

EFFECTS OF AGRICULTURAL PRACTICES  
ON MICROTOPOGRAPHY IN RESTORED PRAIRIES

by

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of

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in

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I would like to take a moment to honor the land of the Dakota people, where this study takes place.

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Please note that the formatting follows the guidelines for publishing in the Journal of Applied Ecology.

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## ABSTRACT

Tallgrass prairies are often restored from agricultural fields that have long since removed the natural microtopography. Therefore, our study investigates how these restored prairies recover microtopography.

We used precise elevation data collected from LiDAR to compare differences in microtopography between crop fields, fallow fields, newer restored prairies (restored within the last 10 years), and older restored prairies (restored 10 to 20 years ago). We also compared plant biodiversity indices between newer and older restored prairies using nested plot vegetation sampling.

Our first research question is how microtopography differs between the sites. Our results show that older restored prairies had the most microtopographic variation, followed by newly restored prairies.

Our second research question is how plant biodiversity correlates with microtopographic variation. Our results show that older restored prairies had the highest biodiversity and the highest microtopographic variation.

Our third research question is how microtopographic variation changes between 2011 LiDAR data to the 2021 LiDAR data. Our results show an increase in microtopographic variation after a decade once farming has ceased.

*Synthesis and application:* Land managers that have better access to LiDAR data may want to add microtopographic variation as a tool for long-term monitoring ecosystem function in restored tallgrass prairie sites. Our study suggests that microtopographic features appear to increase with the age of a restoration site, providing a visual way to show a restoration's success.

*Keywords:* LiDAR, tallgrass prairie, microtopography, biodiversity, monitoring, restoration

## EFFECTS OF MIDWEST AGRICULTURAL PRACTICES ON MICROTOPOGRAPHY IN RESTORED PRAIRIES

### 1. INTRODUCTION

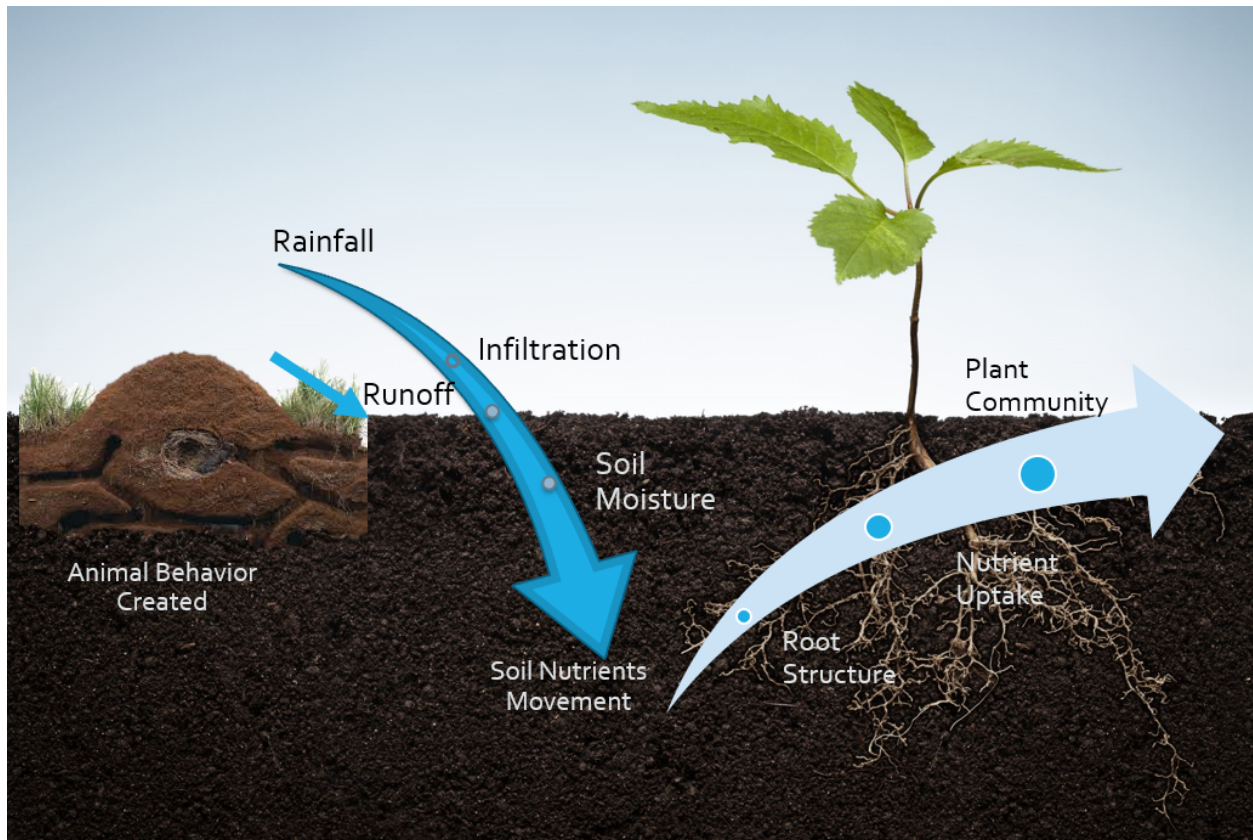
Microtopography is defined as small-scale variation ( $< 1$  m) in surface roughness, and directly interacts with hydrology, biogeochemistry, biodiversity, and soil processes (Liu et al., 2020). These interactions are often difficult to measure, let alone visualize. Using detailed measurements of microtopography may be a tool for monitoring ecosystem functionality in prairie restoration projects.

High-resolution elevation data are needed to detect these minor differences in topography (Moser et al., 2007; Rayburg et al., 2009). One of the best tools for collecting these data is Light Detection and Ranging (LiDAR). LiDAR creates a point-cloud dataset from lasers collecting height (z) measurements with centimeter accuracy (Csanyi and Toth, 2007).

The application LiDAR for characterizing microtopography has sprouted many studies in various ecosystems worldwide, especially in the last decade (Dong and Chen, 2020). The abiotic and biotic interactions with microtopographic variation are becoming clearer with the use of LiDAR (Thomas et al., 2017; Hudak et al., 2009). Researchers can now study the complex interactions between microtopographic variation and ecosystem functions such as the hydrology, vegetation, soil, and animal behavior (Figure 1; Hudak et al., 2009).

During hydrologic processes, water interacts with the earth's surface, especially after precipitation events. Run-off, as sheet flow, creates rills and gullies as the water flows across the

landscape (Jan et al., 2018). Microtopographic variation helps to keep water on the landscape by increasing water infiltration (Caviedes-Voullième, Ahmadinia and Hinz, 2021), recharging the



ground water, and preventing run-off. (Thompson et al., 2010; Dunne, Zhang, and Aubry, 1991)

Previous studies have found that plant distribution patterns are affected by microtopographic variation (Mcgrath et al., 2012; Liu et al., 2020; Moser et al., 2007). One reason for this is the change in microclimates, such in as pits and mounds that harbor species that would not normally

be present in a particular plant community (Duffy et al., 2021; George et al., 2015). The vast

Figure 1. Simplification of microtopographic variation created by animal behavior. In this case, it is a mole hill that creates a mound where water run-off increases the amount of water infiltrating into the soil column. This increases the soil moisture, which in turn releases locked soil nutrients. Plant roots grow toward areas of high nutrient content, altering the root structure and increasing nutrient uptake, and altering the plant community.

diversity in plant growth patterns, from grasses to trees, can alter the soil surface through root structures, biomass, and clumping (Mcgrath et al., 2012; Lefever et al., 2009).

Soil is important for plants, providing a medium for roots to access water and nutrients. Soil moisture changes with variation in microtopography providing landscape heterogeneity (Qingping et al., 2021). This affects the water availability in the soil with concave microtopography holding more soil moisture in deeper layers of the soil column (Engstrom, 2005). Depressions harbor more soil nutrients such as nitrogen and phosphorous, increasing uptake by legumes and other plant species (Liu et al., 2020).

