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Research Article

Agricultural Practices and Residual Corn During Spring Crane and Waterfowl Migration in Nebraska

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ABSTRACT Nebraska's Central Platte River Valley (CPRV) is a major spring-staging area for migratory birds. Over 6 million ducks, geese, and sandhill cranes (*Grus canadensis*) stage there en route to tundra, boreal forest, and prairie breeding habitats, storing nutrients for migration and reproduction by consuming primarily corn remaining in fields after harvest (hereafter residual corn). In springs 2005–2007, we measured residual corn density in randomly selected harvested cornfields during early ($n = 188$) and late migration ($n = 143$) periods. We estimated the mean density of residual corn for the CPRV and examined the influence of agricultural practices (post-harvest field management) and migration period on residual corn density. During the early migration period, residual corn density was greater in idle harvested fields than any other treatments of fields (42%, 48%, 53%, and 92% more than grazed, grazed and mulched, mulched, and tilled fields, respectively). Depletion of residual corn from early to late migration did not differ among post-harvest treatments but was greatest during the year when overall corn density was lowest (2006). Geometric mean early-migration residual corn density for the CPRV in 2005–2007 (42.4 kg/ha; 95% CI = 35.2–51.5 kg/ha) was markedly lower than previously published estimates, indicating that there has been a decrease in abundance of residual corn available to waterfowl during spring staging. Increases in harvest efficiency have been implicated as a cause for decreasing corn densities since the 1970s. However, our data show that post-harvest management of cornfields also can substantially influence the density of residual corn remaining in fields during spring migration. Thus, managers may be able to influence abundance of high-energy foods for spring-staging migratory birds in the CPRV through programs that influence post-harvest management of cornfields.

KEY WORDS agriculture, food, Nebraska, Platte River, sandhill crane, spring migration, waste corn, waterfowl.

Spring migration is a period of high energetic demand in the annual cycle of migratory waterfowl, including costs of flight, thermoregulation during extreme weather events, nutrient acquisition, contour feather molt, and pairing in some species (Alisauskas and Ankney 1992*a*, Arzel et al. 2006, Anteau and Afton 2009). Survival, reproductive success, and concomitant population size of migratory birds are influenced by nutrition during spring migration or upon arrival at breeding areas (Ebbinge and Spaans 1995, Alisauskas 2002, Anteau and Afton 2004, Drent et al. 2006, Newton 2006). Therefore, forage conditions along spring migration corridors probably have important influences on lipid reserves, reproductive success, and ultimately population size of migratory birds (Krapu et al. 1985, 2004; Anteau and Afton 2008, 2009; Devries et al. 2008).

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The Central Platte River Valley (CPRV) of south-central Nebraska is recognized as one of the most significant mid-continent habitats for migratory birds in North America (Krapu et al. 2004). The area hosts >6 million waterfowl during spring, including most of the mid-continental population of greater white-fronted geese (*Anser albifrons*); millions of snow (*Chen caerulescens caerulescens*), Ross's (*C. rossi*), and Canada geese (*Branta canadensis*); and nearly the entire population of mid-continental sandhill cranes (*Grus canadensis*; Krapu et al. 1982, Vrtiska and Sullivan 2009). Moreover, the CPRV is an important migration stopover area for the federally endangered whooping crane (*Grus americana*; Lewis 1995). Therefore, effective management of foods consumed by migratory birds is a critical step to ensuring reproductive success for millions of birds that ultimately breed in the tundra and boreal forests in Canada, Alaska, and Siberia and the prairies of the United States and Canada.

Since the onset of agriculture in south-central Nebraska, natural foods and habitats for migratory birds have declined dramatically; concomitantly, spring-staging migratory waterfowl and cranes have increased dependence on residual corn to meet their energetic needs (Krapu et al. 2004). Waterfowl and cranes staging in the CPRV store significant proportions of nutrient reserves needed for migration and reproduction by consuming corn remaining in fields after harvest (Reinecke and Krapu 1986; Krapu et al. 1995, 2004). However, recent shifts from corn to soybean production combined with increased harvest efficiency have resulted in lower abundance and quality of foods available to spring-staging migratory birds (Krapu et al. 2004). Moreover, the recent increase of the mid-continental population of lesser snow geese, their use of the CPRV, and their preference for residual corn during spring has the potential to dramatically alter the amount of corn available to other species (Alisauskas and Ankney 1992*b*, Krapu et al. 2005, Pearse et al. 2010). Thus, there is a premium on effectively managing this limited resource.

Corn producers in Nebraska implement a variety of post-harvest management practices for several purposes, including preparation for subsequent plantings, weed control, and feeding livestock (Krapu et al. 1995). Examples of the most common post-harvest treatments in the CPRV include: 1) grazing cattle on residual corn and stubble; 2) mulching or mowing corn stubble; 3) grazing cattle on mulched stubble; 4) soil disturbance via tilling, discing, or plowing; or 5) leaving the harvested cornfield undisturbed (with standing stubble). Each of these practices alters structure of the soil or residual corn stubble, suggesting that they also may influence the amount of residual corn available to migratory birds during spring migration (Baldassarre et al. 1983). Thus, estimates of abundance, distribution, spatial extent, and depletion of residual corn in the CPRV should account for variation among post-harvest management practices. These data will be useful to biologists and land managers in the CPRV in predicting consequences of land management activities for spring-staging birds and efforts to model energetics for migratory birds in the CPRV.

Our objectives were to: 1) evaluate the effects of common post-harvest field management practices on residual corn density during early spring, 2) evaluate the effects of post-harvest field management on depletion of residual corn during the spring migration period for migratory birds, and 3) provide unbiased estimates of residual corn density for the CPRV during early and late spring migration of waterfowl and cranes in relation to post-harvest field management.

STUDY AREA

Our study area consisted of all lands within a 4.8-km buffer of the outermost channel of the Platte River between Lexington, Nebraska and Chapman, Nebraska (Fig. 1). This area, approximately 160 km in length, was known as the Big Bend of the Platte River and corresponded to 2 major sandhill crane spring staging areas (Krapu et al. 1982, 1984). Because mean flight distance of sandhill cranes from Platte River roosts to foraging areas is <2 km (Sparling and Krapu 1994), the 4.8-km buffer accounted for most foraging habitats used by cranes.

