Dynamics of Phosphorus in Calcareous Soils after a Fire in the Pine Rockland Ecosystem

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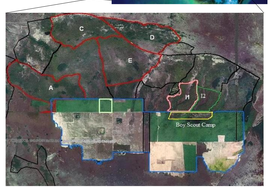
Research objective: To evaluate impacts of prescribed fire on availability of phosphorous in calcareous soils under the Pine Rockland forest

Abstract

Phosphorus (P) is a limiting nutrient in the Pine Rockland ecosystem due to an abundance of calcium. This study assessed fire's influences on P availability in calcareous soils of the Pine Rockland forest. Three specific tasks were: (i) determining availability of P by burning temperatures and soil moistures; (ii) determining changes of P contents after a fire; and (iii) using an equilibrium speciation model to simulate P dynamics after the fire. A field-burning experiment was set up in Long Pine Key, and soil samples were collected at pre-burn and 2 weeks, 1 month, 3, 6, 9, 12, 15, and 18 months after the fire. Four burning temperatures (250^{0}C, 350^{0}C, 450^{0}C, 550^{0}C) and three soil moistures (20%, 50%, and 80% of field capacity) were applied for the laboratory incubation in six different periods. Methods of repeated measure and Tukey's pairwise comparison were used to analyze ANOVA and compare among treatments. Minteq software was utilized to simulate different forms of P after the fire. Results showed that P availability was significant different from burning temperatures, soil moistures, and their interactions ($P < 0.0001$), and were significantly increased in 2 weeks after the fire ($P < 0.0001$). HPO_4^{2-} was the dominant species after the fire. These findings imply that burning at the beginning of dry season will produce a highest effectiveness of P availability in the Pine Rockland forest.

Introduction

Pine Rockland in South Florida is a nutrient-poor and fire-dependent ecosystem. Availability of P in this ecosystem is limited because of an presence of calcium and iron. So far, most researches have focused on studying effects of prescribed fire on changes of nutrients in acidic and neutral soils. We hypothesized that a prescribed fire would increase availability of P in calcareous soils of the Pine Rockland forest. Questions for this study were: (i) how will the P be impacted by fire intensity and changes in soil moisture; (ii) how will a prescribed fire change contents of P in calcareous soils; and (iii) what are major forms of P in the soil after a fire? This research were carried out by laboratory and field experiments. Under the controlled condition of laboratory, soil samples were incubated by four burning temperatures (250^{0}C, 350^{0}C, 450^{0}C, 550^{0}C) and three soil moistures (20%, 50%, and 80% of field capacity) at 24^{0}C in six different periods. Soil and fuel-loading samples for this experiment were collected at the block of Boy Scout Camp in May 2008. The Boy Scout Camp was burned in October 2008 for the field experiment. Changes of P content were measured in 18 months after the fire . Accumulation of fuel loadings underneath the Pine Rockland forest's storey before the fire was 5 years. Block of I1 was chosen for collecting control samples.



Long Pine Key in Everglades National Park, Florida

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4. Snyder, J. R., M. S. Ross, S. Koptur, and J. P. Sah. 2005. Developing Ecological Criteria for Prescribed Fire in South Florida Pineland Ecosystems. USGS Open File Report of 2006-1062
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Methods and Results

Task 1

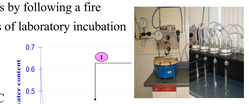
Study Question: How will the P be impacted by fire intensity and changes in soil moisture?