Animal behavior also affects soil roughness through burrowing, trampling, and other animal soil disturbances. The diversity of burrowing animals includes ants, moles, prairie dogs, owls, and foxes, all of which use a subterranean environment for shelter, storing food, and rearing young (Rosario-Carotenuto et al., 2020). In open grassland systems, trampling increases the microtopography of the landscape with herding mammals congregating in certain areas (Tollner et al., 1990). This herding behavior, when done without overgrazing, can benefit the soil nutrient cycle and prevent erosion (Teague and Kreuter, 2020). Eldridge and James (2009) found that soil-disturbing animals, which alter the microtopography of a landscape, affected the soil nutrients, increased infiltration, and increased decomposition of organic matter.

These ecosystem functions provided through animal soil disturbance can be extremely important in flat landscapes, such as the central plains of North America. The keystone species of the tallgrass prairie is bison or buffalo (*Bison bison*) (Knapp et al., 1999). Bison are a sacred animal for the Indigenous people, who honor the bison for providing nourishment and everything else one needs. As the original land caretakers, these people have a timeless relationship with the

large herds of bison and the tallgrass prairie they roam. The near extinction of the bison and the tallgrass prairie causes an immeasurable loss to Indigenous people (Blackstock and McAllister, 2004).

Tallgrass prairie is one of the most affected ecosystems in the midwestern U.S. from soy and corn crop farming, with much going “under the plow” more than 100 years ago (Shirley, 1994). Less than 1% of this expansive landscape remains scattered across central North America (Tester, 1995; Shirley, 1994). The average vegetation richness of these lost prairies is estimated to be 200 to 300 species (Weaver, 1968). Most prairie restorations will only a fraction of those species (Widinski, 2011).

This loss of vegetation biodiversity means many traditional medicines are in jeopardy of being lost and are no longer as abundant as they once were (Shirley, 1994; Blackstock and McAllister, 2004). No longer do large herds of bison trample and create the microtopographic variation that the prairies have evolved with (Knapp et al., 1999). This makes it imperative to monitor biodiversity, along with microtopographic variation, to fully understand the abiotic and biotic interactions. It remains unknown how much prairies restored from previous agricultural practices can recover microtopographic variation.

In this study, therefore, we quantify the spatial distribution of plants and their relationship with microtopography variation. Diversity indices, such as Shannon-Wiener and Simpson’s provide a numerical description of species diversity within a sample of plots ( $\alpha$ -diversity) (Whittaker, 1972). Understanding the relationship between biodiversity and microtopography can help land managers monitor prairie restoration sites.

Microtopography provides heterogeneity in the landscape, thus supplying space for plant species that have different water, nutrient, or light conditions (Liu et al., 2020). In the flatter prairie lands, microtopography is often the only change on the soil surface (Gala and Melesse, 2012; Fisher et al., 2018). Weaver (1968) notes that plants play a key role in soil development in the tallgrass prairie features, stating “Soil is as much a product of vegetation as vegetation is a product of soil.” This underscores the interwoven relationship between microtopography, soil, and vegetation.

Unfortunately, modern agricultural practices still remove microtopographic variation from the landscape, or do not consider it in their grazing plan (Fisher et al., 2018). In the midwestern U.S., it is common to see extensive fields of corn (*Zea mays*) and soybean (*Glycine max*). Large machinery, such as tractors, alter the soil surface through flattening, tilling, disking, plowing, and other forms of cultivation (Fisher et al., 2018). This removal of natural microtopography results in lower soil health by causing erosion, soil degradation, and loss of soil nutrients (Hou et al., 2020).

Restoration efforts only indirectly repair microtopographic variation. The reestablishment of lost microtopography requires restoring suitable habitat. However, restoration of prairie lands has only taken place in the last thirty years (Barber et al., 2017; Bach and Kleiman, 2021). Much is still unknown as to how long it takes to reestablish microtopography in prairies.

The purpose of this research, therefore, is to investigate how microtopography changes after restoration in tallgrass prairies. We will address the following questions: 1) How does microtopography differ among farmed crops, fallow fields, newly restored prairies (restored within last 10 years), and older restored prairies (restored 10 or more years ago)? 2) Is there a

relationship between plant biodiversity and microtopography in newly restored prairies and older restored prairies? 3) In a 10-year period, how does microtopographic variation change on the same sites due to changes in land use (i.e., a site that was farmed in 2011 and is now a restored prairie in 2021)?

To answer these questions, we collected LiDAR derived elevation data and plant biodiversity data to compare among sites and time periods. A total of 20 sites split equally between the different land uses in 2021 included the following: row crop farming (crop), fallow fields (fallow), prairie established since 2011 (new prairie), and prairie established before 2011 (old prairies) (Figure 2). Fifteen of the sites were soybean/maize fields in 2011. The remaining five were newly restored prairies in 2011, with restoration taking place between 2000 and 2010.

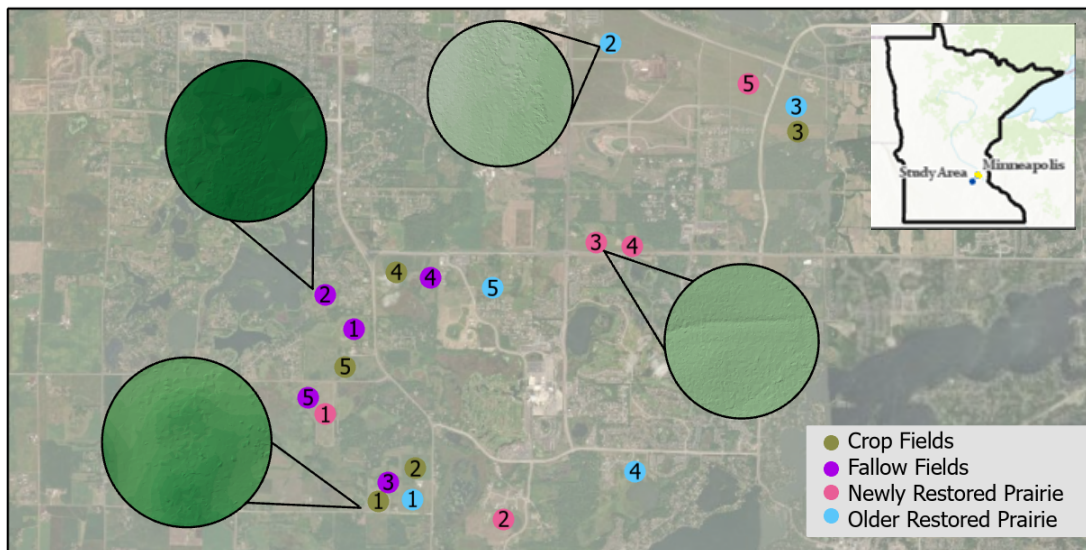


Figure 2. Study area located within 31 km<sup>2</sup> of SMSC tribal boundaries. The four callouts show examples of triangulated LiDAR at 1:1000 for each treatment. The five sites within each treatment were numbered 1-5 by either crop, fallow, new, or older.

## 2. MATERIALS AND METHODS

### 2.1 \Study Area

The study area is in northern Scott County in Minnesota (Mni Sota Makoce) (44°44'37" N 93°28'50 "W). All land is within Shakopee Mdewakanton Sioux Community (SMSC) tribal boundaries (Figure 2). Prairie restoration has long been a practice of this Dakota community since 2000, to honor Ina Maka, Mother Earth, and to honor the value of being good stewards of the earth. Farming leases are given to SMSC Community Members at the discretion of the SMSC Business Council. Therefore, all farming fields and fallow fields in this study are also within SMSC authority. Currently, SMSC boundaries and by extension the research boundaries are within 31 km<sup>2</sup>.

