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James O. Klemmedson
University of Arizona

Brian J. Wienhold
University of Nebraska-Lincoln, Brian.Wienhold@ars.usda.gov

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ABSTRACT

This study was undertaken to extend our knowledge of nutrient availability in soils of the Arizona chaparral. Our objective was to determine the effect of shrub species and topographic aspect on N mineralization of soils from a watershed in central Arizona and to relate N mineralization to other soil properties. Soil for an incubation study was collected from the 0- to 2- and 2- to 10-cm soil layers beneath the canopy of 32 randomly selected shrubs, eight each of birchleaf mountain mahogany (*Cercocarpus betuloides* Nutt. ex. Torr. & A. Gray) and shrub live oak (*Quercus turbinella* Greene) from both north and south aspects. Neither cumulative N mineralization (N_m) nor potentially mineralizable N (N_o) was influenced by shrub species or aspect. Aspect significantly influenced NH_4 released in the 2- to 10-cm layer, with greater amounts released in soils from north and south aspects. Both N_m and N_o were markedly higher in the 0- to 2-cm soil layer than in the 2- to 10-cm layer; NO_3 was the dominant form of mineralized N. Nitrogen-mineralized in both soil layers correlated highly with soil C, N, P, and N/P and C/P ratios. Phosphorus supply (P_{av}) differed markedly between the two soil layers (3.8 and 0.7% of total P, respectively) and was related to N_m. The association of P_{av} with N, however, leaves the real effect of P_{av} on N_m in doubt.

CHAPARRAL ECOSYSTEMS cover extensive areas of the southwestern USA including 1.3 million ha in Arizona (Bolander, 1982). Knowledge of soil–plant–nutrient relations for chaparral is fragmented and sketchy. Research has focused on California chaparral, much of it on N status of the soil–plant system, and including mechanisms of N loss and replenishment (DeBano and Conrad, 1978; DeBano et al., 1979; Dunn and Poth, 1979; Dunn et al., 1979; Schlesinger and Hasey, 1981). However, P also merits attention based on its occasional deficiency (Hellmers et al., 1955; McMasters et al, 1982), susceptibility to loss from chaparral systems, and the important role P plays in accumulation of N and organic C in soil–plant systems (Cole and Heil, 1981; Stevenson, 1986).

In a companion study, we observed that availability of N in soils from a chaparral watershed in central Arizona was quite high, while availability of P was very low (Klemmedson and Wienhold, 1991). In that study, barley (*Hordeum vulgare* L.) plants grown in soils supplemented with P alone produced 70% of the yield of plants grown in soils with both N and P, while yield of barley grown in soils with N alone was low and similar to yield of plants grown in soil with no nutrients added. These results contrast with much of the literature on California chaparral, which reports that soil fertility is quite low and that both N and P are usually deficient (Hellmers et al., 1955; Christensen and Muller, 1975; McMasters et al., 1982; Marion and Black, 1988).

Several studies have been conducted to assess N-mineralization rates in soils from California chaparral, but little is known about this process in Arizona chaparral. The purpose of this study was to extend our knowledge of N availability in soils of Arizona chaparral with a study of N mineralization and its controlling factors. Because biota and aspect commonly have marked effects on N status of soil–plant systems (Aandahl, 1949; Klemmedson, 1964; Jenny, 1980; Klemmedson and Tiedemann, 1986; Marion and Black, 1988), this study was designed to test the null hypothesis that shrub species and topographic aspect have no effect on N mineralization in Arizona chaparral soils. In addition, N-mineralization rates were related to other soil characteristics of the study area.

J.O. Klemmedson, School of Renewable Natural Resources, Univ. of Arizona, Tucson, AZ 85721; and B.J. Wienhold, USDA-ARS Hydrology Lab., Beltsville, MD 20705. This is a contribution of the Arizona Agric. Exp. Stn., Journal Article no. 7352. Research was funded by the Rocky Mountain Forest and Range Experiment Station, Cooperative Agreement 28-K4-321. Received 6 Aug. 1991.
*Corresponding author.

