Changes in Soil Quality Due to Grazing and Oak Tree Removal in California Blue Oak Woodlands[1]

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Abstract

The effects of grazing and oak tree removal on soil quality and fertility were examined in a blue oak *(Quercus douglasii)* woodland in the northern Sierra Nevada foothills. Low to moderate grazing intensity has little affect on soil quality; however, oak tree removal resulted in a decrease in most soil quality parameters investigated (carbon, nitrogen, phosphorus, pH) within 5 to 15 years following tree removal. Following tree removal, total C and N pools in the 0-15 cm depth increment decreased by 10 to 20 percent after 5 years and 20 to 40 percent after 21 years. These changes were largest in the 0-5 cm soil depth, but did occur at a slower rate in the 5-15 cm depth. Because all of the soil quality parameters measured are directly related to soil organic matter quantity and/or nutrient cycling processes, removal of oak trees quickly results in a deterioration of soil quality by cutting off the major input of organic matter to the soil. Thus, oak tree removal in blue oak woodland ecosystems in the Sierra Nevada foothills leads to a rapid decline in soil quality and fertility.

Introduction

Oak woodlands dominate the landscape in an estimated 3 million ha in the foothills and Central Valley of California (Griffin 1977) and are used extensively for cattle grazing, providing approximately 75 percent of the forage on California's rangelands. In these oak woodlands, the landscape is a mosaic of trees and patches of open grassland ecosystems. There is great concern about whether regeneration in these oak woodlands is sufficient to sustain present densities (Griffin 1971, 1976; Muick and Bartolome 1987). Rangeland practices, including tree removal to increase forage production and grazing, have been implicated as contributing factors leading to the lack of oak regeneration in these ecosystems.

Total and available soil nutrients have been shown to be higher under the oak canopy than in the surrounding grasslands (Dahlgren and others 1997), and tree removal has been suggested as a way to increase forage production by decreasing the competition for light, water and nutrients. The removal of oak trees has been shown

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to increase forage production 65-650 percent compared to the adjacent open grassland immediately following tree removal (Johnson and others 1959, Kay 1987, Murphy and Crampton 1964). Long-term studies indicate that this benefit lasts less than 2 decades before forage production returns to levels found in the adjacent grasslands (Kay 1987). In previous studies, soils under the oak canopy have been found to contain up to 50 percent more soil organic carbon than soils in the open grasslands. This suggests that oak trees may have a large capacity for sequestration of atmospheric carbon dioxide as soil organic matter; however, this pool of carbon may be quickly released following removal of the trees.

The primary objective of this study was to determine changes in soil quality in response to grazing and as a function of time (5 to 34 years) following blue oak tree removal. Tree removal and grazing are the predominant rangeland practices currently in California, and have the greatest capacity to influence soil quality, ecosystem sustainability, and carbon sequestration.

Materials and Methods

Study Area

The investigation was conducted in the northern Sierra Nevada foothills at the University of California Sierra Foothill Research and Extension Center (SFREC), approximately 30 km east of Marysville, California. The climate is Mediterranean, with cool moist winters and hot dry summers; mean annual precipitation is 73 cm and mean annual temperature is 15^{o}C. The dominant tree species is blue oak *(Quercus douglasii)*, a winter-deciduous oak, with associated interior live oak *(Quercus wislizeni*), an evergreen oak. Major forbs include filaree *(Erodium* sp.*),* annual clovers *(Trifolium* sp.*),* and geranium *(Geranium* sp.*).* Common annual grass species are soft chess *(Bromus hordeaceus),* ripgut brome *(Bromus diandrus),* red brome *(Bromus madritensis* spp. *rubens),* annual fescue *(Vulpia* sp.*),* wild oats *(Avena fatua* and *Avena barbata),* and medusahead *(Taeniantherum caput-medusa)*. The oak understory community has lower species richness and a somewhat different group of plant taxa than the open grasslands (Jackson and others 1990). Soils within the study area formed in basic metavolcanic bedrock (greenstone) and are classified as fine, mixed, active thermic Mollic Haploxeralfs. Slopes within the study area range between 5 and 15 percent.

