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Evaluation of Fall-Seeded Cover Crops for Grassland Nesting Waterfowl in Eastern South Dakota

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EVALUATION OF FALL-SEEDED COVER CROPS FOR GRASSLAND NESTING WATERFOWL IN EASTERN SOUTH DAKOTA

BY

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THESIS ACCEPTANCE PAGE

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This thesis is approved as a creditable and independent investigation by a candidate for the master's degree and is acceptable for meeting the thesis requirements for this degree. Acceptance of this does not imply that the conclusions reached by the candidate are necessarily the conclusions of the major department.

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ABSTRACT

EVALUATION OF FALL-SEEDED COVER CROPS FOR GRASSLAND NESTING WATERFOWL IN EASTERN SOUTH DAKOTA

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The Prairie Pothole Region is the primary breeding ground for many species of North American waterfowl. This landscape was historically dominated by mixed and tallgrass prairies interspersed with wetlands, but >70% of native grassland area has been lost due to widespread conversion to croplands, which may threaten waterfowl production. Cover cropping is a re-emerging farming technique that may provide suitable nesting cover for grassland nesting waterfowl on active farmlands. My research objectives were to evaluate the utility of fall-seeded cover crops to breeding waterfowl compared to perennial cover, determine if cover crops in rotation with row crops can successfully support grassland nesting waterfowl, and assess landscape scale, agricultural practice, and vegetation structure factors that may influence nest survival. I searched 2,962 ha of cover crops and 2,244 ha of perennial cover during 2018 and 2019, and found 122 nests and 312 nests in each cover type. Estimated daily nest survival was 0.949 (95% CI = 0.942–0.957) for cover crops and 0.957 (95% CI = 0.950–0.964) for perennial cover, equating to seasonal nest survival rates of 17.2% (95% CI =12.4–22.3%) and 22.7% (95% CI = 17.5–28.5%) in cover crops and perennial cover, respectively. Although nest survival was similar between cover types, seasonal nest survival was only 1.3% when cover crops were planted to row crops in the spring. Our results suggest that under current management techniques fall-seeded cover crops may function as ecological traps for nesting waterfowl. Thus, managers may wish to consider not promoting fall

seeded cover crops as nesting cover if they are to be planted to row crops in spring. Although nest survival in cover crops that were planted to row crops was low, the important benefits cover crops provide to soil health, water quality, and other ecosystem services remain. Additional research to understand the influence other cover crop types and management techniques have on duck nests survival would be useful.

INTRODUCTION

The Prairie Pothole Region (PPR) of the United States is located in portions of North Dakota, South Dakota, Iowa, Minnesota, and Montana. The PPR has changed drastically since European settlement, and although it remains a productive area for nesting waterfowl and other grassland nesting birds, it is now dominated by row crop agriculture. This landscape historically consisted of grasslands with millions of interspersed seasonal, semi-permanent, and permanent wetlands formed ~12,000 years ago during the Wisconsin glaciation (Baldassarre and Bolen 2006). The grassland-wetland region of the PPR comprises only 10% of waterfowl breeding habitat in North America (Smith et al. 1964), but accounts for 50-80% of annual waterfowl production (Bellrose 1980, Batt et al. 1989). Certainly, the agricultural context of the modern PPR has a strong influence on the quality of remaining breeding habitat in this ecoregion.

To properly evaluate relationships between wildlife habitats and population parameters it is essential to understand life history traits and vital rates that most strongly influence population growth. Hoekman et al. (2002) reported that variability in mallard (*Anas platyrhynchos*) nest survival had the strongest influence on the finite population growth rate (λ) of this species. Nest survival is the probability that a nest survives from initiation to hatch and produces at least one duckling (Klett et al. 1986, Johnson et al. 1992, Rotella et al. 2004). Similarly, daily nest survival (DNS) is the probability that a nest will survive a single day (Mayfield 1961, Cowardin and Johnson 1979, Dinsmore et al. 2002). Overall, it has been suggested that nest survival needs to be ≥15% to sustain populations of mallards (Cowardin et al. 1985) and northern pintails (*Anas acuta*; Klett et al. 1988), whereas nest survival of blue-winged teal (*Spatula discors*), northern shoveler

(*Spatula clypeata*), and gadwall (*Anas strepera*) should be ≥20%, due to lower re-nesting probabilities (Klett et al. 1988). Nest survival is dependent on the availability of suitable nesting habitat; thus, recent declines in grassland area in the Northern Great Plains is of great concern for the sustainability of waterfowl populations (Environment Canada et al. 1986, Clark et al. 1999, Reynolds et al. 2001, Stephens et al. 2005, Wright and Wimberly 2013). Females may have reduced breeding success if habitat is poor when reaching nesting grounds (Devries et al. 2008).

Advances in farming practices, crop genetics, and wetland drainage have increased the amount of arable land in North America. These actions have correspondingly reduced the area of wetlands and grasslands in the PPR and elsewhere. In North and South Dakota, a large portion of wetlands (~3%/year; 5,203 ha/year) have been drained and ~4% of the grassland area (~60,000 ha/10 year) has been converted to farmland annually (Stephens et al. 2008, Johnston 2013, Wright and Wimberly 2013). Conversion of wetlands and grasslands continues to pose major threats to waterfowl production in the PPR (Hohman et al. 2014). Greenwood et al. (1995) suggested that for every 10% increase in cropland area in the PPR a corresponding 4% decrease in average nest survival was predicted. Indeed, availability and abundance of quality habitat is considered the greatest constraint on waterfowl production (Baldassarre and Bolen 2006).

Cropland is considered poor nesting habitat for waterfowl and other ground nesting birds, although it is occasionally used, especially by northern pintails (Klett et al. 1988, Devries et al. 2008). Waterfowl nest survival in croplands during farming is partially dependent on the implements, their settings, and the timing of planting. In a waterfowl nesting study of farmed land in North Dakota, tillage destroyed 34% of all nests and 93% of active nests (Higgins 1977), whereas another study found that farming operations destroyed 41-57% of northern pintail nests (Milonski 1958, Higgins 1977). Therefore, considerable risks exist for waterfowl nesting in crop fields due to mechanical destruction from the farming process. Nonetheless, research quantifying waterfowl use of croplands is limited, partially due to the risk of damaging crops when searching for nests (Devries et al. 2008).