The same SMSC Community member planted the crop fields with maize or soybean, except for 15 acres of Crop 2 that was planted with sorghum (*Sorghum × drummondii*) (Table 1). These crops have similar requirements in terms of equipment needs. They both were drill seeded, which creates furrows in the soil to create the rows of crops. Fallow fields were all corn or soybean fields in 2011. The fields were then left to go fallow within five years (Table 1).

We selected prairie restoration sites based on specific criteria. First, the restoration management technique had to include tractor use, such as for seeding, cultivating, and/or broadcast herbicide application. Next, the sites had to be considered “established” mesic tallgrass prairie. This was identified using indicators such as dominance by big bluestem (*Andropogon gerardii*), switchgrass (*Panicum virgatum*), little bluestem (*Schizachyrium scoparium*), side-oats grama (*Bouteloua curtipendula*), and/or Indian grass (*Sorghastrum nutans*) (Shirely, 1994). The prairies were further divided into seeding and restoration taking place before 2011 (older

prairies) and after 2011 (newer prairies). Vegetation sampling only took place on these tallgrass prairies (Table 1).

Table 1. The 20 sites that were used within this study. The total acreage for each treatment was as follows: Crop has 189 acres; fallow has 150 acres; new restored prairie (New) has 175 acres; and older restored prairies (Old) has 175 acres.

<b>Site</b>	<b>Acres</b>	<b>Years</b>
Crop 1	18	85+
Crop 2	30	85+
Crop 3	30	85+
Crop 4	40	85+
Crop 5	71	85+
Fallow 1	56	6
Fallow 2	25	6
Fallow 3	31	5
Fallow 4	15	2
Fallow 5	23	3
New 1	44	3
New 2	25	5
New 3	27	6
New 4	14	6
New 5	65	8
Old 1	21	13
Old 2	70	14
Old 3	58	14
Old 4	11	19
Old 5	15	21

## 2.2 Vegetation Data Collection

We sampled using nested frequency plots adopted by Larson et al. (2018). Each plot is 1 m<sup>2</sup> and divided into different subunits (Figure 3). Each subunit has a corresponding size as follows: subunit 1 (50 x 12.5 cm), subunit 2 (50 cm x 25 cm), subunit 3 (50 cm x 50 cm), subunit 4 (100 cm x 50 cm), and subunit 5 (flip frame to get 1 m<sup>2</sup>). Each plant species rooted within the frame is only counted once in the smallest subunit. The percentage vegetation cover for each subunit is as follows: subunit 1 averages 86% cover, subunit 2 averages 61% cover, subunit 3 averages 34% cover, subunit 4 averages 15% cover, and subunit 5 averages 3% cover (Braun-Blanquet et al., 1932; Wikum and Shanholtzer, 1978). Any plants found outside the plot that we had not previously documented were given the code present with an average 0.5% cover (Larson et al., 2018).

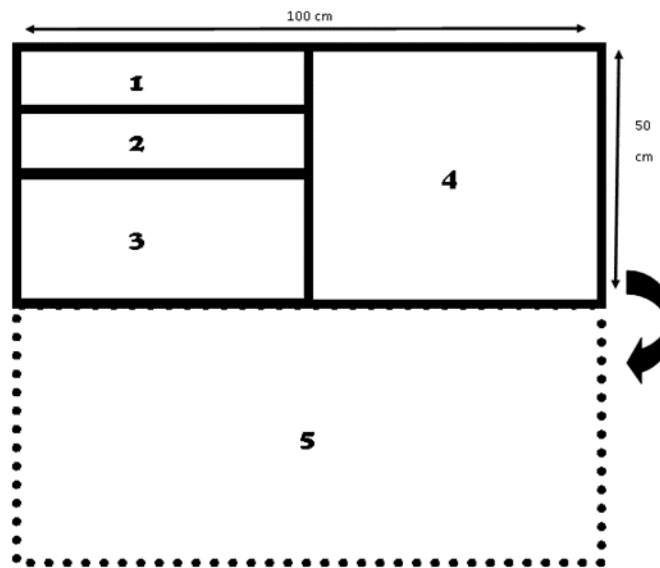


Figure 3. Nested plot frame showing how each subunit is divided and the fifth one is flipped. Each subunit has a corresponding value as follows: subunit 1 (50 x 12.5 cm), subunit 2 (50 cm x 25 cm), subunit 3 (50 cm x 50 cm), subunit 4 (100 cm x 50 cm), and subunit 5 (1 m<sup>2</sup>).

To avoid bias and ensure the entire site was surveyed, the plots were systematically placed as a grid. If the prairie was less than 3 ha it was given the minimum number of plots (10). If the size of the prairie exceeded 13 ha, then it was given the maximum number of plots (40). The average density of plots was 3 per ha across all prairie sample sites. The plots were always placed with the 50 cm side facing in the east-west direction and always flipped to the north for the final subunit.

We calculated the plant species diversity for each vegetation plot in RStudio (R Studio Team, 2021) using richness (S), Simpson reciprocal diversity index (D), Shannon's diversity index (H), Simpson's Evenness Index, and Shannon's Evenness Index. Species richness describes the number of species found in each vegetation plot. To calculate species richness, the R Base package (v 4.1.2) function "rowSums (sign ())" is used for presence/absence of each species (RStudio Team, 2021). The RStudio package "vegan" (v 2.5-7) was installed to calculate Simpson's Diversity Index and Shannon's Diversity Index using Ecological Diversity Indices function (Oksanen. and O'Hara, 2020). The following equations for D, H, D Evenness, and H Evenness use the proportional abundance of each species ( $p_i$ ) and the richness (S) (Maurer and McGill, 2011):

$$D=1 / \sum p_i^2$$

$$H = -\sum p_i \ln(p_i)$$

$$D \text{ Evenness} = D/S$$

$$H \text{ Evenness} = H/\ln(S)$$

### **2.3 LiDAR Data Collection**

LiDAR data were collected at all prairies, hay/fallow fields, and row crop sites in the summer of 2021. We used a Matrice 600 Pro drone (DJI Matrices 600 V 01.00.01.67 2019) with a mounted LiDAR system (YellowScan Surveyor Velodyne VLP-16 UAV LiDAR system Version 3.0 2020). Flight paths were drawn in the field using Pix4D app (Pix4D SA PIx4Dcapture Version 4.13.1 2021), and the flight paths were automatically calculated. The altitude of flight was between 75 and 85 m from ground level. Post-flight processing was done using point-cloud LiDAR software (Yellowscan CloudStation Version 1.1 2019). After post-processing, the point-cloud data were saved as an LASD file and loaded into ArcPro (ESRI V 2.9). All LASD files were then combined using Create LAS Dataset (Data Management Tools) to be processed the same way. Ground points were classified using the Classify LAS Ground (3D Analyst Tools).

We downloaded raw LiDAR data from the 2011 Scott County flight for the Minnesota LiDAR project. These lidar data were collected in the summer of 2011 by Fugro Horizons Inc. with an accuracy of 1.5 point/meter and were post-processed by the Minnesota Geospatial Information Office. (MN DNR and Fugro Horizons Inc, 2011)

### **2.4 Spatial and Data Analysis**

We used ArcGIS Pro (ESRI v 2.9) to transform both the 2011 and 2021 point-cloud data sets into 1 m Digital Elevation Models (DEM) (LAS Dataset to Raster Geoprocessing tool). This transformation was necessary to make the UAV mounted LiDAR data comparable to the state flown LiDAR data (Figure X). Then, we transformed the 1 m DEM to points (Raster to Points Conversion Tool) within each study boundary, to get sample points within each of the sample plots. These sample points contained the elevation data necessary to complete the following data analysis and were placed systematically 1 m apart. Thomas et al. (2017) used similar methods for

analyzing microtopography in open grassland. Each of the three research questions required a different method for comparing data using these points.

