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Fire as a Forcing Function in Ecological Restoration

Katherine Mott
FIRE AS A FORCING FUNCTION IN ECOLOGICAL RESTORATION

by

KATHERINE MOTT

Candidate for Bachelor of Science
Environmental Resource Engineering
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APPROVED

Thesis Project Advisor:

Douglas Daley, P.E.

Second Reader:

Matthew Cowen, M.S. Candidate

Honors Director:

William M. Shields, Ph.D.

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ABSTRACT

Fire is a natural process that both positively and negatively affects the environment humans live in every single day. A soil’s physical characteristics can be altered from fire, resulting in effects such as degraded soil structure, inability for certain plants to regenerate, and production of hydrophobic layers. Researching the effects of fire on soil processes is important for communities with frequent forest fires or controlled burns to understand how to adapt to their altered ecosystems. Management of a community’s soil after burns have occurred is crucial for successful ecological restoration and regeneration of vegetation. The objective was to determine the effect of fire on soil properties for two silt loam soil samples, in particular, carbon/nitrogen content, water infiltration capacity and water retention.
ACKNOWLEDGEMENTS

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INTRODUCTION

Importance

In the past, people have viewed fire to be an "ecological catastrophe" (Kauffman, 2004). The view of fire has shifted over time, with an example being the Society of Ecological Restoration meeting in 1995 to discuss the importance of fire in forest restoration. The USDA Forest Service founder, Gifford Pinchot, and naturalist John Muir claimed that fire was "one of the great factors which govern the distribution and character of forest growth." These experts in the field of forest restoration have brought light to the importance of understanding the effects of fire on ecosystems and how fire can and should be reincorporated into forest ecosystems today (Hardy and Arno, 1996).

Fire is a natural process that both positively and negatively affects the environment in many ways. Fire is considered a disturbance within an ecosystem that plays a major role in processes such as biogeochemical cycling, vegetation composition, atmospheric chemistry, and the global carbon cycle. It expedites nutrient cycles by supplying nutrients to regenerating plants at faster rates because of ash formed throughout the fire process. This one function of fire is extremely important for ecosystems that have poor soil quality, such as sub-Saharan Africa. Closer to home, fire could play an important role in restoring the overworked and degraded soils used in agricultural practices. Heat is transferred into the soil through fire, affecting hydrologic cycles and soil chemistry. A soil's microclimate and several different characteristics can be changed through the ecological process. The focus of this research is to determine the
effect of fire on water infiltration capacity, water retention, and carbon and nitrogen content of forest soils (Thonicke et al., 2001).

Prior Research

A significant amount of research has been done in areas related to the hydraulic properties of burned soils. A study assessing soil water repellency after a fire in Colorado saw that soils experiencing high severity burning had stronger water repellency than soils experiencing moderate severity burning (Lewis et. al, 2005). An increase in water repellency will decrease the infiltration capacity by causing water to flow over soil, rather than sink in. This increase may be due to the burning of organic material. As organic material burns, it releases materials with hydrophobic properties into the soil, creating a water repellent layer. These portions of burned vegetation cause a decrease in infiltration (Robichaud et al, 2014).

For more low-intensity burns, the soil infiltration rate can also decline due to surface crusting. The heat may not be sufficient to break down certain organic molecules, but it is sufficient to dry out the soil surface. This drying leads to a hard, relatively impermeable soil surface that reduces infiltration rate (Cerda and Doerr, 2008).

The low infiltration capacities of burned soils pose several potential problems for ecosystems. Flooding will be more problematic due to additional runoff, plants will have a more difficult time germinating, and erosion rates will increase, leading to water quality and nutrient deficiency issues in the future (Robichaud et al, 2008).

A study done northeast of Aberdeen, Scotland researched the effects of fire on moisture retention of heathland soils. Heathlands are areas with open, low-growing woody vegetation. Moisture retention at different pressure levels was estimated using a
pressure plate apparatus. Results showed that burnt soils retained more water than unburned soils at similar pressure levels and the uppermost soil depths examined retained the highest amount of water when burned. The available water capacity of the burned decreased with depth (Mallik et al, 1984).