METHODS

Study Design

We measured corn density in a sample of fields that was balanced with respect to post-harvest treatment and spatial strata (hereafter, segments; see below). Thus, we used analysis of variance (ANOVA) in an experimental framework to quantify effects of post-harvest treatments and depletion by migratory birds on residual corn density. We used stratified random sampling that allowed us to apply a multi-stage sampling (MSS) design (Stafford et al. 2006*a*,*b*; Brasher et al. 2007; Kross et al. 2008*b*) to estimate density of

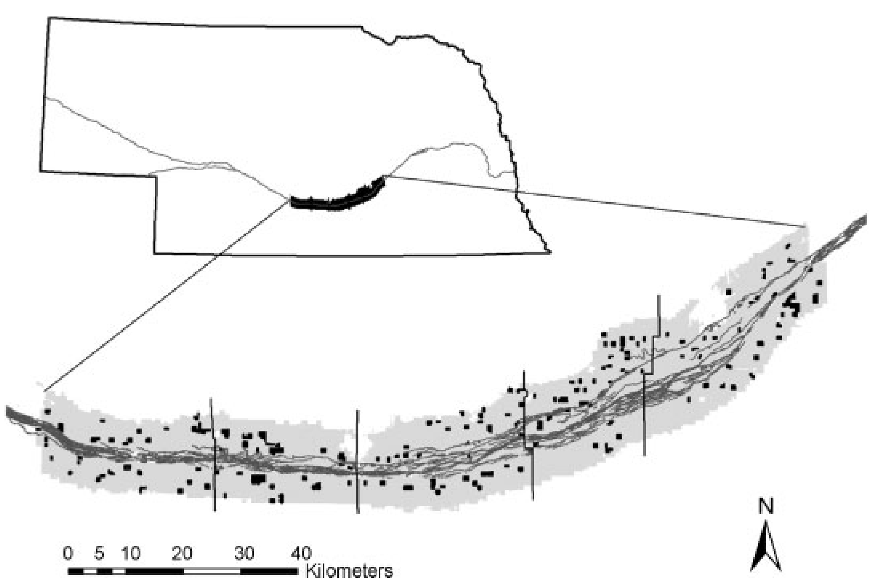

Figure 1. Selected cornfields (2005–2007) within the Central Platte River Valley study area, Nebraska; solid vertical lines indicate locations of segment boundaries. Gray background represents all agricultural fields within 4.8 km of the outermost channel of the Platte River. Dark symbols represent fields in which we measured corn density.

residual corn in each post-harvest field treatment and for the CPRV as a whole. The nonweighted ANOVA analysis is an experimental evaluation of post-harvest management effects on residual corn density, which provided information about the processes that may reduce residual corn density and could have application to areas outside the CPRV. The MSS approach provided weighted unbiased estimates of residual corn for the CPRV.

We divided the study area into 5 segments, each approximately 32 km in length. Bridges over the Platte River at US-183 (Elm Creek), NE-10, NE-11 (Wood River), and US-34 (Grand Island–Phillips) served as segment boundaries (Fig. 1). Each year we randomly selected candidate cornfields within each segment, using the United States Department of Agriculture Farm Service Agency's (FSA) data layer of Common Land Units (CLUs; A. Bishop, U.S. Fish and Wildlife Service, unpublished data) as the sampling frame. We visited these fields in a random sequence until we met our goal of 3 fields in each of 5 post-harvest treatments (see below) within each segment. We selected new fields each year to ensure that our sampling was spatially diverse.

We included fields only if they could be exclusively assigned to one of the following treatments, after visual inspection and discussion with the landowner: 1) grazed–grazed by cattle prior to arrival of birds in the spring; 2) mulched–corn stalks and litter were mulched during or after harvest but prior to arrival of birds in the spring; 3) mulched and grazed–corn stalks and litter may be mulched during or after harvest and cattle have grazed prior to arrival of birds in the spring; 4) tilled–post-harvest tillage by discing, generally during fall but in all cases prior to arrival of birds in the spring; and 5) idle–field not manipulated after fall harvest. Because we were simultaneously interested in migratory bird use of harvested corn, we excluded fields $<$16.2 ha to prevent edge effects on responses by birds. Mean (SD) size of sampled fields was 39.4 (17.9) ha; field size ranged 16.2–121.4 ha.

Sampling

We sampled residual corn twice for each field to quantify corn potentially available to birds at the beginning of spring migration and remaining after many birds had departed. Our sampling generally corresponded with early migration (2 Feb to 4 Mar 2005; 9 Feb to 6 Mar 2006; and 21 Feb to 9 Mar 2007) and late migration (28 Mar to 7 Apr 2005; 28 to 31 Mar 2006; and 26 to 28 Mar 2007) of ducks, geese, and cranes. Due to weather, snow cover, logistical constraints, and producer activities we were unable to time sampling periods to correspond with actual pre-arrival or post-departure, but we believe that we captured most of the staging period for target species.

Some producers began tilling and mulching in early April to prepare for the growing season, causing a treatment change for some of our fields before late-migration sampling could occur (Table 1). We measured late-migration corn density only in fields that did not experience a treatment change between the sampling periods ($n = 143$; Table 1), and we excluded fields with treatment changes from all analyses requiring late-migration data.

We sampled residual corn using methods similar to Frederick et al. (1984), Reinecke and Krapu (1986), and Krapu et al. (2004). We sampled proportionally to area, sampling at 3–6 randomly chosen sampling locations in each field (numbers of locations corresponded to field size) during each sampling period (without replacement); however, we did not sample within 20 m of field edges. At each location, we positioned a 36-m^2 large plot adjacent to a 4-m^2 small plot (Frederick et al. 1984). We collected all loose kernels and ears or pieces of ears from the small plot, and we collected ears or pieces of ears containing $\geq$10 kernels from the large plot (Frederick et al. 1984). We collected corn from the surface of the soil; we moved litter to search for corn within plots. We: 1) removed kernels from cobs, 2) sifted kernels over 6.35-mm wire mesh, 3) dried them to a constant mass at 50–55° C, and 4) weighed them ($\pm$0.01 g).

