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Soil quality manipulation to reduce bird presence at airports

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Abstract: Aviation safety is an important concern in wildlife management as bird strikes risk human lives and result in costly damage. Habitat management can decrease bird abundances locally at airports. We tested soil manipulation as a technique to reduce local bird presence by establishing experimental plots with either intact topsoil or "stripped" subsoil with the aim of decreasing foraging substrate for birds. We estimated invertebrate abundance, and observed bird presence from 2006 to 2008. More birds visited topsoil plots (151.5 birds/ha/hour) than subsoil plots (72.7 birds/ha/hour). Topsoil plots supported a greater biomass of invertebrates than subsoil plots (= 0.39 g/50 cm^3, 0.21 g/50 cm^3, respectively). Bird abundance reflected soil variation in invertebrate abundance. Reducing topsoil quality may merit further consideration as a means of reducing local bird activity and abundances at airports.

Key words: airport habitat management, bird use, human–wildlife conflicts, Illinois, soil invertebrates, soil quality

Bird strikes are a worldwide threat to aviation safety. From 1990 to 2012, the Federal Aviation Administration (FAA) received >127,000 bird strike reports within the United States (Dolbeer et al. 2013). Bird strikes resulted in approximately 815,000 hours of downed aircraft time, >$570 million in damage costs, and loss of human life. Further, the FAA estimates that only about 20% of bird strikes are reported. The probability of bird strikes increases with proximity to airports because of low flight altitudes of planes during take-off and landing (Wright and Dolbeer 2000).

Wildlife habitat on and near airfields is important to flight safety due to the potential attractiveness of an airfield to birds and other animals. Habitat management on airfields can decrease local bird abundance and improve aviation safety at and near airports (Dolbeer et. al 1998, Barras et al. 2000, Barras and Seamans 2002, Dolbeer et al. 2013). Additionally, management within 8 km of the airport can reduce risk of strikes above 150 m (Dolbeer et al. 2013). Proven management techniques include maintaining intermediate grass height by routine mowing, use of chemical repellent on vegetation, removal of perching structures, and removal of standing water (Barras et al. 2000, Barras and Seamans 2002, Dolbeer et. al 1998). Use of specific turfgrass varieties or alternative land covers, such as agricultural crops, can also influence bird foraging, adding to habitat management techniques (Washburn and Seamans 2012, DeVault et al. 2013, Schmidt et al. 2013).

Management of soil quality is a possible technique that has not been assessed. Soil quality may affect the attractiveness of local habitat for birds due to impacts upon vegetation, hydrology, and food (Tanaka and Aase 1989, Gregorich et al. 1994). Airports often undergo construction that requires removal and storage of topsoil (D. Arends, O'Hare Modernization Program, personal communication). Soil conditions in topsoil are typically much more conducive to plant growth than those of subsoil (Brady and Weil 2007). Stripped soil (i.e, subsoil only) differs from topsoil in compaction,

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cation exchange capacity, organic matter content, and nutrients- fertility that reduce crop yields (Tanaka and Aase 1989, Robbins et al. 1997, Preve and Martens 1989) and overall productivity.

Soil quality also affects local abundances of invertebrates and, therefore, food for birds. Compaction, soil fertility, soil organic matter, and soil moisture all influence invertebrate abundance (Schrader and Lingnan 1997, Cortet et al. 2002, Ellis et al. 2004, Stovold et al. 2004, Johnson et al. 2006, Gilroy et al. 2008, Weston and Desurmont 2008). Reduced soil penetrability can reduce abundances of insect-eating birds (Lister 1964, Green et al. 1990, Peach et al. 2004, Gilroy et al. 2008).

Figure 1. Study plot with low quality soil in Urbana, Illinois, USA.

Given that food availability is a major determinant of habitat use by birds (Buler et. al 2007), soil quality may influence the suitability of airport fields as foraging substrates for birds. As the size of a flock increases, the risk of a damaging and potentially fatal strike also increases (DeVault et al. 2011). If stripped soil reduces the abundances and quality of both vegetation and soil invertebrates, then bird activity may also be reduced.