**METHODOLOGY**

Two soil profiles were used and are described below. Soil was collected in several large plastic bins by use of shovel. Twelve eight-inch diameter soil cores were filled with soil and re-compacted using a standard compaction procedure. It is important to note that the soil cores are not undisturbed, as the soil was removed from its original location and re-compacted in a soil core. Infiltration tests were performed with Mini Disk Infilrometers (MDI) on the bare soil cores before burns were conducted. The soil cores were then tightly placed into a half-barrel apparatus filled with sand and leaves to simulate a natural forest burn. Twelve four-inch diameter soil cores were also prepared and six were placed into the half-barrel apparatus for moisture retention tests. Once the burn was completed, infiltration tests were again conducted on the same soil cores and smaller diameter burned cores were used in moisture retention tests.

**Soil Sample Profiles**

- “Lafayette”: Wassaic silt loam (Lafayette Road Experiment Station, Syracuse, NY)
- “Honeoye”: Honeoye silt loam (Pompey, NY)
**Site Description**

Burns took place in a 55-gallon drum in the parking lot behind Baker Laboratory with already-granted permission from SUNY ESF campus police. All further analysis, such as infiltration tests, took place in the Sustainable Construction Management Department Labs in Baker Laboratory.

**Materials**

- 12 four-inch diameter soil cores
- 12 eight-inch diameter soil cores
- Soil obtained from
- 55-gallon drum
- Four cement blocks
- Sand and leaves to replicate natural forest burn
- Lighter
- Fire extinguisher
- Camera

**Instrumentation**

- 5.5 lb Proctor compaction hammer
- Decagon Devices Version 9 Mini Disk Infiltrometers
- Fluke 52-2 Thermocouple Thermometer
- Extech Instruments HD500 Heavy Duty Psychrometer and IR Thermometer
- Pressure Plate Apparatus (located in Forest Soils Lab, Illick Hall)

**Processes**

**Soil Core Preparation**

Re-compacted soil cores were prepared so that the soil was at 90 ± 3% of its optimum dry density and at ± 2% of its optimum water content. Standard basic compaction methods were used. ASTM D698 was referenced for basic compaction methods. Soil cores were re-compacted in the same procedure as outlined in ASTM D698, with a few alterations. Four lifts of loose soil into steel soil cores were performed. The first lift reached up to about 1/3 of total height (loose, relatively even surface). The
second lift (loose) reached up to about 2/3 of total height. The third lift (loose) was even with the rim of the core, and the fourth lift was sufficiently above the core so that after compaction there was additional soil over the rim that could be scraped off to create an even surface. It was very important to make the third lift even with the rim of the core to ensure there was enough soil to create an even surface post-compaction suitable for use with the Mini-Disk Infiltrometer.

The 12 four-inch soil cores were taken directly from the field using a soil corer with four-inch soil cores already placed in the soil corer. Soil cores were wrapped in plastic wrap for stability. This was done to produce both uniform and undisturbed soil cores.

**Modified Proctor Compaction Test**

Standard compaction methods were used (ASTM Int'l, 2013). Large soil cores (8-inch diameter) were filled with a pre-determined weight of soil and compacted in three layers, with 10 blows per layer. Compaction is performed using a mold, hammer, and specified drop depth.

**Infiltration Tests**

A Mini Disk Infiltrometer (MDI) was placed on a sample, either bare soil or post-burn soil. Standard MDI methods were used. After volumes were recorded, hydraulic conductivity, infiltration rates, and cumulative infiltration were calculated through Microsoft Excel Spreadsheets ("Mini Disk Infiltrometers", 2012). Figure 1 shows typical set up of the MDI on a burned soil core.
Two burns took place over the course of the experiment. Half of a metal barrel was placed on cement blocks and filled one-third with sand. Six soil core samples were then placed on top of the sand so that the cores fit snug together and movement was hindered. Leaves were placed on top to replicate a natural forest burn. The leaves were lit on fire, burning the samples. As the burn took place, a camera was used to record the physical appearance of the soil cores. Pictures captured during the burn were only intended for visual representation of the experimental procedure (Figure 2). Proper photo documentation methods were used (United States Department of Agriculture, 2002). Once the burn was completed, the samples were taken back to the lab for post-burn infiltration tests. Any ash formed on the top of the cores was gently brushed off immediately following the burn.