Several conservation programs and easements exist to counteract grassland losses and benefit nesting waterfowl in the PPR. Considered the most important and successful, the Conservation Reserve Program (CRP) began in 1985 to provide financial incentives to landowners who remove land from agricultural production as a means to increase grassland cover and improve environmental quality and wildlife habitat (USDA 2015). The program helped convert ~1.9 million hectares of cropland to perennial cover in the Dakotas and Montana (Reynolds 2005). In South Dakota, there were 395,693 hectares of CRP as of May 2017, of which 76,018 hectares were in the duck nesting habitat initiative (USDA 2017). The CRP has been largely successful in conserving habitat, but reduced funding and high commodity prices have resulted in the conversion of large acreages of CRP back to croplands. CRP has been credited with helping to produce millions of ducks per year (Reynolds 2005), and nest survival in CRP was estimated to be 46% higher compared to simulations with the same acreage in cropland (Baldassarre and Bolen 2006). Because of the ongoing conversion of conservation cover back to croplands it is increasingly important to identify alternative programs that benefit wildlife and agriculture.

The expanse of fall-seeded cover crops may benefit grassland nesting birds in the Northern Great Plains (NGP; Devries et al. 2008, Skone et al. 2016). The use of cover crops in agriculture is an old method that is infrequently practiced in contemporary farming; however, cover crops are becoming more common in crop rotations. Cover cropping is the practice of planting annual grasses and/or broadleaf vegetation in rotation with cash crops to help preserve and improve soil characteristics, suppress weeds, and enhance water quality (Unger et al. 1998). Common cover crops include species of annual grasses (e.g., cereal rye, winter wheat) and brassicas (e.g., mustards, turnips, and radishes). Many farmers use cover crops comprised of a mix of multiple species to address different soil qualities (Fageria et al. 2005). Other benefits of fall-seeded cover crops include reduced wind and water erosion, scavenging and recycling residual nitrogen, converting atmospheric carbon to organic matter, controlling weeds, and increasing mycorrhizae fungi without additional risk of crop disease (Dabney et al. 2001, Hartwig and Ammon 2002, and Snapp et al. 2005). A common practice, and the focus of this project, is fall-seeded cover crops (both mixtures and monocultures) with the intention to plant to row crops in the spring using no-till methods. Most spring cover crop growth (in areas with severe winter weather) comes from winter hardy species, typically cereal rye (*Secale cereale*; Noland et al. 2018). Other cover cropping strategies include inter-seeding into row crops, planting solely for cattle forage, planting for seed harvest, or planting for hay/silage. I am unaware of any previous studies of waterfowl nesting in cover crops; however, they have been conducted in similar cover types.

Waterfowl are of particular research interest due to their economic, cultural, and ecological values (Lewis et al. 1998, Grado et al. 2001, Gray et al. 2013). Nesting waterfowl and ring-necked pheasants (*Phasianus colchicus*) have been known to use small grain and winter cereal cropped fields in North and South Dakota (Devries et al. 2008, Pauly 2014, and Skone et al. 2016). Skone et al. (2016) found waterfowl daily nest survival in winter wheat fields was comparable to that in perennial grasslands and that nest survival was typically >15%, the rate suggested for stable populations of mallards and pintails (Cowardin et al. 1985). Standard row cropped fields rarely have adequate vegetation to attract nesting birds; however, fields with cover crops may be more attractive, perhaps similar to winter wheat or perennial cover.

Alternatively, this cover type could lead to an ecological trap to nesting birds, where cover crops initially attract birds to nest in the area, but result in a high probability of nest failure due to agriculture practices. Ecological traps are detrimental to wildlife by definition and are known to occur when organisms make choices based on mis-matched indicators of habitat quality (Schlaepfer et al. 2002). For example, nesting waterfowl may respond to specific proximate environmental cues (e.g., green-up); however, if the ecosystem is altered without corresponding cues, the mis-match of information may lead to detrimental outcomes, such as reduced nest survival. Waterfowl are generally abundant and localized ecological traps may not impact populations at large (USFWS 2019), but it is important to understand how the potential for such situations to influence nest survival and the possible consequences if the scale increases.

In efforts to promote soil health, water quality, and additional cover on actively farmed lands, entities such as Ducks Unlimited, Inc., the U.S. Department of Agriculture's Natural Resources Conservation Service (NRCS), and local conservation districts are promoting the use of fall-seeded cover crops through field demonstrations and cost-share programs. These programs help producers understand cover crop use and obtain financial assistance to establish cover crops on their properties.

Given recent losses of perennial cover throughout the PPR and the recent increased interest in alternate conservation cover options, it is important to study the value of alternative nesting cover types to wildlife. Due to renewed interest by farmers to conserve soil and improve water quality there is potential for large acreages of fall-seeded cover crops in the Northern Great Plains. The agronomic benefit of cover crops on soil health and water retention are well documented, and preliminary evidence suggests that some waterfowl and other birds use cover cropped fields for nesting (B. Toay and R. Meidinger, Ducks Unlimited, Inc., personal communication), but little known about their value to wildlife. Understanding the functional (e.g., nest survival) and numerical (e.g., use, density) responses of nesting waterfowl to cover crops is required to inform conservation and management decision making and implementation. I addressed these issues with the following objectives: 1) evaluate the utility of cover crops to breeding waterfowl in comparison to perennial cover; 2) determine if cover crops can successfully support upland nesting waterfowl in a rotation with row crops, which historically produce few birds; 3) assess landscape scale, agriculture practice, and vegetation structure factors that may influence nest survival, thereby influencing where cover crops could be most effectively deployed. Using these objectives I developed management recommendations to increase nest survival in cover cropped fields.