Microtopographic variation is explored through descriptive statistics that show the dispersion of the data from the mean elevation, which is considered the “topography.” In this study, we are using standard deviation, variance, and range that were calculated from the ArcGIS Pro Summary Statistics (analysis tool) for each random plot or vegetation plot. Standard deviation shows how close the elevation points are to the mean elevation. Variance shows how the elevation data are spread within the plots. Large variance numbers indicate that the elevation points are widely spread apart. Range is calculated as the difference between minimum elevation point and the maximum elevation point within the plot. The higher the standard deviation, variance, and range the more microtopographic variation was found within the plots.

All analyses were run in R Studio v. 2021.9.1.372 with packages specified below (RStudio, 2021). All statistical tests were from the stats v3.6.2 package, unless otherwise noted. All visuals done in RStudio used ggplot2 V3.3.5 (Wickham, 2016).

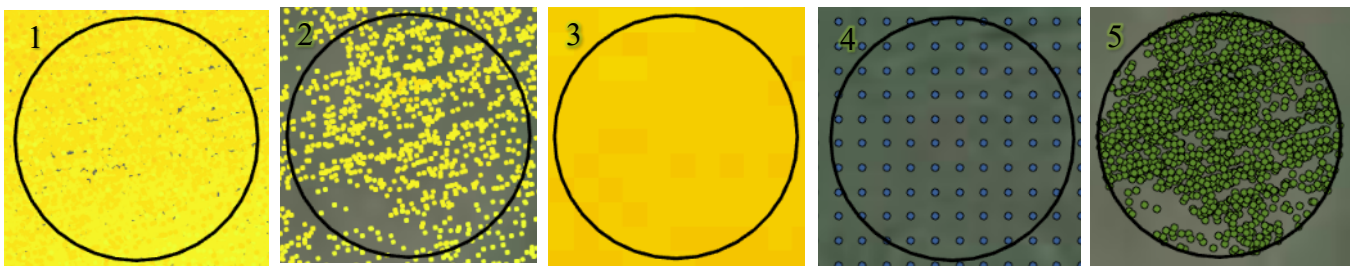


Figure 4. Process of getting LiDAR Point information into usable table format. In frame 1 is all the LiDAR points, which get classified using Classify LAS Ground, which gives the product in frame 2. LAS Dataset to Raster tool is used to get the DEM found in frame 3. Then Raster to Multipoint (3-D Analysis) tool creates a feature class with the elevation data to get frame 4. Finally, using Multipoint to Point tool creates single points, representing the LiDAR points, and creates an attribute table that is usable for statistical analysis.

**2.4.1 Question 1:** *How does microtopography differ among crop farming, fallow fields, newly restored prairies, and older prairies?*

To answer question 1, we placed random circular within the study boundaries at least 100 m apart. Each plot had a diameter of 5 m. To normalize the data and to reduce topographic interference, we subtracted the mean elevation for each sample plot from the elevation of each sample point. The product for each sample point to calculate the mean, standard deviation, and variance of each sample plot using the Summary Statistics (Analysis) tool in Arc Pro. We used the natural log ( $\log()$ ) of standard deviation, variance, and range to normalize the data and improve modeling assumptions. The three dispersion datasets within each plot were used in linear models ( $\text{lm}()$ ), followed by ANOVA ( $\text{aov}()$ ), and then an ad hoc Tukey's HSD test ( $\text{TukeyHSD}()$ ).

First, we ran a one-way ANOVA for the four models for sites within sites of crop, fallow, new prairie, and old prairie to understand if there were pair-wise differences in microtopographic variation between the five sites within each treatment. Second, a two-way ANOVA was done to model the three dispersion datasets as a function of land use type (crop, fallow, new prairie, old prairie) and site. Last, Wilcoxon rank sum test with continuity correction ( $\text{wilcox.test}(x, y, \text{alternative}=\text{c}(\text{"two. sided"}, \text{"less"}, \text{"greater"}, \text{paired}=\text{FALSE}))$ ) was performed. This test was run comparing if there is a difference and the location shift between the dispersion datasets between treatments.

**2.4.2 Question 2:** *Is there a relationship between plant biodiversity and microtopography in new prairies versus older prairies?*

To answer question two, we buffered vegetation plots to 5 m diameters. This made each circular plot have a total area of 78.5 m<sup>2</sup> from which to garner the microtopography data. To

normalize the data and to reduce topographic interference, we subtracted the mean elevation for each sample plot from the elevation of each sample point. The product for each sample point was used to calculate the mean, standard deviation, and variance of each sample plot.

We created boxplots for the diversity data comparing between sites. The biodiversity and microtopographic data are non-parametric and highly skewed, limiting the tests to ones that have few assumptions. Therefore, to determine if there is relationship between the two datasets, we used Kendall's rank correlation tau (`cor.test(x, y, method= "kendall")`) and fit generalized linear models (`summary(glm(x, y, family= "poisson" or "Gamma" or "inverse. gaussian"))`).

**2.4.3 Question 3:** *In a 10-year period, how does microtopographic variation change on the same sites due to changes in land use?*

To answer question three, we derived elevation points from both the 2011 1 m DEM and the 2021 1 m DEM within the study boundary area. The elevation points from each year are within 0.5 m from each other. One meter contour polygons were also generated using the same one m DEM for each year. The contours to calculate the average elevation. Each elevation points within the contour polygon to get the difference in elevation (microtopography) from the topography. We used Summary Statistics (Analysis tool) to calculate the mean, minimum, maximum, range, standard deviation, and variance for the microtopography.

First, we used the non-parametric Kruskal-Wallis (`kruskal.test(x, g)`) using the difference of 2021 and 2011 data for each treatment. Then, we used the natural log (`log()`) of standard deviation, variance, and range to normalize the data to use the parametric ANOVA associated with the following analysis. Two linear regression models (`lm()`) were used to visualize the data with 2011 data on the x-axis and 2021 data on the y-axis for each treatment (crop, fallow, new prairie, and old prairie). The first linear regression model was fit for each entire dispersion

dataset used by treatment. The second linear regression model was fit for each site within the treatment. Then, we performed a summary of the linear regression statistics for treatments giving the r-squared value and the p-value. Finally, we created linear regression models for each site and a summary performed.

### 3. RESULTS

#### 3.1 Question 1: *How does microtopography differ among crop farming, fallow fields, newly restored prairies, and older prairies?*

The first question was to explore differences in microtopographic variation between sites and land use types (treatments). Due to farming practices affecting the soil surface, we wanted to find out if the crop sites would be like each other. Only one site differed with three other sites. Interestingly, fallow fields had no differences in microtopographic variation between sites. Restored prairies had the most differences among sites with half of the newly restored prairie sites differed and 70% of older restored prairie sites differed (Appendix A)

The comparison between farmlands and restored prairies found significant differences in microtopographic variation. Crop fields had a strong significant difference from newly restored prairies ( $p < 0.0001$ ) and older restored prairies ( $p < 0.0001$ ). Fallow fields also had a strong significant difference from newly restored prairies ( $p = 0.002$ ) and older restored prairies

Table 2. The results of the Wilcoxon rank sum test comparing treatments to each other for greater, lower, or similar microtopographic variation using standard deviation, variance, and range. Old prairies (Old) had the greatest microtopographic variation followed by new prairies (New), then fallow fields, and lastly crop fields.