We assessed the effect of stripped soil on patch use by foraging birds. We asked: (1) whether reduced soil quality reduces the presence of birds on small plots? and (2) Does poor soil quality reduce the total biomass of soil invertebrates? We predicted that plots with poorer soil quality would have lower bird abundance and lower soil invertebrate biomass than plots with higher soil quality

Study area

We conducted our study at the Landscape Horticulture Research Center at the University of Illinois in Urbana, Illinois. The average annual precipitation for this area was 104.3 cm (NOAA 2009). The average daily maximum temperature was 16.2° C, and the average daily minimum temperature was 5.3° C. The area immediately adjacent to the study plots consisted of a variety of turfgrass species. The surrounding landscape was dominated by row-crop agriculture, mainly consisting of corn and soybeans.

Methods

Plot establishment and treatments

Beginning in the fall of 2005, we established 6 plots each comprising 165 m^2 on a layer of construction spoil, consisting of subsoil clay (i.e., a low quality soil; Figure 1). We established 6 other plots with the original topsoil layer at the surface (i.e. a high quality soil) and equal in area to the construction spoil plots. The subsoil and topsoil plots were adjacent to each other and all surrounded by mixed turfgrass that was maintained at ≤6 cm. Because capping soil with subsoil permanently damages the soil quality, a large area of subsoil was used for all subsoil plots and was divided by 1-m buffers and with sterilized plots. We randomly selected 3 plots on each soil type for sterilization with dazomet at 560 kg/ha. Sterilization kills nearly all soil organisms, so it was used as a baseline for low soil productivity for which to compare the unsterilized topsoil and subsoil plots.

We seeded the plots with a standard cool season turf grass mix, consisting of 19%

Table 1. Soil quality measurements for topsoil and subsoil plots in central Illinois.

Measurement	Topsoil	Subsoil	$F_{1,11}$	P
TEC[a]	14.15	16.34	27.23	0.0008
pH	6.65	7.72	341.33	<0.0001
OMC[b]	5.24	4.03	11.07	0.0104
ENR[c] (kg/hour)	100.67	90.00	19.41	0.0023
Soluble sulfur (meq/100 g soil)	20.33	13.50	13.56	0.0062
P (ppm)	27.83	14.00	9.84	0.0140
Ca (ppm)	1695.5	2019.5	16.61	0.0004
Mg (ppm)	563.33	651.83	26.75	0.0009
K (ppm)	277.00	208.83	33.31	0.0004
Na (ppm)	60.33	62.67	0.06	0.8077
B (ppm)	1.02	1.40	14.57	0.0051
Fe (ppm)	282.83	164.17	6.68	0.0323
Mn (ppm)	63.17	113.00	40.31	0.0002
Cu (ppm)	2.80	3.23	2.02	0.1932
Zn (ppm)	4.40	3.26	5.05	0.0548
Al (ppm)	599.0	408.5	151.33	<0.0001
Bulk density (g/cm^3)	1.16	1.31	41.44	<0.0001

[a]Cation exchange.
[b] % organic matter content.
[c]Estimated nitrogen release.

Kentucky bluegrass (*Poa pratensis L.*) variety Boutique, 19% Kentucky bluegrass variety Midnight Star, 14% Kentucky bluegrass variety Brooklawn, 14% perennial ryegrass (*Lolium perenne L.*) variety Paragon, and 29% creeping red fescue (*Festuca rubra L.*) variety Fortitude. These grass species are typically used in low maintenance turf mixes at airports (Doug Arends, O'Hare Modernization Program, personal communication). We maintained a turfgrass height of 6 cm by mowing as necessary throughout the growing season, which was typically once every 1 to 2 weeks. Irrigation and fertilization were provided as needed to prevent stress during the study period. All plots maintained >75% cover of the seeded turfgrass mix, clover (*Trifolium* sp.), and annual bluegrass (*Poa annua*) throughout the study period, as observed in routine scans using a grid pattern with a square meter.

