Nutrient Cycling in Managed and Unmanaged Oak Woodland-Grass Ecosystems[1]

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Abstract: The influence of oak trees and grazing on nutrient cycling in oak woodland-grass ecosystems was examined at the Sierra Foothill Range Field Station in the northern-Sierra Nevada foothills of California. Nutrient concentrations in ecosystem waterflows (precipitation, canopy throughfall, and soil solutions) were monitored in a non-managed natural area and in an adjacent grazed area. Grazing increased soil solution concentrations of chloride (Cl) and sodium (Na), but had no effect on major nutrient levels. When comparing between oak and non-oak sites, the oak sites had enhanced soil solution concentrations of Ca, Mg, K, SO_4 and PO_4, and decreased levels of Na. Soil solution pH beneath the oak canopy was 0.5-1.0 units greater than in adjacent grasslands, and appears to be due to neutralization of rainfall acidity by the oak canopy and enhanced base cation cycling by the oak.

Increased land use intensity is apparent throughout California and oak woodland-grass ecosystems are no exception. A large portion of our oak woodland-grass ecosystems is grazed and many woodlands are being cleared to enhance grazing and produce firewood for sale. The potential for site disturbance and land degradation in intensively managed oak woodland ecosystems is great, but little is known about the impact of these practices on nutrient cycling. If nutrients are removed from an ecosystem at a rate greater than they can be made available by natural processes, the productivity of the ecosystem will decrease, forage production or quality may be reduced, and oak seedling reestablishment may be compromised.

To examine nutrient dynamics, ecosystem waterflows were sampled during the period of active growth. These waterflows provide a dynamic pathway for redistribution of elements within different levels of the ecosystem (Likens and others 1977). Because these solutions reveal current processes, their composition is sensitive to management practices and ecosystem disturbances (Cole and others 1975; Dahlgren and Ugolini 1990). Soil solutions also reflect the plant-available nutrient status and therefore provide a basis for comparing differences in nutrient availability between various subsystems within the ecosystem (Wearing and Schlesinger 1985). The major objectives of this study were 1) to examine the role of oaks in nutrient cycling processes, and 2) to determine the impact of grazing on nutrient cycling in oak woodland-grass ecosystems.

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METHODS

The investigation was conducted on two study sites in the Schubert Watershed at the University of California, Sierra Foothill Range Field Station near Browns Valley, CA. The two study sites (183 m elevation) are found on adjacent tracts of land, with one site in pasture and the other preserved as a natural area (no livestock grazing in 17 y). The pasture area was grazed by cattle for approximately three one-month periods with a month recovery period between grazings. The study sites have a mean annual precipitation of 73 cm and a mean annual temperature of 15° C. Major tree species are blue oak (*Quercus douglasii* H. & A.) and interior live oak (*Quercus wislizenii* A. DC.) with a stocking of 10-125 trees per ha. Major forbs include filaree, annual clovers and geranium. Common annual grass species are soft chess, ripgut brome, red brome, annual fescue, wild oats, and medusahead. Perennial grasses include purple stipa. Soils at the study site have formed in basic metavolcanic (greenstone) bedrock and are classified as fine, mixed, thermic Typic Haploxeralfs.

Bulk precipitation, canopy throughfall, and soil solutions were collected from January to June, 1990, which corresponds to the period of active growth. Precipitation was collected at two sites using polyethylene containers fitted with funnels (17.5 cm diameter). Teflon wool was placed in the neck of the funnel to act as a coarse filter and reduce evaporation. Canopy throughfall was collected at six sites beneath each oak species in collectors identical to those used for precipitation. Solutions were collected immediately following major precipitation events to prevent evaporation and microbial mediated alterations to the solution chemistry. Soil solutions were obtained monthly by extracting solutions from duplicate soil cores taken from the A (0-7 cm), AB (7-31 cm), and Bt l (31-55 cm) horizons. Distilled-deionized water was added to bring the solution/soil ratio to 1.5/1 and allowed to equilibrate for 2 h. The soil was filtered through a Whatman #41 filter followed by a final filtration through a 0.2-µm polycarbonate membrane.

The pH was measured potentiometrically immediately following extraction. Base cations (Ca, Mg, K, Na) were determined by atomic absorption spectroscopy and major anions (Cl, NO_3, PO_4, and SO_4) by ion chromatography. Ammonium was measured using the conductimetric method of Carlson (1978). Statistical analysis was performed using SAS statistical software (SAS Institute, Inc. 1985). Differences in mean solute concentrations between grazed/non-grazed and oak/non-oak sites were determined using the ANOVA procedure combined with the Tukey test.

