Forest Composition, Germination, and Soil Health Analysis in a Newly Restored Deciduous Forest in Southeastern Minnesota

Kirsten Koerth

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It is important to follow up on the success of a newly restored forest to determine the health of the plot and improvements for future projects. The goal of this study was to analyze forest composition, germination rate of planted species, and soil health of a recently restored forest as a measure of the condition of the plot. The plot, a conventionally managed agricultural field, was planted with a variety of deciduous forest species in fall of 2017. In my analysis in fall of 2018, the field was divided into four sections to compare composition and soil characteristics within the field and germination rate was calculated. I generally found little difference in forest composition and soil characteristics within the field. There was no significant difference among sections for density and height of species, and there was no difference among heights for the four species. Of the eight species planted, red oak (*Quercus rubra*) and bur oak (*Quercus macrocarpa*) were found, and two species not planted were identified. The germination rate for red oak was 75.4%, and 11.2% for bur oak. These results are important for understanding how land changes after restoration, and how future restoration projects could be improved.

Introduction:

Forest restorations are important to invest time and resources into because of the many ecosystem services that forests provide including water conservation, carbon sequestration and nutrient retention (Qu et al. 2013). In southeastern Minnesota, forests covered approximately 50% of the land before European settlement, but only about 16% of land cover today is forest (MDNR), providing additional incentive to restore this important ecosystem. As land is converted to agriculture or developments, ecosystem services and habitat are lost, and land is fragmented. Agriculture also has damaging effects on soil and water quality (Keeler and Polasky 2014), that can be mitigated by taking the land out of production. Restoration of forests returns some ecosystem services that benefit humans, prevents agricultural pollution, and creates habitat for other organisms.

St. Olaf College in southeastern Minnesota owns several restoration plots converted from corn/soy agriculture to forest or prairie. These restorations began in 1989, and the most recent restoration was in fall of 2017 (St. Olaf College). The plot was actively planted with eight species of trees through a hand seeding method. After tree seeding, a cover crop was planted on the field to prevent some invasive species from seeding in, where they would compete with planted tree species. A combination of active and passive restoration has previously been proven to be an effective way to restore a temperate deciduous forest. In one example, oak species were added in initially through active planting of tree seedlings, and then other desired trees like maple and ash species seeded in passively as seeds from neighboring trees blew in. Active seeding is done because oak seeds are heavier and therefore less likely to be brought in by wind (Ruzicka et al. 2010). Three of the nine species seeded in the 2017 plot were oak species, and the other species also had larger, non-wind dispersed seeds.

Evaluation of restorations is valuable and necessary, as assessment contributes to understanding of the functioning of the restoration. Multiple studies have been done to evaluate the older restoration plots in the St. Olaf College Natural Lands, but there has been little research into the 2017 plot's health, aside from one study done earlier this year (Raduege 2018). Evaluation of restorations can be done through analysis of nutrient cycling and chemical processes in the plot, and through physical analysis of land cover, height, species composition, germination, etc. (Stanturf et al. 2014). This assessment can also provide baseline data for comparison in future studies.

This project is focused on evaluation of the 2017 planting by measuring characteristics of the trees and soil, including germination rate, height of trees, species composition, tree density, and soil health. Soil characteristics, including percent moisture and soil type, can influence the growth of tree species (Cogliastro et al. 2003).

I hypothesized that there would not be differences between sections for the trees, but that there would be differences in heights between species. I hypothesized that there would be density differences between sections based on the topography of the field, with greater density toward the edges, and at lower topography. I predicted there would be a difference in species distribution, with greater numbers of Siberian elm on the edges of the field. I also hypothesized that there would be differences in the soil characteristics, with greater soil moisture and organic matter at the edges of the field, and that these soil differences would help explain some of the variation in the heights or densities of the trees. This project is focused on: 1. Determining differences in heights between sections of the field and between species, 2. Determining differences in density between sections of the field, 3. Evaluating differences in species composition for different parts of the field, 4. Establishing whether soil health or type influences the differences in plant height, density, or composition, 5. Calculating germination rates for planted species, 6. Making recommendations for future restorations.

Methods:

Site description:

My study site was situated on St. Olaf College landholdings in Lower Heath Creek Woods (44˚ 26′ 56″ N, 93˚ 11′ 16″ W). The field was surrounded on all sides by forest, with one side being a highly managed oak savanna, and the other side being woods closely bordering a creek. The field is approximately ten acres.

Tree sampling:

To set up the sampling plots, I divided the field into 6x4 grid and took samples at each intersection. Plots were placed 60 feet (18.2 m) apart in one direction, and 80 (24.3) feet apart in the other direction (Fig.1). Twenty-four sample plots were taken in total, and each sample plot was numbered accordingly. At the transect intersection, 1x1 square meter plots were placed, and the trees in the plot were counted, the species identified, and their heights in centimeters were taken with a ruler.