STUDY AREA

My study sites were located in South Dakota, east of the Missouri River, in the PPR (Figure 1). Sites were spread throughout many of the ecoregions of eastern South Dakota, including the: James River Lowland, Glacial Lake Basins, Prairie Coteau, Big

Sioux Basin, Drift Plains, and Missouri Coteau. The James River Lowland is known for a milder climate and fertile soil, making it prime farmland for common crops such as corn, soybeans, and wheat (Bryce et al. 1998). The Glacial Lake Basins ecoregion has a smooth topography with fertile soils, leading to intense cultivation with common crops of soybeans and corn (Bryce et al. 1998). The Prairie Coteau has a hilly topography interspersed with closely spaced wetlands (Bryce et al. 1998), where grazing dominates rather than row crop agriculture. The Big Sioux Basin is in the core of the Prairie Coteau and dominated by tilled lands because of its gentle topography, fertile soils, and lower wetland density (Bryce et al. 1998). The Drift Plains have an undulating topography with deep, fertile soils, making it productive agriculture land that retains valuable waterfowl habitats, but mainly in the form of federally-owned waterfowl production areas and state managed game production areas (Bryce et al. 1998). The Missouri Coteau has rolling hills interspersed with wetlands, where the flatter areas are used for tilled agriculture and hilly areas for grazing lands. This ecoregion is one of North America’s most important for waterfowl production.

I selected study sites that contained ≥1 cover cropped field and ≥1 perennial cover field, the latter defined as grassland, CRP, pasture, or hayfields. I chose study sites with ≥50 wetland basins in the surrounding 10.4 km^2 landscape when possible, because this density of wetland basins would likely support adequate numbers of breeding ducks to complete a successful nest survival study (Skone et al. 2016). Due to the fact that cover crops are a re-emerging practice in South Dakota, no comprehensive sampling frame existed to draw potential study sites from. Thus, study sites were not randomly chosen and relied on permission from landowners who were planting cover crops. Biologists from Ducks Unlimited, Inc. helped locate appropriate study sites, and most study sites were on private lands and required permission from landowners.

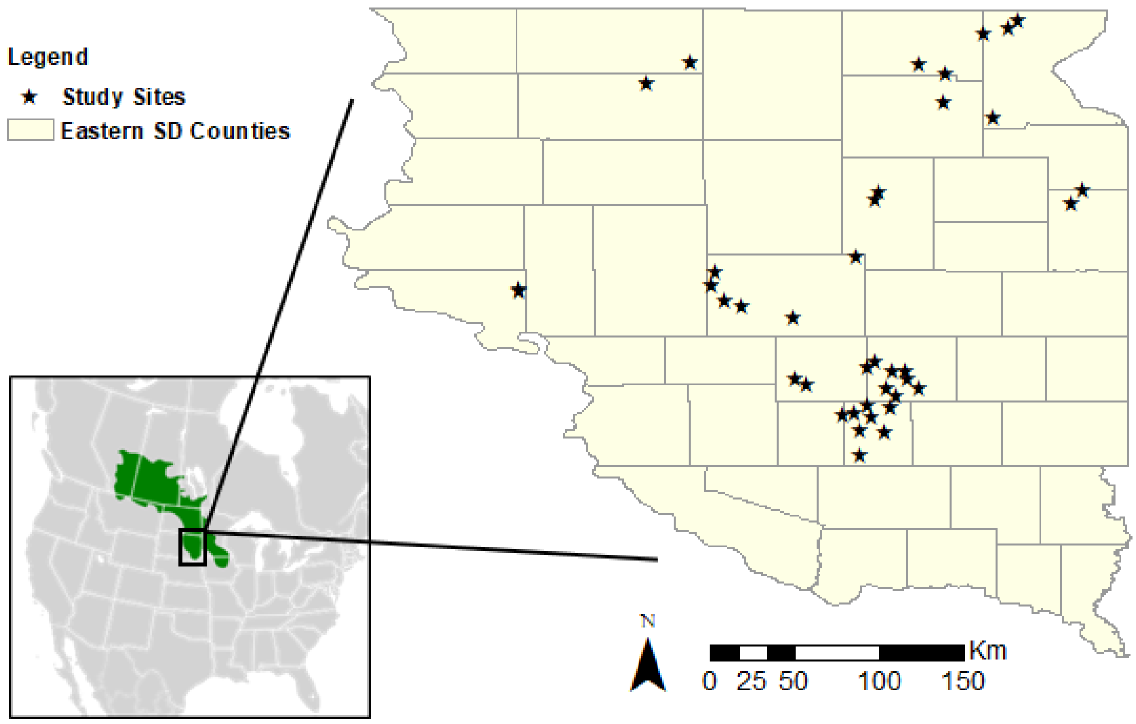

Figure 1. Location of paired perennial cover and fall-seeded cover cropped sites searched for duck nests within the Prairie Pothole Region (green) across eastern South Dakota.

COVARIATES AND HYPOTHESES

I collected data to use as covariates that were ecologically supported as influencing nest survival. Categorical covariates included cover type, year, and if the cover crops were planted to row crops. Cover type was included to account for differences in nest survival between fall-seeded cover crops and perennial cover. I included year as a fixed effect to account for differences between study years that may influence nest survival, but acknowledge that the ability to identify the ecological causes of such differences is difficult in a 2-year study.

I further included covariates accounting for nest age, nest initiation date, vegetation density, percent of perennial cover, percent of cropland, wetland area, and planting date. I included nest age because, in most cases, nest survival increases with nest age and initiation date to account for any temporal variation in nest survival. Land-cover covariates (number of wetlands, percentage of cropland, and percentage of perennial cover) were measured at two spatial scales (10.4 km^2 and 41.4 km^2; Reynolds et al. 2001, Stephens et al. 2005), and I hypothesized a positive relationship between nest survival and percentage of perennial cover (Stephens et al. 2005, Skone et al. 2016). Conversely, I predicted nest survival would be negatively associated with percentage of cropland at both spatial scales (Stephens et al. 2005, Skone et al. 2016). I also hypothesized nest density would be higher in areas with more wetlands (Arnold et al. 2007), however, nest survival may be lower due to known predator foraging behavior around wetlands (Krapu et al. 1997, Stephens et al. 2005, Thompson et al. 2012). There have been equivocal results in studies that evaluated relationships between vegetation density and nest survival; however, I hypothesized that these two variables would be positively related

(Stephens et al. 2005, Skone et al. 2016). Higher vegetation densities likely provided better concealment for nests and females tending nests, thereby decreasing predator foraging efficiency (Stephens et al. 2005).