In springs 2006 and 2007 we conducted roadside surveys to classify CPRV cornfields by post-harvest treatment. We randomly located surveys within each segment by driving the shortest drivable route between 2 randomly selected fields. We were unable to classify fields in 2005, so we pooled data from 2006 to 2007 to calculate the overall proportion of cornfields in each post-harvest treatment for each segment and for the entire study area. We conducted these surveys before producers began late spring field preparation, so these data reflect relative abundance of field treatments during early migration.

Area Planted to Corn

We obtained color infrared (CIR) aerial photography for the growing season prior to each of our field seasons (1 Aug to 1 Sep 2004, 2005, and 2006). We created a mosaic of orthorectified, color-balanced imagery for each study year, and clipped the images to our study area boundary.

The CLU data layer is a vector data set representing the agricultural field boundaries used to administer Federal farm programs. It was created by digitizing tract boundaries by county and verified by producers. We merged the applicable

Table 1. Numbers of corn fields sampled during early and late migration each year by post-harvest treatment type in the Central Plate River Valley, Nebraska, 2005–2007. The late-migration sample is a subset of the fields sampled during early migration that did not experience a post-harvest treatment change.

	2005		2006		2007	
Post-harvest treatment	**Early**	**Late**	**Early**	**Late**	**Early**	**Late**
Idle	13	5	14	10	15	9
Grazed	13	4	15	11	15	9
Mulched	12	11	13	13	11	11
Mulched and grazed	10	5	14	13	10	10
Tilled	9	8	13	13	11	11

county CLUs and clipped them to our study area boundary. We used this data layer to create a mask over the aerial photography and refined the field boundaries in the CLU based on the applicable year's photography. This step accounted for parcels on which agricultural production had started or terminated during that year, ensuring that our annual revision of the CLU accurately depicted agricultural activities in the study area.

For each agricultural tract identified in the CLU, we determined cultivated crop types based on the National Agricultural Statistics Service (NASS) cropland data layer (National Agricultural Statistics Service 2002–2007). The NASS data layer is a statewide inventory of cropping patterns derived from Indiana Remote Sensing Advanced Wide Field Sensor satellite imagery with a 56-m pixel size. Because this pixel size could limit applicability of the NASS data set at our desired spatial scale (Thogmartin et al. 2004), we integrated the CLU and NASS data to produce an appropriately scaled, spatially explicit cropping inventory for our study area. We used zonal statistics commands in Earth Resources Data Systems software (ERDAS 1999) to populate each CLU feature in the study area with the major crop type identified in the NASS data set. We then validated the cropping practice identified for each feature through photo interpretation using the corresponding year's CIR imagery. Each year a subset of agricultural producers report area planted to county FSA field offices, and these data are recorded using the county-based CLU data sets. We extracted a subset of these data to assess accuracy of our annual cropping inventories.

Statistical Analyses

We used mixed model ANOVA to test hypotheses for objectives 1 (post-harvest treatment effects on corn density) and 2 (post-harvest treatment effects on depletion of residual corn). We accounted for the right-skewed distribution of corn density data by conducting ANOVAs on corn densities (kg/ha) that we log-transformed (ln $[x + 1]$) at plots. Because our interest in these objectives was in experimental effects, we used unweighted observations, and we present back-transformed geometric means for objective 1 that are appropriate for comparison between levels of effects. We met objective 3 using PROC SURVEYMEANS to estimate mean and 95% confidence limits of residual corn density for the CPRV under the MSS design (SAS Institute 2002; Stafford et al. 2006*a*,*b*; Brasher et al. 2007; Kross et al. 2008*b*). Because our interest in this objective was in corn density for the CPRV as a whole, we weighted our observations and computed arithmetic means.

We used linear models in PROC MIXED (SAS Institute 2002) to test for effects of post-harvest treatment of cornfields on density of residual corn. These models included data from all cornfields sampled during the early migration period, regardless of whether a treatment change occurred between sampling periods ($n = 188$ fields). We included field(segment $\times$ year $\times$ treatment) as a random term to ensure that fields were properly specified as the experimental unit. Models contained main effects of treatment, year, segment, and the treatment $\times$ year interaction and either total corn density or cob-corn density as the response variable. We conducted our a priori test on post-harvest treatment by contrasting corn density of Idle fields to other post-harvest treatments using the Dunnett-adjusted PDIFF = CONTROL option of the LSMEANS statement ($\alpha = 0.05$; PROC MIXED; SAS Institute 2002). We back-transformed least squares means and confidence intervals to generate geometric means for comparison of corn density among post-harvest treatments.

We evaluated corn depletion using a data set containing only fields for which treatment did not change between sampling periods (early vs. late migration; $n = 143$ fields). We tested null hypotheses of no treatment effects on magnitude of total corn depletion using a linear model in PROC MIXED containing the main effects of segment, year, sampling period, treatment, and the sampling period $\times$ treatment and sampling period $\times$ year interactions. We included field(year $\times$ treatment $\times$ segment) and field $\times$ sampling period(year $\times$ treatment $\times$ segment) as random variables to ensure proper model structure and degrees of freedom. We used separate models to examine total corn density and cob-corn density. We removed nonsignificant interaction terms from our models, which included the term suitable for evaluating our corn depletion research question (sampling period $\times$ treatment; see Results Section). Therefore, we evaluated corn depletion by interpreting main effects and CPRV-wide estimates of corn density for early and late migration.

We applied a MSS design to our data by using weights and selection probabilities that were derived from field surveys and remote sensing to generate unbiased arithmetic mean and variance estimates for early migration residual corn density for the CPRV (PROC SURVEYMEANS; SAS Institute 2002, Stafford et al. 2006*a*). We considered segments ($n = 5$) as strata and fields ($n = 188$) as clusters for this analysis and generated arithmetic means from raw (untransformed) data. Similarly, we described the pattern of corn depletion during spring migration for the CPRV by generating arithmetic mean estimates for early and late migration total corn density in each year, using the subset of fields with no change in post-harvest treatment ($n = 143$).

