Effects of tree canopies on soil characteristics of annual rangeland

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Abstract

In the central California region of annual rangeland, herbage production beneath blue oak (*Quercus douglasii* Hook & Arn.) canopies is greater and production beneath the canopies of interior live oak (*Quercus wislizenii* DC) and digger pine (*Pinus sabiniana* Dougl.) is less than that in adjacent open grassland. The objective of this investigation was to assess the impact of these major overstory species on soil-associated characteristics in an effort to explain this tree-herbage production relationship. Greater amounts of organic carbon (OC), greater cation exchange capacity (CEC), lower bulk density, and greater concentrations of some nutrients were found beneath blue oak canopies than in open grassland. This explains, at least in part, the increased herbage production beneath blue oak canopy.

Key Words: hardwood rangeland, tree-soil interaction, soil physical and chemical characteristics

In the central Sierra Nevada foothills, herbage production beneath blue oak (*Quercus douglasii* Hook & Arn.) canopies is 15 to 100% greater than in adjacent open areas (Holland 1980, Holland and Morton 1980, Ratliff et al. 1988, Frost and McDougald 1989). The increased herbage production beneath blue oak canopies has been attributed to higher soil fertility and more favorable moisture and temperature regimes (Holland 1973, Holland 1980). However, in northern California herbage production beneath blue oak canopies is lower than in adjacent open areas (Murphy and Berry 1973, Kay and Leonard 1980, Murphy 1980). Removal of blue oak in the northern region results in increased herbage production which may last for up to 15 years (Kay 1987). Such a response suggests a residual store of nutrients, derived from oak litter inputs, which is gradually depleted following tree removal. This store of nutrients is also indicated in central California where removal of blue oak results in a gradual decline in annual forage production to levels comparable to those of the less productive open grassland (Holland 1973, Holland 1980). Klemmedson and Tiedemeann (1986) found similar effects where mesquite (*Prosopis juliflora* DC) was removed.

Other predominant overstory species in the central region of the blue oak woodland are interior live oak (*Quercus wislizenii* DC) and digger pine (*Pinus sabiniana* Dougl.). Total annual herbage production beneath the canopies of both species is over 30% less than in adjacent open grassland (Ratliff et al. 1988). The reduction beneath interior live oak has been partially attributed to the high level of shading from the evergreen canopy (Duncan et al. 1983).

The objective of this investigation was to: assess the impact of 3 major overstory species (blue oak, interior live oak, and digger pine) on physical and chemical properties of the soil in an effort to explain the tree-forage production relationship.

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Study Area

The San Joaquin Experimental Range (SJER) is located in Madera County, within the Sierra Nevada foothills of central California, 37 km northeast of Madera and 45 km north of Fresno. The SJER is typical of the blue oak phase of the foothill woodland vegetation type (Griffin 1977). The SJER lies primarily between 300 and 500 m elevation; predominant aspect is southwest.

Climate at the SJER is Mediterranean, with mild, rainy winters, and hot, dry summers. The rainy period extends from October until late May or early June. Annual precipitation averages 482 mm with recorded extremes of 229 and 940 mm (Coon 1989).

The study area consisted of open rolling sites in 2 pastures: the Research Natural Area (RNA), which has been ungrazed and unburned since 1934, and Range Unit 41 (RU 41), which has been grazed yearly since at least 1934 when the SJER was established. The overstory consists of scattered blue oak, interior live oak, and digger pine. Canopy cover within the study area was 6% blue oak, 12% interior live oak, and 3% digger pine (Frost and McDougald 1989). The major soil of the study area belongs to the Ahwahnee series (coarse-loamy, mixed, thermic mollic Haploxeralf) developed from intrusive igneous rocks of the Sierra Nevada Batholith.

The RNA and RU 41 comprised 1 pasture prior to acquisition and formation of the SJER by the USDA Forest Service in 1934, thus, they received similar grazing treatment. A fenceline constructed in 1934 eliminated grazing from the RNA. Range Unit 41 has received moderate grazing use on a yearly basis since at least 1934. The study site consisted of open rolling areas with a southwest aspect. The fenceline provides the contrast between grazing treatments.

Open rolling sites with similar tree canopy cover, southern exposure, slopes of less than 15% and Ahwahnee soil series were identified prior to sampling. Sites were numbered and a random number table utilized to select sampling sites. A similar procedure was used to select individual trees to sample beneath on each site. These were the same sites as in a companion study on tree canopy effect on forage production (Frost and McDougald 1989).

Materials and Methods

Eighty soil samples were collected beneath the canopies of randomly selected blue oak, interior live oak, and digger pine trees and in adjacent open grassland within the grazed (RU 41) and ungrazed (RNA) areas in 1987. This provided 5 replications beneath each species canopy category and in open grassland at 2 depths in each area. Each soil sample consisted of a composite of 3 soil cores collected from random locations along the mid-point between tree trunk and drip line. Samples were collected in April at 0–5 cm and 5–20 cm depths. These samples were air-dried for several days, sieved through a 2-mm screen and stored in plastic bags.