Two variables in my study only relate to nests found in cover crops: if cover crops were planted to row crops and row spacing. I anticipated nest survival would be higher in fields that were planted later in the nesting season, because later planting allows early nesting species (e.g., northern pintails and mallards) to hatch before destructive agriculture practices begin. If fields were planted early, initial nests may get destroyed but enough cover crop residue may exist to benefit re-nesting and later-nesting species. Additionally, I included planting date to help make management recommendations to optimize the time of planting with respect to nest survival.

METHODS

Nest Searching

I searched for duck nests in Springs 2018 and 2019 in paired cover crop and perennial fields with traditional nest dragging methods using a double strand of manila/nylon rope rather than a chain (ATV; Klett et al. 1988, Skone et al. 2016), because the lighter alternative to chain reduced crop damage (Devries et al. 2008, Skone et al. 2016). Cover-cropped fields were intended to be planted each spring to row crops using no-till methods, typically to corn or soybeans, if conditions allowed. Once cash crops reached ~10–15 cm I switched to a less invasive search method of hand dragging rope (Duebbert and Kantrud 1974, Klett et al. 1988, Emery et al. 2005) to reduce potential crop damage. Nest searching occurred between 0800 and 1400 to maximize the chance that hens were on nests and to reduce the likelihood of nest abandonment

(Gloutney et al. 1993). Each site was searched at least 3 times during the nesting season. Paired perennial cover sites were within 10.4 km^2 from the center of each cover cropped field because previous research indicated that nest survival at a 10.4 km^2 scale was positively related to surrounding grassland cover (Reynolds et al. 2001, Stephens et al. 2005, and Skone et al. 2016) and because this scale is widely used for conservation planning purposes.

After a hen was flushed, I located and marked each nest by placing a flagged stake 4m to the north of the nest (Klett et al. 1986). I recorded the date, species, number of eggs, nest age, litter depth (cm), vegetation height (cm), vegetation composition, and geographic coordinates (UTM) for each nest (Stephens et al. 2005, Skone et al. 2016). I estimated incubation stage of the nest by candling (Weller 1956, Klett et al. 1986) and nest initiation date by back dating, assuming eggs were laid at a rate of 1/day. I revisited nests every 7-10 days until fate was determined. After each nest visit I covered nests with down and two pieces of vegetation to form an "X" on top of the nest to help identify abandonment due to disturbance (Martorelli 2017).

My primary focus was on nesting waterfowl; however, I also collected data on ring-necked pheasant nests. Pheasant nests were difficult to locate via nest dragging because pheasant hens tended to run from the nest before flushing. Pheasants were also more likely to abandon nests than waterfowl. Despite attempts, I found few nest and did not have a large enough sample size of pheasant nests to draw any conclusions for this species.

Vegetation Measurements

I evaluated vegetation characteristics of the two cover types using four common metrics: vegetation height (cm), vegetation density, litter depth (cm), and composition (Martorelli 2017). I measured vegetation height (cm) using a modified Robel pole at or below the point where 80% of the vegetation was growing and estimated vegetation density via visual obstruction readings (VOR; cm) using a modified Robel pole (Robel et al. 1970, Skone et al. 2016, Martorelli 2017). I estimated vegetation composition (grass, forbs, and woody) to the nearest 10% within a $1m^2$ quadrat at nest locations (Daubenmire 1959). Litter depth was measured at each of the four corners of a quadrat using a ruler and classified as dead vegetation and not standing vegetation (Haffele 2012, Martorelli 2017).

Agricultural Variables

My research took place on actively farmed lands; thus, I collected data on several variables related to producer-specific agriculture practices. These included: the date cover crops were planted, cover crop plant species, species of row crop planted, date of herbicide treatment and row crop planting, and row spacing. I used these variables as covariates in analyses to estimate the magnitude and influence of these factors on duck nest survival.

Landscape Characteristics at Multiple Spatial Scales

I quantified various landscape characteristics using ArcGIS to evaluate the influence of landscape scale variables on duck nest survival. As mentioned, landscape characteristics were measured at two spatial scales, $10.4km^2$ and $41.4km^2$ circular buffers, surrounding the centroid of each searched field (Stephens et al. 2005, Walker et al. 2013, and Skone et al. 2016). I chose these two spatial extents because Stephens et al. (2005) evaluated nest survival at five different scales and found these two to be the most relevant to nest survival. Within each fixed area site, I estimated percent cropland, percent cover cropped land, total number and percent area of wetlands, and the percent of perennial cover using data from CropScape, which is a publicly available database from the United States Department of Agriculture. In the final model I only included landscape scale variables at the 10.4km^2 because results from initial analysis (based on Akaike's Information Criterion (AIC)) suggested there was no meaningful difference in influence on nest survival between spatial scales. I selected variables at the 10.4km^2 scale to include into models because it was most similar to the extent of current waterfowl four square-mile surveys (Cowardin et al. 1995) and would be most useful for implementing management decisions.