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MATERIALS AND METHODS

Study Area

The study area was a 55-ha drainage of the Battle Flat Watershed in the Bradshaw Mountains of central Arizona (34°19′N, 112°22′W). The topography is rough and highly dissected. The prevailing aspect of the watershed is southeast; slope gradient ranges from 15 to 60%. Elevation is ≈1700 to 1770 m above sea level. Geologic parent material is massive bedded crystalline tuff with recent gravels along stream beds (Anderson and Blacet, 1972). The Moano very rocky loam soils common to the study site are classified as loamy, mixed, nonacid, mesic Lithic Torriorthents.

The dense shrubby vegetation averages ≈75 to 80% crown cover. Canopy height varies from 1 to 3 m; shrub height and cover are greatest on northerly aspects. Dominant shrubs are manzanita (*Arctostaphylos pungens* HBK), shrub live oak, and birchleaf mountain mahogany. Subdominant shrubs include emory oak (*Quercus Emoryi* Torr.), alligator juniper (*Juniperus Deppeana* Steud.), desert ceanothus (*Ceanothus Greggii* A. Gray), apache plume (*Fallugia paradoxa* D. Don), and yerba santa (*Eriodictyon angustifolium* Nutt.). The herbaceous understory is sparse.

Mean annual precipitation of 480 mm is about equally divided between cyclonic winter and convective summer storms. About 15 to 20% of total precipitation is snow. Mean daily temperature is 15°C; the annual maximum range is from −29 to 39°C.

Collection of Soil

A pool of 80 mature shrubs, 20 each of mountain mahogany and shrub live oak from both north and south aspects (median azimuths = 354 and 202°C) was identified. From this pool, 32 shrubs, eight of each species on each

Abbreviations: N_m, cumulative N mineralization; N_o, potentially mineralizable N; P_{av}, available P; C_{org}, organic C; P_t, total P; P_{org}, organic P.

aspect, were randomly chosen for sampling locations. Shrubs for this pool were widely scattered among several laterals of the main drainage. They were selected according to a sampling model (for details see Klemmedson and Wienhold, 1991) designed to control within narrow limits extraneous variation (i.e., that associated with environmental factors other than shrub species and aspect) to minimize the effect of those factors (climate, topography other than aspect, and parent material) on dependent variables (Cochran, 1983).

Because of the small study area, climate was invariant. The stand of vegetation occupying the Battle Flat watershed last burned ≈1900 (Deiterich and Hibbert, 1990) and only mature shrubs of similar size were considered; hence, differences in time of soil–plant system development also were negligible. Only one geologic parent material is described for the study area and field inspection disclosed no discernible parent material differences. There was no evidence of differences in grazing, fire, or erosion within the study area. Differences in understory vegetation and microflora within the study area were thought to be associated primarily with aspect and vegetal cover differences, hence should show up as effects of aspect and shrub species.

In October 1985, soil was sampled in plots centered midway between the main stem and the canopy edge on the upslope side of each of the 32 selected shrubs. Samples of the 0- to 2- and 2- to 10-cm mineral soil layers were collected from soil columns of all plots. Soil was passed through a 2-mm sieve to remove coarse fragments, then stored at −5°C until the N-mineralization study was initiated. For chemical analysis, subsamples of soil were air dried and ground to pass a 0.150-mm sieve. Soil samples were analyzed for C_{org} by dry combustion (Nelson and Sommers, 1982) in a Leco high-frequency induction furnace (Leco Corp., St. Joseph, MI). Total N was determined by semimicro-Kjeldahl (Bremner and Mulvaney, 1982). Total P was determined by ascorbic acid color development (Olsen and Sommers, 1982) following HF digestion (Bowman, 1988) and P_{av} was determined by ascorbic acid color development following 0.5 *M* $NaHCO_3$ extraction. Organic P was determined by the ignition method (Olsen and Sommers, 1982). All data are expressed on the basis of the oven-dry <2-mm soil fraction.