We used our roadside survey data to derive the estimated proportion of cornfields in treatment t and segment s, denoted as P_{ts}. We denoted the known number of available fields from our cropland inventories in segment s as C_s. The probability a given field was selected for sampling was $F_{tsy}/(P_{ts} \times C_s)$ for year-specific estimates and $F_{ts}/(P_{ts} \times C_s)$ for the overall estimate, where F_{tsy} denotes number of fields sampled in treatment t, segment s, and year y, and F_{ts} is the total number of fields sampled in treatment t and segment s in all years. The probability of selecting a plot within a field was $n_{its}/(A_{its}/Q)$, where n_{its} is the number of plots sampled in field i in treatment t and segment s, A_{its} is the area of the field, and Q is the area of the sampling plot. We used the inverse of the product of these selection probabilities as the sample weight in all analyses (Stafford et al. 2006*a*). Because P_{ts} was estimated from sampling and not known without error, we used domain analyses in PROC SURVEYMEANS to estimate mean corn abundance for treatments and years. We estimated mean corn density (total corn and cob corn) for the CPRV for each year of our study (2005–2007) and across all years (SAS Institute 2002, Stafford et al. 2006*a*). We also estimated geometric means of total and cob-corn density to facilitate comparisons with historical and future studies. We calculated geometric means by running the SURVEYMEANS analysis on ln $(x + 1)$-transformed data and back-transforming the mean estimates and confidence intervals.

RESULTS

We measured corn density in 188 cornfields in springs 2005 ($n = 57$), 2006 ($n = 69$), and 2007 ($n = 62$) during the early-migration period and 143 of these cornfields during the late migration period (Table 1). Treatment changes occurred on 45 fields before we could collect late-migration samples.

The effect of post-harvest treatment did not vary among years for total corn density (treatment × year interaction, $F_{8,169} = 0.90, P = 0.51$) or cob-corn density ($F_{8,169} = 0.91, P = 0.51$), nor was there variation among segments for total corn density ($F_{4,169} = 1.01, P = 0.405$) or cob-corn density ($F_{4,169} = 0.99, P = 0.413$). However, there was variation among treatments in both total corn density ($F_{4,169} = 34.23, P < 0.001$) and cob-corn density ($F_{4,169} = 15.13, P < 0.001$). Idle fields had substantially higher total corn density than all other post-harvest treatments ($|t_{169}| > 2.77, P < 0.006$), exceeding the density estimate for grazed fields by 42%, for mulched fields by 53%, for mulched and grazed fields by 48%, and for tilled fields by 92% (Fig. 2). Idle fields also had substantially higher cob-corn density than all other post-harvest treatments ($|t_{169}| > 2.73, P < 0.007$), exceeding the density estimate for grazed fields by 89%, for mulched fields by 61%, for mulched and grazed fields by 92%, and for tilled fields by 89% (Fig. 2). Year was a significant effect in our ANOVA for cob corn ($F_{2,169} = 13.42, P < 0.001$) but was nonsignificant in the total corn density ANOVA ($F_{2,169} = 1.09, P = 0.339$).

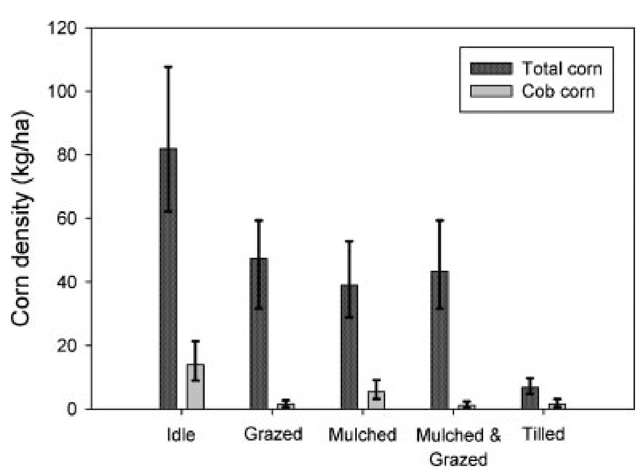

Figure 2. Geometric least squares mean total corn density (±95% CL; free kernels and kernels from cobs) and cob-corn density (±95% CL; kernels from cobs) by post-harvest treatment of cornfields in the Central Platte River Valley, Nebraska prior to waterfowl migration in springs 2005–2007.

Total corn density varied by year ($F_{2,132} = 4.65, P = 0.011$), post-harvest treatment ($F_{4,132} = 28.00, P < 0.001$), sampling period ($F_{1,140} = 53.81, P < 0.001$), and sampling period × year ($F_{2,140} = 4.99, P = 0.008$), but not by segment ($F_{4,132} = 1.46, P = 0.217$). Cob-corn density varied by year ($F_{2,132} = 13.80, P < 0.001$), post-harvest treatment ($F_{4,132} = 12.04, P < 0.001$), and sampling period ($F_{1,142} = 17.45, P < 0.001$), but not by segment ($F_{4,132} = 1.05, P = 0.385$). The magnitude of total and cob-corn depletion during spring staging of waterfowl and cranes did not vary among post-harvest treatments (sampling period × post-harvest treatment interaction; $P > 0.05$). Our MSS-based estimates for the CPRV showed that total corn density decreased between early and late migration by 8% in 2005, 56% in 2006, and 5% in 2007 (Fig. 3).