Forty additional soil samples were taken from random locations mid-way between tree trunk and drip line and in open areas to be used for bulk density determinations. Aluminum cylinders of known volume were used to extract these samples. Soil cores were placed in metal cans, oven dried at 105° C for 24 hours, and weighed. Bulk density was calculated on an oven-dried weight per unit volume basis.

Table 1. Results of analysis of variance for soil physical and chemical characteristics beneath tree canopies and in open grassland at the San Joaquin Experimental Range, California.

	Area+tree species	Soil depth	Area+tree species × soil depth
OC	**[1]	**	
CEC	**	**	
BD	**	**	
P	**	**	
N	*	**	
Ca	**	**	
Mg	**	**	
Na	**		
K	**	**	*
Mn		**	
pH	**		

[1]**indicates significance at p=.01
*indicates significance at p=.05

Cation exchange capacity (CEC) was determined by index cation saturation and displacement (Page 1982). Sodium bicarbonate soluble phosphorus (P) was extracted using the procedure described by Page (1982).

Soluble and exchangeable cations were extracted and potassium (K), sodium (Na), magnesium (Mg), and manganese (Mn) concentrations were determined by atomic absorption. Calcium (Ca) concentrations were determined by flame photometer. Organic carbon (OC) content was estimated using the Walkley-Black method (Page 1982). Total nitrogen was determined by a micro-Kjeldahl method (Page 1982). Soil pH was determined by glass electrode in a 1:1 (soil:water) mixture. Values of pH were converted to their arithmetic equivalent values before statistical analysis was conducted.

Analysis of variance was conducted as a split block with area+tree species as main plots and soil depths as subplots. Treatment means were separated by Student-Neuman-Keuls test (Little and Hills 1978). Significant differences were declared at $p \leq .05$.

Results and Discussion

There were significant differences among the area+tree species for all physical and chemical soil characteristics with the sole exception of Mn (Table 1). The general trend toward greater amounts of organic carbon, lower bulk density, larger cation exchange capacity and greater amounts of some nutrients beneath the canopies of oaks than in open grassland (Table 2) may be attributed to greater organic matter inputs from leaf fall than occurs in open grassland. However, leaching of nutrients through rainwater drip may also be important. Similar relationships have been found for blue oak—open grassland comparisons, with no grazing, at the Hastings Reservation in central California (Holland 1973), for N, K, S, and organic matter beneath mesquite (Tiedemann and Klemmedson 1973), for soil N beneath canopies of *Larrea, Acacia,* and *Cassia* (Garcia-Moya and McKell 1970) and for bulk density beneath blue oaks at the U.C. Sierra Foothill Range Field Station in northern California (Kay 1987, Kay and Leonard 1980). Increasing concentrations of a number of nutrients has also been found as the amount of basal area of gambel oak (*Quercus gambelii* Nutt.) increased in pine forests of Arizona (Klemmedson 1987).

Significant differences also existed among the 2 soil depths for all soil characteristics with the exception of Na and pH (Table 1). Larger amounts of OC, larger CEC, greater concentrations of nutrients, and lower bulk densities were present in the 0–5 cm depth than in the 5–20 cm depth. We also found that among the area+tree species more significant differences occurred in the 0–5 cm soil depth than in the greater depth, indicating the effect of leaf fall on soil characteristics. This relationship of greater amounts of OC,

Table 2. Soil properties for the Research Natural Area and Range Unit 41 of the San Joaquin Experimental Range, California.