Nest Survival Analyses

I used a global model to evaluate several biologically plausible covariates potentially affecting daily nest survival using a Bayesian hierarchical modeling framework that incorporated fixed and random effects (Gelman and Rubin 1995, Hobbs et al. 2012). This approach accounted for variables that were measured at different scales with different levels of replication: site-level covariates that were shared among all nests in a given field, nest-level covariates that were shared across multiple visits to each nest, and visit-specific covariates such as nest age that change between individual nest check intervals. At the field level, I used a logistic regression model that took the form:

$$logit(DSR_i) = \beta_0 + \boldsymbol{\beta_i X_i} + \varepsilon_i$$

where $logit(DSR_i)$ was the logit of mean daily survival rate for nests in field i, β_0 a common intercept, $\boldsymbol{\beta_i}$ a vector of fixed regression coefficients for variables measured at the field scale, $\boldsymbol{X_i}$ a matrix of field-specific covariates such as proportion of cropland, number of wetlands, cover, and year, and ε_i a field-specific random effect that applies to all nests in each field. At the nest level, these field-specific estimates of logit DSR were further modified based on nest- and visit-specific covariates as follows:

$$logit(DSR_{i,j}) = logit(DSR_i) + \boldsymbol{\beta_j X_j}$$

where $logit(DSR_{i,j})$ was the logit of mean daily survival rate for nests in field i including nest specific covariates measured at nest j, $logit(DSR_i)$ the logit of mean daily survival rate for nests in field i, $\boldsymbol{\beta_j}$ a vector of fixed regression coefficients measured at the nest level, and $\boldsymbol{X_j}$ a matrix of nest-specific covariates such as VOR, initiation date, if planting occurred, and nest age.

Before running the model, I standardized variables by subtracting each observation from the mean and dividing the result by the standard deviation (Gelman and Hill 2009, Schmidt et al. 2010, Specht et al. 2020). I used the pairs function in R to examine if correlations between variables were independent and warranted inclusion in the model. I fit the Bayesian model using JAGS (Plummer 2003) with the jagsUI package in R (Version 3.6.2; R Core Team 2019), which uses a Markov Chain Monte Carlo (MCMC) simulation to estimate parameters in Bayesian hierarchical models. The full model included 11 fixed effects that have been known to influence nests survival. Model estimates were based on 3 chains of 25,000 iterations with a burn-in of 5,000 iterations and a thin rate of 5, yielding 12,000 total samples. I analyzed the global model using the estimated effect size, standard deviation, and 95% credible interval of each parameter.

Using results from the global model, I averaged the mean nest daily survival rate (DSR) estimates per field site for each cover type to obtain DSR estimates for each cover type. DSR is the probability that a nest will survive a single day. I converted average DSR estimates to average seasonal nest survival estimates by assuming a 34-day exposure period, which is an approximate average length of the nesting period for dabbling ducks in this region (Klett et al. 1988). I compared seasonal nest survival estimates to those presented in previous studies and the rate assumed necessary to maintain stable waterfowl populations (20%; Cowardin et al. 1985, Klett et al. 1988).

RESULTS

Nests Found

In 2018, I searched ~1,547 hectares of cover crops and ~1,174 hectares of perennial cover, and found 50 and 118 nests, respectively. In 2019, I searched ~1,415 hectares of cover crops and ~1,070 hectares of perennial cover, finding 72 nests and 194 nests, respectively. Nest searching began on 21 April in 2018 and 2 May in 2019 and was completed on 15 July of both years. Of the 122 nests found in cover crops, 32 (26.2%) were successful, 27 (22.1%) destroyed by equipment, 51 (41.8%) depredated, and 12 (9.8%) abandoned. Of the 312 nests found in perennial cover, 117 (37.5%) were successful, 171 (54.8%) depredated, 22 (7.1%) abandoned, and 2 (0.6%) failed for unknown reasons. Species of waterfowl nesting in cover crops included blue-winged teal (32.2%), northern pintail (26.1%), mallards (24.3%), northern shoveler (16.5%), and gadwall (0.9%). Species nesting in perennial cover included blue-winged teal (56.6%), mallard (17.9%), northern pintail (10.7%), northern shoveler (7.9%), gadwall (5.2%), redhead (1%; *Aythya americana*), and American green-winged teal (0.7%; *Anas* *carolinensis*). I also found nests of ring-necked pheasants, killdeer (*Charadrius vociferous)*, American bitterns (*Botaurus lentiginosus*), and upland sandpipers (*Bartramia longicauda*) in perennial cover.

Nest Survival

The average DSR for cover-cropped sites for the study period was 0.949 (95% CI =0.942–0.957; Table 2). This resulted in an average seasonal nest survival estimate of 17.2% (95% CI =12.4–22.3%). Perennial cover sites had an average DSR rate of 0.957 (95% CI =0.950–0.964), equating to an average seasonal nest survival percentage of 22.7% (95% CI = 17.5–28.5%; Table 2).

Bayesian Hierarchical Model

The parameter estimates and their associated levels of uncertainty from my nest survival modeling suggested that three covariates most influenced nest survival (Table 3). Planting had the largest negative influence on nest survival ($\beta_{planting}$ = -1.084, SD = 0.286); the average DSR per field when no planting occurred was 0.956 but only 0.879 when fields were planted, which corresponds to estimated seasonal nest survival of 21.7% compared to 1.3%, respectively. Nests initiated earlier in the nesting season had higher nest survival than nests initiated later in the year ($\beta_{initiation}$ = -0.240, SD = 0.102). Model estimates also indicated a large positive influence of study year on nest survival (β_{year} = 1.545, SD = 1.281); however, this estimate was imprecise and, thus, equivocal. The random effect of specific field site had a pronounced effect on nest survival (β_{year} = 0.864, SD = 0.159). All other variables included in the model had small and variable effect sizes with little influence on nest survival (Table 3).

Hatched nests per hectare

In both years, more nests were initiated in perennial cover than in cover crops. Overall nest density in cover crops averaged 1.1 hatched nests/100 ha searched, whereas nest density in perennial cover averaged 5.2 hatched nests/100 ha. Thus, the number of successful nests/100 ha was, on average, 4.8 times greater in perennial cover than in cover crops.