Comparisons of soil quality

We collected 3 soil cores randomly from each plot using a 75-mm cylinder sampler in October 2008. Soil cores were weighed at field condition, dried in an oven at 40° C until there was no change in weight, and weighed again. Coarse fragments were removed, using a 2-mm sieve, and weighed. Bulk density was determined using the standard core method (Klute 1986). We composited samples for each plot and sent the composite samples to Brookside Lab, New Knoxville, Ohio for nutrient and particle analyses. We ran a particle size analysis using the hydrometer method and determined that the subsoil cap was a clay loam (21% sand, 52% silt, 27% clay, 4.03% organic matter) and the intact topsoil was a silt loam (16% sand, 66% silt, 18% clay, 5.24% organic matter).

Estimating avian presence

During October-November 2006, April-November 2007, and April to November 2008, we monitored all plots for avian presence. We recorded the species and number of birds present every 5 minutes for 1-hour time

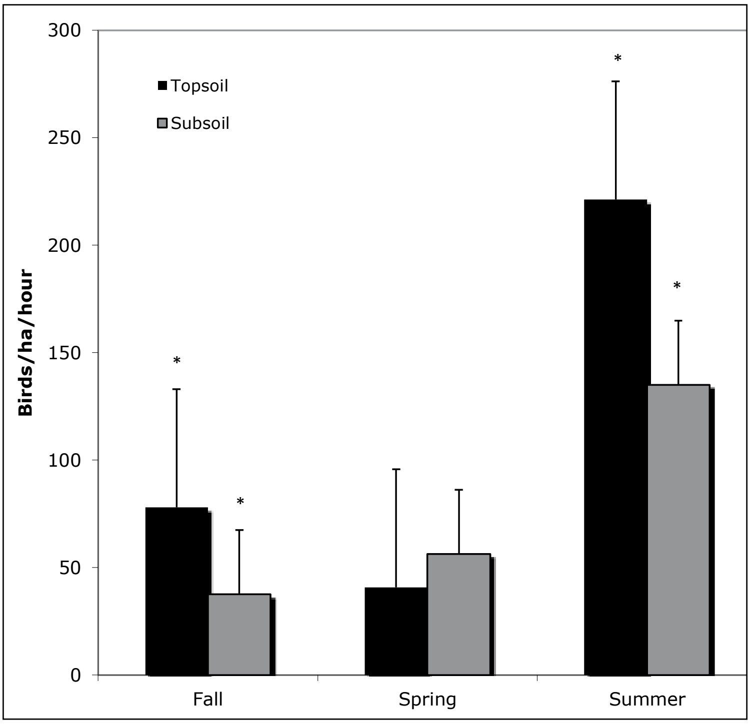

Figure 2. Seasonal presence of birds measured as birds/hour on topsoil and subsoil plots in central Illinois during 2006 to 2008.

intervals at various times between dawn and dusk (summing to 8 hours/week), with a minimum of 2 hours per week in each category of morning (dawn +2 hours), day, and evening (2 hours before dusk). Observations were made from either a nearby woodlot with cover or the entrance of a building using binoculars and a spotting scope. The woodlot was across a drive, approximately 50 m from the nearest plot. The building entrance was approximately 100 m from the nearest plot. All plots were clearly visible from both locations. We did not sample when the plots were covered with snow.

Estimating invertebrate abundance

Soil invertebrate samples were collected October 10, 2006; April 30, 2007; September 25, 2007; May 10. 2008; and October 1, 2008. We collected 4 random soil cores that were each 324 cm^3 from each plot. All cores for each season were collected within a 4-day period at approximately the same time of day. Samples from each plot were composited and placed in a Berlese funnel. We covered the sides of the cores with plastic wrap to reduce drying from the sides and to increase drying from the surface downward. Soil cores were left in the funnels until the core was fully dry. Invertebrates were collected in 70% ethyl alcohol. We dried the samples using a hot plate and recorded dry biomass.