RESULTS AND DISCUSSION

Statistical analysis of mean solute concentrations showed relatively few differences between grazed and non-grazed systems (table 1). However, the effect of the oak canopy on soil solution composition had an influence on most of the solute concentrations. It should be noted that relatively high variability occurred between some of the monthly soil solution samples. This results from both spatial and temporal variability. In particular, large changes in environmental conditions (eg. temperature and moisture) occurred between January and June which strongly affected microbial processes and plant nutrient demands. As a result of the large variability, what appears to be large differences between sites in figures 1-4 are not always significant.

Table 1—*Statistical analysis comparing the effects of grazing (pasture [P] vs natural area [N]) and oak trees (oak [O] vs grassland [G]) on soil solution solute concentrations.*

	A Horizon		AB Horizon		Bt Horizon	
	Grazing	Oaks	Grazing	Oaks	Grazing	Oaks
pH	=†	O>G*	=	O>G*	=	O>G*
Cl	P>N**		=	=	P>N*	=
NO_3	=	=	P>N*	O>G*	P>N**	=
PO_4	=	O>G*	=	O>G*	=	=
SO_4	=	O>G**	=	O>G*	P>N*	O>G*
NH_4	=	O>G*	=	=	=	=
Ca	=	O>G*	=	O>G*	=	O>G*
Mg	=	O>G*	=	O>G*	=	O>G*
K	=	O>G*	=	O>G*	=	O>G*
Na	P>N**	G>O*	P>N*	G>O*	P>N*	G>O*
Si	P>N*	O>G*	=	O>G*	P>N*	=

† = no statistical difference among treatments; *p<0.05; **p<0.10

Base Cations (Ca, Mg, K, Na)

Inputs of base cations in the precipitation were relatively low (fig. 1). Concentrations of K, Ca, and Mg increased by a factor of 8, 7, and 6 times, respectively, in the canopy throughfall, while Na concentrations increased only by a factor of two. Live and blue oak canopies leached similar amounts of base cations except for K, which had higher concentrations in the blue oak throughfall. In the soil solutions, concentrations of the macro-