Soil sampling:

I took six soil samples within the field, two on the east side of the field, two on the west side of the field, and two in the center of the field. The samples were taken at specifically at transects 1, 6, 9, 15, 19, and 24 (Fig.2). I used a soil corer of known volume to take the samples, so I could calculate bulk density in the lab. The soil samples were weighed before and after drying in the drying oven for 48 hours at 105 degrees Celsius to measure percent moisture. The sample was then sieved and between 5 and 9 grams of soil were weighed out. These samples were then placed in the muffle furnace for five hours at 500 degrees Celsius and then weighed again to determine percent organic matter. Percent moisture was calculated through the following formula: ((wet weight-dry weight)/ (dry weight)) *100. Percent organic matter was calculated with the formula: ((dry weight-burned weight)/ (dry weight)) *100. Bulk density was determined through the following equation: wet weight/ the volume of the soil corer. For soil type determination, the United States Department of Agriculture Web Soil Survey website was used to generate a map with soil types listed (USDA year).

Data analysis:

The tree data were divided into four sections to make comparison within the field easier, and the soil data was divided into three sections for inter-field comparison. Germination rate was calculated with the following formula: (pounds of seed per acre * number of bushels of seed) * (# seeds per pound) = number of seeds planted per acre. That number was then then converted to seeds put on the field per one meter squared. The measured density was then divided by the seeds put on the field per one meter squared to get the germination rate. A series of analyses of variances were ran to determine the difference between the mean tree densities within the field, the difference in the heights of the trees between the different section, the heights between the different species, and between the percent soil moisture, percent soil organic matter, and bulk density among the different sections. A contingency table was created to compare the species composition between the different sections. R Studio (version 3.2.3) and R Commander (version 3.2.3) were used for all statistical tests.

Results:

In total, there were 147 trees counted within the 24 sample plots. There were four species identified within these plots, two of which were planted and two of which were seeded in. I found red oak (*Quercus rubra*) and bur oak (*Quercus macrocarpa*), (Fig. 3) which were the two species that had been planted, and I found boxelder (*Acer negundo*), and Siberian elm (*Ulmus pumila*), which were two species that were not planted. The red oak's germination rate was 75.4%, and the bur oak's germination rate was 11.2% (Fig.3). There was a significant difference between the species composition between the different sections, with sections 1 and 4 having greater proportions of Siberian elm than the other sections (Fig.4). The most common tree in sections 1 and 4 was Siberian elm, and red oak was the most common tree in sections 2 and 3 (Fig. 4).

For the height analysis, there was no significant differences in heights between sections of the field, as the mean height for trees in each section was approximately 10-11 centimeters (Fig. 5). There was also no significant difference in heights for the different species, with the boxelder trees having slightly larger height (Fig.6).

Through analysis of density data, I found that there was no significant difference between the densities among the different sections, but there was slightly higher density in sections 1 and 4, which are the sections closest to the edges (Fig. 7).

The soil investigation also yielded few statistically significant results. I found no difference in percent moisture between the sections (Fig. 8), no difference in percent organic matter between sections (Fig. 9), and no difference among sections for bulk density (Fig. 10). The percent organic matter data are likely due to error, as they are extremely high, but there were still no differences between their means. All sections had very similar physical soil characteristics. The soil types are Moland Silt Loam, Hayden Loam, and Ripon Silt Loam, but there was no correlation of soil type and differences in soil characteristics, as these were similar throughout the field (Fig. 11).

Discussion:

Composition and germination

Red oak and bur oak are some of the most common trees growing in other restoration plots in the Natural Lands and considering the restoration method used in previous projects of planting species with heavy seeds like oaks, and letting other species passively seed in, it makes sense that oaks are the species that are the most abundant in other restored plots in the Natural Lands, especially red oak, which is very common in all restored plots (Raduege 2018). Although only two of the eight species planted were identified in this study, it does not mean that the seeding of those species is a failure. There may be individuals of those species that were not in the plots I analyzed, and there may be some seeds that have yet to germinate or are too small to identify.

While many of the remaining results were not significant, many are still interesting. The result demonstrating that there are significantly more Siberian elms on the edges of the field was intriguing and suggests that there are edge effects influencing the species composition. The many surrounding Siberian elms are likely seeding in passively and having a greater effect on the areas that are proximal to the edge.

It has been shown the proximity to existing forest influences the species that are present in a restoration, with higher diversity plots being closer to existing forest (Matlack 1994). This may also be true for this plot, as it easier for existing trees to disperse their seeds into the field, but because many of the trees surrounding the plot are Siberian elms, they may be disproportionately represented in the field's species composition. There is potential for native species like ironwood (*Ostrya virginiana*) and hackberry (*Celtis occidentalis*) that are present in the surrounding woods to seed into the plot, generating greater diversity closer to the edges.

Height and density:

The height results for both the section analysis and the species analysis suggests that the trees are limited by nutrients that are spread evenly throughout the field. This was true regardless of species as well. The density data was somewhat surprising, as the topography of the field and density of cover crops was different throughout, with a ridge toward the center of the field, and generally greater cover crop density toward the center of the field. It has been shown that gullies and topographic changes in a field can influence the soil moisture (Collins et al. 2012), and therefore the growth of the trees. In this case, the topography did not appear to affect the density of the tree species. My results suggest that the seeds were spread relatively evenly throughout the field when the trees were planted, even though they were spread by hand.

Soil:

There is no evidence that the soil characteristics influence the growth or density of trees, as the soil is homogenous throughout for all tested features. The soil type also did not appear to affect the trees, as there was no difference between the heights or means of the trees in the parts of the field with different soil types. Research suggests that soil moisture can impact the growth of trees in restored plots (Cogliastro et al. 2003), but considering our homogenous soil results, it would be logical to conclude that moisture does not factor into any differences seen in the field. Although there was little difference between species height and soil type, the germination of red oaks and bur oaks may be due to the soil types that the field has, as red oaks grow well on loamy soils, and bur oaks grow well on many types of soil, including loams (Cogliastro et al. 1997). The other species that did not germinate may not grow as well in loamy soils.