Estimated Hatch and Initiation in Cover Crops

To further understand the relationship between agricultural practices and duck nesting, I plotted the number of nests in relation to estimated nest initiation (Figure 2) and estimated hatch dates (Figures 3). The mean nest initiation Julian date was 135 (15 May) ± 13.5 d (SD). Approximately 68% of nests in cover crops were initiated between 2 May and 29 May. The mean estimated hatch date in cover crops was 168 (17 June) ± 13.2 d (SD). I further estimated that if all nests in cover crops were successful, 68% would have hatched between 4 June and 30 June. Additionally, approximately 50% of nests in cover crops were initiated between 7 May and 26 May. If all nests were successful I estimated that 50% would hatch between 10 June and 26 June.

DISCUSSION

Nest Survival

My results provide the first estimates of waterfowl nest survival in fall-seeded cover crops and suggest that although some duck production from this agricultural practice may be anticipated, cover crops do not appear to be equivalent to perennial cover in terms of habitat quality for nesting ducks. Because of the unique nature of my study, comparable estimates of nest survival on actively farmed lands are limited; however, the studies most similar to mine estimated duck nest survival in winter- and spring- seeded wheat and compared these values to those in perennial cover (Deubert and Kantrud 1987, Devries et al. 2008, and Skone et al. 2016). Though winter wheat is similar to fall-seeded cover crops, there are differences dependent on specific cover cropping practices, and my estimates may not be directly comparable to these aforementioned studies.

Nest survival is highly variable by location, year, date, cover type, species, landscape characteristics, and region (Klett and Johnson 1982, Johnson et al. 1992, Greenwood et al. 1995, Emery et al. 2005). In contrast to my hypothesis, model results showed no meaningful difference in nest survival between cover crops and perennial cover. Although results indicated that nest survival was highly variable in both cover crops and perennial cover, nest survival on average was slightly higher in perennial cover. In addition to the highly variable survival rates, weather conditions were dramatically different between the study years, which contributed to different management of the cover cropped sites. In 2018, all cover cropped fields were planted with row crops in the spring, whereas very few were planted in row crops in 2019 due to abnormally wet conditions. In 2019, the east central climate division of South Dakota reported 34.5cm of precipitation (100 yr mean = 18.8cm) between January and May, ranking the wettest year to date since 1895 (NOAA 2020). Precipitation in the same region was slightly below average, with only 16.3cm in 2018. Fields were too wet in 2019 for producers to enter fields with planting equipment, so those fields functioned similar to small grain cash crops, which receive minimal disturbance during the nesting season. Unavoidable differences in cover crop management between years may explain increased nest survival in cover crops, but also provided the opportunity to identify the factor most influencing nest survival.

Average nest survival in perennial cover was above the recommended 20% threshold for sustaining waterfowl populations (Klett et al. 1988), whereas on average nest survival in cover crops was slightly below this threshold. Other recent studies reported similar nests survival rates for winter wheat and perennial cover (Devries et al. 2008, Skone et al. 2016), but nest survival in both cover types exceeded the aforementioned 20% threshold. Cereal Rye is the dominant cover type contributing spring growth in fall-seeded cover crops in regions of harsh winter temperatures, and this was true for cover cropped sites in my study. Vegetation structure differs between cereal rye and winter wheat, especially at later stages when cereal rye is taller and produces fewer tillers (Stoskopf 1985). Fall-seeded cover crops that did not get planted in the spring due to excessively wet conditions and received minimal agriculture disturbances during nesting appeared to function similar to winter wheat. Thus, although model results suggested no large difference in nest survival between cover types, reduced nest survival was largely caused by the disturbance in fields related to agriculture practices.

I also hypothesized that agricultural disturbances, specifically planting, would negatively influence nest survival. As predicted, model results showed that planting had the largest negative impact on nest survival. Although intuitive, it has not been documented for this cover type. Previous studies reported similar results for nest survival on actively farmed lands (Milonski 1958, Higgins 1977). Nests initiated in agriculture fields that are planted in the spring tended to have lower survival rates because of mechanical destruction associated with the planting process. In the Northern Great Plains, a short growing season leaves a narrow time window for planting to allow for crop maturation and harvest before winter halts farming activities. In addition to weather conditions, planting is subject to regulations, specific to commodities and locations, which dictate the earliest and latest dates that producers may plant crops. These regulations are set by the United States Department of Agriculture Risk Management Agency, primarily for crop insurance purposes (USDA 2016). For instance, corn can be planted in South Dakota no earlier than 10 April and no later than 31 May, and in some counties no later than 25 May. Soybeans cannot be planted earlier than 26 April and not later than 10 June. Unfortunately, weather conditions and regulations result in the planting season in South Dakota that directly overlaps with the peak of the waterfowl nesting activity.

Because plant date is dependent on a variety of controllable and uncontrollable factors, it is difficult to develop set management recommendations for cover crops to maximize duck nest survival. Terminating cover crops and planting row crops before 1 May would mean most mechanical disturbance would occur before the peak of duck nest initiation (Figure 2). In this period some early initiated nests may be destroyed, but those females would be more likely to re-nest than those whose nests are destroyed later (Arnold et al. 2010). Although this would be the ideal timing of planting, this may not be realistic for most years considering only 18% of corn and 3% of soybeans are planted by 3 May in South Dakota, based on the five year average (USDA 2020). Based on the 5-year average, 84% of corn is planted and 64% of soybeans were planted by 31 May (USDA 2020). Given that planting is driven by annual weather conditions, it may be best to plant as early in May as conditions allow. Overall, in my study few nests were initiated in cover crops before 1 May, presumably because minimal spring growth had occurred. Terminating cover crops and planting row crops early would likely decrease the quality and attractiveness of cover for nesting ducks but this approach could encourage females to use nearby perennial cover instead.