Area	Canopy classification	Organic carbon (pct)	Cation exchange capacity (meq/100g)	Bulk density gm/cm3)	P (pct)	Total N (pct)	Ca (meq/-100g)	Mg (meq/-100g)	Na (meq/-100g)	K (meq/-100g)	Mn (meq/-100g)	pH
0–5 cm												
RNA												
	Open	1.21efg	5.78defg	1.28bc	0.001de	0.09cd	3.88efg	0.40def	0.06c	0.36cde	0.07bcd	5.2cde
	Blue Oak	2.05cde	8.42bcd	1.08de	0.0012de	0.16bcd	6.96abc	0.66bcd	0.07bc	1.10a	0.09ab	5.6e
	Live Oak	3.08ab	10.19ab	1.06e	0.0016bcd	0.29a	7.30ab	1.20a	0.07bc	0.61cd	0.07bcd	5.3cde
	Digger Pine	2.72abc	7.12cdefg	1.03e	0.0006e	0.14bcd	3.94efg	0.66bcd	0.07bc	0.51cde	0.10a	4.5a
RU 41												
	Open	2.11cd	8.06bcde	1.36abc	0.0020abc	0.15bcd	5.12bcdef	0.59cde	0.07bc	0.43cde	0.08abc	5.3cde
	Blue Oak	3.55a	12.10a	1.02e	0.0026a	0.25ab	9.28a	0.92ab	0.09a	1.07ab	0.08abc	5.3cde
	Live Oak	3.32ab	9.12bc	1.03e	0.0022ab	0.20abc	6.46bcde	1.15a	0.07bc	1.35a	0.07bcd	5.3cde
	Digger Pine	2.66bc	6.96cdefg	1.22cd	0.0016bcd	0.10cd	3.76fg	0.56cde	0.07bc	0.56cde	0.07bcd	4.7b
5–20 cm												
RNA												
	Open	0.65g	4.47g	1.42ab	0.0010cd	0.06d	3.14fg	0.26f	0.06c	0.21e	0.04ef	5.3cde
	Blue Oak	1.57def	8.30bcd	1.33abc	0.0012bcd	0.13cd	6.58bcd	0.54cdef	0.07bc	0.39cde	0.06cde	5.6e
	Live Oak	1.67def	7.44bcdef	1.36abc	0.0014bcd	0.12cd	4.98bcdefg	0.73bc	0.07bc	0.34cde	0.04ef	5.2cde
	Digger Pine	1.19efg	5.20efg	1.30bc	0.0010cd	0.09cd	3.10bfg	0.41def	0.08ab	0.31cde	0.05def	5.0bcd
RU 41												
	Open	0.95fg	6.69cdefg	1.42ab	0.0012de	0.09cd	4.10defg	0.36ef	0.07bc	0.25de	0.04ef	5.1cde
	Blue Oak	2.15cd	10.18ab	1.37ab	0.0016bcd	0.15bcd	5.64bcdef	0.58cde	0.08ab	1.29a	0.05def	5.4de
	Live Oak	1.45defg	6.73cdefg	1.37ab	0.0014cd	0.12cd	4.36cdefg	0.56cde	0.07bc	0.68bc	0.03f	5.3de
	Digger Pine	1.22efg	5.10fg	1.47a	0.0014cd	0.09cd	2.40g	0.33ef	0.06c	0.42cde	0.04ef	4.8bc
	s.e.	0.12	0.33	0.02	0.001	0.01	0.29	0.04	0.001	0.05	0.003	

Numbers in a column within a sampling area followed by a different letter are significantly different (p = .05).

larger CEC and higher nutrient concentrations at a shallow soil depth than deep in the soil is similar to that found beneath mesquite (Tiedemann and Klemmedson 1986).

Lower OC, CEC, and some nutrient levels beneath digger pine canopy and in the open grassland than beneath blue oak canopy are attributed to small organic matter inputs into the system. The leaves (needles) which fall from digger pine are resistant to decomposition, persisting on the ground for long periods of time. Thus, the OC and nutrients contained in the needles are not rapidly returned to the soil. The lower pH values beneath digger pine canopies than in other situations were expected as the acidifying effect of decomposing pine litter has been well documented (Zinke 1962, Barth 1980). Virtually no leaf fall occurs in the open grassland, resulting in low organic matter inputs to add to the nutrient pool as compared to the contribution of leaves beneath blue oak canopies.

Management Implications

Higher percentages of organic carbon, lower soil bulk density (in the top 5 cm), larger cation exchange capacity and higher concentrations of some nutrients found in soils beneath blue oaks as compared to those in open grassland explains, at least partially, the increased forage production found beneath blue oak canopies on these same sites (Frost and McDougald 1989, Frost 1990). Many of the same soil conditions exist beneath both interior live oak and blue oak canopies. Reduced total annual herbage production beneath these interior live oak compared to that beneath blue oak (Frost and McDougald 1989, Frost 1990) indicates that the effects of shading of the evergreen canopy of interior live oak in moderating light intensity, air and soil temperature, and soil moisture may be limiting herbage production. If this hypothesis is correct, selective removal of interior live oak may lead to increased herbage production over that of open grassland for as long as the tree-induced favorable soil conditions persist. This has been demonstrated for blue oak removal in northern California where favorable soil conditions have persisted for 14 years following removal (Kay 1987). Following blue oak removal the reservoir of nutrients was maintained by the nutrient cycle of the herbaceous plants which contain more biomass and nutrients than the herbaceous plants in the open grassland. The loss of continuous nutrient inputs from living trees does result in a gradual decline of the nutrient content in the soil and forage and a loss in herbaceous production. Eventually this will decline to levels comparable to those of open grassland (Holland and Morton 1979), a relationship also found for nutrient availability 13 years following removal of mesquite (Klemmedson and Tiedemann 1980).

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