Acid and Alkaline Phosphatase Dynamics in Soils of a Piñon-Juniper Woodland

Susanne Krämer

Abstract.—Plant roots and soil organisms increase phosphorus availability by releasing acid and alkaline phosphatase. Organic phosphorus compounds are hydrolysed into plant-available forms through the action of these enzymes. Phosphatase is of particular importance under conditions of low phosphorus availability which is commonly found in piñon-juniper soils. Acid and alkaline phosphatase activities (mg p-nitrophenol released g⁻¹ soil h⁻¹) were studied at two research sites in northern Arizona. At monthly intervals, soil samples were collected underneath Juniperus monosperma canopies and in interspace areas dominated by Hilaria jamesii. In both juniper and interspace soils, alkaline phosphatase activities were significantly higher than acid phosphatase activities. Alkaline phosphatase activity ranged from 57.3 to 167.2 µg p-nitrophenol g⁻¹ soil h⁻¹ and was similar to values reported for acid farmfield and grassland soils. Acid phosphatase activity varied between 9.3 and 29.5 mg p-nitrophenol g⁻¹ soil h⁻¹ and corresponded to values in Juniperus occidentalis and a range of western coniferous forest soils. The results indicate that soil microbes are the dominant producers of phosphatase in the studied piñon-juniper soils.

INTRODUCTION

Traditionally, most nutrient cycling studies in forests and rangelands have focused on the measurement of nutrient pool sizes and the return of nutrients from plants to soil in litterfall. Only recently have we turned our attention to the dynamics of nutrient fluxes and the underlaying processes by which the supply of nutrients to plants is sustained.


Phosphatase activity has been studied in various agricultural and forest soils. However, very limited information exits on phosphatase dynamics in semiarid rangeland soils. The present study determined acid and alkaline phosphatase levels in a piñon-juniper woodland of northern Arizona and compares it to values reported for soils from a range of ecosystems. Possible relationships of...
phosphatase activity levels to various soil and vegetation characteristics are discussed.

**MATERIALS AND METHODS**

Two study sites were established in a one-seed juniper/galleta (*Juniperus monosperma/Hilaria jamesii*) dominated woodland of the Colorado Plateau in northern Arizona. The sites were located about 30 miles northeast of Flagstaff at Wupatki National Monument at an elevation of 1650 m. The climate at Wupatki National Monument is semiarid with 54% of the total annual precipitation occurring during thunderstorms in July, August, and September (fig. 1) (Sellers and Hill 1974). Longterm average precipitation at the visitor center (1492 m elev.) is 188 mm (Sellers and Hill 1974).

Soils for the analysis of pH, loss on ignition, and texture were collected during August 1993. Prior to sampling, each study site was subdivided into three equal sized rectangular plots. In each plot, soil subsamples were collected from 5 to 15 cm depth from 10 randomly located areas under both juniper trees and in interspace areas. Subsamples were composited within plots. Soils were air dried and passed through a 2 mm sieve. Standard analysis techniques were used for soil pH (1:1 soil/CaCl₂), loss on ignition, and texture (Bouyoucos hydrometer) (Klute 1986, Page et al. 1982). Soil textural classes follow the USDA classification scheme (Gee and Bauder 1982). The depth of cinders and litter covering the soil surface was measured to the nearest half centimeter at three random locations in each interspace and tree plot used for phosphatase analysis. Variations in soil properties between sites, trees, and interspace areas were analyzed with *t*-tests at the 0.05 level.

Tree canopy cover was determined at 10 random locations with a spherical densiometer (Lemmon 1956). Understory cover of dominant herbaceous species was estimated in 20x50 cm plots. At each site, 30 plots were read at 1 m intervals along 5 transects. Cover was estimated based on Daubenmire cover classes (Daubenmire 1968). Canopy and understory cover differences between sites were compared with *t*-tests at the 0.05 level.

Within each study site, four juniper and four interspace plots were randomly selected for the study of soil phosphatase. Soil was collected from 0 to 20 cm depth at monthly intervals from September 1993 to June 1994. At each plot, 3 randomly located subsamples were obtained with a core sampler lined with a 2.5 cm diameter butyrate sampling tube. Samples in juniper plots were collected at approximately half the distance between the tree trunk and canopy edge. Sampling tubes were capped and transported to the laboratory on ice. At the laboratory, the 5 to 15 cm core sections were passed through a 2 mm sieve and composited within sample plots. Sieved samples were stored in polyethylene bottles at 4 °C.