Pressure-Plate Analysis

ASTM D6836 was used for 12 four-inch diameter cores. The pressure plate apparatus was used to estimate moisture contents at pressure levels of 1, 5, and 15 bar. Setup of the pressure-plate analysis appears in figure 3.

Carbon and Nitrogen Analysis

The Dumas method (dry oxidation/combustion) was used to determine changes in carbon and nitrogen content. This was done using a THERMO Flash EA 1112 in the soil lab (Bicklehaupt and White, 1982). Four uniform samples were used, each containing a
mixture of the top half-inch of soil from each of the six cores for both soil types, both pre-burn and post-burn.

RESULTS

Moisture Content & Weather

Burns took place on July 25, 2014 and August 9, 2014 in the most eastern parking lot behind Walters Hall. Average temperatures were 71.5 degrees Fahrenheit with 63.5% average humidity and winds at 3.5 mph from the west. University Police and Chief of Health and Safety were notified before each burn took place. The average temperature of the burns was 520.9+-329.9 degrees Fahrenheit using Extech Instruments IR Thermometer and 184.5+-63.3 degrees Fahrenheit using Thermocouples. The average moisture content prior to burning was 17.83%. After burning, the average moisture content was 6.32%.

Infiltration

Figure 4 represents the time it took for one cm of water to infiltrate into the soil. Post burn soils took about 10 minutes longer to infiltrate one cm of water in comparison to pre burn soils. Figure 5 represents the soil water characteristic curve.

Moisture Retention

Lafayette soil’s field capacity had substantial changes from pre burn to post burn. Values for field capacity and wilting point for both soils, pre burn and post burn, are
found in Table 1. Plant available water decreased in Lafayette soil from 0.13 to 0.06. Plant available water for Honeoye soil did not experience a large change.

**Carbon and Nitrogen Content**

Values for percent nitrogen and percent carbon are shown in Table 2.

**DISCUSSION**

**Infiltration**

Fire can reduce the infiltration capacity of soils by destroying soil structure, creating a hydrophobic layer, depositing ash, and removing vegetation. If infiltration capacity is reduced, less soil water is available to support soil microbial and plant life. Groundwater recharge will also be hindered, but surface runoff will increase.

The study done by Cerda and Doerr, 2008, suggests that low-intensity burns can cause infiltration rates to decline due to surface crusting. This could be one reason why post burn soils took longer to infiltrate one cm of water, although the ash on top of each soil core was brushed off before any testing was done. The slower infiltration rate of post burn soils suggest that flooding could be of more concern, as water is not able to infiltrate into the soil as quickly as it could have prior to burns (Robichaud et al., 2008).

Suggesting that the soil may have developed hydrophobic properties is hard to prove given the scope of my research experiment. Lewis’ study of water repellency in soils dealt with high severity and moderate severity burns in Colorado, while my research dealt with low-severity, short duration burns. Lewis’ also examined infiltration rates post burn with portions of burned vegetation still on the soil, whereas my experiment involved
brushing the top half-inch of any ash or burned vegetation off of the soil cores prior to any testing. In order to better compare the results of my experiment to those of Lewis’, I would have needed to simulate a natural, high severity forest fire burn and leave all ash and burned vegetation on the soil cores for infiltration tests. The top half-inch of burned vegetation and ash were brushed off because the Mini Disk Infiltrometer needs a flat surface for best connection to the soil and most accurate infiltration.

**Soil Water Characteristic Curve**

As soil is burned, soil water retention decreases, which can affect regeneration. Changes in a soil water characteristic curve affect what plants will be able to regenerate given the different soil conditions because moisture capacity and plant available water both decrease.

The soil water characteristic curve changed dramatically for the Lafayette soils from pre burn to post burn, whereas there was not much change in the Honeoye soils. The soil profiles for both Lafayette and Honeoye show the soils to be classified as silt loam soils. They differ in that the Honeoye soils are shown to have moderate available water storage (about 7.2 inches), whereas Lafayette soils are shown to have low available water storage (about 5.2 inches). The small differences in the Honeoye soil water characteristic curve could be supported by the fact that the Honeoye soils had greater available water storage to begin with and burns did not fully diminish the available water storage. Therefore, the available water storage was not as greatly affected for Honeoye as it was for Lafayette. Lafayette began with low available water storage. Burning that soil could have had more dramatic effects on available water storage by diminishing the already low
available water storage. Communities that have frequent fires may choose to invest in drought tolerant plants to better respond to the lowered water holding capacity of their soils.