Statistical analysis

We assessed the effects of soil type and sterilization on estimated bird activity (birds per hour) using a repeated measures design and nested ANOVA with SAS 9.1 (PROC MIXED, SAS Institute 2003). Normality of all data was determined using diagnostic plots (histogram and Q-Q plots). Sterilization treatment was nested within soil type because the topsoil and subsoil were spatially segregated. Monthly observations were the within subjects (i.e., time) factor. Seasons were divided as follows: spring (March, April, May), summer (June, July, August), and fall (September, October, November). We compared mean invertebrate biomass (g/50 cm^3) on each soil type using a repeated measures and nested plot ANOVA using SAS 9.1 (PROC MIXED, SAS Institute 2003). Invertebrate abundance was collected only once each spring and fall, so each season was used as a repeated measure in the analysis for overall invertebrate biomass. We estimated Spearman's rank correlation coefficients to test for correlation between number of birds observed and invertebrate biomass using a bootstrap routine with 1,000 replications

We classified bird species into 2 food guilds: granivores and insectivores. The composition of these guilds changed as bird diets changed seasonally. We compared bird use (birds per hectare per hour) on the two soil types and sterilization treatment for each guild using ANOVA with repeated measures in SAS 9.1 (PROC MIXED, SAS Institute 2003) and Tukey's test for differences. The two years were pooled because we did not find any difference across years for each calendar season.

Table 2. Presence (birds/ha/hour) of individual bird species averaging >6 birds/ha/hour in ≥1 soil type each season during 2007 to 2008 in central Illinois.

		Topsoil		Subsoil cap	
Season	Bird species	Mean	SE	Mean	SE
Spring 2007	Common grackle (*Quiscalus quiscula*)	18.79	4.85	22.42	6.67
	American robin (*Turdus migratorius*)	16.97	2.42	33.33	8.48
Summer 2007	Killdeer (*Charadrius vociferous*)	17.58	4.85	1.21	0.61
	Brown-headed cowbird (*Molothrus ater*)	190.30	14.55	115.15	3.64
	Common grackle	13.94	6.06	0.61	0.00
	American robin	5.45	1.21	6.67	0.61
Fall 2007	Killdeer	33.94	10.91	3.03	1.82
	Brown-headed cowbird	249.70	41.21	12.12	7.88
Spring 2008	Common grackle	30.91	3.64	35.76	5.45
	American robin	12.73	3.03	15.15	1.21
Summer 2008	Brown-headed cowbird	182.42	13.33	89.09	12.73
	Common grackle	24.85	5.45	22.42	4.85
	American robin	5.45	1.82	34.55	5.45
Fall 2008	Killdeer	12.73	6.06	1.21	1.21
	Brown-headed cowbird	91.52	13.33	32.12	10.91
	Common grackle	6.06	1.21	6.67	1.82
	American robin	1.21	0.61	10.30	2.42

Results

Comparison of soil quality

Topsoil plots had a lower percentage coarse fragment content ($F_{1,35}$ = 2.96, P = 0.0005), higher percentage moisture content ($F_{1,35}$ = 6.39, P = 0.0002), lower bulk density, higher percentage organic matter, and lower pH than subsoil plots (Table 1). Topsoil plots had higher levels of important macronutrients than subsoil; subsoil plots had about 50% as much phosphorus, 90% as much nitrogen, and 75% as much potassium as topsoil plots. Topsoil also had higher levels of soluble sulfur, iron, and aluminum. Subsoil had higher levels of calcium, magnesium, boron, and manganese.