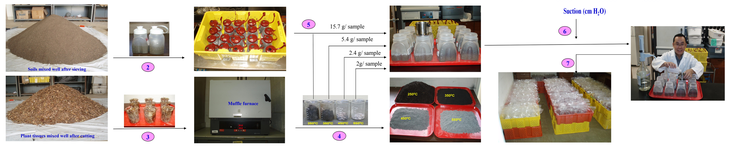
♦ **Hypothesis:** Fire intensity and soil water content will alter availability of P in calcareous soils by following a fire

♦ **Task:** Determining how temperatures and soil moistures change P under controlled conditions of laboratory incubation

♦ **Materials and Methods**

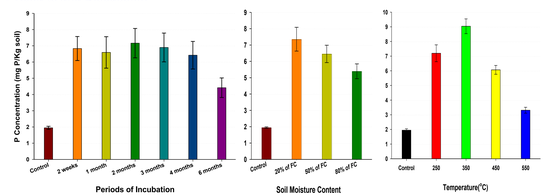
- (1) Using data from Tempe cell, Richard plate, and Retc model to fit a soil moisture curve
- (2) Putting soils into bottles (~ 150g soil/bottle)
- (3) Heating fuel-loading samples in a furnace at temperatures: 250^{0}C, 350^{0}C, 450^{0}C, and 550^{0}C
- (4) Mixing well ashes and charcoals at each heating temperature together
- (5) Putting ashes and charcoals on the top of soil in the bottles
- (6) Putting DI water into bottles at three soil moistures: 20%, 50%, 80% of field capacity (FC)
- (7) Incubating soil samples at 24^{0}C for six different periods: 2 weeks, 1, 2, 3, 4, 6 months





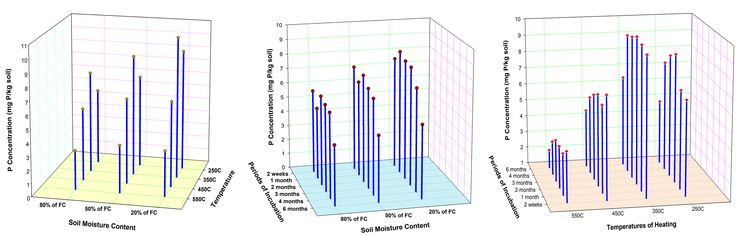
- The Olsen method was used to extract phosphorus, and P concentration was determined by Spectrophotometer by the colorimetric method
- The methods of Repeated Measures and Tukey's pairwise comparison were used to determine significant differences among treatments

♦ **Results and Discussion**



Results of Repeated Measure ANOVA

Source	Pr > F	Significance
Moisture	< 0.0001	***
Temperature	< 0.0001	***
Period	< 0.0001	***
Moisture*Period	< 0.0001	***
Temperature*Period	< 0.0001	***
Moisture*Temperature	< 0.0001	***
Moisture*Temperature*Period	0.0431	*



- P availability after the fire was significantly increased by burning temperatures and soil water content in different incubation periods
- The P available concentration of approximately 7 ppm was maintained until four months after the fire
- P availability was decreased as an increase of soil water content. This availability was highest at 350^{0}C in soil moistures and periods

Task 2

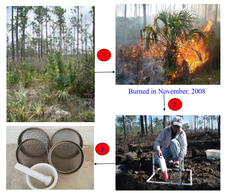
Study Question: How will a prescribed fire change contents of phosphorus in calcareous soil?

❖ **Hypothesis:** P availability and total P concentration will be reduced by following a fire

❖ **Task:** Determining changes of P in eighteen months after a fire in the field condition

❖ **Materials and Methods**

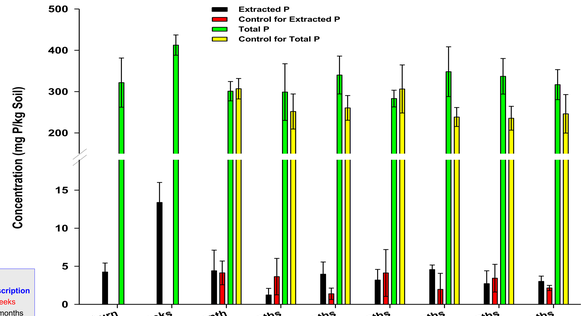
- (1) Burning the Pine Rockland in Long Pine Key with fuel-loading accumulation of 5 years
- (2) Collecting ashes and soils after burning: Ash samples were gathered right after the fire. Soils were randomly collected at pre-burn, 2 weeks, 1, 3, 6, 9, 12, 15, and 18 months after the fire. 25 soil samples were collected at each period, and 5 samples mixed into a replicate. Soil samples for control were also collected at the block of I1
- (3) Soils were air-dried and sieved at 2mm. Plant tissues and litters were also collected and dried in Oven at 65^{0}C in 5 days for analyzing content of P