Mineralization Experiment

The laboratory incubation experiment involved two shrub species, two aspects, two soil layers, eight field replicates, and two laboratory replications. The experiment was based on procedures described by Stanford and Smith (1972) with exceptions noted below. Soil (15 g) for each experimental combination was mixed with an equal weight of silica sand, mixed thoroughly, and moistened slightly with 0.01 *M* $CaCl_2$. The mixture was then transferred to an incubation–leaching tube (8.5 cm by 3.4-cm diam.) with a fritted glass base sealed to a funnel outlet. The base of the tube was first covered with glass-fiber filter paper and 3 cm of glass wool before addition of the substrate. After slightly compacting the substrate in the tube, a 1-cm layer of glass wool was added to prevent disturbance of the substrate during leaching. Tubes were leached with 100 mL of 0.01 *M* $CaCl_2$ in several increments to remove mineral N; leachate was collected in a 100-mL volumetric flask. The remaining solution was removed under a vacuum of 0.04 MPa for 15 min and collected in the volumetric flask. Leachate was brought to 100 mL with 0.01 *M* $CaCl_2$, transferred to a screw-cap plastic bottle, and frozen. The leaching tube was then covered with Parafilm (America National Can, Greenwich, CT) held in place with a rubber band. A single hole was made in the center of the Parafilm cover with a hot needle to ensure aeration.

Tubes were first weighed and then placed upright in an incubator at 35 °C for 4 wk. Tubes were reweighed twice weekly and the weight adjusted by addition of distilled water. At the end of 2 wk, tubes were leached with 100 mL of 0.01 *M* $CaCl_2$, equilibrated to a moisture content equivalent to 0.04 MPa and returned to the incubator. The leaching procedure was repeated at the end of the second 2-wk incubation. Leachates were stored at −5°C until they could be analyzed for inorganic N content. For analysis, leachates were quickly thawed and aliquots taken for analysis of NH_4 and NO_3 by steam distillation (Keeney and Nelson, 1982).

Data Analysis

Means of the two laboratory replicates were expressed as NH_4, NO_3, and total N mineralized (NH_4 + NO_3). Cumulative N mineralized, NH_4, and NO_3 in the two soil substrates were analyzed separately by analysis of variance. Shrub species and aspect, the fixed main effects, and their interactions were tested with an error term of 28 degrees of freedom. Based on preliminary analyses, only the N_m values for the 4-wk incubation (excluding the initial leaching) are reported here. Relationships between N_m in these soils and soil nutrient properties (Table 1) were assessed by regression analysis. Regressions were considered significant at $P < 0.05$.

RESULTS AND DISCUSSION

Net Nitrogen Mineralized

Shrub species and aspect did not significantly affect N_m in these experiments. However, the data showed a tendency toward higher N_m (40% higher) in the 0- to 2-cm soil layer of north aspects. During the 4-wk incubation, peak N_m activity occurred in the surface layer and declined with soil depth (Table 2). From 2.1 to 3.9 times more N was mineralized in the 0- to 2- than in the 2- to 10-cm soil layer. Greater N mineralization in the surface layer is consistent with the results of similar studies (Charley and West, 1977; Cassmann and Munns, 1980; Lyons and Gifford, 1980; Powers, 1980; Marion et al., 1981).

Nitrate was the predominant form of mineralized N (Table 2); it accounted for 92 to 99% of the N released from the 0- to 2-cm soil layer (Table 2). In the 2- to 10-cm soil layer, nitrification declined and NH_4 was a larger percentage of total N mineralized, and this change in distribution was influenced by aspect ($P < 0.05$). In the 2- to 10-cm soil layer, NH_4 concentration as a percentage of total N mineralized was significantly greater ($P < 0.05$) in soil from north than from south aspects (Table 2). The decline in nitrification with depth was similar to that observed for semiarid shrub communities of Utah (Charley and West, 1977), except in our chaparral soils nitrification remained the dominant process below the surface layer.