Conclusion and Future Recommendations:

In future restoration projects, fewer red oaks should be planted, as they have high germination rates, and more money should be invested in buying seeds for species that did not germinate as well. More bur oak seeds at $50 per bushel, black walnut at $15 per bushel, and wild plum at $40 per pound would be cost effective seeds to buy more of, and greater germination rate could then be obtained (Fig. 12). When seeding the area, species that survive better when planted on edges with more light should be concentrated in those areas, and not spread over the entire field, as this will lead to better germination, and more efficient use of seeds (Holmes R. 2017). For future management of the field, emphasis should be placed on managing edges, where there is the highest number of invasive species, and also on removing invasive species growing in the existing forest surrounding the plot to prevent further seeding in of these species.

Future studies should include analysis of nutrients present in the field, including nitrogen and phosphorus, which are applied as fertilizer in agricultural fields, and may persist in the soil. Those data could then be used to better understand whether chemical characteristics of the soil are impacting the growth or density of the trees, as high nutrient soils remaining after agricultural use can positively influence the growth of trees (Kooijman et al. 2016). Follow up studies may also detect differences in plant height or density corresponding to soil characteristics, as trees grow larger and take more nutrients from the soil. Additionally, the data collected in this study can be used for future analysis of restoration project health, and they can also be used in future studies looking into the effectiveness of planting seeds versus seedlings in future restorations, as the germination rates for seeds can be compared to the survival of seedlings planted in other restoration plots.

This forest restoration, while still in its infancy, is contributing to gains in lost ecosystem services and habitat, and its placement in Heath Creek Woods allows for greater forest continuity as the forest ages, providing more continuous habitat.

Acknowledgements:

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Figures:

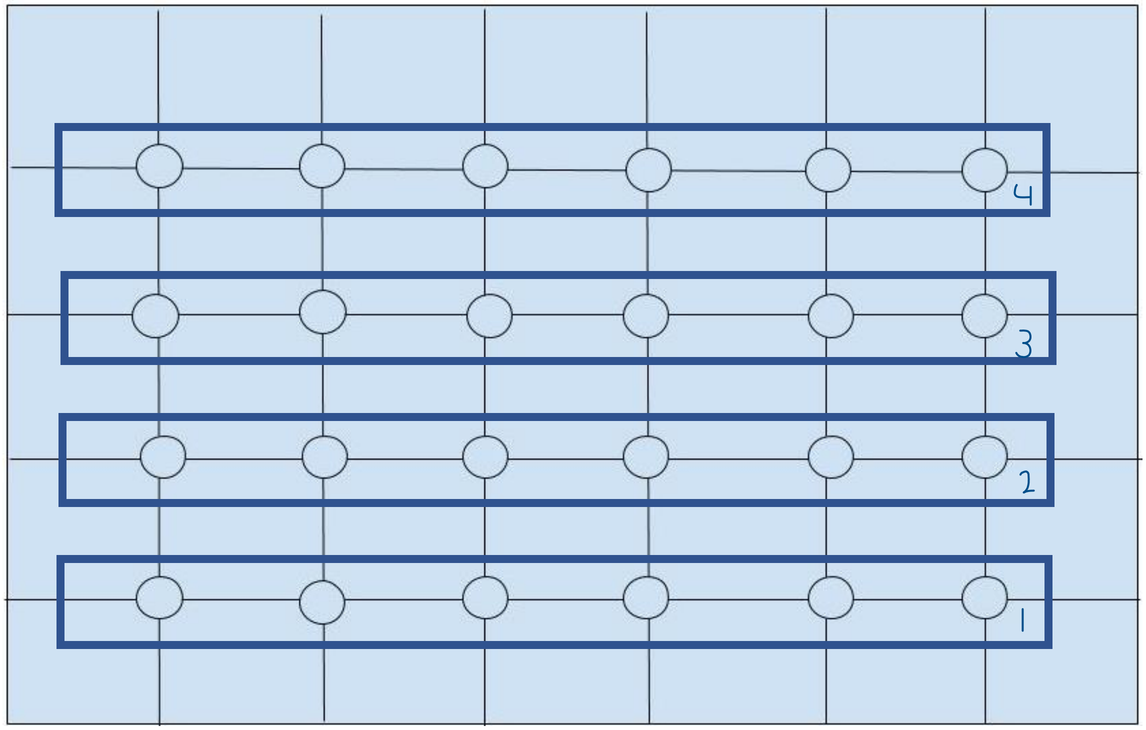

Fig. 1. Schematic of tree sampling locations. Section are indicated with blue boxes. The transects were each numbered and 1x1 square meters large.