Because nest survival is reduced by mechanical disturbance under current practices, fall-seeded cover crops planted to row crops appear to function as an ecological trap (Gates and Gysel 1978, Schlaepfer et al. 2002, Duncan and Devries 2018). Spring cover crop growth attracts some female ducks to initiate nests, but when agriculture practices take place (e.g., spraying, planting) active nests have a very low probability of survival (1.3%). However, although planted cover crops in my study met the definition of an ecological trap, any meaningful impact on nesting ducks is uncertain for several reasons. For example, ducks nested in cover crops at lower densities than perennial cover, nest survival in perennial cover was still productive, and continental waterfowl populations remain large (USFWS 2019). Thus, I believe it unlikely that any negative impact of cover crops on nesting ducks would result in a noticeable influence on population size. If fall-seeded cover crops were adopted more broadly across the PPR this impact could change; thus, monitoring the annual acreage of this cover type seems warranted. Finally, although I suspect this practice may not impact waterfowl populations at large, the low nest survival I documented may be important when making management decisions in areas with low or declining acreages of perennial cover.

Because nest survival in cover crops is negatively affected by planting, other cover cropping techniques that receive less disturbance during the nesting season may improve nest survival. Such management techniques include grazing, haying and cutting for silage, or harvesting the cover crop itself. These practices typically receive less intense disturbances during the nesting season and the greatest portion of nests would have the chance to hatch before disturbances take place. Producers still receive the important soil health benefits cover crops provide, yet these techniques may be less time sensitive than planting, thereby offering safer nesting cover.

Nest survival often varies throughout the nesting season (Grant and Shaffer 2012). My results indicated that nest survival decreased slightly with initiation date; that is, nest survival was higher for nests initiated earlier in the season and decreased over time. Although some studies have found similar results (Emery et al. 2005, Grant and Shaffer 2012), others have found no trend between nest survival and initiation date (Klett and Johnson 1982), whereas a few have found higher nest survival with later initiation dates (Emery et al. 2005).

Landscape

Results from the global model revealed no meaningful relationship between nest survival and the percentage of cropland or the number of wetland basins in the surrounding $10.4 km^2$ of each field. Many other studies have found that nest survival decreased with increasing amounts of cropland and increased with increasing amounts of perennial cover near study sites (Greenwood et al. 1995, Reynolds et al. 2001, Stephens et al. 2005, Skone et al. 2016). A few studies have also reported little relationship between nest survival and these landscape characteristics (Arnold et al. 2007, Walker et al. 2013). Thus, although many results indicate a negative relationship between nest survival and cropland area near duck nesting habitat, my results did not strongly support this pattern.

Hatched Nest Density

The density of hatched nests/100 ha in my study averaged 4.8 times higher in perennial cover than in cover crops. Hatched nest densities were lower in my study than a similar study that compared nest survival in winter and spring wheat to perennial cover (Devries et al. 2008, Skone et al. 2016). In my study, average hatched nest density in perennial cover was most comparable to densities found in winter wheat, whereas densities found in cover crops were most comparable to those reported for spring seeded wheat (Devries et al. 2008, Skone et al. 2016). Although nest survival was similar between cover types in my study, there were more nests hatched from perennial cover than cover crops. The comparison between these cover types emphasizes the important value of conservation of perennial cover and the benefits it has on the landscape. The number of successful nests in cover crops may increase as the practice becomes more established and improvements in crop management reduces disturbance and nest destruction, but perennial cover remains the most valuable nesting habitat for waterfowl based on my findings.

MANAGEMENT IMPLICATIONS

Increasing nest survival on actively farmed lands continues to present a conservation challenge. Overall, my results suggested that given current management practices, planting row crops into cover crops significantly reduced nest survival, in fact to below a threshold considered necessary to support populations of upland nesting waterfowl. Although nest survival in cover crops that were planted to row crops was low, the important benefits cover crops provide to soil health, water quality, and other ecosystem services remain. If nest survival and waterfowl production is the focus when cover crops are planted, producers may consider altering their management techniques from current practices to maximize nest survival. Cover types with minimal disturbance during the nesting season will likely be the best practice for waterfowl production; however, agriculture technology and management strategies are constantly changing. Thus, efforts to improve cover-cropping practices that consider wildlife benefits should be encouraged.

Unless producers avoid active nests in cover crops, which seems impractical, mechanical destruction will remain a critical factor influencing nest survival in these systems. Due to high variability in the timing of planting caused by uncontrollable factors and the inability to prescribe specific recommendations on timing of practices, I would not recommend promoting cover crops as nesting cover if they will be planted to row crops. If producers intend to plant cover crops to cash crops, as is usually the case, I recommend planting before 1 May so that disturbances take place before peak nest initiation. The timing may vary regionally, and managers should evaluate local cropping phonology to determine the best planting time to avoid peak nesting. I further recommend that organizations working to promote increased avian nest survival on actively farmed land consider promoting the addition of small grain cash crops in crop rotations and fall-seeded cover crops with minimal mechanical disturbances during nesting.

Table 1. Number of nests found in each cover type, their fate, and cause specific mortality.

			Unsuccessful			
Cover Type	**Total**	**Successful**	**Ag. Practices**	**Depredated**	**Abandoned**	**Unknown**
Cover Crops	122	32	27	51	12	0
Perennial Cover	312	117	0	171	22	2

Table 2. Daily nest survival rate (DSR) and 95% confidence intervals with their associated seasonal nest survival percentages (SNS %) and 95% confidence interval (SNS 95% CI) for both cover types.

Cover Type	**DSR**	**DSR 95% CI**	**SNS %**	**SNS 95% CI**
Cover Crops	0.949	0.942–0.957	17.2	12.4–22.3
Perennial Cover	0.957	0.950–0.964	22.7	17.5–28.5

Table 3. Results from the global model, including parameter estimates (β), standard deviation (SD) and lower (L 95% CL) and upper (U 95% CL) credible limits.