We classified post-harvest treatment of harvested cornfields on 18% (2006) and 25% (2007) of our study area. For springs 2006 and 2007 combined, we classified the cornfield area of the CPRV as 19% idle, 44% grazed, 14% mulched, 9% mulched and grazed, 13% tilled, and 1% other. We calculated unbiased estimates of mean corn density of the CPRV for all years (Table 2) and treatments (Table 3), including overall arithmetic mean estimates of 107.0 kg/ha (95% CI = 71.5–142.6 kg/ha) for total corn density and 40.0 kg/ha (95% CI = 21.0–58.9 kg/ha) for cob-corn density. For comparison to prior studies, we also calculated geometric mean total corn density in the CPRV for 2005 (43.5 kg/ha; 95% CI = 32.0–59.0 kg/ha), 2006 (35.6 kg/ha; 95% CI = 29.3–43.3 kg/ha), 2007 (50.1 kg/ha; 95% CI = 32.3–77.3 kg/ha), and all years combined (42.4 kg/ha; 95% CI = 35.2–51.5 kg/ha).

We estimated that 93,687 ha (70%) of the total cropland in our study area (134,601 ha) was planted in corn and 26,237 ha (19%) was planted in soybeans. The remaining cropland was planted in alfalfa, grass, sorghum, and small grains. Relative abundance of crop types varied <1% among years. Accuracy of our image classification was 94–96%.

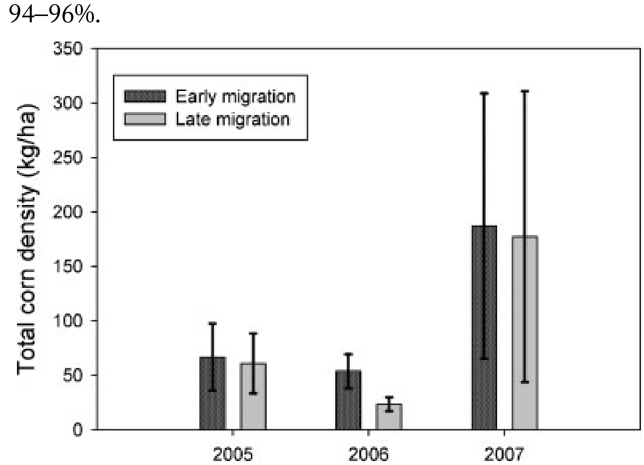

Figure 3. Arithmetic mean density (kg/ha) of total waste corn by year during early and late spring waterfowl migration in the Central Platte River Valley (CPRV), Nebraska in 2005–2007. Estimates account for relative abundance of post-harvest management treatments in the CPRV, which we derived using multi-stage sampling procedures in PROC SURVEYMEANS with fields as sampling units.

Table 2. Arithmetic mean density (kg/ha) of waste corn by year during early spring waterfowl migration in the Central Platte River Valley (CPRV), Nebraska, 2005–2007. Estimates account for relative abundance of post-harvest management treatments in the CPRV, which we derived using multi-stage sampling procedures in PROC SURVEYMEANS with fields as sampling units.

	Cob corn		Total corn	
Year	$\bar{x}$	95% CL	$\bar{x}$	95% CL
2005	42.8	11.9–73.7	96.6	57.8–135.3
2006	7.6	4.1–11.0	54.1	40.6–67.7
2007	70.5	23.7–117.3	176.4	76.9–275.8
All years	40.0	21.0–58.9	107.0	71.5–142.6

DISCUSSION

Post-Harvest Treatment

Post-harvest tilling of cornfields has been cited as a conservation concern for its potential to cause a reduction in the amount of corn available to migratory birds during spring in the CPRV (Krapu et al. 2004). Our results indicate that post-harvest treatments, particularly tilling, do indeed negatively affect density of residual corn in fields, and likely influence the amount of corn available to cranes and waterfowl during spring migration in the CPRV. Further, our results are similar to previous findings of post-harvest treatment effects on corn and rice fields in other agricultural regions. Baldassarre et al. (1983) reported that tilling of cornfields in Texas reduced residual corn density by 77–97%. Similarly, Havens (2007) and Kross et al. (2008*a*) found that waste rice abundance in the Mississippi Alluvial Valley was higher in standing stubble than in fields treated by rolling, burning, mowing, or disking, and Warner et al. (1985) found that residual corn in Illinois was substantially more abundant in untilled than in intermediately tilled or moldboard-plowed fields.

Three of the treatments we studied (grazed, mulched, and mulched and grazed) had intermediate corn densities, with total residual corn approximately half that in idle fields and 4–5 times that in tilled fields (Fig. 2). Of these intermediate treatments, mulched fields had the lowest total corn density but highest cob-corn density (Fig. 2). Mulching primarily influences above-ground structure, reducing standing stubble, producing litter, and lightly disturbing the soil surface. In the mulching process, cobs and kernels are probably broken up or buried under the surface litter. We only collected whole kernels; therefore additional forage may have been present in these fields in the form of kernel fragments. It also is likely that effort required for foraging birds to obtain loose or partial kernels in mulched fields would be higher due to increased litter. Baldassarre et al. (1983) proposed that burning stubble may make corn more available to birds because it removes litter that covers residual corn, although this was not a commonly used management practice in the CPRV during our study. Despite lower corn abundance, Anteau et al. (2011) noted that sandhill cranes in the CPRV used mulched cornfields more than any other treatment, potentially because cranes favored fields with less standing stubble or because mulched fields may have higher densities of other food items (e.g., invertebrates). Thus, field use by cranes may be influenced by trade-offs among desirable structure (e.g., low cover), abundance of residual corn, and efficiency of foraging through litter.

Mean corn densities in the mulched, grazed, and mulched and grazed treatments (Fig. 2) suggest that grazing and mulching effects were not additive in reducing total corn density. Baldassarre et al. (1983) suggested that producers graze cattle on fields with the highest residual corn mass after harvest, although those authors reported a pre-grazing residual corn density (787 kg/ha) that was an order of magnitude greater than their post-grazing estimate (73 kg/ha) and our density estimate for idle fields (82 kg/ha; Fig. 2). We could not determine whether producers made nonrandom decisions to graze cattle; however, our residual corn density estimates were consistently low relative to other studies, suggesting that any such effect would be minor and would make our estimate of the grazing treatment conservative. Reinecke and Krapu (1986) noted that winter depletion of residual corn in the CPRV was weakly positively correlated with cattle grazing, and Baldassarre et al. (1983) reported that 84% of total corn mass and 98% of cob-corn mass was lost to grazing in Texas. Magnitude of the grazing effect would be influenced by stocking rate and duration, which were not controlled in our study. However, variation in mean total corn density was generally similar among treatments we evaluated, suggesting that grazing treatments were

Table 3. Arithmetic mean density (kg/ha) of waste corn by post-harvest treatment during early spring waterfowl migration in the Central Platte River Valley, Nebraska, 2005–2007. Estimates account for annual variation in corn density, which we derived using multi-stage sampling procedures in PROC SURVEYMEANS with fields as sampling units.