The steep gradient in N_m between the two soil layers was largely a function of the steep gradient in organic matter in these soils (Table 1). Organic matter simultaneously serves as the energy source for heterotrophic organisms and as substrate for N mineralization. Thus, the strong functional relations between N_m and C_{org} (Fig. 1) and total soil N (Fig. 2) were expected. Regressions coefficients for the two soil layers were not significantly different in either the N_m vs. C_{org} or the N_m vs. total N functions, hence the data for the two soil layers were pooled and a single regression used for both relations (Fig. 1 and 2). The *r* values

Table 1. Chemical properties of soils used in mineralization experiments.

Species	Aspect	Soil layer	Organic C	N	Total P (P_t)	Available P (P_{av})	C/N	C/P_t	N/P_t
		cm	g kg^{-1}						
Mahogany	North	0–2	111	7	0.6	0.024	16	194	11
		2–10	27	2	0.5	0.002	14	54	4
	South	0–2	67	4	0.4	0.020	16	165	11
		2–10	17	1	0.3	0.002	12	79	6
Oak	North	0–2	95	5	0.6	0.018	18	151	8
		2–10	33	2	0.4	0.002	17	73	4
	South	0–2	74	5	0.5	0.012	15	147	10
		2–10	27	2	0.3	0.002	14	85	6

Table 2. Cumulative N mineralized during 4 wk as a function of shrub species and topographic aspect.†

Soil layer and N component	Mountain mahogany				Shrub live oak			
	North		South		North		South	
	µg g^{-1}	%	µg g^{-1}	%	µg g^{-1}	%	µg g^{-1}	%
0 to 2 cm								
NH_4	7.1 ± 4.6‡	3.4	3.6 ± 2.5	2.6	14.3 ± 9.2	7.8	1.8 ± 1.2	1.3
NO_3	199.4 ± 29.4	96.6	136.6 ± 30.7	97.4	168.1 ± 24.4	92.2	137.6 ± 27.2	98.7
Total	206.5 ± 32.2	100.0	140.2 ± 31.0	100.0	182.4 ± 25.4	100.0	139.3 ± 27.9	100.0
2 to 10 cm								
NH_4	5.3 ± 1.9	9.7	1.1 ± 0.6	3.1	15.5 ± 6.8	27.0	1.1 ± 0.8	1.7
NO_3	49.3 ± 9.1	90.3	34.8 ± 5.2	96.9	41.9 ± 9.9	73.0	63.5 ± 12.7	98.3
Total	54.5 ± 10.0	100.0	35.9 ± 5.2	100.0	57.4 ± 15.5	100.0	64.6 ± 12.9	100.0

† In the 2- to 10-cm layer, aspect significantly influenced NH_4 production at the $P < 0.05$ level (LSD = 10.3 µg g^{-1}); other differences were not significant.
‡ Mean ± standard error.

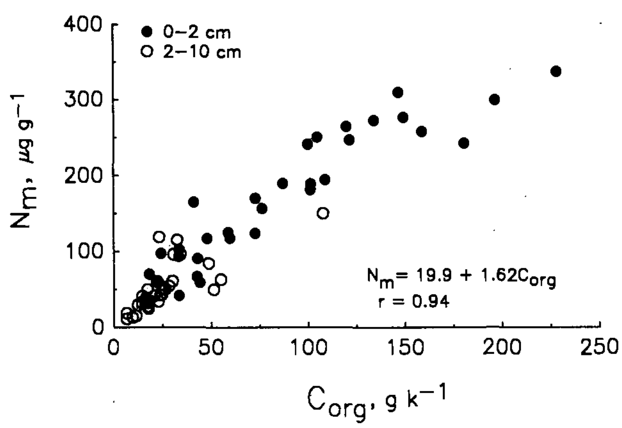

Fig. 1. Cumulative N mineralized as a function of organic C for soils of the 0- to 2- and 2- to 10-cm layers.