Decreasing available water storage ties back into the title of this research experiment, "Fire as a Forcing Function in Ecological Restoration." When available water storage decreases in a soil due to fire, it is harder for plants to regenerate and the characteristics of the soil are altered which would limit the types of plants able to regenerate and survive given the changed moisture capacity and plant available water. This is extremely important when using fire as a type of ecological restoration. If fire is used to restore a certain ecosystem, existing vegetation should be examined and further literature studies should be looked into to better understand the effects before implementing these techniques.

Carbon and Nitrogen Content

The top half-inch of each soil core was brushed off post-burn, therefore eliminating the large amount of soil carbon and nitrogen that would have been present. In order to determine significance of findings, a larger number of samples are needed. For the characteristics of my research experiment, there is not much literature available to use for comparing my results.

Further Research

The topic of fire as a forcing function in ecological restoration, specifically looking at changes in soil characteristics, is one that can still be explored and in much
more detail. Characteristics such as thermal conductivity, differences in evapotranspiration rates, hysteresis, and presence of soil microorganisms all influence fire’s ecological presence and should be looked into. If possible, estimating the ground heat flux for evaporation would be very beneficial.

Another future research objective for could be to determine if there are any changes in infiltration capacity over time. A study done to assess post-fire soil water repellency saw that if burned soil is exposed to moisture at different periods of time, the infiltration capacity will gradually increase (Robichaud et al, 2008). The steady moisture exposure could eventually break down hydrophobic layers, improving infiltration capacities. Different plant species may be able to improve moisture retention of soils after burns and could be very important overall in using fire as a restoration tool.

**Areas for Improvement**

There are many suggestions I would provide if reenacting or conducting similar studies in the future. When taking temperature readings, be sure to take the readings at consistent intervals and at the same distance throughout the entire burn. Also, take note of the start and end times of the burns. Although replications require a significant amount of work and time, the more replications done will provide a larger sample size, which could possibly allow one to determine the actual significance of results. When infiltration tests are being done, use diatomaceous earth to ensure a better connection of the porous plate to the soil surface.

The soil cores used needed to have a large enough diameter and depth in order to eliminate any interference due to the presence of boundaries. After the first sample was
tested, the soil core was sliced in half to see the wetting boundary. Two different
diameter soil cores were used for testing; four-inch diameter cores and eight-inch
diameter cores. Because infiltration tests on soil cores were preformed until 15 mL of
water had infiltrated into the soil, not all cores reached steady-state conditions.

CONCLUSION

Fire as a tool in ecological restoration has several effects on the physical
characteristics of soils. The objectives of this research were to determine the effect of fire
on soil properties for two silt loam soil samples, in particular, carbon/nitrogen content,
water infiltration capacity and water retention. Further research and improvements to the
experimental portions will help people using these techniques to continue to better
understand exactly how fire affects the environments in which it exists or is implemented.
Understanding fire as a forcing function in ecological restoration will continue to gain
importance as the global climate experiences more dramatic changes with more serious
effects on the environment in which we live.
REFERENCES


APPENDIX
Figure 1: Infiltration tests on post-burn soils
Figure 2: Set up of burn
Figure 3: Set up of pressure plate apparatus
Figure 4 Cumulative Infiltration
Soil Water Characteristic Curve

Figure 5 Soil Water Characteristic Curve
Table 1 Soil Water Characteristic Curve Data

<table>
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<tr>
<th>Measurement</th>
<th>Lafayette Field Capacity</th>
<th>Lafayette Wilting Point</th>
<th>Honeoye Field Capacity</th>
<th>Honeoye Wilting Point</th>
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<tr>
<td>Pre Burn</td>
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<td>Post Burn</td>
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Table 2 Carbon and Nitrogen Content

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<th>Sample</th>
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<th>% Carbon</th>
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<td>Honeoye Pre Burn</td>
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<tr>
<td>Honeoye Post Burn</td>
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