	Cob corn		Total corn	
Post-harvest treatment	$\bar{x}$	95% CL	$\bar{x}$	95% CL
Idle	116.6	51.3–181.9	234.1	120.2–348.1
Grazed	20.3	−5.5–46.2	90.9	37.6–144.1
Mulched and grazed	8.1	1.6–14.7	57.6	46.7–68.6
Mulched	32.1	16.7–47.4	77.4	45.9–108.9
Tilled	17.6	6.9–28.2	23.7	16.6–30.7

consistently applied. Evaluation of the true effect of grazing on availability of spring foods for migratory birds would require that 1) corn densities prior to stocking cattle are controlled and 2) differences in foraging behavior and selection of cranes, waterfowl, and cattle are understood.

Tilled fields had the lowest corn density of any treatment, likely because corn cobs and kernels were broken up and buried during tillage. Despite low corn abundance, Anteau et al. (2011) noted that geese in the CPRV used tilled fields more than other treatments. Jorde et al. (1983) suggested that foraging efficiency of mallards (*Anas platyrhynchos*) was higher in tilled fields because of a decrease in litter at the surface. Alternatively, when above-ground foods are not available, snow geese commonly forage by rooting or grubbing for subsurface foods (Kerbes et al. 1990), whereas cranes forage by probing for invertebrates and gleaning foods from the soil surface (Reinecke and Krapu 1986, Tacha et al. 1987). These differences in foraging suggest that residual corn in tilled fields may not be equally available to geese and cranes, although it is not clear if geese can effectively search below the soil surface for residual corn. Rooting and grubbing for residual corn likely is less efficient than gleaning it from the soil surface. Krapu et al. (1984) noted that foraging and walking accounted for greater percentages of the time budget for cranes in disced and plowed cornfields than in grazed cornfields due to greater search effort required in these habitats.

Depletion of Corn Among Post-Harvest Treatments

Optimal foraging theory predicts that food depletion should be density-dependent (Charnov 1976), as observed by Greer et al. (2009) for wintering waterfowl foraging on waste rice. Density-dependent depletion should produce late-migration residual corn densities that are less variable among treatments than early-migration densities. We found the opposite result, with declines in corn density during migration being comparable among post-harvest treatments that differed substantially in early-migration density (Fig. 2). Further, depletion was most pronounced in the year with lowest overall corn density (2006) and least pronounced in the year with highest overall corn density (2007; Fig. 3). We suspect that these outcomes resulted from differences among post-harvest treatments in foraging efficiency and field selection probability by migratory birds. A companion study in the CPRV (Anteau et al. 2011) showed that tilled fields had the highest probability of use by geese and the lowest probability of use by cranes, suggesting that foraging by geese may be a primary factor influencing corn depletion in these fields. Little is known about the relative foraging efficiency of geese and cranes, or how foraging efficiency varies among management treatments. Because stubble structure varies substantially, ranging from bare dirt in tilled fields to standing stubble in idle fields, it is also likely that residual corn is not equally available to foraging birds among treatments, even if density were comparable. Thus, depletion of corn is probably driven by a complex interaction of residual corn abundance, post-harvest treatment, foraging efficiency, and proximity to suitable goose and crane roost sites (Anteau et al. 2011). Greer et al. (2009) also found that density of waste rice remaining in fields after waterfowl stopped feeding (i.e., giving-up density) did not differ among post-harvest management treatments, suggesting that food density was the primary factor driving foraging decisions in that system. Although forage may be important in driving the distribution of birds in the CPRV (Pearse et al. 2010, Anteau et al. 2011), we found that corn was depleted to different levels among post-harvest treatments, suggesting that changes in stubble structure are an important influence on the threshold forage density at which cranes and waterfowl no longer forage for corn. We also note that our depletion estimates are conservative, because our late spring sampling occurred prior to departure of migratory birds from the study area.

Corn Mass Estimates for the Central Platte River Valley

Cropland acreage planted to soybeans in the CPRV grew from <1% in the 1970s to about 18% in 2000 (Krapu et al. 2005). Within the 3 years of our study, the proportions of various agricultural commodities planted in the CPRV were stable. However, we suspect changes in proportions of corn and soybeans will be sensitive to shifting commodity prices because these crops are typically well suited for the same growing conditions (e.g., soils and climate). A shift from corn to soybean production has the potential to profoundly influence availability of high-quality food for migratory birds because soybeans provide less available energy to wildlife than corn does (Krapu et al. 2004). Accordingly, managers may need reliable strategies to provide high quality foods to cranes and waterfowl in the event that wider policy (e.g., energy or agricultural subsidies) or commodity prices rapidly shift the balance of plantings in favor of soybeans.

In the winter of 1979, Krapu et al. (1984) estimated that cropland in the CPRV was 9% idle, 37% tilled, and 52% grazed, with corn being the dominant crop. The percentage of cornfields tilled in the fall of 1997 and 1998 was substantially lower (13%; Krapu et al. 2004) and was identical to the percentage we observed in springs 2006 and 2007. The very low corn density in tilled fields and the declining trend in their relative abundance should have positively influenced overall corn density in the CPRV. However, overall residual corn density has declined markedly since the 1970s. Our total corn density estimate for idle fields (82 kg/ha; Fig. 2) was low relative to the pre-grazing estimate of Baldassarre et al. (1983; 787 kg/ha), suggesting that increases in harvest efficiency are a principal cause for the observed low residual corn abundance in the CPRV. Although variation in relative abundance of post-harvest treatments would influence overall corn density in the CPRV, it is insufficient to explain the decline in corn density since the 1970s.