Four sites were selected in 1999 from grazed rangelands at SFREC in which blue oaks were removed in either 1965, 1978, 1984 or 1994. We also chose four sites within the non-grazed Schubert Natural Area (not grazed in past 28 years) to evaluate the effects of grazing on soil properties. Site characteristics, including soils, vegetation, and topography, were similar between sites. Over the past 28 years, grazing intensity on the grazed sites has remained consistent within the low to moderate range. Cattle are rotated through the grazed portion of the study site for 4-8 weeks per year. At each site *(table 1)*, a composite soil sample (consisting of four subsamples) was collected for the 0-5 cm and 5-15 cm depth increments from four replicates of each experimental condition: (i) beneath an oak canopy, (ii) tree removal sites (identified by stump remains), and (iii) in adjacent grasslands not affected by the oak canopy. For the oak canopy and tree removal sites, soil samples were collected two meters from the tree or stump. For the grazed versus non-grazed comparison, we selected sites from beneath the canopy and from adjacent open grasslands.

Table 1—*Samples were taken at two depths (0-5 cm and 5-15 cm) from grazed and non-grazed sites. Grazed samples were taken from grass, stump and tree areas where trees were removed in 1994, 1984, 1978, and 1965. Non-grazed samples were taken from grass and tree areas.*

Grazed		Non-grazed
1994	1978	Tree Grass
Tree Stump Grass	Tree Stump Grass	
1984	1965	
Tree Stump Grass	Tree Stump Grass	

Analysis

Soil samples for microbial biomass and extractable mineral nitrogen were collected in early May 1999 to coincide with peak standing biomass of the annual grasses. Soil samples for all other analyses were collected in early January 1999 prior to the onset of leaching for the water year. Soil samples were passed through a 2-mm sieve; roots passing through the sieve were removed with a forceps. The <2-mm fraction was split, with one fraction retained at field-moisture content for microbial biomass and extractable mineral nitrogen determinations. The field-moist samples were refrigerated at 3°C until analyses were begun within 24 h. The remaining soil was air-dried at room temperature and used for all other analyses. Bulk density was determined by the quantitative pit method. Bulk density is reported for the <2-mm fraction on a dry-weight basis.

Soil pH was determined in distilled-deionized water and in 0.01 M $CaCl_2$ (1:2, soil:water) following a 15 min equilibration period. Total carbon and nitrogen were determined on ground samples (<250 µm) by dry combustion with a Carlo Erba C/N analyzer. Plant-available phosphorus was estimated using the Bray extraction (1 M NH_4F for 60 s) and the ascorbic acid colorimetric method for PO_4 quantification (Olsen and Sommers 1982). Microbial biomass was determined using the chloroform incubation method (Horwath and others 1994). Microbial biomass nitrogen, mineral N (NH_4^+ and NO_3^-) and potentially mineralizable N were extracted with 2 M KCl. Concentrations of NH_4^+ and NO_3^- in KCl extracts were quantified using a Lachat flow-injection analyzer. In determining potentially mineralizable N, the hot KCl method was utilized with 1 g of soil incubated in 7 ml KCl at 100°C for 4 hours.

Statistical analysis was performed using two-way Analyses of Variance (ANOVA) for all the sites together and one-way ANOVA for each individual site. The two-way ANOVA splits the experimental effects into main effects (are results different for trees, stumps and grasslands?) and site*treatment interaction (is the magnitude of the tree/stump/grassland difference the same at all sites?). A one-way ANOVA was performed on the data stratified by year, along with a post-hoc Fisher's least-significant-difference test to make pair-wise comparisons between treatment means (tree/stumps/grassland) for each site (1965, 1978, 1984 and 1994). The experimental design to examine the effects of grazing was a split-plot; the management regime (grazing versus non-grazed) was the whole-plot treatment factor and the vegetation (oak canopy versus grassland) was the split-plot treatment factor. Tests for the main effects and interactions were performed using ANOVA and a post-hoc Fisher's least-significant-difference test was used for pair-wise comparisons among means. All statistical analyses were performed at a *p*=0.05 significance level using SYSTAT for Windows, Version 9 (SPSS Inc. 1998).

Result and Discussion

Tree Removal

Total C concentrations were more than twice as high beneath trees as compared to adjacent grasslands, reflecting the "islands of soil fertility" created by the oak trees *(table 2)*. This organic carbon accumulation was rapidly reduced to levels near those of the grassland sites within 5 to 15 years following tree removal. There was a 24 percent loss of organic carbon from the 0-15 cm depth increment over the first five years following tree removal, with 14 Mg/ha lost out of a total of 59 Mg/ha *(table 3)*. Loss of organic carbon appeared to plateau between 30 to 40 Mg/ha after 15 years following tree removal.