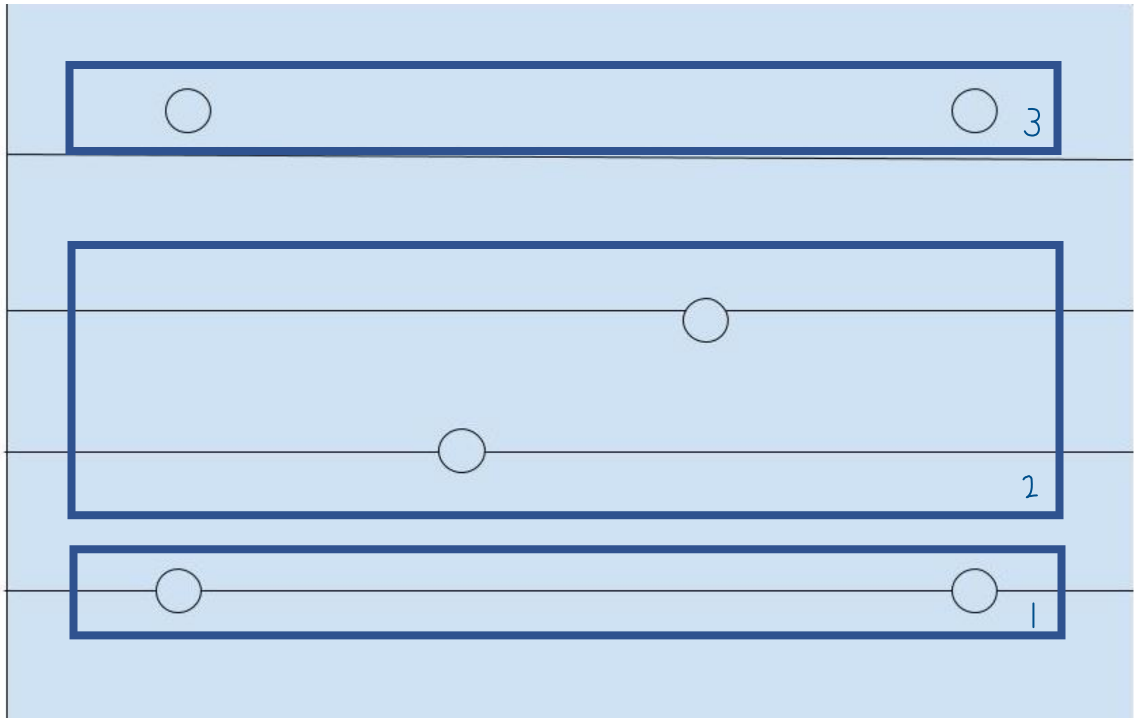

Fig. 2 Schematic of soil sampling locations. Sections are indicated by blue boxes. The sampling sites were placed at transects 1, 6, 9, 15, 19, and 24.

Table. 3. Germination rates of planted species. Red oak and bur oak were the species identified through this study.

Germination rates	
Red Oak (*Quercus rubra)*	0.754
Bur Oak (*Quercus macrocarpa)*	0.112
Swamp white oak (*Quercus bicolor)*	0.000
Kentucky coffee tree (*Gymnocladus dioicus)*	0.000
Black walnut (*Juglans nigra)*	0.000
Black cherry (*Prunus serotine)*	0.000
Wild plum (*Prunus americana)*	0.000
Bitternut hickory (*Carya cordiformis)*	0.000

Table. 4a. Contingency table for differences in species composition between sections. Number of individuals of each species per plot recorded and the proportion of that number out of the total number in the plot is recorded (p-value=0.01554, X-squared=20.411, df=9).

	Sections							
Species	**1**		**2**		**3**		**4**	
	Number	Proportion	Number	Proportion	Number	Proportion	Number	Proportion
RO	13	0.26	16	0.76	16	0.53	17	0.37
BO	1	0.02	0	0	0	0	2	0.04
BE	2	0.04	0	0	0	0	0	0
SE	34	0.69	5	0.23	5	0.17	27	0.59
			X-squared		20.411			
			df		9			