We observed that tilling of fields in springs 2005–2007 was initiated in mid- to late-March, prior to the departure of cranes from the CPRV, which could drastically alter the amount of corn during late staging of sandhill cranes, particularly at a time when much of the corn in fields that are attractive to cranes for foraging likely is depleted. The potential impact of spring tillage on residual corn abundance is not captured in our study and may occur at a critical time for cranes just prior to their departure from the CPRV.

Krapu et al. (1984) and Iverson et al. (1987) concluded that there was adequate residual corn and habitat to support fat deposition and population stability of cranes migrating through Nebraska during spring. Several studies of residual corn abundance in the CPRV collectively illustrate a long-term trend of declining residual corn abundance (Reinecke and Krapu 1986, Pearse et al. 2010, this study). The 95% confidence interval for our highest arithmetic mean early migration residual corn density for the CPRV (176.4 kg/ha in 2007; Table 2) overlapped the late-migration arithmetic mean residual corn density reported by Reinecke and Krapu (1986) for the CPRV (128 kg/ha). Thus, cranes arriving in the CPRV during our study were faced with forage densities comparable to or substantially lower than densities that historically remained after spring migration in the CPRV. Our early-migration arithmetic means for total corn density (Table 2), along with those of Pearse et al. (2010), also demonstrate considerable among-year variation, and our estimate for 2006 (54.1 kg/ha) is the lowest recorded early-migration corn density for the CPRV. Our means for the CPRV are also low relative to post-harvest estimates from Tennessee (239 kg/ha; Foster et al. 2010) and Ontario, Canada (188 kg/ha; Barney 2008), further illustrating the importance of cropland management for migratory birds in the CPRV.

Pearse et al. (2010) modeled spring carrying capacity of the CPRV for sandhill cranes relative to abundance of residual corn and other migratory birds and predicted that future reductions in corn abundance could increase foraging flight distances by cranes, potentially impacting the ability to store lipids prior to migration. The model by Pearse et al. (2010) potentially could be used to derive foraging habitat objectives for the CPRV to aid in targeting management actions for the benefit of cranes. Our data could contribute to such a model application by allowing prediction of the consequences of changing cornfield management practices on landscape-scale estimates of food abundance for migratory birds.

MANAGEMENT IMPLICATIONS

If providing residual corn for spring-staging cranes and waterfowl is a management goal for the CPRV, then our study would have 2 principal applications. First, incentives could be provided to landowners to encourage implementation of practices that maximize abundance of residual corn during spring migration. Second, management of conservation lands planted to corn could be targeted by using these practices. Our data suggest that idled stubble is the most favorable post-harvest management practice with respect to early-migration residual corn density, followed by grazed, mulched, and mulched and grazed stubble. Management to enhance residual corn density for the benefit of cranes should be most beneficial in areas with highest probability of use by cranes, including fields that are closest to roost sites and wet grassland areas, particularly along eastern portions of the CPRV (Anteau et al. 2011). Because post-harvest tillage substantially reduces residual corn abundance during spring, incentives to avoid this practice also could benefit cranes. Post-harvest tillage is often employed near the end of the spring migration period, which may correspond to the greatest energetic need of migratory birds preparing to depart for the breeding grounds. If future climate trends favor earlier spring application of this treatment, there could be a growing conflict with the ability of the CPRV landscape to provide food for migratory birds, particularly cranes.

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LITERATURE CITED

Alisauskas, R. T. 2002. Arctic climate, spring nutrition, and recruitment of midcontinent lesser snow geese. Journal of Wildlife Management 66:181–193.

Alisauskas, R. T., and C. D. Ankney. 1992a. The cost of egg laying and its relationship to nutrient reserves in waterfowl. Pages 30–61 *in* B. D. J. Waterfowl, A. D. Batt, M. G. Afton, C. D. Anderson, D. H. Ankney, J. A. Johnson, G. L. Kadlec, and G. L. Krapu, editors. Ecology and management of breeding, University of Minnesota Press, Minneapolis, USA.

Alisauskas, R. T., and C. D. Ankney. 1992b. Spring habitat use and diets of mid-continent adult lesser snow geese. Journal of Wildlife Management 56:43–54.

Anteau, M. J., and A. D. Afton. 2004. Nutrient reserves of lesser scaup during spring migration in the Mississippi Flyway: a test of the Spring Condition Hypothesis. Auk 121:917–929.

Anteau, M. J., and A. D. Afton. 2008. Diets of lesser scaup during spring migration throughout the upper-Midwest are consistent with the spring condition hypothesis. Waterbirds 31:97–106.

Anteau, M. J., and A. D. Afton. 2009. Lipid reserves of lesser scaup (*Aythya affinis*) migrating across a large landscape are consistent with the spring condition hypothesis. Auk 126:873–883.

Anteau, M. J., M. H. Sherfy, and A. Bishop. 2011. Location and agricultural practices influence spring use of harvested cornfields by cranes and geese in Nebraska. Journal of Wildlife Management 75:in press.

Arzel, C., J. Elmberg, and M. Guillemain. 2006. Ecology of spring-migrating Anatidae: a review. Journal of Ornithology 147:167–184.

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

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

Brasher, M. G., J. D. Steckel, and R. J. Gates. 2007. Energetic carrying capacity of actively and passively managed wetlands for migrating ducks in Ohio. Journal of Wildlife Management 71:2532–2541.

Charnov, E. L. 1976. Optimal foraging, the marginal value theorem. Theoretical Population Biology 9:129–136.

Devries, J. H., R. W. Brook, D. W. Howerter, and M. G. Anderson. 2008. Effects of spring body condition and age on reproduction in mallards (*Anas platyrhynchos*). Auk 125:618–628.

Drent, R. H., A. D. Fox, and J. Stahl. 2006. Traveling to breed. Journal of Ornithology 147:122–134.

Ebbinge, B. S., and B. Spaans. 1995. The importance of body reserves accumulated in spring staging areas in the temperate zone for breeding in dark-bellied brent geese *Branta b. bernicla* in the high Arctic. Journal of Avian Biology 26:105–113.