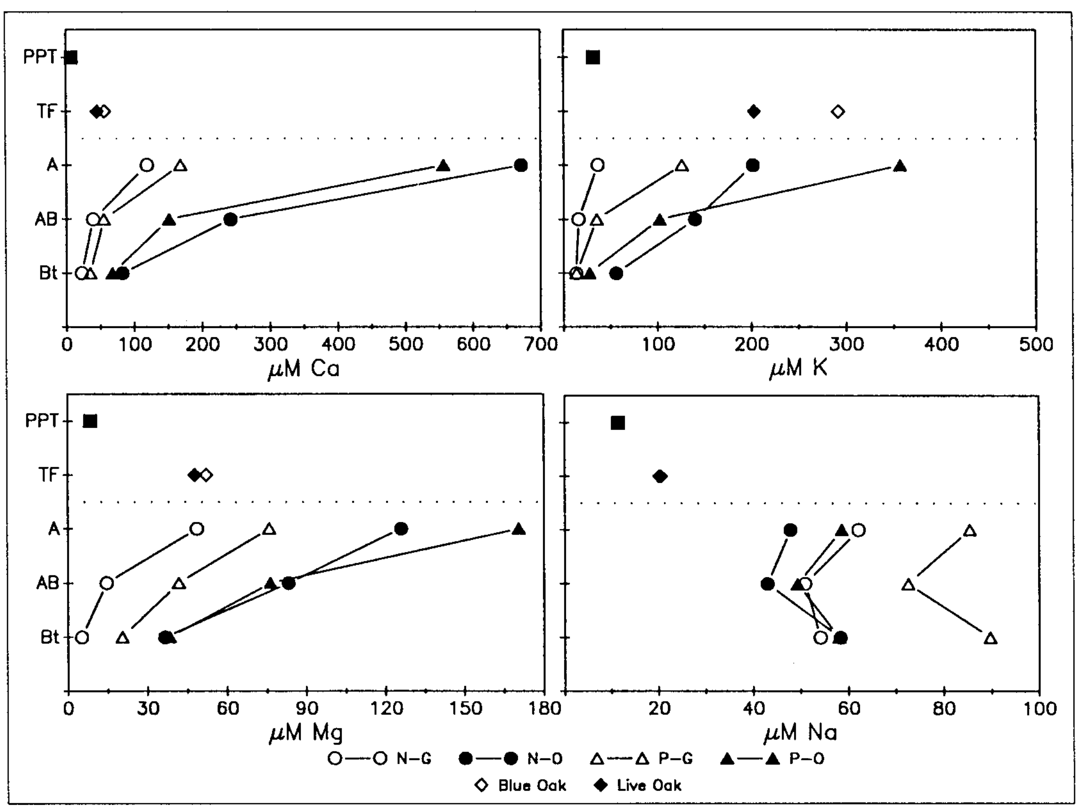

Figure 1—Concentrations of Ca, Mg, K, and Na in precipitation (PPT), canopy throughfall (TF), and the A, AB, and Bt horizon soil solutions. Treatments consisting of non-grazed/grass (N-G), non-grazed/oak (N-O), pastured/grass (P-G), and pastured/oak (P-O) were examined.

nutrients Ca, Mg, and K were highest in the A horizon and showed a progressive decrease in the AB and Bt horizons. This pattern of high concentrations in the upper soil horizons and sharply decreasing concentrations with depth are characteristic for elements which are strongly affected by nutrient cycling. Cycling of essential nutrients maintains an abundant supply of nutrients for incorporation into new biomass while at the same time limiting nutrient losses from the soil profile. Elements which are available in excess of plant requirement are leached from the soil profile in quantities greater than elements which are in short supply. An example of this is shown with Na, a nonessential element. Sodium concentrations remain relatively constant throughout the soil profile and are not attenuated within the rooting zone.

The effect of the oak canopy on increasing base cation concentrations in the soil solution was readily apparent for the essential nutrients Ca, Mg, and K. Differences were greatest in the A horizon and decreased with depth as plant uptake removed cations from solution. An interesting contrast occurred for Na which had higher concentrations in the grassland sites. The oak rooting system may extend well beyond the oak canopy and invade the adjacent grasslands (Thomas 1980). The rooting system may selectively accumulate Ca, Mg, and K leading to a depletion of these cations from the grassland sites. Cycling of Ca, Mg, and K by the oak will lead to high solution concentrations of these elements beneath the oak canopy, which will initiate a mass action displacement of Na from the cation exchange sites. The displaced Na will then be leached from the soil profile.

Sodium was also unique among the base cations in being the only cation to show differences between grazed and non-grazed sites. Sodium concentrations were greater on the grazed sites and may result from additions by the cattle which receive supplemental salt.

Anions (Cl, NO_3, SO_4, PO_4)

Concentrations of NO_3 and PO_4 in the precipitation were greater than the trace levels normally found in non-polluted precipitation (fig. 2). The NO_3 originates primarily from anthropogenic sources while the source of the PO_4 is unknown (Laird and others 1986). Anion concentrations in canopy throughfall were similar to the precipitation levels for NO_3 and SO_4, while Cl and PO_4 concentrations increased approximately fourfold. No significant differences occurred between the live and blue oak canopies. Upon entering the soil, all anions showed an attenuation with depth indicating plant uptake and cycling. There was complete retention of PO_4 within the rooting zone