Avian presence

We observed brown-headed cowbirds (*Molothrus ater*) more than any of the other 6 species observed on the research plots. We observed them in high numbers only in late summer and early fall. Common grackles (*Quiscalus quiscula*), American robins (*Turdus migratorius*), and killdeer (*Charadrius vociferus*) were seen most often during spring. Other species observed included house sparrows (*Passer domesticus*), American crows (*Corvus brachyrhynchos*), and mourning doves (*Zenaida macroura*; Table 2).

Birds were observed in the high-quality topsoil plots more than low-quality subsoil plots overall in summer ($F_{1,5}$ = 29.03, P < 0.0001) and fall ($F_{1,5}$ = 51.72, P < 0.0001; Figure 2). Bird use of topsoil plots and subsoil plots did not differ in spring ($F_{1,5}$ = 0.83, P = 0.3899). We also observed an interaction between soil type and season ($F_{10,13}$ = 30.72, P < 0.0001), such that bird presence in fall declined on subsoil, but not topsoil. Avian presence on the sterilized plots did not differ from unsterilized plots at any point in the study ($F_{1,13}$= 0.63, P = 0.4324).

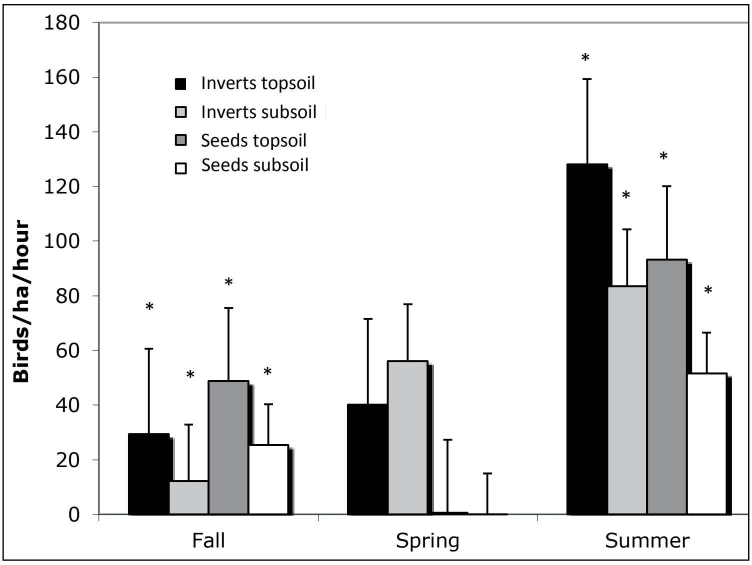

Figure 3. Seasonal abundance of herbivores and insectivores on topsoil and subsoil plots in central Illinois during 2006 to 2008.

Overall, bird presence was greater on topsoil than subsoil for both insectivores ($F_{1,11}$ = 31.91, P < 0.0001) and granivores ($F_{1,5}$ = 9.18, P < 0.0001). We also found an interaction between soil type and season for both guilds ($F_{1,7}$ = 18.72, P < 0.0001; Figure 3), whereby topsoil had higher bird activity than subsoil in summer and fall, but lower bird activity in spring.

Invertebrate abundance

Topsoil ($\bar{x}$ = 0.39 g/50 cm^3) supported a higher abundance of invertebrates than subsoil ($\bar{x}$ = 0.21 g/50 cm^3, $F_{11, 46}$ = 3.24, P = 0.002). Dry invertebrate biomass ranged from 0.00 g/50 cm^3 to 2.07 g/50 cm^3 on topsoil plots and from 0.00 g/50 cm^3 to 0.73 g/50 cm^3 on subsoil plots throughout the study period. Soil invertebrate abundance was extremely low in fall 2006 ($\bar{x}$: topsoil = 0.13 g/50 cm^3, 95% CI: 0.03, 0.23; subsoil = 0.14 g/50 cm^3, CI: 0.02, 0.26), the season when plots were established. Subsoil plots maintained a low average invertebrate biomass throughout the study. Invertebrate biomass increased on topsoil in both fall 2007 and fall 2008. The average invertebrate biomass in topsoil was >300% that of the subsoil (0.13 g/50 cm^3) in fall 2007, and slightly <300% as much in fall 2008 (subsoil $\bar{x}$ = 0.37 g/50 cm^3). Invertebrate biomass increased greatly on topsoil plots from spring to fall, but did not increase similarly on subsoil plots (interaction between soil type and season; $F_{1,11}$ = 3.89, P = 0.001). Sterilized plots did not differ in invertebrate biomass from unsterilized plots at any point in the study ($F_{1,11}$ = 0.44, P = 0.51).