Microbial biomass C concentrations were greater beneath the oak canopy as compared to the adjacent grasslands *(table 2)*. Following tree removal, microbial biomass C in the 0-5 cm depth was decreased to levels equal to that of the grassland soils within 5 years. Concentrations appeared to decrease more slowly in the 5-15 cm depth, requiring between 5 to 15 years to decrease to levels equal to that of the grassland soils. Microbial biomass C generally represented between 2 to 4 percent of the total carbon pool and contributed a larger fraction to the grassland soils compared to the tree and stump soils.

Total N concentrations followed a pattern similar to organic carbon with considerably higher concentrations beneath trees as compared to grassland soils and much higher concentrations in the 0-5 cm depth compared to the 5-15 cm depth *(table 2)*. Total N concentrations generally decreased in both the 0-5 and 5-15 cm depth increments following tree removal. A total of 11 percent (0.45 Mg/ha out of a total of 4.0 Mg/ha) of the total nitrogen pool in the 0-15 cm depth was lost from the tree-removal plots five years after tree removal *(table 3)*. Loss of nitrogen reached a maximum value of about 1.2 Mg/ha after 21 years following tree removal.

Microbial biomass N concentrations were generally greater beneath the oak canopy as compared to the adjacent grassland soils *(table 2)*. In contrast to microbial biomass C, the microbial biomass N concentrations did not show a significant decrease at either the 0-5 or 5-15 cm depths five years after tree removal. Microbial biomass N concentrations decreased in the 1965 to 1984 tree-removal sites to levels that were similar to the grassland soils. The microbial biomass N fraction represented from 4 to 8 percent of the total nitrogen pool and did not display any differences between tree, stump and grassland sites.

Potentially mineralizable N (PMN) concentrations were similar in magnitude to microbial biomass N concentrations *(table 2)*. PMN concentrations in the 0-5 cm depth did not decrease in the tree-removal plot in the five years following tree removal, but did decrease to concentrations similar to those of the grassland plots within 15 years after harvest. PMN concentrations in the 5-15 cm depth were highly variable and did not show any strong trends either between treatments or with time since tree removal.

Mineral N concentrations (KCl extractable NH_4^+ and NO_3^-) were about twice as high in the tree plots compared to the grassland plots *(table 2)*. Concentrations decreased rapidly following tree removal and approached levels similar to those in the grassland plots within 5 years of tree removal. In all cases, NH_4^+ was the dominant form of mineral nitrogen. Mineral N concentrations represented approximately 4 to 5 percent of the PMN pool. As with PMN, the concentrations of mineral N in the 5-15 cm depth did not display as clear of a trend as for the 0-5 cm depth.

Table 2—*Mean (± SE) values for selected soil properties comparing the effects of vegetation and tree removal (grass, stump and tree) where trees were removed in 1965, 1978, 1984 and 1994 in a California blue oak woodland. Means in each column within each year (1965, 1978, 1984 and 1994) followed with the same letter are not statistically different at p=0.05.*

