Microbial control of total nitrogen and total organic carbon in soils across two climatic provinces

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Introduction

Mineralized terranes (areas enriched in metal-bearing minerals) occur throughout the Western US, resulting in highly variable soil trace metal concentrations across small spatial scales. Assuming that non-lithologic (extrinsic) soil forming factors are relatively constant between mineralized and their proximal unmineralized zones, the mineralized areas should allow us to evaluate the effect of lithology on soil microbial activity.

Results of our work include empirical models for Total Organic Carbon (TOC) and Total Nitrogen (TN) in soil, as a function of measurements that describe the activity level of the microbial community. Regression models based upon these measurements fit a disparate dataset of soil ecosystems developed on 3 unique styles of mineralogically/chemically-altered bedrock (acid sulfate, Mo/Cu porphyry, and serpentinization). The first 2 sites are located within the Bailey Intermountain Semi-desert and Desert Province (Mono and Lahontan Basin Sections: MAT = 6-13 C; MAP = 300-500mm), while the serpentine site is located within the Bailey Sierra Steppe Province (Sierra Nevada Foothills Section: MAT = 12-18 C; MAP = 510-1015mm). We wish to test whether the microbial parameters employed by our model will explain variations in TN and TOC among other climate regimes, and their potential utility as a monitoring tool.

Measures of ecosystem function

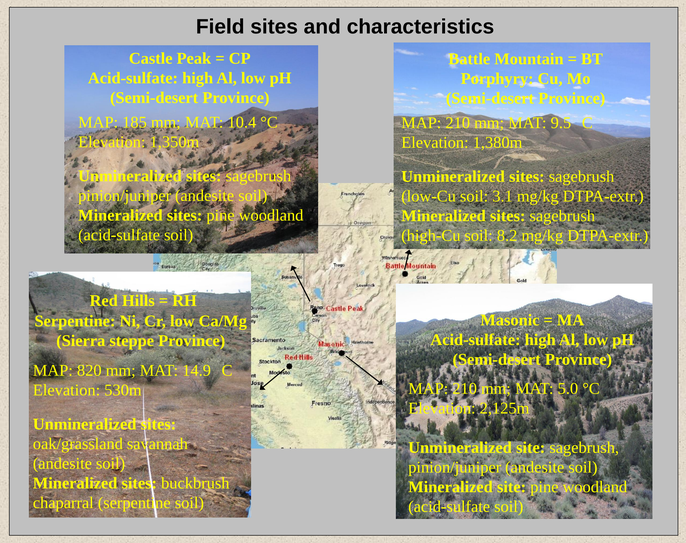
Parameters were selected to provide a range of variables that examined belowground biotic activity (see table below). Soil physical (texture, bulk density, moisture content) and chemical (pH, electrical conductivity, Total C,N,S, DTPA-extractable metals, water-soluble metals, total metals) parameters were also analyzed (data are not reported here).

Parameters	Variables	Method(s)
Soil microbial indicators	Soil enzyme activity	Fluorescein diacetate (FDA) hydrolysis, Arylsulfatase (S), Acid and Alkaline Phosphatase (P)
	C, N mineralization potential	10-d static incubation
	Soil microbial biomass and community structure	Phospholipid fatty acid analysis (PLFA)
	Soil microbial activity and functional diversity	Carbon substrate utilization, using Biolog Ecoplates, which contain C substrates similar to root exudates and other soil compounds

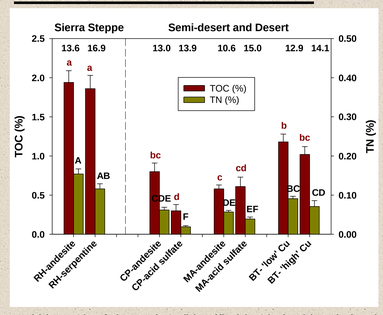
Field sites and sampling

Each field site included mineralized (enriched in metal-bearing minerals), and unmineralized (background) soils within the same watershed. Two acid-sulfate mineralized sites were chosen as replicates to examine biotic and abiotic variability. A total of 18 soil samples per field site were taken (0-15cm); unmineralized (n=9), mineralized (n=9). Sites were sampled one time in the spring (2008) near peak vegetative productivity.