Bird use and invertebrate biomass

The estimated abundances of birds and biomass of soil invertebrates were strongly correlated (0.86 Spearman's rank correlation coefficient) throughout the seasons on the topsoil plots (Figure 4a) and subsoil plots (Figure 4b). The abundances of both birds and invertebrates were relatively low in spring and increased during the growing season, especially on the topsoil plots.

Discussion

Our experiment offers evidence that management of soil can be part of the solution to reducing bird abundances at airports. Several bird species that have been involved in damage-causing aircraft strikes in the United States apparently preferred topsoil to low-quality soil. Blackbirds and grackles caused >$1.7 million in costs due to damaged aircraft and down town from 1990 to 2012 (Dolbeer et al. 2013). Killdeer caused about $4 million in costs during that time period and also demonstrated a preference for topsoil.

We demonstrated that lower soil quality caused ecological changes, reducing animal use in 2 trophic levels by impacting both soil invertebrates and birds. Organic matter content, fertility, and nutrient release are considered important contributors to soil quality (Tanaka and Aase 1989, Gregorich et al. 1994, Robbins et al. 1997, Brady and Weil 2007) and invertebrate abundance (Riley et al. 2008). High bulk density and coarse fragments can limit root growth and organism mobility (Riley et al. 2008). Additionally, clay soil supports lower species diversity and abundances of birds and other wildlife than loam or sand (Woinarski et. al 1999). Any of these factors may have contributed to higher invertebrate populations and bird use on the topsoil plots. As expected, the physical characteristics of the 2 soil types indicated that the topsoil plots were more conducive to soil productivity than the subsoil plots.

We, therefore, believe that manipulation of soil quality can initiate a bottom-up effect on local bird presence. Bird species richness is positively correlated with arthropod species richness (Provencher et. al 2003) and stopover site selection for insectivorous migratory birds is largely associated with arthropod abundance (Buler et. al 2007). Considering birdstrikes are most common during migration (Cleary et al. 2006, Dolbeer et al. 2013), trends of soil invertebrates are important during this time. Bird abundances tracked invertebrate biomass in both soil types. The large difference in invertebrate biomass between topsoil and subsoil in fall was likely a major factor for the greater abundance of insectivorous birds on topsoil plots, though other variables that were not within the scope of this study, including edge effects, predation, vegetation structure, and vegetation density, also have an influence on avian presence. We believe the influence of low quality soil can be multi-trophic and can reduce bird abundance.