		Bulk density (g/cm^3)		**pH**		**Organic C (g/kg)**	
	Depth	0 – 5 cm	5 – 15 cm	0 – 5 cm	5 – 15 cm	0 – 5 cm	5 – 15 cm
1965	Grass	1.14 (0.04) a	1.28 (0.04) a	6.71 (0.09) a	6.40 (0.09) a	35.1 (2.1) a	17.1 (3.4) a
	Stump	1.12 (0.03) a	1.26 (0.03) a	6.53 (0.11) a	6.45 (0.11) a	41.9 (5.9) b	20.7 (3.5) a
	Tree	0.97 (0.04) b	1.19 (0.04) a	7.12 (0.06) b	6.75 (0.11) b	66.4 (11.1) c	35.5 (6.0) b
1978	Grass	1.21 (0.04) a	1.34 (0.03) a	6.32 (0.04) a	6.44 (0.11) a	20.7 (1.5) a	10.7 (1.9) a
	Stump	1.19 (0.03) a	1.34 (0.05) a	6.76 (0.04) b	6.51 (0.02) a	31.8 (1.3) b	13.4 (1.1) a
	Tree	1.09 (0.04) b	1.16 (0.04) b	7.13 (0.03) c	6.69 (0.14) b	57.2 (3.0) c	30.9 (0.9) b
1984	Grass	1.15 (0.03) a	1.29 (0.05) a	6.67 (0.09) a	6.51 (0.09) a	38.0 (5.2) a	10.4 (2.0) a
	Stump	1.14 (0.05) a	1.26 (0.05) a	6.84 (0.09) a	6.67 (0.10) ab	47.9 (4.8) a	13.7 (0.9) a
	Tree	0.99 (0.03) b	1.21 (0.04) a	7.26 (0.07) b	6.81 (0.07) b	68.8 (5.4) b	32.7 (4.0) b
1994	Grass	1.18 (0.02) a	1.33 (0.03) a	6.66 (0.05) a	6.28 (0.10) a	30.6 (4.1) a	6.80 (0.7) a
	Stump	1.09 (0.03) ab	1.29 (0.04) a	7.06 (0.06) b	6.61 (0.04) b	41.4 (1.1) b	17.0 (0.8) b
	Tree	1.05 (0.03) b	1.26 (0.03) a	7.22 (0.11) b	6.62 (0.03) b	50.6 (2.0) b	25.5 (6.2) c

		Organic N (g/kg)		**Microbial C (mg/kg)**		**Microbial N (mg/kg)**	
	Depth	0 – 5 cm	5 – 15 cm	0 – 5 cm	5 – 15 cm	0 – 5 cm	5 – 15 cm
1965	Grass	3.05 (0.19) a	1.45 (0.02) a	782 (22) a	404 (7.5) a	145 (5.4) a	63.7 (5.4) a
	Stump	3.60 (0.53) a	1.56 (0.25) a	755 (10) a	388 (20) a	141 (4.6) a	68.1 (11) a
	Tree	5.05 (0.76) b	2.28 (0.40) b	1507 (300) b	451 (123) a	234 (44) b	84.9 (20) b
1978	Grass	1.80 (0.11) a	0.83 (0.14) a	890 (76) a	262 (26) a	188 (23) a	42.2 (3.9) a
	Stump	2.85 (0.13) b	1.20 (0.03) b	881 (104) a	336 (63) a	205 (15) a	73.5 (9.8) b
	Tree	4.45 (0.29) c	1.90 (0.24) c	1642 (207) b	520 (82) b	284 (44) b	80.4 (4.8) b
1984	Grass	3.75 (0.54) a	1.00 (0.11) a	841 (78) a	218 (15) a	140 (11) a	28.5 (1.7) a
	Stump	4.25 (0.38) a	1.20 (0.05) b	887 (37) a	294 (13) a	152 (7.7) a	52.3 (3.5) b
	Tree	5.18 (0.54) a	1.70 (0.20) c	1338 (43) b	623 (36) b	217 (17) b	99.9 (9.9) c
1994	Grass	2.85 (0.32) a	0.60 (0.03) a	1014 (148) a	252 (36) a	172 (10) a	40.5 (4.0) a
	Stump	3.43 (0.05) a	1.30 (0.08) b	938 (60) a	469 (35) b	203 (14) a	94.4 (16) b
	Tree	3.78 (0.41) a	1.60 (0.50) c	1406 (175) b	678 (40) c	238 (39) a	108 (20) b