❖ **Laboratory and Statistical Analyses**

- Extracted P was extracted by the Olsen and total P was digested by the Ignition method
- The methods of Repeated Measures and Tukey's pairwise comparison were used to determine significances among treatments
- Plots of NPP, Residuals vs. Fitted Values, and Residuals vs. Time were to check an error normality, variance equality, and independence

❖ **Results and Discussion**



Tukey Grouping (Mean, Description)

Grouping	Mean	Description
A	13.383	2 weeks
B	4.564	12 months
B	4.502	2 months
B	4.407	1 month
B	4.239	Pre-burn
B	3.953	6 months
B	3.188	9 months
B	3.014	18 months
B	2.713	15 months
B	2.420	4 months
B	1.225	3 months

Results of Statistical Analysis

	Pr > F			
	Extracted P		Total P	
	After fire	*Control*	*After fire*	*Control*
ANOVA	< 0.001***	0.1714	0.0572	0.0539
Levene's Test for Homogeneity of Variances	0.0771	0.4101	0.1975	0.347

Percents of total C, total N, and total P in oven-dried plant tissues and ashes

	Ash and Charcoal					Plant tissues and litters underneath Pine's storey	
	Laboratory Incubation				Field	Incubation	Field
	250^{0}C	*350^{0}C*	*450^{0}C*	*550^{0}C*			
Total N (%)	0.9352	1.8864	1.2211	0.6593	0.9028	0.5403	0.5304
Total C (%)	53.23	47.16	32.86	27.49	38.33	46.59	46.25
Total P (%)	0.0301	0.0893	0.1979	0.2619	0.1261	0.0187	0.0193
Extracted P (mg P/g ash or tissue)	0.1077	0.0892	0.0263	0.0050	0.0254	0.0534	0.0786
C:N ratio						86.22	87.20
N:P Ratio						28.90	27.48

- Available contents of P were significantly different after the fire. The P availability was dramatically increased from 4.24 ppm in pre-burn to 13.38 ppm in 2 weeks after the fire. This availability went back its original content in 1 month after the fire
- An increase of P availability raised the total P concentration, but total P was not significantly different from the sampling periods
- C:N ratio (86.2 to 87.2) and N:P ratio (27.5 to 28.9) indicated that the Pine Rockland has both N limitation and P limitation

Task 3

Study Question: What are major forms of P in calcareous soil after a fire?

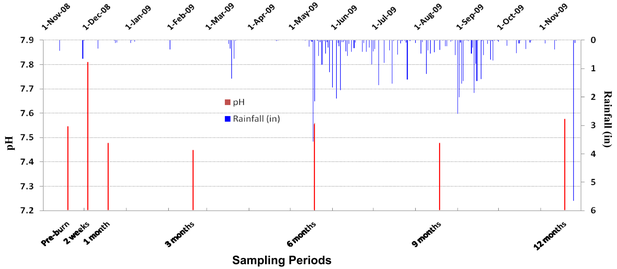
❑ **Hypothesis:** Fire will decrease concentrations of $H_2PO_4^-$ and HPO_4^{2-} due to abundance of calcium

❑ **Task:** Using an equilibrium speciation model of MinTeq to simulate availability of $H_2PO_4^-$ and HPO_4^{2-} after a fire