Field moist soil samples were analyzed for acid and alkaline phosphomonoesterase activity with a buffered disodium *p*-nitrophenyl phosphate tetrahydrate solution (Tabatabai 1982, Schinner et al. 1991). Results were calculated in µg *p*-nitrophenol released per gram dry soil per hour at 37 °C. A hierarchical ANOVA (Zar 1984) was used to test differences in acid and alkaline phosphatase activity, juniper and interspace plots, and between sites within sampling dates.

**RESULTS AND DISCUSSION**

Soil and vegetation characteristics varied considerably between study sites (table 1 and 2) although the sites were located within 500 m of each other. Soils were alkaline and ranged from pH 7.4 to 7.9 in interspace plots, and 7.9 to 8.0 in juniper plots (table 1). At site 1, soil pH was significantly lower in interspace than juniper plots (*P* ≤ 0.01). Both interspace and juniper soil pH levels were significantly lower (*P* ≤ 0.01) at site 1 than site 2.

Soil organic matter estimated by percent loss on ignition was between 3.4 and 4.1% and did not differ significantly within or between study sites (table 1).

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**Figure 1.**—Longterm precipitation and temperature averages (1941-1970) at Wupatki National Monument (Sellers and Hill 1974).
Site 1 soils were of a sandy loam texture with significantly less sand \((P \leq 0.05)\) in interspace \((54.3\%)\) than juniper plots \((63.6\%)\) (table 1). Soils at site 2 were finer textured and classified as loam.

Both study sites are covered with black cinders from the eruption of Sunset Crater. Cinder cover was significantly deeper at site 1 than site 2, and under juniper trees as compared to interspace areas \((P \leq 0.05)\). Interspace plot cinder cover was 3.2 cm at site 1 and 1.6 cm at site 2 (table 1). Under juniper trees, cinders are mixed with tree litter. Average cinder/litter depth for juniper plots was 8.6 and 4.3 cm for site 1 and 2, respectively (table 1). Rocks and plant residue on the soil surface act as a mulch and can significantly decrease evaporative loss of soil moisture, and decrease soil temperature fluctuations (Brady 1984). These factors may be critical in determining aboveground vegetation and belowground soil phosphatase characteristics associated with the study sites.

One-seed juniper and galleta were the dominant plant species on both study sites. Juniper canopy cover was 8.2\% at site 1 and 3.5\% at site 2 (table 2). Galleta cover was significantly higher \((P \leq 0.05)\) at site 1 (7.0\%) than site 2 (4.5\%) (table 2). Mixed oak \((Quercus spp.)\) forest soils, and acid farmfields was considerably higher than levels found in this study (fig. 3) (Adams 1992, Eivazi and Tabatabai 1977, Herien and Neal 1990, Ho 1979).

Alkaline phosphatase activity varied between 57.3 and 145.4 \(\mu g\) \(\text{p-nitrophenol g}^{-1}\ \text{h}^{-1}\) in juniper soil and 75.9 and 167.2 \(\mu g\) \(\text{p-nitrophenol g}^{-1}\ \text{h}^{-1}\) in interspace soil (fig. 2). These values are similar to alkaline phosphatase activities reported for grassland and acid farmfield soils (fig. 3) (Eivazi et al. 1996).

### Table 1: Chemical and physical soil characteristics of research sites. Lower case letters indicate significant differences between interspace and juniper soils within study sites. Numbers indicate significant differences in interspace or juniper soils between study sites.

<table>
<thead>
<tr>
<th>Species</th>
<th>Site 1</th>
<th>Juniper</th>
<th>Site 2</th>
<th>Juniper</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>pH</strong></td>
<td>7.4 a1</td>
<td>7.9 b1</td>
<td>7.9 a2</td>
<td>8.0 a2</td>
</tr>
<tr>
<td><strong>Loss on ignition (%)</strong></td>
<td>3.6 a1</td>
<td>3.4 a1</td>
<td>3.6 a1</td>
<td>4.1 a1</td>
</tr>
<tr>
<td><strong>Texture</strong></td>
<td>sandy loam</td>
<td>sandy loam</td>
<td>loam</td>
<td>loam</td>
</tr>
<tr>
<td><strong>% Sand</strong></td>
<td>54.3 a1</td>
<td>63.6 b1</td>
<td>48.2 a1</td>
<td>50.6 a2</td>
</tr>
<tr>
<td><strong>% Clay</strong></td>
<td>20.0 a1</td>
<td>14.1 a1</td>
<td>21.4 a1</td>
<td>20.2 a1</td>
</tr>
<tr>
<td><strong>Cinder/litter depth (cm)</strong></td>
<td>3.2 a1</td>
<td>8.6 b1</td>
<td>1.6 a2</td>
<td>4.3 b2</td>
</tr>
</tbody>
</table>

### Table 2: Cover of dominant plant species at research sites. Values are means ± SE. Lower case letters indicate significant differences between interspace and juniper soils within study sites. TR = trace (< 0.5%).