		Mineral N (mg/kg)		**Available P (mg/kg)**		**PMN (mg/kg)**	
	Depth	0 – 5 cm	5 – 15 cm	0 – 5 cm	5 – 15 cm	0 – 5 cm	5 – 15 cm
1965	Grass	3.19 (0.30) a	3.19 (1.45) a	2.16 (0.30) a	1.59 (0.20) a	153 (15.5) a	94.9 (9.8) a
	Stump	5.28 (0.80) b	4.37 (0.57) a	3.12 (0.25) a	1.69 (0.30) a	152 (9.2) a	111 (14.1) a
	Tree	12.9 (0.50) c	5.20 (1.10) a	6.15 (0.36) b	2.79 (0.20) b	229 (7.5) b	97.8 (11.2) a
1978	Grass	6.05 (1.30) a	2.07 (0.23) a	1.35 (0.09) a	0.94 (0.12) a	117 (6.4) a	44.2 (9.5) a
	Stump	7.50 (1.80) a	3.74 (0.32) b	2.35 (0.35) a	1.32 (0.10) a	159 (25.0) b	101 (16.4) b
	Tree	13.0 (1.07) b	4.47 (0.40) b	6.47 (0.85) b	3.39 (0.35) b	224 (20.5) c	134 (11.9) b
1984	Grass	4.35 (0.08) a	1.67 (0.10) a	1.67 (0.56) a	1.16 (0.50) a	155 (6.4) a	65.6 (12.1) a
	Stump	7.90 (1.35) a	2.60 (0.25) ab	2.95 (0.60) a	1.32 (0.02) a	191 (25.5) a	81.6 (15.8) a
	Tree	12.0 (1.70) b	4.01 (0.50) b	6.58 (0.90) b	1.93 (0.27) b	244 (25.0) b	93.9 (18.7) a
1994	Grass	5.18 (0.60) a	2.72 (0.36) a	1.94 (0.05) a	0.96 (0.05) a	137 (12.2) a	61.6 (15.3) a
	Stump	7.45 (1.15) a	3.20 (0.40) ab	3.58 (0.60) b	1.35 (0.20) a	202 (18.5) b	89.6 (11.7) a

Table 3—*Carbon and nitrogen pools in 0-15 cm soil depth for tree canopy, stump (tree removal sites) and open grasslands; changes in carbon and nitrogen pools are calculated as a function of tree removal (Loss=Tree–Stump).*

Site	Years since tree removal	Carbon					Nitrogen				
		Grass	Stump	Tree	Loss		Grass	Stump	Tree	Loss	
		Mg/ha	Mg/ha	Mg/ha	Mg/ha	Pct	Mg/ha	Mg/ha	Mg/ha	Mg/ha	Pct
1994	5	27.1	44.5	58.7	14.2	24	2.48	3.55	4.00	0.45	11
1984	15	35.3	44.6	73.6	29.1	40	3.45	3.93	4.62	0.69	15
1978	21	26.9	36.9	67.0	30.1	45	2.20	3.30	4.63	1.33	29
1965	34	41.9	49.5	74.4	24.9	33	3.59	3.98	5.16	1.18	23

Available P concentrations were generally three-fold higher for tree plots compared to grasslands *(table 2)*. Concentrations of available P decreased rapidly following tree removal to levels similar to those in the grassland soils.

Soil pH (water) was generally higher in the tree plots as compared to the grassland plot for the 0-5 cm depth *(table 2)*. The pH of the 0-5 cm depth decreased following tree removal, but the decrease was not observed until more than 5 years after tree removal. In contrast, the pH of the 5-15 cm depth showed a tendency for higher values in the grasslands as compared to the tree plots, and there was no consistent trend resulting from tree removal. Soil pH values measured in $CaCl_2$ were 0.5 to 1 unit lower than those measured in water. The trends for pH($CaCl_2$) were similar to those described for pH (water).

Bulk density of the 0-5 cm depth interval decreased by 0.1 to 0.2 g/cm^3 after 15 years following tree removal. In contrast, the bulk density of the 5-15 cm depth interval was generally the same for all treatments.

Islands of Enhanced Soil Quality

Blue oaks display a striking ability to create islands of enhanced soil quality/fertility beneath their canopy in oak woodlands and savanna. Compared to the adjacent grasslands, soils beneath the oak canopy have a lower bulk density, higher pH, and greater concentrations of organic carbon, microbial biomass C and N, total and mineral N, potentially mineralizable N, and available P. This enhancement of soil fertility is especially pronounced in the 0-5 cm depth and occurs to a lesser extent in the 5-15 cm depth increment.

The ability of the oaks to create islands of enhanced soil quality results primarily from additions of organic matter and nutrient cycling. Blue oaks at the study site returns an average of 9,100 kg/ha/yr of litterfall to the soil surface with its associated nutrients (Dahlgren and others 1997). The added organic matter stores nutrients within its structure (e.g., N, P, S) and also provides nutrient storage capacity in the form of cation exchange capacity. Additionally, canopy throughfall contributes appreciable fluxes of calcium, magnesium, potassium, sulfate and ammonium to the soil surface. Nutrient fluxes in canopy throughfall originate from root uptake and capture of atmospheric aerosols and particulate matter. Because oak roots are found at greater depths (>100 cm) compared to the shallow rooted annual grasses (<50 cm), nutrient uptake by oak roots attenuates leaching losses of nutrients from the soil profile. The extension of oak roots beyond the edge of the canopy may also contribute to nutrient differences between soils beneath the oak canopy and open grasslands. Selective uptake of nutrients by oak roots will deplete the open grasslands of nutrients, while concentrating these nutrients beneath the oak canopy. Further enrichment in the grazed plots may be attributed to shading-up by cattle resulting in some transport of nutrients from open grasslands to soils beneath the oak canopy. Similar mechanisms of nutrient enrichment beneath tree canopies in savanna have been previously proposed (e.g., Belsky and others 1989, Coughenour 1990, Kellman 1979, Weltzin and Vetaas 1992).