		p-value	0.01554	

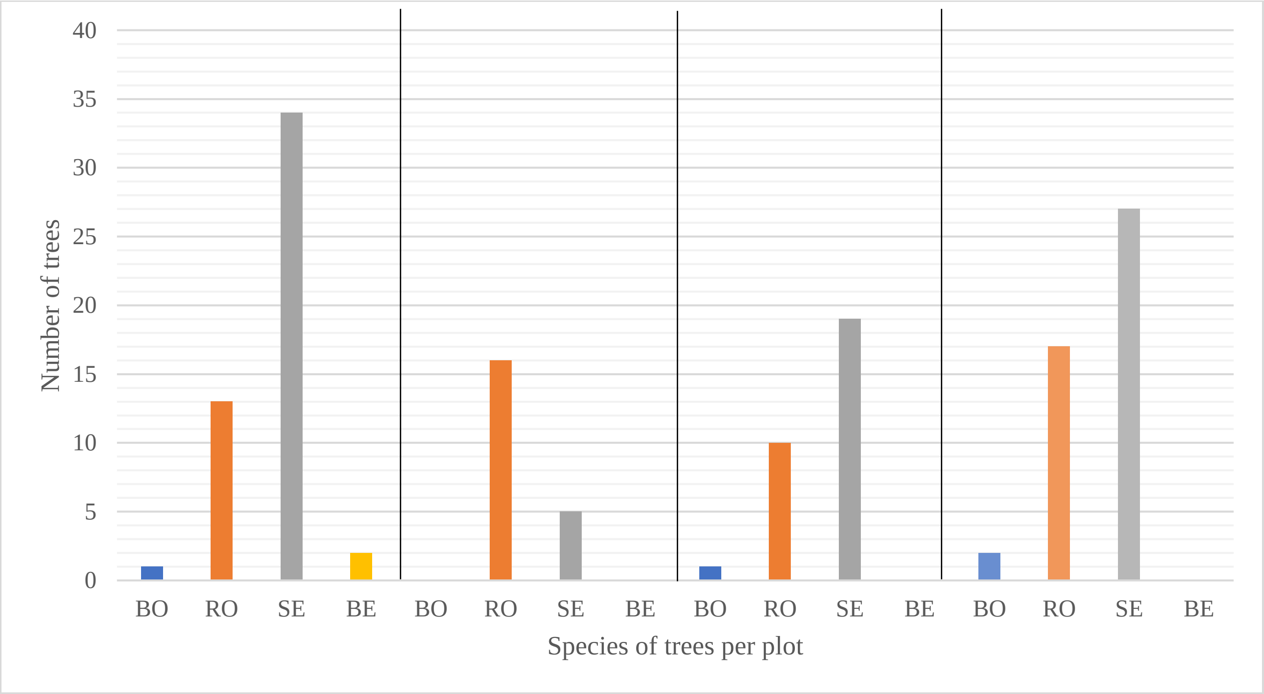

Fig. 4b. Species composition for each section. The x-axis displays the different species of trees per section, and the y-axis displays the number of trees. The four sections are partitioned by section, with the first four bars for section 1, and so on.

Table. 5a. ANOVA table for comparison of heights among sections. P=0.0647, F=2.466.

Section	**Means**	**s.d.**	**Number of samples**	**p-value**	**F-value**	**d.f.**
1	12.366	3.47	50	0.0647	2.466	49
2	10.04762	3.79	21	0.0647	2.466	20
3	10.54	3.53	30	0.0647	2.466	29
4	10.79348	4.74	46	0.0647	2.466	45

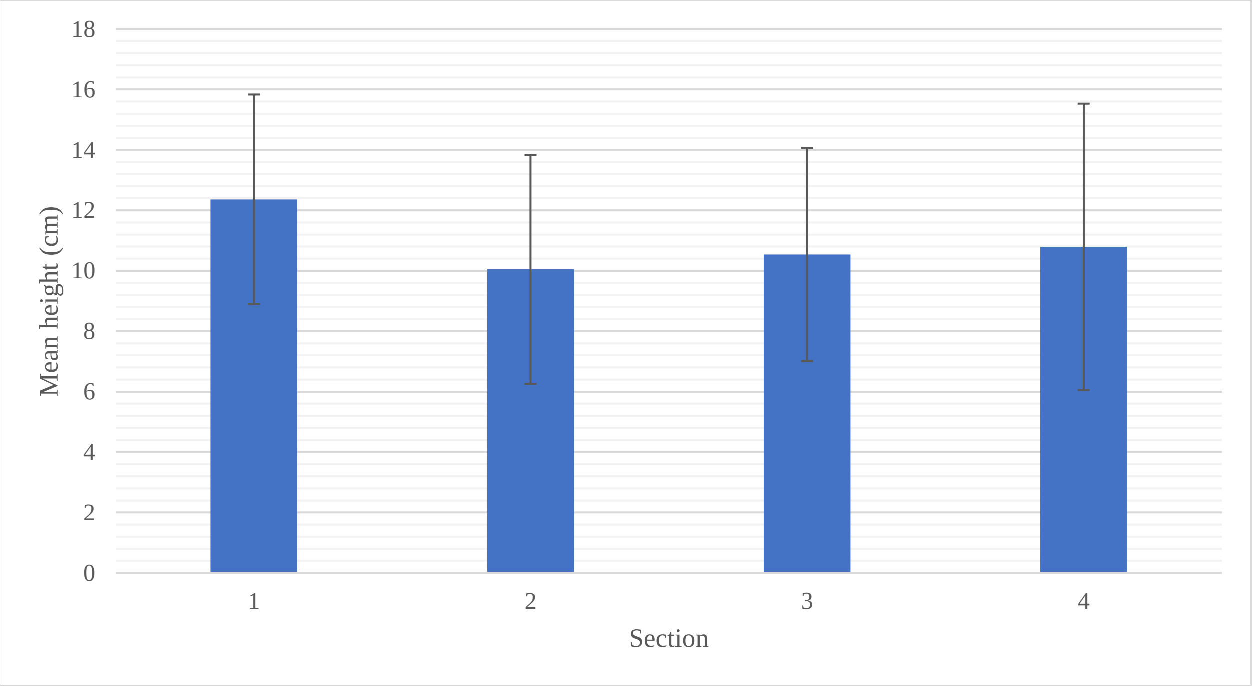

Fig. 5b. Mean height for each section. Section number is represented on the x-axis, and mean height is represented on the y-axis. Heights were relatively the same throughout the field (p=0.0647, F=2.466).

Table. 6a. ANOVA table for heights of each species. P=0.931, F=0.148.

