Effects of prescribed fire on soil properties in a pine rockland ecosystem

Ariel Freidenreich1 | Brittany Harris2 | Sanku Dattamudi1 | Eric Betancourt1 | Mariana Santos Reis3 | Krishnaswamy Jayachandran1

1 Dep. of Earth and Environment, Florida International Univ., Miami, FL 33199, USA
2 International Center for Tropical Botany, Dep. of Biological Sciences, Florida International Univ., Miami, FL 33199, USA
3 Federal Univ. of ABC, Santo Andre, SP, Brazil

Correspondence
Sanku Dattamudi, Dep. of Earth and Environment, Florida International Univ., Miami, FL 33199, USA.
Email: sdattamu@fiu.edu

Abstract
We investigated the impact of a single prescribed fire on soil properties of a pine rockland (PR) ecosystem (South Florida, USA) that had never been burned since establishment in 1978. Soil samples were collected before the prescribed fire (T0) and 1 wk (T1), 4 wk (T4), and 10 wk (T10) postburn and analyzed for chemical characteristics (pH, C, N, P, organic matter) and culturable bacterial and fungal cells. Soil organic matter showed a significant decrease after the burn as a result of fuel combustion. However, a significant increase in soil fungal and bacterial communities in postburn samples was observed, possibly resulting from higher P, N, and micronutrient availability in the soil after burning. Our study indicates that culturable soil microbes can respond to even small and undetectable soil chemical changes. This case study suggests that fast-growing soil microbes respond more rapidly than chemical properties to a prescribed burn and may have an impact on recovering of native vegetation communities.

1 | INTRODUCTION

Pine rockland (PR) is a globally endangered sparse pine forest with a tropical herbaceous understory, adapted to periodic fire intervals of 6–9 yr (Jones et al., 2017). Historically occurring along the Miami Rock Ridge, from the eastern coast of South Florida to the Lower Florida Keys, only about 1.8% of the original 75,000 ha remains preserved in small patches outside of Everglades National Park (Possley, Maschinski, Maguire, & Guerra, 2014; Trotta et al., 2018). This ecosystem supports over 400 different species of native plants, 41 of which are exclusive to Florida and 25 that are exclusives to the PR ecosystem (Gann, 2018). A characteristic pine rockland is often dominated by a sparse Florida slash pine canopy (Pinus elliottii var. densa), a fire-tolerant palm and shrub subcanopy, like thatch palm (Thrinax radiata Lodd. ex Schult. & Schult. f.) and locust berry [Byrsonima lucida (Mill.) DC.], and a diverse herbaceous understory (Snyder et al., 2005). The PR that survived rapid urbanization are rarely exposed to natural fires because many of the systems have been fragmented into small pockets surrounded by development (Diamond & Heinen, 2016). Prescribed burns are frequently suggested as a solution to manage the PR ecosystem, but fires are often delayed due to political barriers, community opposition, and insufficient resources, making it difficult for conservation objectives to be sustained (Hiers et al., 2003).

Abbreviations: CFU, colony-forming units; PR, pine rockland; SOM, soil organic matter; T0, preburn; T1, 1 wk postburn; T4, 4 wk postburn; T10, 10 wk postburn.

This is an open access article under the terms of the Creative Commons Attribution License, which permits use, distribution and reproduction in any medium, provided the original work is properly cited.

© 2020 The Authors. Agricultural & Environmental Letters published by Wiley Periodicals LLC on behalf of American Society of Agronomy, Crop Science Society of America, and Soil Science Society of America
The PR fragment located within the Florida International University campus not only serves as the habitat for native plant species but is also used to teach forest and environmental ecology students. This forest ecosystem has traditionally been maintained by mechanical removal of non-native plant species and had never been burned since its establishment in 1978. Fire was not implemented as a management tool on this forest because of safety concerns with proximity to a large student population and regular university activities. We raised public awareness to conduct a single prescribed burn for cleaning excess fuel buildup and to provide a healthy ecosystem for native plant proliferation. We hypothesized that even a single prescribed burn may alter the soil ecosystem (chemical and microbiological components) of this PR fragment. Our specific goal was to understand whether the introduction of fire, following decades of complete fire exclusion, is an applicable strategy to manage a small, fire-suppressed PR fragment.