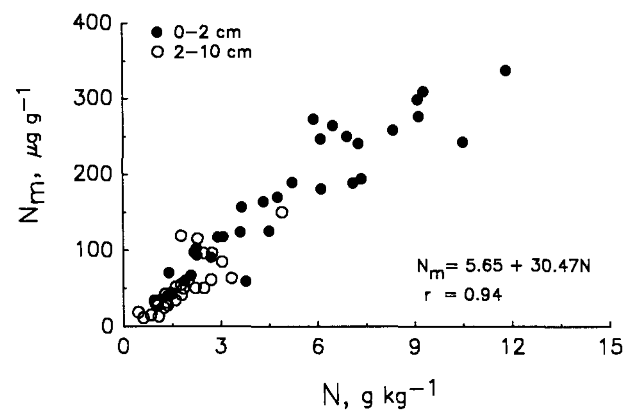

Fig. 2. Cumulative N mineralized as a function of total N for soils of the 0- to 2- and 2- to 10-cm layers.

portray the obvious correlation between C and N. Other investigators (Haque and Walmsley, 1972; Charley and West, 1977; Marion et al., 1981; Klopatek, 1987) also have reported high correlation between N mineralization and soil C and N.

While a high correlation between N_m and soil N has been commonly observed, as noted above, few studies have demonstrated an association between N_m and soil P content (Lyons and Gifford, 1980). For this chaparral soil, which by pot test proved to be low in P_{av} (Klemmedson and Wienhold, 1991), we speculated that soil P might exert some control over N mineralization if P was limiting to the decomposer population (Gosz et al., 1973; Purchase, 1974; Swift et al., 1979; Stevenson, 1986; Tate, 1987).

Nitrogen mineralization was linearly related, but not highly correlated with P_t, and regression coefficients for the two soil layers differed significantly ($P < 0.05$). This suggests differential partitioning or availability of P between the two soil layers and possibly a concomitant effect on N_m. In fact, P_{av} and P_{org} differed more between soil layers than did P_t (Table 3), and both of these P fractions were associated with N_m, especially that for P_{av}. The latter relation (Fig. 3) differs markedly from that for N_m vs. P_t (not shown here) and manifests the large mean difference in P_{av} (18.8 vs. 2.4 mg kg^{-1}) between the 0- to 2- and 2- to 10-cm soil layers (Table 3), even though the range in P_t was nearly the same for both soil layers (0.19–0.83 vs. 0.21–.92 g kg^{-1}). The difference in P_{av} as a percentage of P_t (3.8 vs. 0.7%) between the two soil layers was equally large (Table 3).

Table 3. Chemistry of soil from 0- to 2- and 2- to 10-cm soil layers by level of cumulative N mineralized (N_m).

Soil layer	N_m	Organic C	N	Total P (P_t)	Available P (P_{av})		Organic P		C/N	C/P_t	N/P_t	N/P_{av}
cm	μg g^{-1}	g kg^{-1}	g kg^{-1}	mg kg^{-1}	mg kg^{-1}	% of P_t	mg kg^{-1}	% of P_t				
0–2	>200	149	7.7	628	27.1	4.4	369	58.8	18.1	245	13.7	374
	100–200	81	4.6	480	13.8	3.0	261	57.7	17.8	177	10.3	453
	<100	38	2.1	473	15.1	3.6	214	46.5	17.8	83	5.4	330
	Average	92	5.1	530	18.8	3.8	285	54.2	17.9	174	10.0	391
2–10	>60	44	2.8	449	2.8	0.6	190	41.9	15.0	94	5.3	1434
	33–60	24	1.6	409	2.0	0.7	181	43.1	15.0	64	4.4	1004
	<33	13	1.0	273	1.9	0.8	125	36.2	13.1	65	4.9	626
	Average	26	1.8	382	2.4	0.7	164	42.2	14.2	73	5.1	990

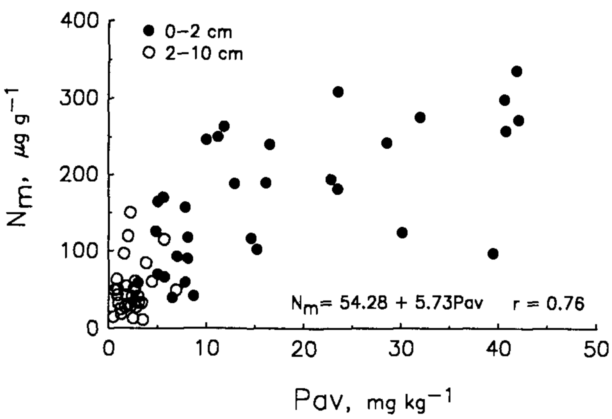

Fig. 3. Cumulative N mineralized as a function of available P for soils of the 0- to 2- and 2- to 10-cm layers.