Species	**Means**	**s.d.**	**Number of samples**	**p-value**	**F-value**	**d.f.**
BE	13.00	2.83	2	0.931	0.148	1
RO	11.10	4.97	56	0.931	0.148	55
SE	11.19	3.34	85	0.931	0.148	84
BO	10.88	4.37	4	0.931	0.148	3

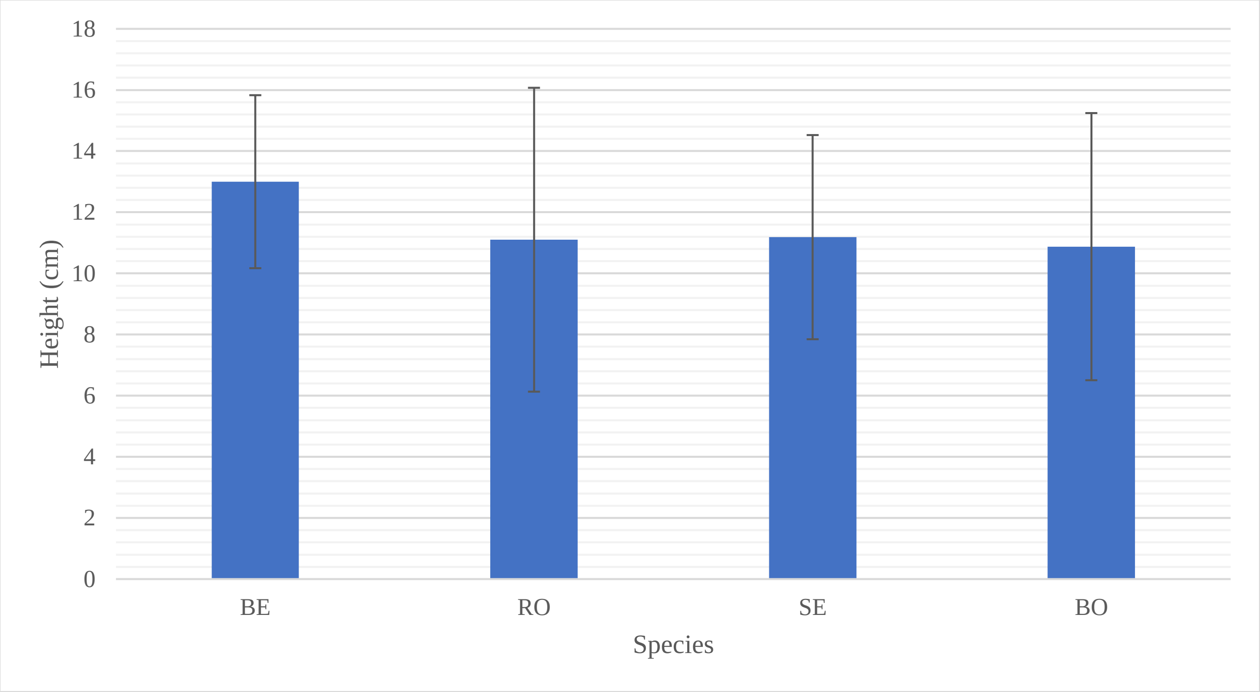

Fig. 6b. Mean height for each species. The x-axis displays the species type, and the y-axis displays the height in centimeters for the tree.

Table. 7a. ANOVA table for differences in density between sections. P=0.462, F=0.894.

Section	**Means**	**s.d.**	**Number of samples**	**p-value**	**F-value**	**d.f.**
1	8.17	9.97	6	0.462	0.894	5
2	3.50	1.97	6	0.462	0.894	5
3	5.00	1.67	6	0.462	0.894	5
4	7.67	5.05	6	0.462	0.894	5