Parameter	B	SD	L 95% CL	U 95% CL
dsr.mu	1.552	1.267	-0.96	4.053
Initiation	-0.238	0.102	-0.436	-0.035
Age	0.003	0.009	-0.014	0.02
VOR	-0.078	0.094	-0.262	0.105
Planting	-1.087	0.288	-1.656	-0.524
Year	1.519	1.262	-0.939	4.043
Cover	0.023	1.749	-3.447	3.465
Cover.Year	0.020	1.743	-3.42	3.429
Crop	-0.103	0.430	-0.931	0.749
Ponds	0.085	0.139	-0.185	0.358
Site[a]	0.862	0.161	0.584	1.214

[a] Random effect on dsr.mu

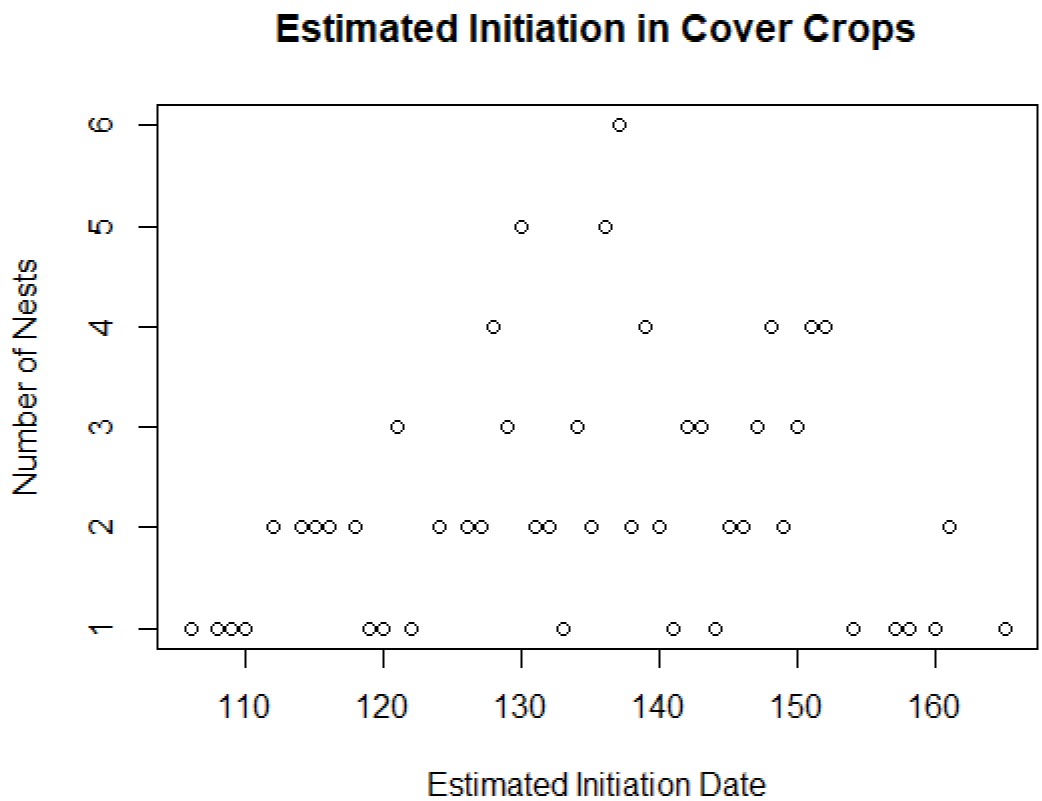

Figure 2. The number of nests initiated on each date during the nesting season in cover cropped fields in 2018 and 2019.

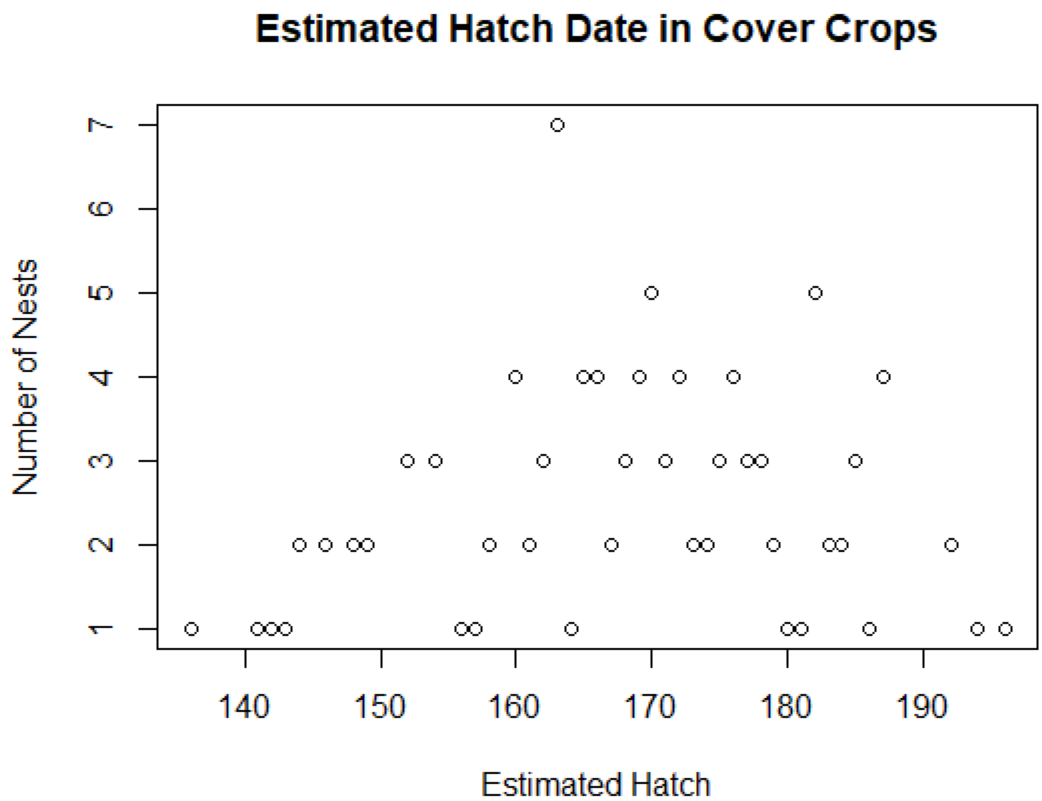

Figure 3. Number of nests plotted against estimated hatch dates during the nesting season for cover cropped sites in 2018 and 2019.

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