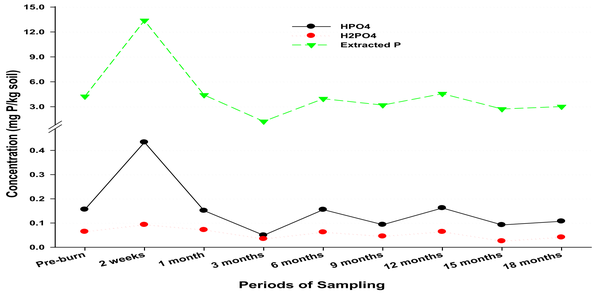
❑ **Materials and Methods**

- Input parameters needed to simulate $H_2PO_4^-$ and HPO_4^{2-} included pH, ionic strength (IS), and extracted P and cations
- Ionic strength was estimated from electrical conductivity by Marion-Babcock equation: Log(IS) = 1.159 + Log(EC)
- Cations were extracted by the AB-DTPA method and measured by Atomic Absorption Spectrophotometer
- At each time of speciation of $H_2PO_4^-$ and HPO_4^{2-}, the species which react among cations and phosphates, including strengite, vivianite, apatites, $Mg_3(PO4)_2$, $MgHPO_4.3H_2O$, $Mn_3(PO4)_2$, $MnHPO_4$, also added into the model

❑ **Results and Discussion**



Sampling periods	Extracted concentrations of cations (mg/kg soil)								P (mg/kg soil)	EC (µS/cm)	pH	IS (mol/L)
	Mg	*Ca*	*K*	*Na*	*Mn*	*Zn*	*Cu*	*Fe*				
Pre-burn	52.15	1059.76	164.79	290.91	69.22	3.46	3.44	177.87	4.24	333.33	7.55	0.000481
2 weeks	143.66	904.61	277.33	359.12	256.37	5.11	4.12	153.31	13.38	697.64	7.82	0.001006
1 month	80.12	1035.04	193.48	358.31	89.22	5.39	3.06	207.18	4.41	543.84	7.48	0.000784
3 months	40.20	972.20	187.56	309.89	46.95	5.27	3.83	169.80	1.22	370.08	7.45	0.000534
6 months	53.64	1094.06	236.42	277.05	53.12	5.34	3.81	158.06	3.95	383.34	7.56	0.000553
9 months	55.65	988.70	121.79	301.27	89.32	4.16	3.58	288.91	3.19	348.22	7.48	0.000502
12 months	53.41	1161.85	144.82	277.89	72.65	5.29	4.24	172.77	4.56	328.16	7.57	0.000473
15 months	61.80	1048.94	159.86	313.03	113.92	4.03	3.96	196.97	2.71	452.72	7.72	0.000653
18 months	33.73	971.95	136.82	307.29	58.87	2.38	3.79	222.59	3.01	331.50	7.58	0.000478



- Concentrations of HPO_4^{2-} species were always higher than concentrations of $H_2PO_4^-$ at the different sampling periods
- $H_2PO_4^-$ concentrations at different collection times were almost the same and lower than 0.1ppm
- Concentrations of HPO_4^{2-} at different periods fluctuated with the extracted P concentrations and soil pH.

Conclusions

- Phosphorus is limited in the Pine Rockland due to the abundance of Ca. Bio-availability of P was significantly increased in 2 weeks and went back to its original value in 1 month after the fire. The increase of P content was due to a release of P from ashes during the fire
- HPO_4^{2-} was the dominant species of ortho-phosphate in the Pine Rockland, and its content was depended on the extractable P content
- Availability of P after a fire was replied on both the fire intensity during the burning and soil water content after the fire. This availability was decreased as an increase of the water content. The highest P content was at the burning temperature of 350^{0}C
- From results of ash analysis, the average burning temperature of fire in the field was approximately 450^{0}C

Implications in Ecological Management

Fire intensity and soil moisture content are two important factors in creating and maintaining the P available content after the fire. The burning temperature which is from 350^{0}C to 450^{0}C will produce a maximum amount of P in soil. A high content of soil moisture after a fire will reduce bio-availability of P for plant uptake. Thus, selection of burning time is very important. From the above findings, we suggest that November or December (the beginning of dry season) will be a good time to use a prescribed fire in ecological management of Pine Rockland forest.