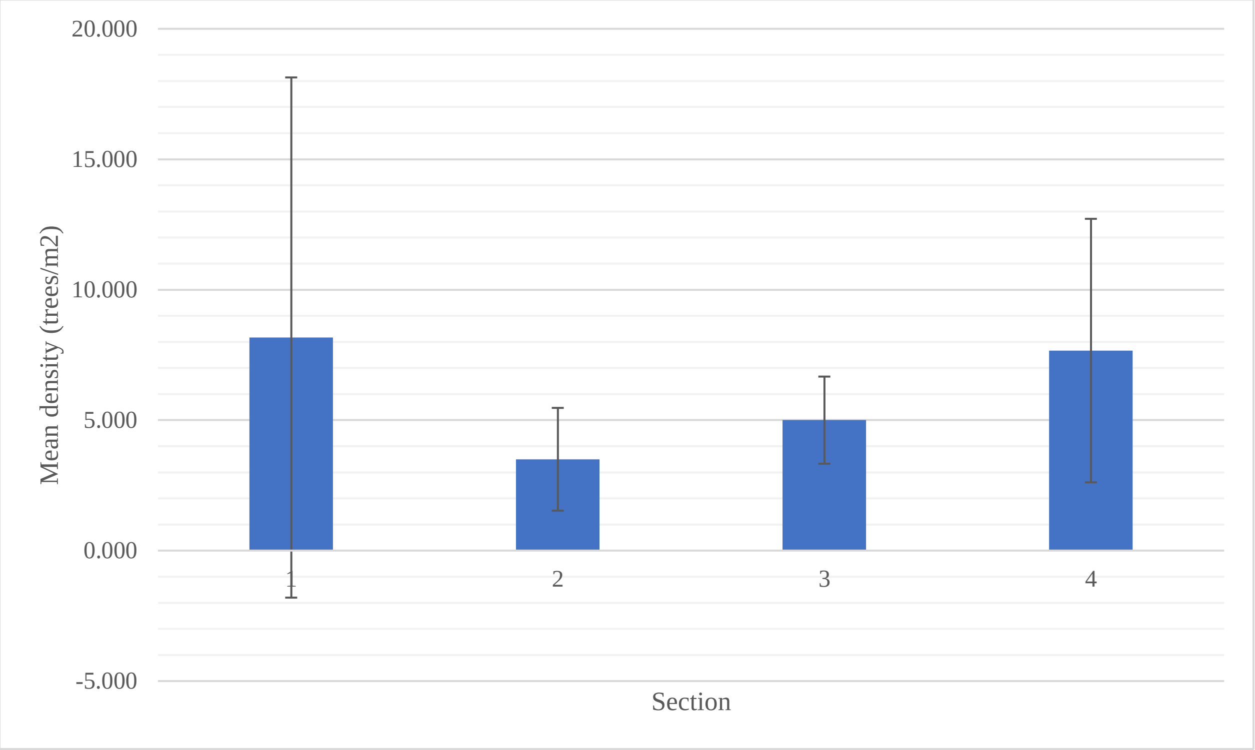

Fig. 7b. Mean tree density per section. The x-axis displays the section, and the y-axis displays the mean density in trees per meter squared.

Table 8a. ANOVA table comparing mean percent moisture between sections. P=0.799, F=0.242.

Section	**Means**	**s.d.**	**Number of samples**	**p-value**	**F-value**	**d.f.**
1	95.96	0.11	2	0.799	0.242	1
2	96.42	0.01	2	0.799	0.242	1
3	96.01	1.18	2	0.799	0.242	1

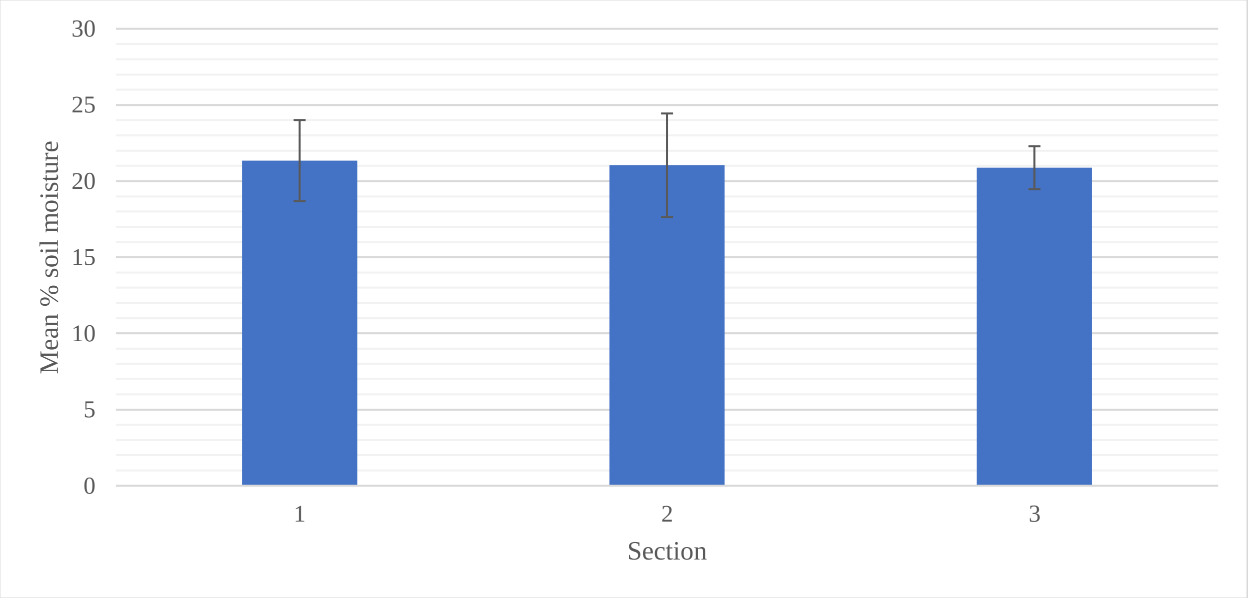

Fig. 8b. Mean percent moisture per section. The x-axis displays section, while the y-axis displays percent soil moisture.

Table 9a. ANOVA table comparing means of percent organic matter between sections. P=0.984, F=0.016.

Section	**Means**	**s.d.**	**Number of samples**	**p-value**	**F-value**	**d.f.**
1	21.35	2.66	2	0.984	0.016	1
2	21.04	3.4	2	0.984	0.016	1
3	20.88	1.41	2	0.984	0.016	1