<table>
<thead>
<tr>
<th>Species</th>
<th>Site 1</th>
<th>Site 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Juniperus monosperma</td>
<td>8.2 (±22.7) a</td>
<td>3.5 (±.57) a</td>
</tr>
<tr>
<td>Hilaria jamesii</td>
<td>7.0 (±2.1) a</td>
<td>4.5 (±1.1) b</td>
</tr>
<tr>
<td>Sporobolus cryptandrus</td>
<td>TR</td>
<td>TR</td>
</tr>
<tr>
<td>Aristida arizonica</td>
<td>TR</td>
<td>TR</td>
</tr>
<tr>
<td>Spiro neomexicana</td>
<td>TR</td>
<td>TR</td>
</tr>
<tr>
<td>Sitanion hystrix</td>
<td>-</td>
<td>TR</td>
</tr>
</tbody>
</table>

![Figure 1: Longterm precipitation and temperature averages (1941-1970) at Wupatki National Monument (Sellers and Hill 1974).](image-url)
and Tabatabai 1977, Herbien and Neal 1990). Alkaline phosphatase levels in alkaline farmfields and a cornfield were much higher than activities found in this study (Eivazi and Tabatabai 1977, Herbien and Neal 1990). However, much less information exits on alkaline soil phosphatase compared to acid phosphatase and comparisons are therefore limited.

Alkaline phosphatase activity was significantly higher ($P \leq 0.01$) than acid phosphatase in both juniper and interspace soil throughout the study period (fig. 2). This agrees with the conclusion of Eivazi and Tabatabai (1977) that alkaline phosphatase predominates over acid phosphatase in high pH soils. Plant roots can be a major source of acid phosphatase (Dinkelaker and Marschner 1992, Juma and Tabatabai 1988, Neal 1973, Speir and Cowling 1991), but do not produce any alkaline phosphatase (Nakas et al. 1987, Tarafdar and Claassen 1988). Alkaline phosphatase originates from soil bacteria, fungi, and fauna (Ho and Zak 1979, Nakas et al. 1987, Pang and Kolenko 1986, Tarafadar and Claassen 1988). Soil microbes appear to be the main producers of phosphatase in the studied piñon-juniper soils.

Phosphatase activities were not significantly different between juniper and interspace soils. However, with the exception of the June 1994 sampling date, alkaline phosphatase activity was consistently higher in interspace than in juniper soil (fig. 2). Soil water potential measurements at the study sites indicate that juniper soils are drier than interspace soils (S. Krämer, unpubl. data). Since soil microbial activity is positively correlated with soil water potential (Griffin 1981, Wilson and Griffin 1975), higher microbial activity and therefore higher alkaline phosphatase levels can be expected in interspace soils. This explanation agrees with Hoffmann and Elias-Azar (1965) and Tarafdar and Claassen (1988), who observed higher phosphatase activity in soils with higher microbial populations. Physical and chemical soil properties (table 1) may further influence the measured alkaline phosphatase levels in juniper and interspace soils (Skujins 1976, Speir and Ross 1978).

Phosphatase activities at site 1 were generally higher than those at site 2 (fig. 2). Values were significantly different ($P \leq 0.1$) during September, November, and December 1993, and during January and June 1994. Differences in phosphatase activities between sites are likely to be caused by dissimilar soil moisture and temperature regimes due to variations in soil texture and cinder/litter cover.

Phosphatase levels reported in this study are comparable to those of a range of soils with similar pH values. Variations in activities observed appear to be related to site specific soil and vegetation conditions. However, further studies are necessary to establish more detailed relationships between phosphatase activity and soil conditions.

Research is presently underway to examine soil moisture and temperature changes relative to organic phosphorus cycling and relate them to levels of observed phosphatase activities reported in this study. To more completely understand phosphorus dynamics in piñon-juniper soils, we must look at phosphatase as part of an environmental matrix that consists of many individual, yet interacting factors.
LITERATURE CITED


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plants through the activity of phosphatase produced by plant roots and microorganisms. Biology and Fertility of Soils. 5: 308-312.