2 MATERIALS AND METHODS

The study was conducted on a 0.4-ha PR fragment (25.7548° N, 80.3794° W) within a nature preserve at Florida International University in Miami, FL, USA. Soil of the study site was moderately alkaline (pH > 8.0) and derived from a limestone parent material. A prescribed burn on the PR site was conducted by the Florida Department of Agriculture and Consumer Services Division of Forestry in March 2016. Prescribed burning techniques and ignition methods included ground ignition backing fires, strip head fires, flanking fires, spot fires, and head fires with a maximum acceptable crown scorch between 10 and 40%. The burned area was not completely blackened, which indicates low fire severity. The burn was specifically prescribed (a) to reduce leaf litter buildup (hazardous fuel source) and (b) to aid in perpetuation of native fire-dependent species such as Pinus elliottii and Thrinax radiata, while ridding the system of invasive plant species (e.g., Ardisia elliptica Thunb., Schinus terebinthifolius Raddi).

An aerial image of the site was used to select quadrats with a grid overlaid, and 10 random center points were selected in 1 x 1 m² area. A 5-m buffer was added to reduce edge effect or possible nonburned areas. We used a GPS unit (Garmin Oregon 650t, Garmin International, Inc.) to mark sampling coordinates, which were revisited across the four sampling dates. We collected composite soil samples from the top 10 cm (after leaf litter was removed) of 10 randomly distributed 1-m² quadrats (four samples per quadrant, thoroughly mixed) for each sampling period: 3 d before the burn (T0), at 1 wk (T1), 4 wk (T4), and 10 wk (T10) after the burn (Figure 1). Some uncertainties may remain since we were not able to collect background soils for different time periods; however, we assume that pre-burn soil conditions (T0) would not change much within the 10 wk of this study. Chemical soil parameters including percentage of soil organic matter (SOM), pH, total carbon, total nitrogen, and total phosphorus were analyzed in the soil–plant–microbiology laboratory at Florida International University. Soil organic matter was measured using the standard loss on ignition method (500 °C for 5 h; Storer, 1984). Total N and total C of oven-dried (30 °C for 48 h) soil samples were measured by dry combustion with a TruSpec Carbon/Nitrogen Analyzer (LECO Corporation). Soil samples were analyzed for total P following the USEPA determination of phosphorus by semi-automated colorimetry soil method 365.1 (USEPA, 1993) in an AQ2 Discrete Analyzer (SEAL Analytical Inc.). We also prepared soil slurries (1:3 ratio of soil/deionized water) and determined pH using an Orion 3 Star Benchtop pH meter (Thermo Scientific).

Bacterial and fungal colony-forming units (CFU) in collected soil samples were measured through serial dilution and plating methods. In this approach, 1 g of wet soil was mixed in 9 ml of sterile water (autoclaved) (Pepper, Gerba, Gentry, & Maier, 2011), serially diluted. The samples were then vortexed for 60 s to assist in dislodging the bacteria from soil particles. One hundred microliters of diluted soil suspension was spread on one plate per soil sample at each dilution level. We prepared serial dilutions of 10⁻², 10⁻³, and 10⁻⁴ for fungi and 10⁻⁴, 10⁻⁵, and 10⁻⁶ for bacteria. Tryptic soy agar (2 g L⁻¹) containing cycloheximide solution (0.05 g L⁻¹, to prevent fungal growth) was used as plating media for bacterial colonization, and rose bengal agar (15.8 g L⁻¹) with streptomycin sulfate (1 g L⁻¹, to prevent bacterial growth) was used as fungal colonization media. Approximately 25 ml agar was poured for each plate. Sterilized water on the agar plates was used as control. Following incubation at 26 °C for 3 d, we counted the colonies on dilution plates. We chose dilution 10⁻² for bacteria and 10⁻³ for fungi as lower dilutions were over 300 colonies and

Core Ideas

- Fire is a critical component for pine rockland ecosystems to maintain biodiversity.
- Chemical and biological soil properties after prescribed fire were evaluated.
- Burning enhanced culturable soil microbe abundance, but chemical parameters remained unchanged.
- Prescribed burning can play a significant role in maintaining pine rockland ecosystems.
higher dilutions grew only a few colonies. Previous studies reported that microbial plate count generally takes 48–72 h (Dattamudi, Banta, Sidhu, Singh, & Chanda, 2018; Russell, 2005), although fast-growing microorganisms may be partial to this limited incubation time.