Wilcoxon Rank Sum Test				
Paired Treatments	Standard Deviation	Variance	Range	Result
	P-Value	P-Value	P-Value	
Crop-Fallow	0.34	0.35	0.35	Crop ~ Fallow
Crop-New	<b><math>p &lt; 0.0001</math></b>	<b><math>p &lt; 0.0001</math></b>	<b><math>p &lt; 0.0001</math></b>	New > Crop
Crop-Old	<b><math>p &lt; 0.0001</math></b>	<b><math>p &lt; 0.0001</math></b>	<b><math>p &lt; 0.0001</math></b>	Old > Crop
Fallow-New	<b>0.00061</b>	<b>0.00061</b>	<b>0.00052</b>	New > Fallow
Fallow-Old	<b><math>p &lt; 0.0001</math></b>	<b><math>p &lt; 0.0001</math></b>	<b><math>p &lt; 0.0001</math></b>	Old > Fallow
New-Old	<b>0.019</b>	<b>0.019</b>	0.063	Old > New

( $p < 0.0001$ ). Next, we wanted to know which land use type had the greatest microtopographic variation. Older restored prairies had the greatest microtopographic variation followed by newly restored prairies with fallow fields and crop fields having the least (Table 2).

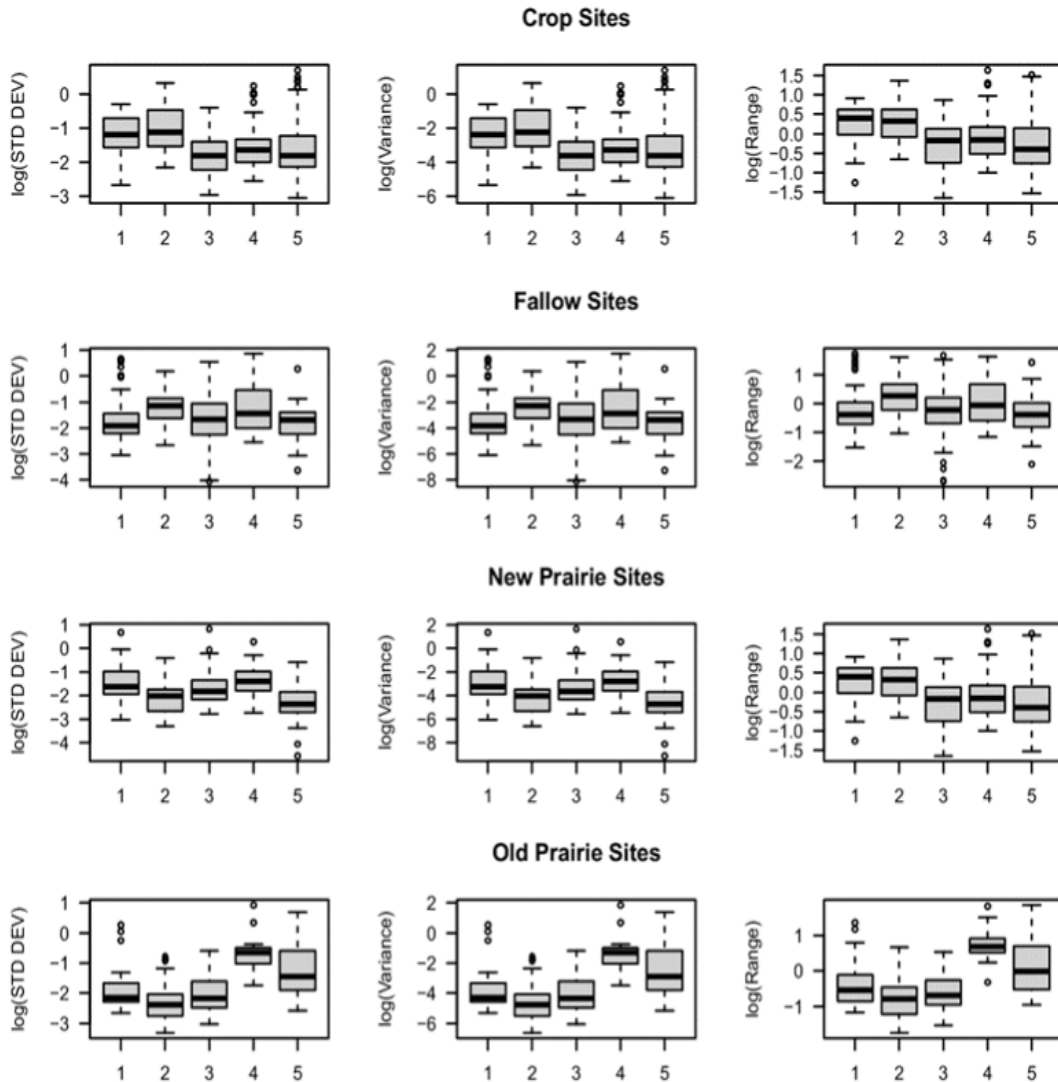


Figure 5. Boxplots comparing the natural log of the standard deviation, variance, and range between the sites of the four land use types. Each site is numbered 1-5. This complements the statistical analysis results showing the differences and similarities between sites.

**3.2 Question 2:** *Is there a relationship between plant biodiversity and microtopography in new prairies versus older prairies?*

The second question investigated if there was a relationship between microtopographic variation and plant biodiversity. Due to the older restored prairies having the greatest microtopographic variation, we wanted to see if those sites also had the greatest biodiversity. The Inverse Simpson's Diversity Index (D), Shannon's Diversity Index (H), Evenness D, and Evenness H showed that four of the five older prairie sites had the highest diversity, along with one newly restored prairie site (Figure 6). There was a strong significant difference between the high diversity sites and the low diversity sites for D ( $p < 0.0001$ ), H ( $p < 0.0001$ ), Evenness D ( $p < 0.0001$ ), and Evenness H ( $p < 0.0001$ ).

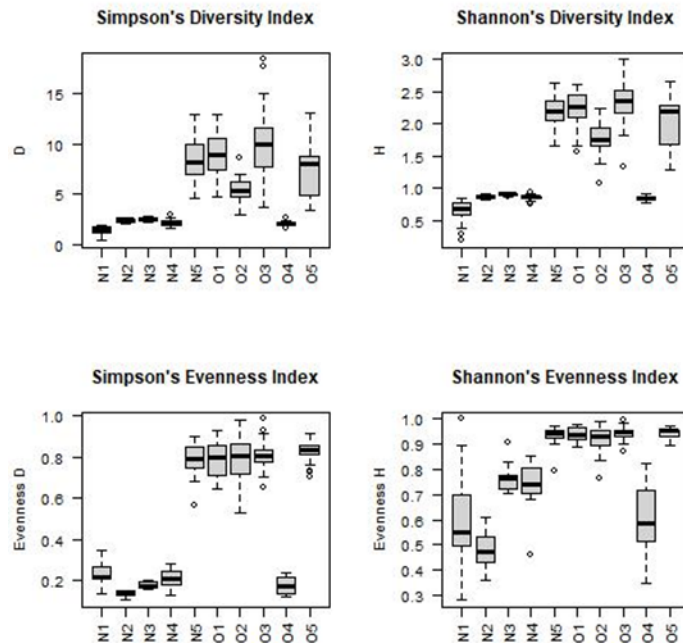


Figure 6. Diversity indexes by the five newly restored prairie sites (Nx) and the five older restored prairie sites (Ox). N1, N2, N3, N4, and O4 have lower diversity than N5, O1, O2, O3, and O5. D represents the Simpson's Diversity Index calculation; H represents the Shannon's Diversity Index calculation.

However, directly comparing the 2021 LiDAR microtopography data to the diversity indices resulted in mostly weak negative relationships in the correlation models (Appendix B). There was a strong correlation between D for the standard deviation ( $p=0.0014$ ), variance( $p=0.0014$ ), and range ( $p=0.016$ ). H has a strong correlation with standard deviation ( $p=0.0013$ ), variance( $p=0.0013$ ), and range ( $p=0.016$ ).