A further effect of the oak canopy on nutrient cycling occurs through canopy processes reducing the leaching and erosion potentials (Dahlgren and Singer 1994). Evapotranspiration at the study site is approximately 30 percent greater for the oak canopy plots as compared to the grasslands. This results from greater extraction of water from the soil profile by the deeply rooted oak trees and also due to canopy interception (evaporation of precipitation directly from canopy). This loss of water greatly reduces the leaching intensity beneath the oak canopy as compared to the grassland sites. In addition to the positive effect of organic matter on the soil nutrient status, higher organic matter concentrations lead to lower soil bulk density and greater porosity. This, in turn, provides increased infiltration rates which reduces surface runoff and the loss of nutrients through erosion. Thus, there are several biogeochemical processes by which oak trees concentrate nutrients and create islands of enhanced soil quality beneath their canopy.

Changes in Islands of Soil Quality Following Oak Removal

Changes were evident for all soil quality parameters in the 0-5 cm soil depth within 5 to 15 years. Total C, microbial biomass C, total N, mineral N, and available P concentrations showed a significant decrease within five years. In contrast, microbial biomass N, potentially mineralizable N, and pH values showed a significant decrease within 15 years. We were particularly surprised by how quickly large nutrient pools, such as total C and N, changed following tree removal.

These data indicate that oak trees are capable of sequestering rather large amounts of organic C in the soil profile, and that this carbon is quickly released following tree removal, suggesting that organic matter turnover rates are very rapid in oak woodland ecosystems. Thus, when the litterfall from the oak is eliminated, there is a quick loss of organic carbon as the soil organic matter pool approaches a new steady-state with respect to detrital inputs from the annual grasses. Total litterfall from blue oak at this study site returned an average of 9.1 Mg/ha/yr of organic material (about 4.5 Mg/ha/yr of carbon). This immediate loss of organic matter inputs is quickly reflected in soil organic carbon storage. These data show that oaks may have a large capacity for sequestration of carbon as soil organic matter; however, this pool of carbon is quickly released following removal of the trees.

A similar decrease occurred in the total N pool which has potentially serious ramifications with respect to water quality. Where did this nitrogen go? The two most plausible pathways are losses to denitrification or NO_3^- leaching. In a previous study, Singer and coworkers did not detect any increase in streamwater N concentrations following removal of 14 percent of the trees from the Schubert watershed at SFREC (Singer, personal communication). Furthermore, denitrification rates measured at sites within the SFREC are not sufficient to account for such a large loss of N from the tree removal sites (Davidson and others 1990). We will continue to investigate the potential mechanisms responsible for this loss of N following tree removal.

As with total C and N, the other measured soil quality parameters all respond to tree removal. All of the soil quality parameters measured are directly related to soil organic matter quantity and/or nutrient cycling processes. Microbial biomass is strongly related to the availability of substrate. A large portion of this food source results from the litterfall originating from the oak. Similarly, nutrient recycling is responsible for maintaining available P levels and base cations in the soil surface horizons. The return of base cations to the soil surface appears to increase the pH of the surface horizon. Besides acting as a source of nutrients upon decomposition, soil organic matter also contributes an appreciable quantity of cation exchange capacity that serves as a reservoir for nutrient cations. Thus, removal of the oak tree quickly results in a deterioration of soil quality by cutting off the major input of organic matter to the soil and by breaking a major pathway for the recycling of nutrients to the soil surface.