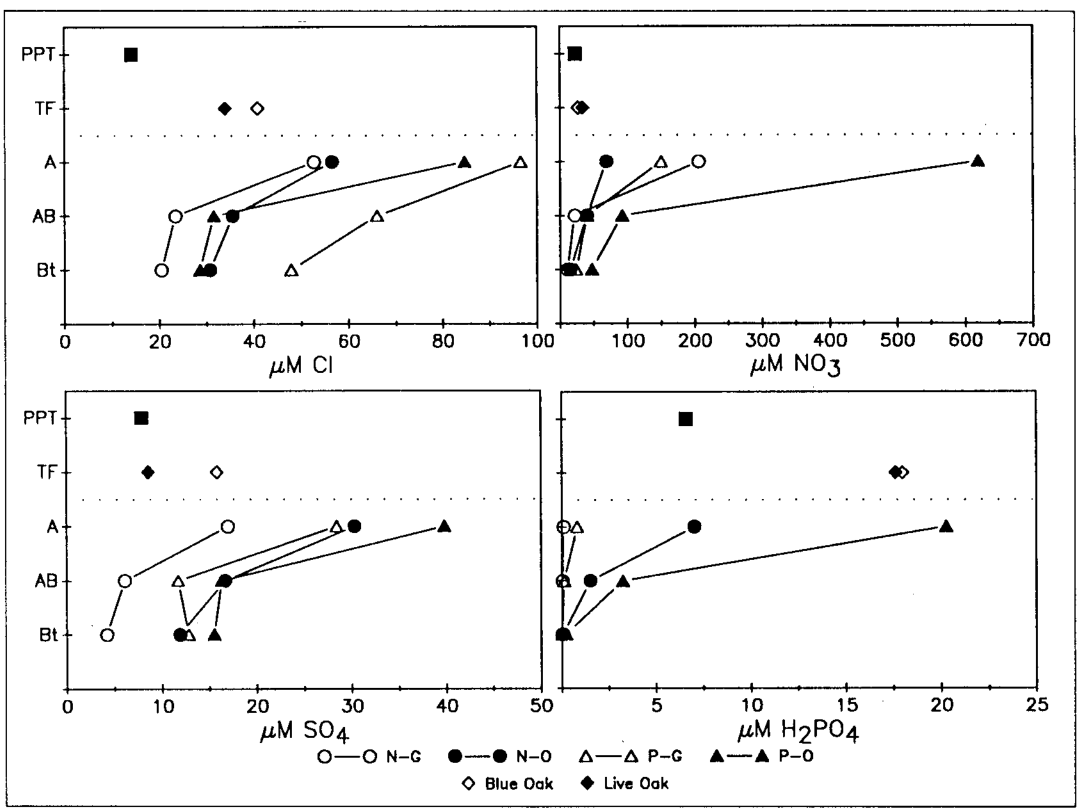

Figure 2—Concentrations of Cl, SO_4, NO_3, and PO_4 in precipitation (PPT), canopy throughfall (TF), and the A, AB, and Bt horizon soil solutions. Treatments consisting of non-grazed/grass (N-G), non-grazed/oak (N-O), pastured/grass (P-G), and pastured/oak (P-O) were examined.

indicating that PO_4 may be a limiting nutrient in this ecosystem. In contrast, NO_3 levels leaching from the soil profile remain in the 15-50 μM range which is similar to the mean streamwater concentration of 20 μM over the same time period. Therefore, N appears to be present in sufficient quantities to meet the plant requirement; the excess being leached from the soil profile into the surface waters.

Grazed sites had increased Cl levels similar to Na. This increase further supports the additions of both Na and Cl from the salt supplement which the cattle receive. Extremely high NO_3 levels in the grazed-oak canopy site may also be due to the influence of the cattle which appear to preferentially use the shaded area beneath the oak canopy. The oak canopy resulted in increased levels of PO_4 and SO_4 as compared to the grassland soil solutions. Increased NO_3 concentrations in the grazed-oak site were also apparent but not statistically different due to the large variability. These data indicate that P and S are being enriched in the soil solutions beneath the oak canopy due to nutrient cycling, while N does not appear to be strongly affected by the oak.

Ammonium

Inputs of NH_4 in the precipitation (44 μM) were approximately twice that of NO_3 (23 μM) (fig. 3). The combined input of these two nitrogen sources represents a nitrogen input of 6.9 kg/ha/yr based on the mean annual precipitation. Ammonium concentration increases upon interaction with the canopy and may reflect leaching of NH_4 from the foliage or washout of dryfall trapped by the canopy and not accounted for in the bulk precipitation. When comparing the two oak species, the blue oak leached 50 μM more NH_4 than the live oak. Concentrations of NH_4 remain relatively constant in the soil solutions. Only the A horizon showed a significant increase due to the influence of the oak canopy. Nitrate was the dominant form of mobile N in the soil solutions of this ecosystem as has been shown for other oak woodland ecosystems (Parker and Muller 1982).

pH

The interaction of the precipitation with the canopy resulted in an increase of the pH from 5.6 to 5.9 and 6.2 for the live and blue oak throughfalls, respectively (fig. 4). The exchange of base cations for H^+ is the primary neutralization mechanism occurring in the canopy (Weaver and Jones 1981). Solution pH was further increased by neutralization processes in the soil profile. There was a clear pH difference between oak canopy soils and grassland soils. The pH beneath the oak canopy was approximately 0.5 - 1.0 unit higher. Soil solution pH also showed a general trend of decreasing with depth in the profile. This trend was more pronounced in the oak canopy site. These data suggest that increased base cation cycling by the oaks is responsible for enriching the base status of the oak canopy soils and in particular the upper soil horizons and thus leads to the elevated pH values observed. Partial neutralization of acidity by the canopy may also contribute to the higher pH by reducing the acidity of the waters incident on the soil surface.