**3.2 Question 3:** *In a 10-year period, how does microtopographic variation change on the same sites due to changes in land use?*

We examined how microtopography changed over the course of a decade (Figure 7). The older restored prairies, which were newly established prairies in 2011, had the greatest increase in microtopographic variation ( $p<0.0001$ ;  $r^2=0.43$ ). The newly restored prairies and fallow fields



Figure 7. The linear models comparing the trends of microtopography variation between 2021 and 2011 for standard deviation (STD), variance, and range. There appears to be positive relationship indicating increase in microtopographic variation between 2011 and 2021 LiDAR data for Fallow, New Prairie, and Old Prairie.

sites were all crop fields in 2011 and had a similar significant change in microtopography (new prairie:  $p < 0.0001$ ,  $r^2 = 0.23$ ; fallow fields:  $p < 0.0001$ ,  $r^2 = 0.20$ ). The crop fields had a much higher significance ( $p = 0.004$ ) with a level change ( $r^2 = 0.035$ ).

Next, we compared the sites individually to understand how microtopographic variation changed at the site level. All older prairie sites showed significant difference from 2011 to 2021, but two sites did not have strong trend lines (Table 3). The oldest restored prairie, Old 5, had the most change in microtopographic variation (STD:  $p < 0.0001$ ;  $r^2 = 0.68$ ). Three sites in both the new restored prairies and fallow fields had significant changes from 2011 to 2021, however these changes were markedly weaker than the older prairies (Table 3). Only two crop sites significantly changed between 2011 and 2021 (Table 3).

Table 3. Linear model results comparing differences between 2011 and 2021 LiDAR data with the significant value ( $<0.05$ ) and r-squared values greater than 0.1 is bolded. Variance had the same values as Standard Deviation, and thus was left out of this model. \*Indicates at least one microtopographic variation difference or slightly strong relationship, \*\*Indicates two.

Site	Ln (STD Dev)		Ln (Range)	
	P-Value	R <sup>2</sup>	P-Value	R <sup>2</sup>
Crop 1	0.64	0.020	0.85	0.0032
Crop 2	0.41	0.017	0.50	0.012
Crop 3**	<b>0.0026</b>	<b>0.22</b>	<b>0.0029</b>	<b>0.22</b>
Crop 4**	<b>1.2E-5</b>	<b>0.30</b>	<b>4.6E-07</b>	<b>0.38</b>
Crop 5	<i>0.054</i>	0.045	<i>0.053</i>	0.040
Fallow 1*	<b>1.8E-5</b>	<b>0.25</b>	<b>4.4E-5</b>	<b>0.23</b>
		0.0005		
Fallow 2	0.91	4	0.61	0.011
Fallow 3*	<b>0.0039</b>	<b>0.18</b>	<b>0.0034</b>	<b>0.19</b>
Fallow 4	0.155	0.099	0.12	<i>0.12</i>
Fallow 5**	<b>6.5E-5</b>	<b>0.67</b>	<b>5.9E-07</b>	<b>0.67</b>
New 1**	<b>0.0049</b>	<b>0.15</b>	<b>0.0012</b>	<b>0.19</b>
New 2	0.20	0.052	0.46	0.017
New 3*	0.12	0.069	<b>0.025</b>	<b>0.14</b>
New 4*	<i>0.072</i>	<b>0.19</b>	<i>0.088</i>	<b>0.17</b>
New 5*	<b>0.0050</b>	<i>0.10</i>	<b>0.033</b>	0.059
Old 1**	<b>0.0021</b>	<b>0.36</b>	<b>0.0035</b>	<b>0.33</b>
Old 2*	<b>0.033</b>	0.057	0.21	0.020
Old 3*	<b>0.0055</b>	<i>0.10</i>	<b>0.011</b>	0.09
Old 4**	<b>0.029</b>	<b>0.30</b>	<b>0.028</b>	<b>0.30</b>
Old 5**	<b>8.0E-5</b>	<b>0.68</b>	<b>8.8E-5</b>	<b>0.67</b>

#### 4. DISCUSSION

Tallgrass prairies are commonly restored from crop fields, where the natural microtopography has been destroyed. Due to the many interactions of microtopography with ecosystem functions such as run-off, infiltration, microclimates, vegetation, erosion, soil moisture, and soil nutrient capture, the loss of microtopographic variation means the loss of these ecosystem functions.

In a restored prairie, it is unknown how long it takes for natural microtopography to re-establish. However, improved understanding of the time it takes for microtopography to re-establish in these restored prairies can help land managers to show the long-term effects of restoration on the landscape. Visually showing these changes can also be more appealing to stakeholders. Given how many studies have shown the interconnectedness of microtopography with these different ecosystem function, LiDAR derived microtopography can be a great asset to long-term monitoring programs for restored prairies.

This study addressed three research questions: 1) How does microtopography differ among crop farming, fallow fields, newly restored prairies, and older prairies? 2) Is there a relationship between plant biodiversity and microtopography in new prairies versus older prairies? 3) In a 10-year period, how does microtopographic variation change on the same sites due to changes in land use?

After restoration from farm fields, microtopographic variation is influenced by different land use types and time. The row crop sites were similar to each other, with only the site (crop 2) having differences with three others. This shows that each of these sites are farmed similarly to each other, which is due to four of the sites being corn and soybean. Crop 2 had differences due

to half of the site being planted with sorghum (*Sorghum × drummondii*), while the other half was soybean. Sites that were left fallow for at least one year were similar to each other. This indicates that the microtopographic variation recovers similarly after disking and other farming disturbances. The new prairies had half of the 10 pairs, which included every site, as significantly different from one another. Old prairies had most of the pairs as significantly different from one another.

Our results showed that it is possible for a recovery in microtopographic variation to take place during the restoration process. Restored prairies recover and increase microtopographic variation after farming practices have ceased and seems to take more than 10 years to establish. We found that prairies had greater microtopographic variation than the crop fields or fallow fields. Older prairies had greater microtopographic variation than newer prairies. Thus, the establishment of microtopographic variation on the landscape is related to the restoration of prairies and increases with time. (Appendix C)

From the diversity measurements, four out of the five older restored prairies had higher diversity than the four of the newer restored prairies. The one older prairie that had low diversity had encroachment by weedy species pressuring on all sides from neighboring farm fields, rural road, and a maintenance building. The new prairie that had higher diversity was also older than the other new prairies by 3 years.

Our results suggest a negative relationship between biodiversity and microtopographic variation. These data were highly dispersed, non-parametric, and highly skewed, which made statistical analysis difficult. Therefore, it is unclear if there is a true direct relationship. There are too many other influences on microtopographic variation for a direct measure at the plot level.

Moser et al. (2007) had comparable results comparing microtopography and biodiversity in disked vs non-disked wetlands. However, we would argue that due to the older prairies having higher microtopographic variation and having higher biodiversity, it would make sense that there is some sort of positive correlation. A follow-up study with more restored prairies sites and using remnant prairies would be necessary to understand how the microtopography relates to biodiversity.