Grazing

Differences in soil properties between grazed and non-grazed sites were relatively small compared to differences occurring between vegetation types (i.e., oak canopy versus grassland soils) *(table 4)*. In the 0 to 5 cm depth increment, grazing resulted in a slight increase in bulk density, consistent with compaction effects from livestock activity. The increase in bulk density did not extend to the 5-15 cm depth increment. The soil solution pH was approximately 0.2-0.3 units lower in the 0-5 cm depth increment of the grazed soils compared to those in the non-grazed area. Greater nitrification and nitrate leaching and/or export of base cations from the site by livestock may contribute to this apparent decrease in pH. While organic carbon was lower in the 0-5 cm increment of the grazed treatment, it was correspondingly higher in the 5-15 cm depth increment. It is not possible to ascertain whether these differences are the result of natural soil variability or activities associated with grazing. Microbial biomass carbon was higher on the grazed site and may reflect the processing of organic matter by cattle. With a readily mineralizable organic matter source in urine and the high enzyme activity associated with dung, it is likely that cattle excrement stimulates microbial activity. Greater inputs of labile organic matter may increase the availability of substrate for the microbial community, resulting in the higher microbial biomass carbon in the grazed site. The effects of grazing on soil properties were less evident in the 5 to 15 cm depth increment. In contrast, there were large differences in all soil properties between oak canopy and grassland soils throughout the upper 15 cm of the soil profile.

Soils in the grazed area were sampled about six months after the last grazing activity by livestock. We purposely avoided sampling during active livestock grazing to avoid detecting short-term changes that may result from recent grazing activity. Therefore, our sampling was designed to search for longer-term impacts of grazing rather than short-term impacts. Our data suggest that there is no evidence of detrimental effects to the long-term sustainability of the soil quality and nutrient status by low- to moderate-intensity grazing. However, larger impacts would be expected under the more intensive grazing practices utilized on many oak woodland rangelands. Our findings concerning grazing are supported by an analysis of a worldwide data set containing data from 236 sites. This analysis showed no relationship between grazing and several soil properties, including soil organic matter, nitrogen, phosphorus, and pH (Milchunas and Lauenroth 1993).

Table 4—*Mean (± SE) values for selected soil properties comparing the effects of vegetation (oak canopy versus grassland) and grazing (grazed versus non-grazed) in a California blue oak woodland. Means in each row followed with the same letter are not statistically different at p=0.05.*

	Depth	**Grazed**		**Non-grazed**	
	(cm)	**Tree**	**Grass**	**Tree**	**Grass**
Bulk density	0 – 5	1.05 (0.07)ab	1.18 (0.04)c	0.94 (0.06)a	1.08 (0.05) b
(g/cm^3)	5 – 15	1.26 (0.13)a	1.32 (0.11)a	1.27 (0.07)a	1.29 (0.10)a
pH	0 – 5	6.63 (0.14)c	6.09 (0.12)a	6.89 (0.15)d	6.21 (0.15)b
	5 – 15	6.34 (0.19)b	5.87 (0.24)a	6.44 (0.19)b	6.02 (0.13)a
Organic C	0 – 5	59.2 (3.1)b	24.6 (1.9)a	67.1 (7.3)c	25.9 (8.1)a
(g/kg)	5 – 15	26.3 (2.1)c	7.9 (1.2)a	19.7 (4.6)b	9.3 (2.4)a
Organic N	0 – 5	3.9 (0.4)b	2.4 (0.4)a	4.6 (0.9)b	2.9 (0.4)a
(g/kg)	5 – 15	1.6 (0.7)b	0.8 (0.1)a	1.7 (0.7)b	0.9 (0.2)a
Microbial C	0 – 5	1,423 (410)c	1,031 (253)b	1,273 (307)b	737 (241)a
(mg/kg)	5 – 15	657 (80)b	273 (85)a	601 (89)b	329 (128)a
Microbial N	0 – 5	241 (163)b	168 (42)a	217 (41)b	132 (89)a
(mg/kg)	5 – 15	113 (45)b	47 (17)a	91 (32)b	55 (23)a
Mineral N	0 – 5	11.4 (2.3)b	5.4 (2.1)a	18.7 (4.3)c	6.1 (3.8)a
(mg/kg)	5 – 15	4.3 (2.5)b	2.7 (1.8)a	6.6 (2.1)c	2.5 (1.3)a
Available P	0 – 5	6.0 (3.1)b	2.0 (0.6)a	7.7 (2.1)b	2.1 (1.5)a
(mg/kg)	5 – 15	2.9 (1.7)b	0.9 (0.3)a	3.1 (1.8)b	0.7 (0.5)a

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