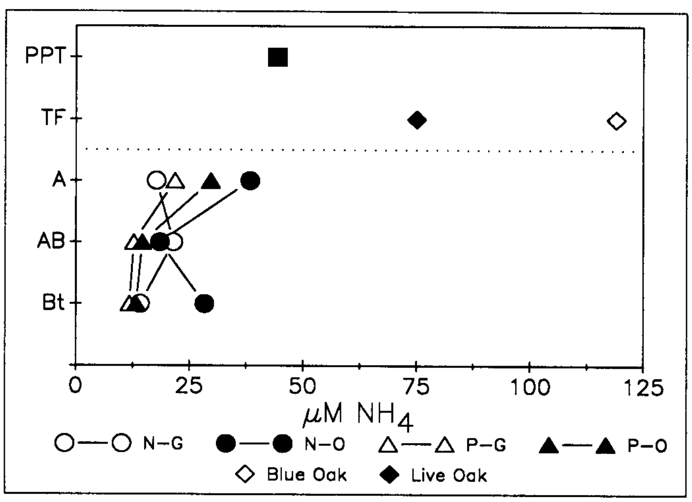

Figure 3—Ammonium concentrations In precipitation (PPT), canopy throughfall (TF), and the A, AB, and Bt horizon soil solutions. Treatments consisting of non-grazed/grass (N-G), non-grazed/oak (N-O), pastured/grass (P-G), and pastured/oak (P-O) were examined.

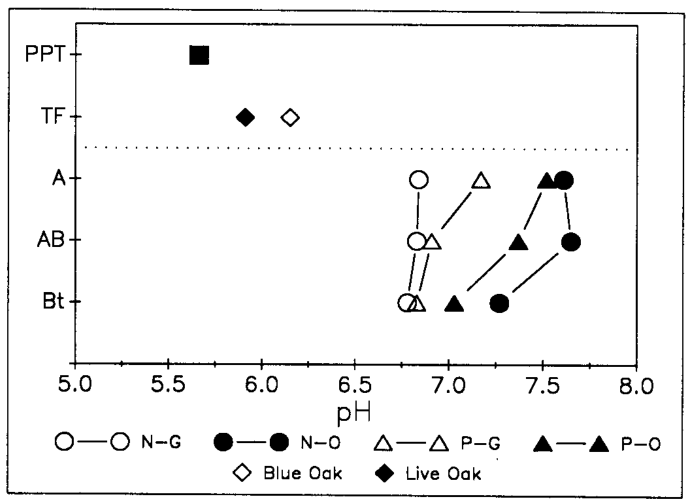

Figure 4—Solution pH of precipitation (PPT), canopy throughfall (TF), and the A, AB, and Bt horizon soil solutions. Treatments consisting of non-grazed/grass (N-G), non-grazed/oak (N-O), pastured/grass (P-G), and pastured/oak (P-0) were examined.

SUMMARY

The presence of an oak canopy resulted in enhanced cycling of Ca, Mg, K, SO_4, and PO_4 and decreased levels of Na. Soil solution concentrations were increased from 2-10 times that found in adjacent grassland sites. Higher nutrient levels suggest greater plant availability of these nutrients. Greater forage nutrient concentrations have been reported beneath oak canopies as compared to grasslands (Holland and Morton 1980; Kay 1987). Decreased levels of Na beneath the oak canopy may result from selective accumulation of Ca, Mg, and K beneath the oak canopy which in turn displaces Na from exchange sites by mass action.

Grazing in this oak woodland-grass ecosystem had no significant effect on major plant nutrient levels. Only Na and Cl concentrations were increased in the soil solutions. Supplemental salt feeding to the cattle could account for these increased levels. High NO_3 levels in the grazed-oak canopy site, although not significantly different, may also be the effect of preferential cattle use of the shaded area beneath the oak canopy.

Based on the degree to which nutrients are retained within the ecosystem by nutrient cycling, it appears that P may be the most limiting plant nutrient. Phosphorus is reported to be in short supply in many foothill ecosystems (Dunn 1980). This ecosystem receives an input of 6.9 kg/ha/y of N in the precipitation and loses 5.0 kg/ha/yr in the streamwaters draining the watershed. The loss of N suggests that N is present in excess of that required by plants. All other nutrient levels appear to be adequate to support the present vegetative regime.

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