Farming affects microtopographic variation for years after the last production year. The results showed that there was a difference between the 2011 crop sites that are still farmed in 2021 (Figure 8). The reason this happened is due to the 2011 LiDAR being flown in the late fall

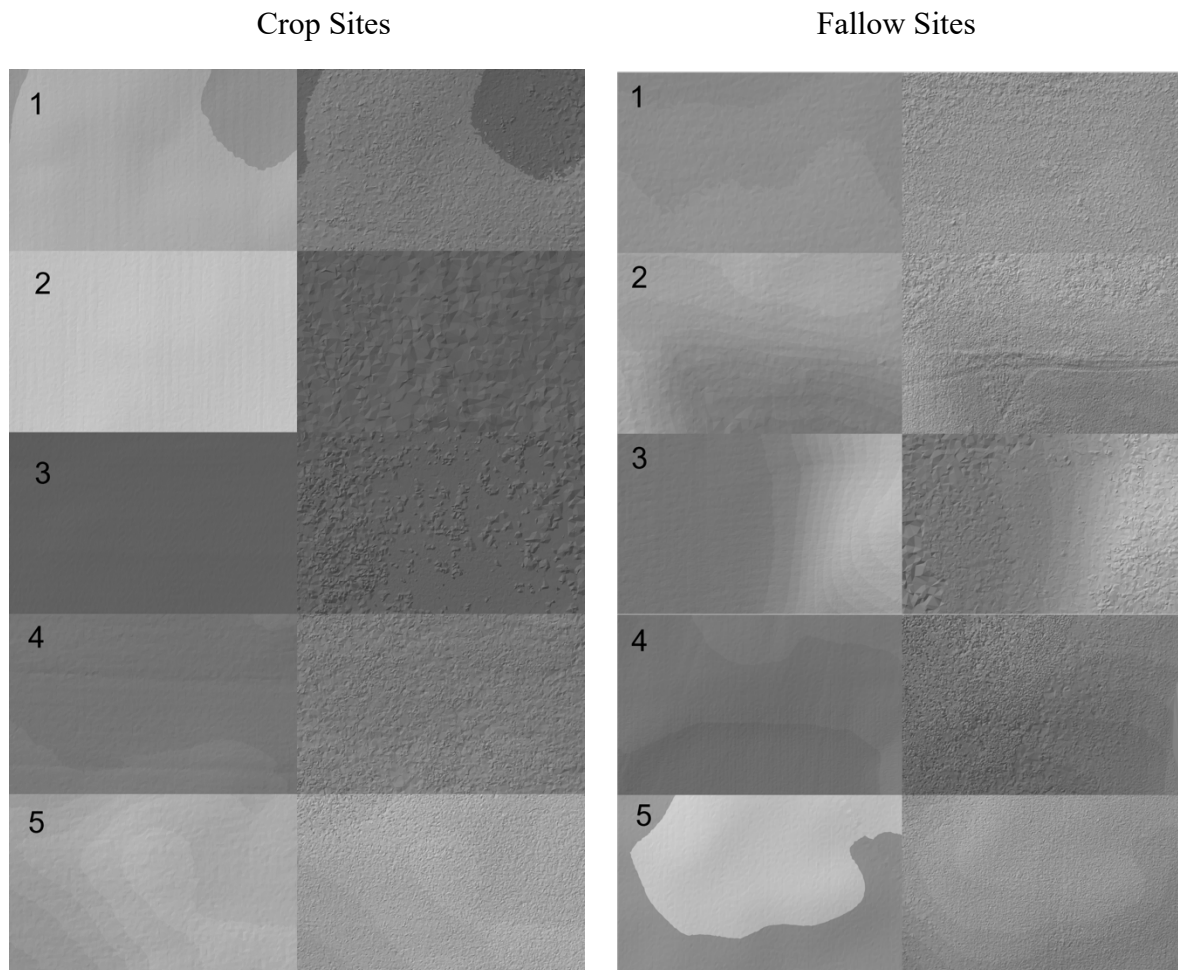


Figure 8. Comparison of 2011 LiDAR (left side) and 2021 LiDAR (right side) for crop and fallow sites.

post-harvest, while we collected our LiDAR data during the summer of 2021 (Fugro Horizons, Inc and Minnesota Department of Natural Resources, 2012). Sites that were crops in 2011 and are now either fallow fields or a newly restored prairie had a similar pattern of a small recovery of microtopographic variation post-cropping (Figure 9). Newly restored prairies had some form of rolling to increase seed to soil contact, which ends up flattening the soil (Figure 10). The restored prairies sites and the fallow fields sites had the same timeframe since farm related soil disturbance (Figure 9).

Microtopographic variation seems to recover after a decade post-restoration. The new prairies in 2011 increased in microtopographic variation as older restored prairies in 2021. This shows that it is possible to use LiDAR derived microtopography to monitor restoration success and return of ecosystem functions. A follow-up study investigating microtopography between sites in 2011, 2021, and 2031 would help to solidify these results, and see how restored prairies continue to develop. A future study on how microtopographic variation changes after bison are reintroduced to a restored prairie.

## 5. CONCLUSION

Monitoring ecosystems at the landscape scale is aided using geospatial data. Using LiDAR point-cloud data and digital elevation models (DEM) can help us understand the changes occurring at a fine scale without relying on ground-based surveys. Long-term monitoring can be challenging with incomplete or nonexistent data to help understand how a landscape has changed over time. With many states conducting LiDAR flight surveys every decade, using these data in a meaningful way can help with future management and conservation goals.

Often restoration of tallgrass prairie is done on previously farmed land, with tractors and implements removing natural microtopography from the landscape. Older prairies, restored in the 2000s, showed higher variability in microtopography than new prairies, fallow fields, or corn/soybean fields. Prairies that have higher vegetation diversity also had more variability in microtopography. Thus, recovering natural microtopography from previous farming practices takes both time and plant species diversity. Since LiDAR data are publicly available, land managers can use this approach to get quick, accurate, and cost-effective assessments of prairies.

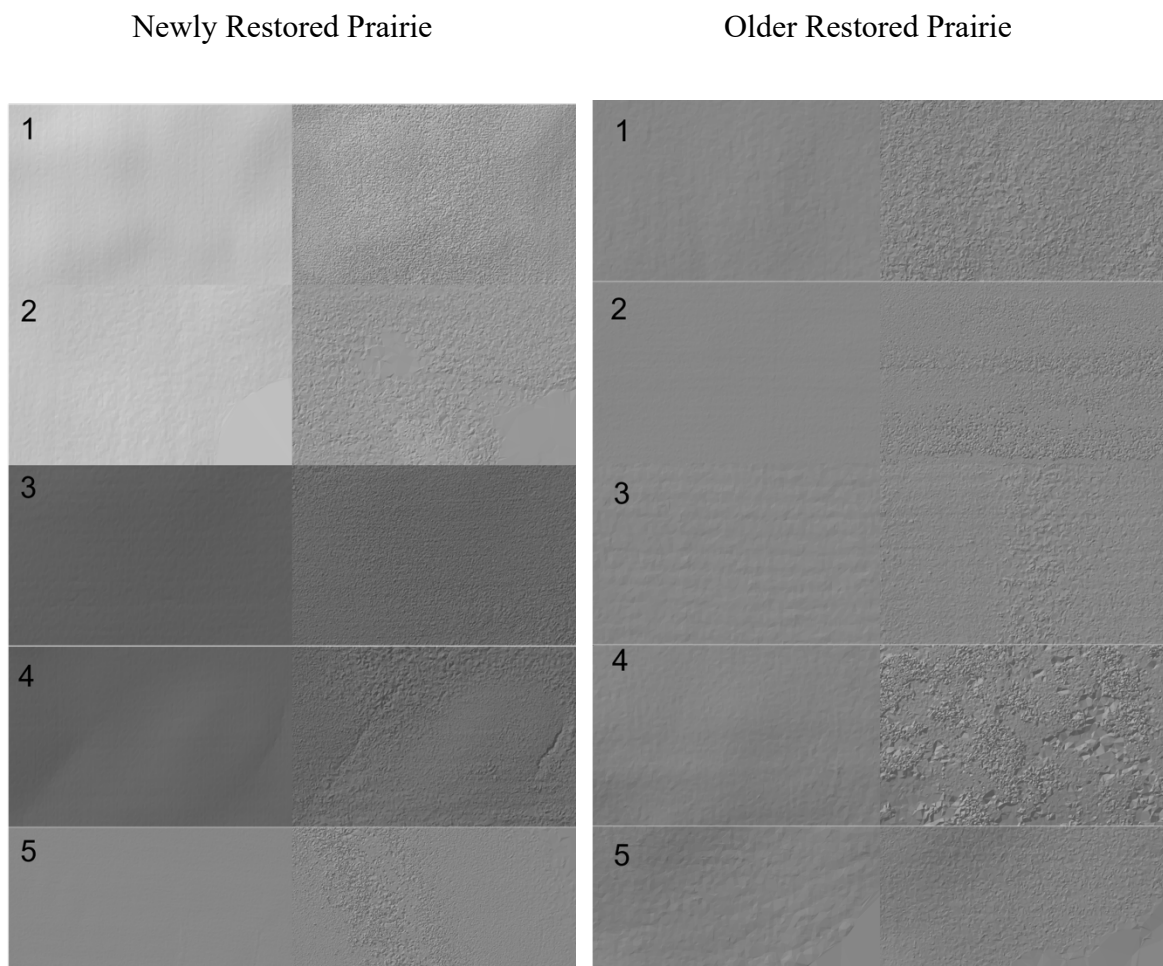


Figure 9. Comparison of 2011 LiDAR (left side) and 2021 LiDAR (right side) for newly restored prairie sites and older restored prairie sites.