2.1 Statistical analysis

We analyzed soil data using SPSS statistical software, version 22 (IBM Corp., 2013). Analysis of variance tests allowed us to compare means between sampling periods for total C, N, P, percentage SOM, pH, and bacterial and fungal CFU. Colony forming units were calculated into CFU per grams dry weight of soil by obtaining soil moisture readings for each sample. From there, fresh sample weights were converted to 1 g dry soil weight, and CFU were multiplied accordingly. We separated the means at different time periods using Tukey’s honestly significant difference (HSD) post hoc.

3 RESULTS AND DISCUSSION

3.1 Chemical properties of soil

Soil pH remained moderately alkaline with no significant difference ($p > .05$) found between sampling times (T0, T1, T4, and T10) (Table 1). However, a slight increase in soil pH (~3.1%) was observed from T0 to T4, likely resulting from high ash deposition (Molina et al., 2007) and release of a large quantity of basic cations in the
soil (Heydari, Omidipour, Abedi, & Baskin, 2017). The pH was expected to return to preburn conditions over a longer time period (Alcañiz, Outeiro, Francos, Farguell, & Úbeda, 2016) depending on the buffering capacity of the soil.

An increase (39–55%) in total N concentration was observed from preburn (T0) to postburn (T1, T4, and T10) conditions (nonsignificant at p > .05, Table 1). Previous studies reported that burning can increase nitrate-N through the release of plant-available N in the soil (Bárcenas-Moreno, García-Orenes, Mataix-Solera, Mataix-Beneyto, & Bäath, 2011; Heydari et al., 2017) and proliferation of N-fixing microorganisms in burned areas (Johnson & Curtis, 2001).

Average concentration of total P in the soil after burning remained statistically insignificant throughout the experiment (T1 to T10); however, an elevation (70% increase) of concentration was detected immediately after burning (T0 to T1). This observation can be attributed to vegetation combustion, incorporation of ash in the soil profile, and possible P mineralization (Alcañiz et al., 2016). A slight (nonsignificant) reduction in soil total P concentrations at the T4 and T10 sampling periods could be an expression of immediate P uptake by surviving plant species (Francos, Stefanuto, Úbeda, & Pereira, 2019). A total of 20.5 cm of precipitation was received during the 10-wk sampling period, which possibly resulted in leaching of P from the soil profile. Total C content remained unchanged (Table 1) after burning, with no significant differences found between treatments (T0, T1, T4, and T10). However, SOM significantly (p < .05) decreased (6.6-fold) immediately after the burn (Table 1) and then remained stable over time. Burning of leaf litter and residues are reported to release CO₂ and CH₄ into the atmosphere (Dattamudi et al., 2019; Wang et al., 2013), which subsequently can reduce SOM content. Use of prescribed burning to reestablish fire regimes in PR forest systems can have a large impact on reducing the depth of the O-horizon and therefore reducing SOM in the surface layer, although C and N stocks may not show signs of immediate change (Matosziuk et al., 2019).

| Time | pH | SOM | TC | TN | TP | C/N |
|------|----|-----|----|----|----|-----|
| T0   | 8.05 ± 0.10a | 44.43 ± 1.31a | 32.9 ± 5.52a | 1.65 ± 0.22a | 0.06 ± 0.01a | 19.59 ± 0.94a |
| T1   | 8.15 ± 0.12a | 6.72 ± 2.13b | 44.04 ± 7.04a | 2.3 ± 0.31a | 0.20 ± 0.12a | 20.04 ± 1.83a |
| T4   | 8.18 ± 0.10a | 7.86 ± 1.10b | 53.08 ± 6.67a | 2.57 ± 0.29a | 0.07 ± 0.01a | 20.52 ± 0.91a |
| T10  | 8.30 ± 0.12a | 8.68 ± 0.93b | 49.21 ± 8.42a | 2.50 ± 0.35a | 0.06 ± 0.03a | 19.01 ± 0.91a |

Note. SOM, soil organic matter; TC, total C; TN, total N; TP, total P. All nutrient factors are represented in mg g⁻¹ dry weight. Like letters indicate no significant difference between sampling times; means were separated using Tukey’s honestly significant difference post hoc at (p < .05).

### 3.2 Soil microbiological properties

Our results showed a slight increase (nonsignificant at p > .05) of fast-growing culturable fungal CFU from T0 (87.93 ± 14.52) to T1 (158.32 ± 36.20) conditions (Figure 2). However, a significant increase (p < .05) in fungal colony count from preburn to T4 (246.77 ± 54.47) and T10 (266.11 ± 42.83) was also observed. Fire can reorganize fungal communities, and fire-sensitive fungi species are likely to be replaced by fire-adapted species over time (Semenova-Nelsen, Platt, Patterson, Huffman, & Sikes, 2019). In a recent study by Salo (2019), researchers found that the population of saprotrophic macrofungi (Basidiomycota, Ascomycota) were significantly higher postfire in a pine forest because fire increased the availability of C sources for fungi in the soil. The presence of fungi, specifically endophytic varieties, can have great impacts on plant establishment and community structure (Afkhami & Strauss, 2016).