Field sites and characteristics



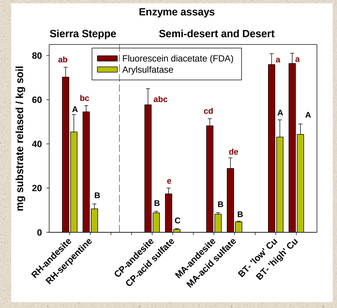
Results – Soil TOC and TN



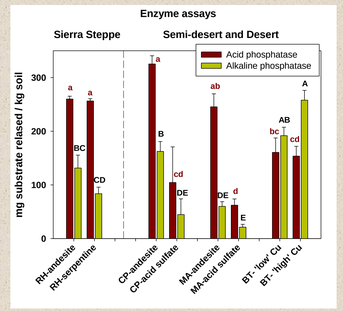
Within each of the 4 sites (identified by their abbreviations) the unmineralized soil is listed first, followed by the mineralized soil. Different letters indicate significant differences among the means at ά = 0.05. Bailey Ecoregion Provinces are listed at the top of the graph. The numbers just below the upper x-axis represent soil C/N ratios.

Serpentine and andesite soils in the Sierra Steppe have similar TOC and TN values despite extreme differences in vegetation, and values from both those sites are greater compared to the drier Semi-desert sites. Within the Semi-desert Province, CP was the only site to show a difference in TOC and TN between mineralization types. The MA and BT sites had similar TOC and TN between mineralization types, despite the former having extremely different land cover and vegetation. Overall, climate seemed to impact TOC and TN values to a greater extent than mineralization type in this study

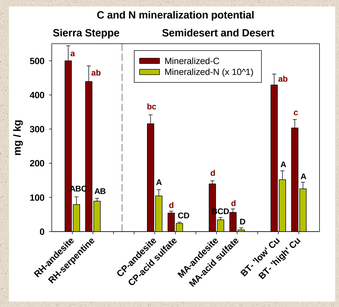
Results – Soil microbial activity



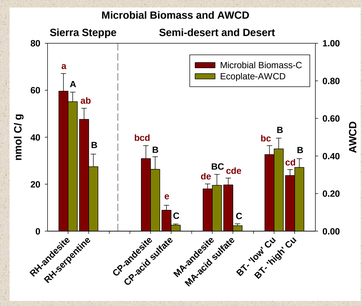
Mineralized soils showed the lowest arylsufatase activity regardless of climate; FDA activity is impacted to a lesser extent by within site mineralization differences. Overall mineralization style seems to have a greater impact than climate on these measures.



Acid sulfate mineralization has a greater impact on both acid and alkaline phosphatase activity compared to the other mineralization styles. Overall, mineralization type seemed to impact phosphatase activity to a greater extent than climate.



Both mineralized-C and -N differed between soil types only within the CP site. Overall, climate differences between the provinces did not seem to impact these measures to the same extent as geology.



The Sierra steppe sites have greater overall microbial biomass compared to the drier semi-desert sites. Only one of acid sulfate soils (CP) showed decreased values for microbial biomass and AWCD relative to their andesite counterpart. In the case of microbial biomass, climate appears to have a greater impact than mineralization style.

Regarding soil moisture:

Volumetric soil moisture content at the time of sampling was similar across all Semi-desert sites (10.6% 0.59) and slightly greater than the Sierra Steppe sites (6.2% 0.52), emphasizing the potential importance of metals and nutrients in controlling microbial activity and diversity in these semi-arid systems.

Data Synthesis

1. To examine the key microbial drivers within and across these ecosystems, we used Multiple Linear Regression (MLR) equations to model the biochemical variables that best correlated with TOC or TN, comparing predicted v. measured values
2. The underlying assumption with this approach is that soil organic matter (in the form of TOC or TN) and biological activity are in equilibrium in undisturbed systems. The ratio of predicted/measured TOC or TN values has been used to measure the impact of disturbances (natural and anthropogenic), which result in ratios either lower or higher than their undisturbed counterparts.

