage of seed loss to decomposition and germination for the latter species. For agencies interested in modeling fate-based seed loss on a landscape scale, rates of loss in Table III-1 could be used. Rates of germination generally decreased and decomposition rates increased from October through January for scattered corn and grain sorghum. Rates of loss were related to ambient temperature, relative humidity, and duration post-harvest. For corn, a greater percentage of seed germinated when fields were harvested earlier. Thus, I recommend that high-priority cornfields planted for waterfowl should be harvested as close as possible to the arrival of fall migrants whenever logistically and economically feasible. I also found that rates of seed loss on aggregated seed heads (e.g., corn cobs) are slower than scattered seed. Thus, biologists on refuges should consider knocking down food plots instead of mowing, which scatters seeds and increases loss. Agricultural seed mass declined 40−300% more rapidly underwater than on dry land. Thus, when possible, managers should delay flooding agricultural fields until immediately prior to the arrival of waterfowl.

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VITA

Melissa Ann Foster was born in Lansing, MI on August 13, 1983. She was raised and completed high school at Holt High School in 2001 in Holt, MI. From there, she went to Lansing Community College then to Michigan State University where she received her B.S. in Zoology (Ecology and Evolutionary Biology Concentration) in 2006. Melissa went on to the University of Tennessee to receive her M.S. in Wildlife and Fisheries Science in Spring 2009.