Bacterial population (CFU g⁻¹ dry soil × 10⁵) was also significantly increased (p < .05) from preburn to postburn sampling times. Average colony counts at T1 (330.81 ± 82.32) were almost six times higher than T0 (55.92 ± 15.85) conditions (Figure 2). Similar results were reported by Mittal et al. (2019), who observed more than five times higher (p < .001) cultivable bacterial populations in soils collected from burnt forest compared with unburnt forest. The elevated bacterial population immediately after burn could have possibly resulted from increased nutrient (specifically, N, P, and some micronutrients) concentrations (Yeager, Northup, Grow, Barns, & Kuske, 2005) and increased pH of the soil (Jaatinen, Knief, Dunfield, Yrjälä, &Fritze, 2004; Mataix-Solera et al., 2009). Overall, even without significant changes in nutrients and pH, our study shows that undetectable changes in soil chemistry can influence microbial populations. Also, in the short term, increase in soluble organic C is capable of elevating bacterial population in postfire soils (Bárcenas-Moreno et al., 2011; Mataix-Solera et al., 2009). However, no significant difference in bacterial population was found among postburn treatments (T1, T4, and T10).
Our study evaluated the importance of a single prescribed fire event to maintain environmental and ecological sustainability for a managed natural system. Prescribed fires can restore ecosystems and mitigate biodiversity loss that has been degraded by urban expansion (Dunn, Gavin, Sanchez, & Solomon, 2006). When managed with public access, these fragile ecosystems can be an experiential and educational tool for culture, science, and conservation awareness (Elmqvist et al., 2015).

CONCLUSION

Prescribed burning did not significantly change the soil chemical properties of this PR ecosystem, with the exception of SOM, which was significantly reduced postburn. Overall, the outcomes of this study indicate that fire encourages proliferation of soil microbial communities, which may facilitate plant establishment and growth. Although microbial communities were altered, results suggest that a single prescribed fire after a history of prolonged fire suppression may not be effective for ecosystem management when considering change in soil chemical properties. Future studies are required to better understand the effect of more frequent fire on small managed natural systems like PR forests.

ACKNOWLEDGMENTS

This research was funded through Florida International University’s Agroecology Program via the USDA National Institute of Food and Agriculture National Needs Fellowship (2013-38420-20499).

CONFLICT OF INTEREST

The authors declare no conflict of interest.

ORCID

Ariel Freidenreich https://orcid.org/0000-0002-0665-3569
Brittany Harris https://orcid.org/0000-0002-0667-4853
Sanku Dattamudi https://orcid.org/0000-0001-6875-4640

REFERENCES

Afkhami, M. E., & Strauss, S. Y. (2016). Native fungal endophytes suppress an exotic dominant and increase plant diversity over small and large spatial scales. Ecology, 97(5), 1159–1169. https://doi.org/10.1890/15-1166.1
Alcañiz, M., Outeiro, L., Francos, M., Farguell, J., & Úbeda, X. (2016). Long-term dynamics of soil chemical properties after a prescribed fire in a Mediterranean forest (Montgrí Massif, Catalonia, Spain). Science of the Total Environment, 572, 1329–1335. https://doi.org/10.1016/j.scitotenv.2016.01.115
practices and greenhouse gas emissions from Louisiana soils. *Louisiana Agriculture*, Spring, 8–9.
Yeager, C. M., Northup, D. E., Grow, C. C., Barns, S. M., & Kuske, C. R. (2005). Changes in nitrogen-fixing and ammonia-oxidizing bacterial communities in soil of a mixed conifer forest after wildfire. *Applied and Environmental Microbiology*, 71(5), 2713–2722. https://doi.org/10.1128/AEM.71.5.2713-2722.2005

**How to cite this article:** Freidenreich A, Harris B, Dattamudi S, Betancourt E, Reis MS, Jayachandran K. Effects of prescribed fire on soil properties in a pine rockland ecosystem. *Agric Environ Lett.* 2020;5:e20026. https://doi.org/10.1002/ael2.20026