ERDAS. 1999. ERDAS Field Guide. ERDAS, Inc., Atlanta, Georgia, USA.

Foster, M. A., M. J. Gray, and R. M. Kaminski. 2010. Agricultural seed biomass for migrating and wintering waterfowl in the southeastern United States. Journal of Wildlife Management 74:489–495.

Frederick, R. B., E. E. Klaas, G. A. Baldassarre, and K. J. Reinecke. 1984. A method for sampling waste corn. Journal of Wildlife Management 48:298–303.

Greer, D. M., B. D. Dugger, K. J. Reinecke, and M. J. Petrie. 2009. Depletion of rice as food of waterfowl wintering in the Mississippi Alluvial Valley. Journal of Wildlife Management 73:1125–1133.

Havens, J. H. 2007. Winter abundance of waterfowl, waterbirds, and waste rice in managed Arkansas rice fields. Thesis, Mississippi State University, Mississippi State, USA.

Iverson, G. C., P. A. Vohs, and T. C. Tacha. 1987. Habitat use by mid-continent sandhill cranes during spring migration. Journal of Wildlife Management 51:448–458.

Jorde, D. G., G. L. Krapu, and R. D. Crawford. 1983. Feeding ecology of mallards wintering in Nebraska. Journal of Wildlife Management 47:1044–1053.

Kerbes, R. H., P. M. Kotanen, and R. L. Jefferies. 1990. Destruction of wetland habitats by lesser snow geese: a keystone species on the west coast of Hudson Bay. Journal of Applied Ecology 27:242–258.

Krapu, G. L., K. J. Reinecke, and C. R. Frith. 1982. Sandhill cranes and the Platte River. Transactions of the North American Wildlife and Natural Resources Conference 47:542–552.

Krapu, G. L., D. E. Facey, E. K. Fritzell, and D. H. Johnson. 1984. Habitat use by migrant sandhill cranes in Nebraska. Journal of Wildlife Management 48:407–417.

Krapu, G. L., G. C. Iverson, K. J. Reinecke, and C. M. Boise. 1985. Fat deposition and usage by arctic-nesting sandhill cranes during spring. Auk 102:362–368.

Krapu, G. L., K. J. Reinecke, D. G. Jorde, and S. G. Simpson. 1995. Spring-staging ecology of mid-continent greater white-fronted geese. Journal of Wildlife Management 59:736–746.

Krapu, G. L., D. A. Brandt, and R. R. Cox. Jr., 2004. Less waste corn, more land in soybeans, and the switch to genetically modified crops: trends with important implications for wildlife management. Wildlife Society Bulletin 3:127–136.

Krapu, G. L., D. A. Brandt, and R. R. Cox. Jr., 2005. Do arctic-nesting geese compete with sandhill cranes for waste corn in the Central Platte River Valley, Nebraska? Proceedings North American Crane Workshop 9:185–191.

Kross, J. P., R. M. Kaminski, K. J. Reinecke, and A. T. Pearse. 2008a. Conserving waste rice for wintering waterfowl in the Mississippi Alluvial Valley. Journal of Wildlife Management 72:1383–1387.

Kross, J. P., R. M. Kaminski, K. J. Reinecke, E. J. Penny, and A. T. Pearse. 2008b. Moist-soil seed abundance in managed wetlands in the Mississippi Alluvial Valley. Journal of Wildlife Management 72:707–714.

Lewis, J. C. 1995. Whooping crane (*Grus americana*). *in* A. Poole, and F. Gill, editors. The birds of North America, no. 153. The Academy of Natural Sciences, Philadelphia, and The, American Ornithologists' Union, Washington, D.C., USA.

National Agricultural Statistics Service. 2002–2007. Cropland data layer. <http://www.nass.usda.gov/research/Cropland/SARS1a.htm>. Accessed 3 Sep 2010.

Newton, I. 2006. Can conditions experienced during migration limit the population levels of birds? Journal of Ornithology 147:146–166.

Pearse, A. T., G. L. Krapu, D. A. Brandt, and P. J. Kinzel. 2010. Changes in agriculture and abundance of snow geese affect carrying capacity of sandhill cranes in Nebraska. Journal of Wildlife Management 74:479–488.

Reinecke, K. J., and G. L. Krapu. 1986. Feeding ecology of sandhill cranes during spring migration in Nebraska. Journal of Wildlife Management 50:71–79.

SAS Institute. 2002. SAS/STAT User's Guide, Version 9. SAS Institute, Cary, North Carolina, USA.

Sparling, D. W., and G. L. Krapu. 1994. Communal roosting and foraging behavior of staging sandhill cranes. Wilson Bulletin 106:62–77.

Stafford, J. D., R. M. Kaminski, K. J. Reinecke, and S. W. Manley. 2006a. Waste rice for waterfowl in the Mississippi Alluvial Valley. Journal of Wildlife Management 70:61–69.

Stafford, J. D., K. J. Reinecke, R. M. Kaminski, and P. D. Gerard. 2006b. Multi-stage sampling for large scale natural resources surveys: a case study of rice and waterfowl. Journal of Environmental Management 78:353–361.

Tacha, T. C., P. A. Vohs, and G. C. Iverson. 1987. Time and energy budgets of sandhill cranes from mid-continental North America. Journal of Wildlife Management 51:440–448.

Thogmartin, W. E., A. L. Gallant, M. G. Knutson, T. J. Fox, and M. J. Suárez. 2004. A cautionary tale regarding use of the National Land Cover Dataset 1992. Wildlife Society Bulletin 32:970–978.

Vrtiska, M. P., and S. Sullivan. 2009. Abundance and distribution of lesser snow and Ross's geese in the Rainwater Basin and Central Platte River Valley of Nebraska. Great Plains Research 19:147–155.

Warner, R. E., S. P. Havera, and L. M. David. 1985. Effects of autumn tillage systems on corn and soybean harvest residues in Illinois. Journal of Wildlife Management 49:185–190.

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