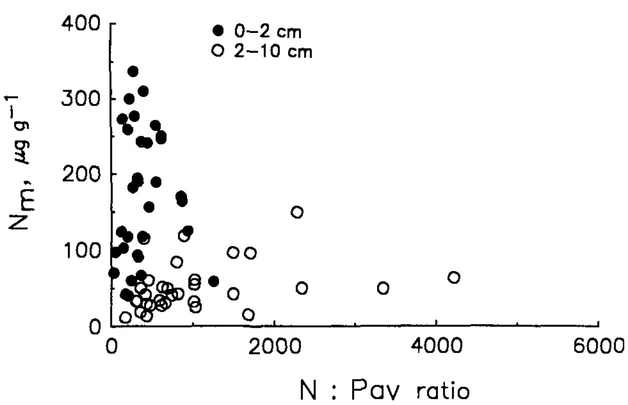

Fig. 4. Cumulative N mineralized as a function of N/P_{av} (available P) ratio for soils of the 0- to 2- and 2- to 10-cm layers.

While N_m and C/N ratio were only weakly associated, a result similar to that reported by Marion et al. (1981) for California chaparral soils, N_m was linearly related and highly correlated with N/P_t ratio ($r = 0.77$) and C/P_t ratio ($r = 0.91$) for the combined data of both soil layers. These correlations follow from the relations in Fig. 1 and 2 and the fact that a significant fraction of P_t was in the organic form in both soil layers (Table 3).

The relation of N_m to N/P_{av} ratio (Fig. 4) stands in marked contrast to the N_m – N/P_t ratio function described above. This figure portrays two distinct populations of data points representing soils of the two layers. Soils of the 0- to 2-cm layer show a wide range in N_m across a narrow range in the N/P_{av} ratio, while soils of the 2- to 10-cm layer display just the opposite. This arrangement of data (Fig. 4) is associated with high correlation between P_{av} and N for soils of the upper layer ($r = 0.78$), but low correlation ($r = 0.37$) for soils of the lower layer (compare Fig. 2 and 3). Although P may have an effect on N_m distinct from its association with N, that is not clear in these data. A controlled experiment is probably needed to clarify the role of P.

Table 4. Estimates for potentially mineralizable N (N_o), N_o as a percentage of soil N, and N mineralization rate constants (*k*) from several mineralization studies.†

N_o	Soil N as N_o	*k*	Reference
μg g^{-1}	%	week^{-1}	
20–300	10–29	0.035–0.095	Stanford and Smith, 1972
96–131	14–21	0.183–0.308	Smith et al., 1980
30–121	3–10	0.04–0.09	Cassmann and Munns, 1980
0.4–54	0.2–4.4	0.035–0.073	Marion et al., 1981
35–255	3–8	0.036–0.164	Juma et al., 1984
120–241	7–22	0.060–0.274	El Gharous et al., 1990
392 ± 73 (0–2 cm) 152 ± 33 (2–10 cm)	8.1	0.131 ± 0.007	this study

† Data from Marion et al. (1981) were corrected for gravel content to express on a field basis; all others are expressed on the <2-mm soil fraction.