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APPENDICES

APPENDIX A

## ANOVA PAIRWISE COMPARISON FOR QUESTION 1

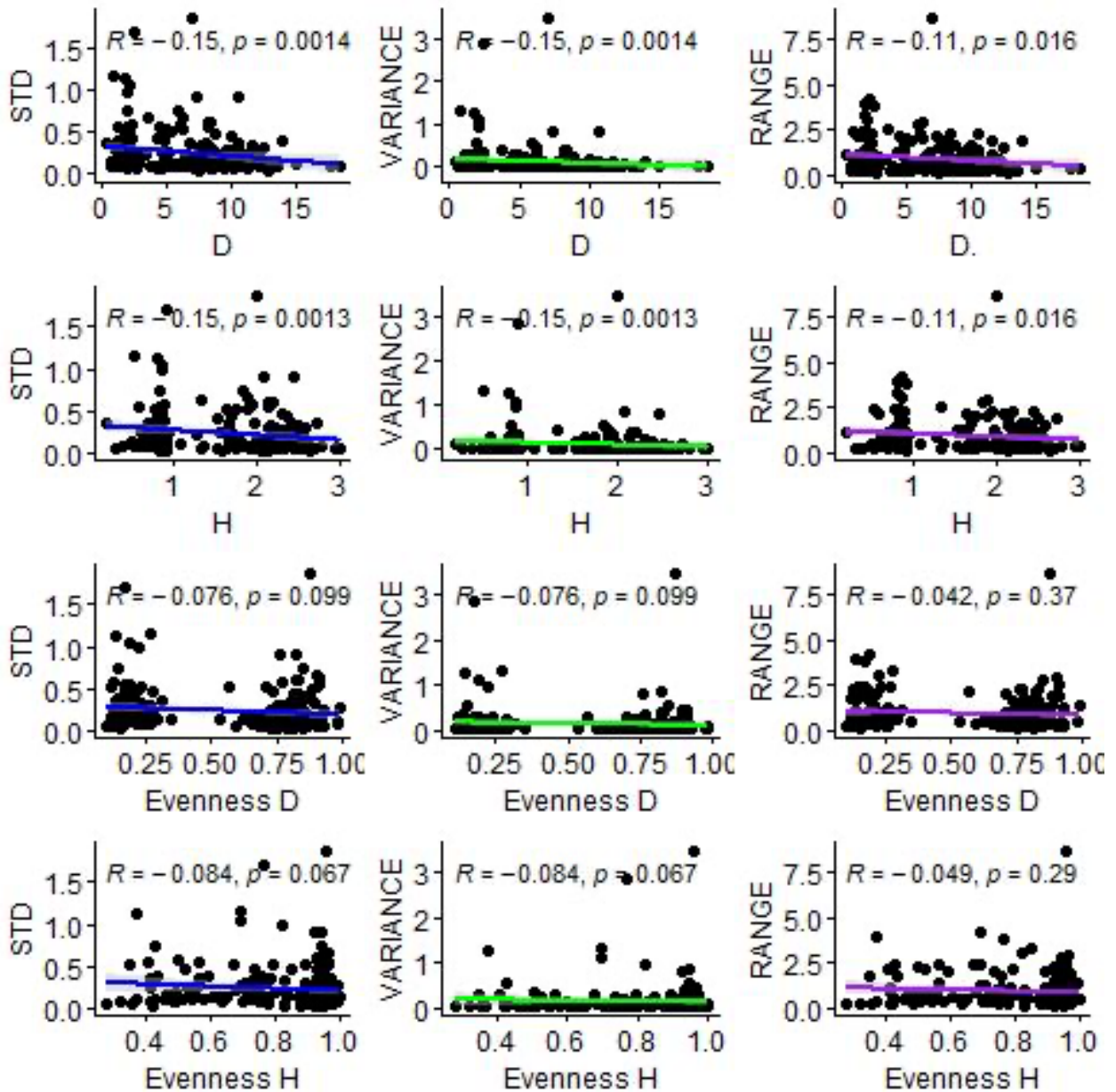
APPENDIX A: ANOVA ad hoc comparing the sites within the same treatment for differences. Bolded p-values are <0.05.

Pair	P-Value
Crop 1 – Crop 2	0.97
Crop 1 – Crop 3	0.18
Crop 1 – Crop 4	0.66
Crop 1 – Crop 5	0.52
Crop 2 – Crop 3	<b>0.00073</b>
Crop 2 – Crop 4	<b>0.028</b>
Crop 2 – Crop 5	<b>0.0059</b>
Crop 3 – Crop 4	0.63
Crop 3 – Crop 5	0.72
Crop 4 – Crop 5	0.99
Fallow 1 – Fallow 2	0.066
Fallow 1 – Fallow 3	0.99
Fallow 1 – Fallow 4	0.15
Fallow 1 – Fallow 5	0.99
Fallow 2 – Fallow 3	0.14
Fallow 2 – Fallow 4	0.99
Fallow 2 – Fallow 5	0.11
Fallow 3 – Fallow 4	0.25
Fallow 3 – Fallow 5	0.99
Fallow 4 – Fallow 5	0.20
New 1 – New 2	<b>0.002</b>
New 1 – New 3	0.71
New 1 – New 4	0.98
New 1 – New 5	<b>&lt;0.0000009</b>
New 2 – New 3	0.16
New 2 – New 4	<b>0.009</b>
New 2 – New 5	0.58
New 3 – New 4	0.57
New 3 – New 5	<b>0.00036</b>
New 4 – New 5	<b>0.00024</b>
Old 1 – Old 2	<b>0.014</b>
Old 1 – Old 3	0.51
Old 1 – Old 4	<b>0.0000009</b>
Old 1 – Old 5	<b>0.046</b>
Old 2 – Old 3	0.15
Old 2 – Old 4	<b>&lt;0.0000009</b>
Old 2 – Old 5	<b>0.0000001</b>
Old 3 – Old 4	<b>&lt;0.0000009</b>
Old 3 – Old 5	<b>0.0000695</b>
Old 4 – Old 5	0.0895729

## APPENDIX B

## CORRELATION MODELS FOR QUESTION 2

APPENDIX B: Correlation models with the standard deviation (STD), variance, and range on the y-axis and the diversity indices on the x-axis. All the trend lines are negative and flat, showing a very weak relationship and/or no relationship at all.



APPENDIX C

## 2021 LIDAR OF SITES

APPENDIX C: LiDAR data from 2021 comparing the five sites within each land use, using a simple overlay. This shows how microtopography changes with land use. The fallow sites and newly restored prairie sites look remarkably similar with little microtopographic variation. Older restored prairies appear to have more microtopographic variation than the other land use types. This indicates that time and biodiversity are key factors in increasing microtopographic variation to the landscape.