TOC MLR model variables for the Semi-Desert/Desert Sites

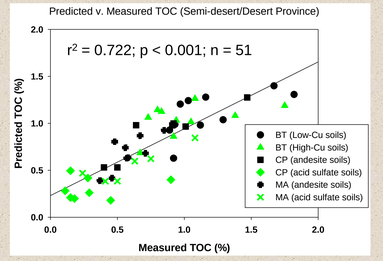
Site(s)	Data set used to develop model	Best explanatory variables	r^2
Castle Peak	Andesite	Mineralized-N***; Acid-P**	0.98
	Acid-sulfate	AWCD*; (-)Acid-P; Mineralized-C	0.66
	Andesite and acid-sulfate	Mineralized-N****	0.74
Masonic	Andesite	Acid-P***; (-)Mineralized-C***; Microbial biomass-C***	0.95
	Acid-sulfate	Microbial biomass-C**; Arylsulfatase*	0.93
	Andesite and acid-sulfate	Microbial biomass-C****; Alkaline-P**	0.72
Battle Mountain	Low-Cu	Alkaline-P***; Mineralized-C**; Microbial biomass-C*	0.93
	High-Cu	Acid-P***; Mineralized-N***	0.88
	Low and High -Cu	Arylsulfatase***; Acid-P**; Mineralized-N**	0.60
Semi-desert/Desert	CP, MA, BT	FDA****; Microbial biomass-C**	0.72

TN MLR model variables for the Semi-Desert/Desert Sites

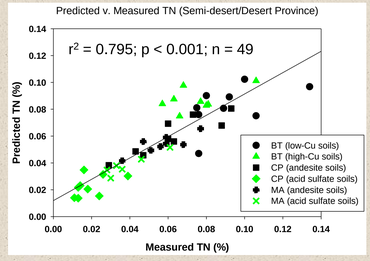
Site(s)	Data set used to develop model	Best explanatory variables	r^2
Castle Peak	Andesite	FDA*; Arylsulfatase; Mineralized-N	0.88
	Acid-sulfate	FDA*; (-)Arylsulfatase*; (-)Acid-P*; Mineralized-C	0.80
	Andesite and acid-sulfate	FDA**; Microbial biomass-C**; Arylsulfatase*; (-)Acid-P**	0.97
Masonic	Andesite	Alkaline-P***; FDA**; Mineralized-N*	0.94
	Acid-sulfate	Arylsulfatase***; Microbial-biomass-C**	0.98
	Andesite and acid-sulfate	FDA****, Alkaline-P***; (-) Mineralized-C**	0.94
Battle Mountain	Low-Cu	Alkaline-P**; Arylsulfatase*; Microbial biomass-C*	0.77
	High-Cu	Acid-P****; Mineralized-N**	0.91
	Low and High -Cu	Mineralized-N***; AWCD**	0.40
Semi-desert/Desert	CP, MA, BT	FDA****; Arylsulfatase**	0.79

The results above represent the best MLR models based on: (1) a small number of parameters with a correlation coefficient as close to 1.00 as possible, and acceptable p-value; 2) a Mallows' Cp statistic close to the total parameter number; 3) a variance inflation factor < 10, and 4) a low Akaike Information Criterion (AIC) compared to the other models. Many of the microbial variables correlate well with TOC and TN, and thus the variables for the "best" models can look quite different. Are the variables listed above the key drivers in each of these systems or would others work equally well? If so, could we then add cost as a criteria in indicator selection? We're hoping that additional study will help clarify the sensitivity and utility of these microbial indicators and this overall approach.

Predicted v. Measured TOC and TN based on the combined data from the Semi-desert/Desert sites



Predicted TOC (%) = 9.34 x 10^{-3} (FDA) + 2.16 x 10^{-1} (Microbial Biomass-C) – 0.35



Predicted TN (%) = 5.78 x 10^{-4} (FDA) + 9.21 x 10^{-3} (Log Arylsulfatase+1) + 5.79 x 10^{-3}

The regression line, equation and model parameters are presented for each model. Given the high correlation between TOC and TN within this data set (r^2 = 0.908), it is not surprising that both models contain the same microbial indicator (FDA) and perform in a similar manner. It's remarkable that the correlation coefficients are so high given the range of observed TOC and TN values and the disparity of the ecosystems studied.

Conclusions

1. This study suggests that these microbial measures can provide accurate models of TOC and TN for different mineralization types within these climate zones.
2. Overall, mineralization type tends to impact microbial activity to a greater extent than climate when looking at the data set as a whole, whereas climate tends to have a greater impact on microbial biomass, TOC and TN.
3. Additional data is necessary to expand this approach beyond the limited data set used in this study to see how the observed trends and models are impacted.
4. Microbial indicators may be helpful in understanding monitoring long-term changes in soil organic matter (TOC and TN) associated with shifting precipitation and climate regimes across the Great Basin.