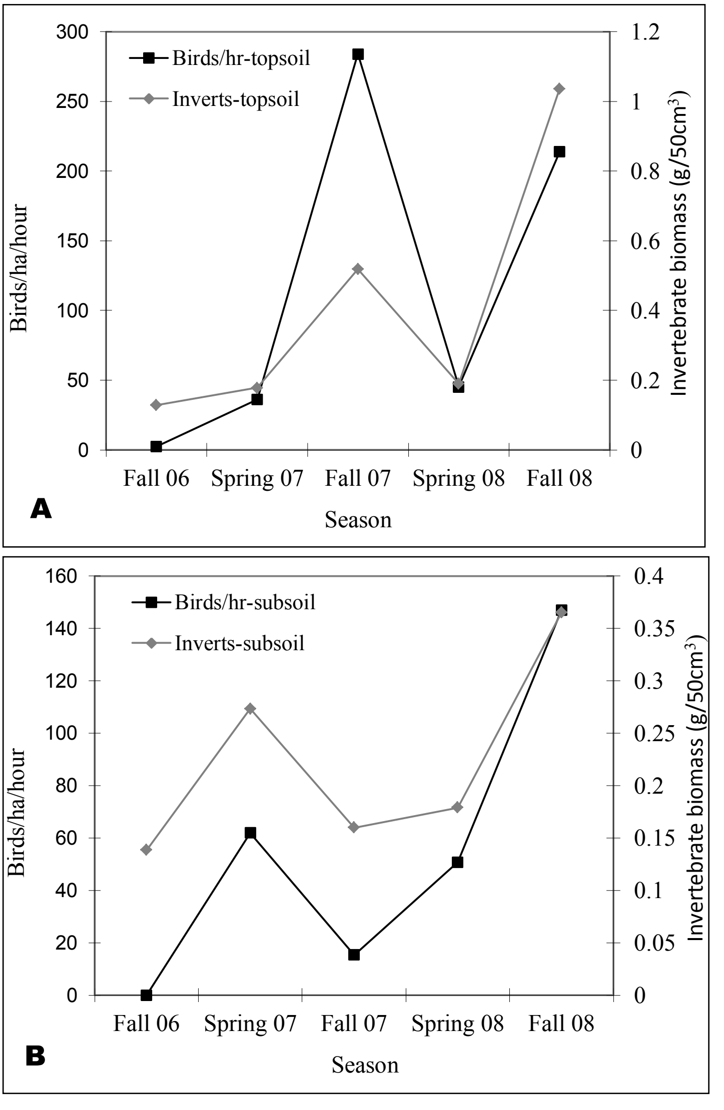

Figure 4. (**A**) Trend of mean bird presence on topsoil plots compared to the trend of mean invertebrate biomass on topsoil plots in spring and fall 2006 to 2008 on the study plots in central Illinois. (**B**) Trend of mean bird presence on subsoil plots compared to the trend of mean invertebrate biomass on subsoil plots in spring and fall 2006 to 2008 on the study plots in central Illinois.

Soil quality is often discussed but can be difficult to quantify (Karlen et. al 1997). The subsoil used in this study was established in turf during 1993 and managed as a low-maintenance turf but with irrigation to maintain growth. Fertility was sporadic and limited during this time but constant turf and weed cover was maintained. Thus, while the soil quality was reduced compared to native topsoil, soil quality most likely improved over the 12 years of grass growth that added organic matter and fertility to the soil. Very poor quality subsoil could lead to turf loss under drought or high temperature, which could lead to significant problems, e.g. excessive airborne dust. Additional research is needed to determine what minimum level of soil quality is required to sustain a turf under airfield conditions.

Management implications

Manipulating soil quality may be a promising technique for reducing patch use by both granivores and insectivores, especially in late summer to early fall, when low strike altitudes are most frequent (Cleary et. al 2006, Dolbeer 2006). By making airports low-quality patches, birds may choose to abandon airports as foraging locations. Soil manipulation does affect bird abundance, but may not be possible for all airports due to infeasibility and high costs of moving soil. However, airports undergoing construction should consider soil quality as a possible management practice by not requiring the typical replacement of topsoil post-construction. In this type of situation, airports could save money by avoiding soil replacement costs, while reducing habitat quality. Additionally, effective reduction in bird abundance would reduce the need for ongoing bird-scaring tactics.

Increased effort to establish and maintain turf may be necessary in the lower quality soil, but this initial effort can potentially be a valuable investment in aviation safety. Soil management will not eliminate strikes, but it will lower the potential for strikes and lessen the need for reactive management, improving the safety of aviation and costs of both management and damage. Larger-scale studies are currently underway. Our observations in this study were limited to small birds. The effect of soil quality on large herbivorous birds, such as Canada geese (*Branta canadensis*) merits study, as these pose a higher hazard to aviation safety than small birds (Cleary et al. 2006, Dolbeer et al. 2013).

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