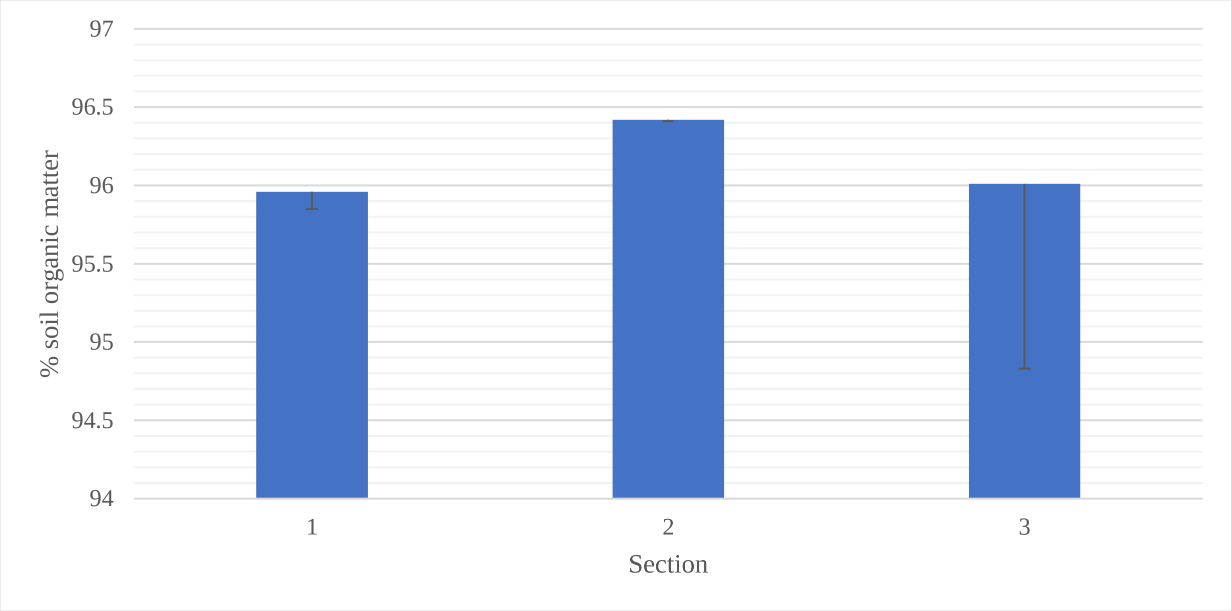

Fig. 9b. Mean percent organic matter per section. The x-axis displays section, while the y-axis displays percent soil moisture.

Table 10a. ANOVA table comparing differences in bulk density between sections. P=0.796, F=0.246.

Section	Means	s.d.	Number of samples	p-value	F-value	d.f.
1	1.33	0.06	2	0.796	0.246	1
2	1.3	0.15	2	0.796	0.246	1
3	1.26	0.02	2	0.796	0.246	1

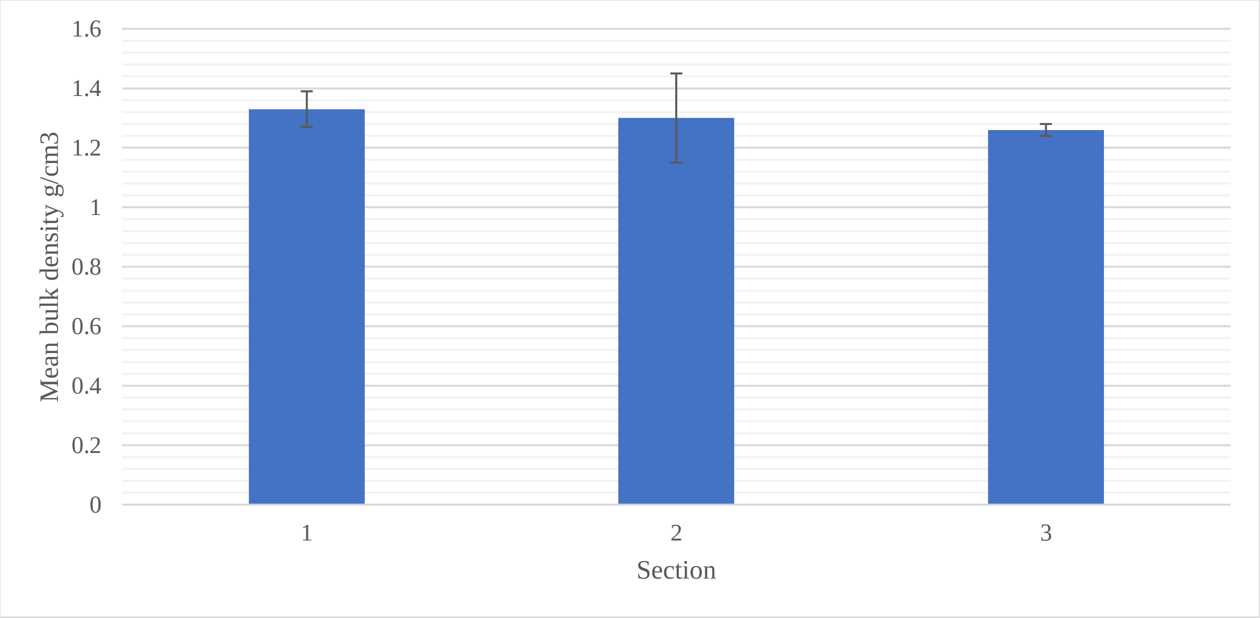

Fig. 10b. Mean bulk density per section. The x-axis is the section, and the y-axis is the mean bulk density in grams/cm³.

Fig. 11. Soil map for Heath Creek site. 376B corresponds to Moland Silt loam soil type, 104B is Hayden loam, and 529 B corresponds to Ripon silt loam.

Species	**Cost per bushel or pound**
Red oak	$80/bu.
Bur oak	$50/bu.
Swamp white oak	$175/bu.
Kentucky coffee tree	$150/bu.
Bitternut hickory	$70/bu.
Black walnut	$15/bu.
American chestnut	$60/lb.
Black cherry	$65/lb.
Wild plum	$40/lb.

Fig. 12. Costs of planted species. The left-hand column is species name and the right-hand column is cost either per bushel or per pound.

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