Potentially Mineralizable Nitrogen

Estimates of N_o and the mineralization rate constant (*k*) provide a means of comparing the N-supplying power of these soils to that of other soils. Estimates of N_o and *k* were obtained using the two-parameter equation described by Smith et al. (1980):

$$N_o - N_m = N_o \exp(-kt). \quad [1]$$

where *t* is time. Estimates of N_o and *k* were not influenced by aspect or species. Potentially mineralizable N for the 0- to 2-cm soil layer (392 ± 73 μg g^{-1}) was significantly greater ($P < 0.001$) than that for the 2- to 10-cm soil layer (152 ± 33 μg g^{-1}). As in the case of N_m, the decline in N_o with depth was associated with decline in N and P_{av} with depth (Table 3). While our estimate of N_o for the 0- to 2-cm soil layer appears high compared with other N_o estimates re-

ported in the literature (Table 4), it should be noted that four of the estimates in Table 4 are for soils collected from the plow layer (15–20 cm) of cultivated soils that lack the steep C and N gradients of undisturbed soils. The value of N_o cited by Marion et al. (1981) for California chaparral also is low compared with ours, even if we use N_o for the 0- to 10-cm layer (i.e., 200 $\mu g\ g^{-1}$); moreover, their data were expressed on the field soil basis by adjusting for gravel content.

As a percentage of total oil N, N_o did not differ significantly with depth, exposure, or shrub species. It averaged 8.1% for the 0- to 10-cm soil layer and was comparable with values for other N mineralization studies reported in Table 4 except for that reported for soils of the California chaparral (Marion et al., 1981).

Estimates for the rate constant ($k = 0.131 \pm 0.007$ wk^{-1}) are within the range reported for most soils (Table 4), but high compared with California chaparral soils. In contrast to N_o, k did not differ significantly between the two soil layers nor was it correlated with parameters of C, N, or P. This is consistent with other studies (Stanford and Smith, 1972; Oyanedel and Rodriguez, 1977; Marion et al., 1981) where k has been found to be relatively constant for similar soils.

Estimates of N_o and k in this study suggest that these soils have a relatively high capacity for supplying available N. By regressing N_o on total soil N, using data from several N-mineralization studies, it is possible to compare estimated N_o at a common level of soil N. From this analysis, estimates of N_o for a soil with a N concentration of 1.5 g kg^{-1} is 160 μg g^{-1} for this study. This compares with 43 (Marion et al., 1981), 175 (Oyanedel and Rodriguez, 1977), and 233 $\mu g\ g^{-1}$ (Stanford and Smith, 1972) for other soils at the same N concentration. The latter two values are for soil from arable fields; that from Marion et al. (1981) was for a soil (field basis) from the California chaparral. As a group, California chaparral soils are considered low in N fertility (Hellmers et al., 1955; Gray and Schlesinger, 1981).

CONCLUSIONS

Based on evidence from this study, we accept the hypothesis that shrub species and topographic aspect had no influence on N mineralization in soil from the surface 10 cm of the Battle Flat watershed. Neither N_m nor N_o responded to species or aspect. Our data suggest, however, that more intensive sampling might disclose higher rates of N_m in soil of the 0- to 2-cm layer of north aspects. Nitrogen mineralization was about two to four times greater in the 0- to 2- than in the 2- to 10-cm soil layer. This steep gradient in N_m with depth was associated with steep gradients in P_{org}, N, and P_{av}. Nitrate was the predominant form of mineralized N in the upper soil layer, while NH_4 was predominant in the lower soil layer.

Soil N, P, and P_{org} exhibited strong association with N mineralization. Of these, N showed the strongest relation to N_m. Because C/N ratios averaged below 20 for both soil layers, we would not expect N mineralization to be inhibited by immobilization in either soil layer (Swift et al., 1979).

The effect of P on N_m in these soils is uncertain. Total P was similar for the two soil layers and was not especially low based on comparative values of California chaparral soils (DeBano an Conrad, 1978; Marion and Black, 1988) and the observed C/P ratios (Stevenson, 1986). However, the supply of P differed markedly between the two soil layers, and may limit N_m, especially in the 2-to 10-cm soil layer. Whether P_{av} does, in fact, affect N needs to be explored with incubation experiments that permit control of N and P_{av}. An answer to this question will help to clarify the role of P in productivity of these soils described previously (Klemmedson and Wienhold, 1991, 1992).

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