Soil Characteristics of Blue Oak and Coast Live Oak Ecosystems[1]

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Abstract: *In northern San Luis Obispo County, California, soils associated with blue oaks (*Quercus douglasii*) are slightly more acidic, have finer textures, stronger argillic horizons, and sometimes higher gravimetric water content at -1,500 kPa than soils associated with coast live oaks (*Quercus agrifolia*). Soils associated with coast live oaks generally are richer in organic matter than those associated with blue oaks. Blue oaks seem to grow more frequently on erosional surfaces and in soils that sometimes have a paralithic contact at about 1 m depth, whereas coast live oaks may be found more frequently on depositional surfaces. Although the two species sometimes occupy seemingly comparable sites, results point to significant microsite differences between them. Full, conclusive characterizations useful in managing and enhancing oak woodlands will require study of many more sites.*

The distribution and productivity of California's 3 million hectares of oak woodlands are controlled in part by the soils of these ecosystems; moreover, proficient management of oak woodlands requires ample knowledge of one of the most important, but least understood, habitat components—the soil. Blue oak (*Quercus douglasii* Hook. & Arn.) and coast live oak (*Quercus agrifolia* Née) are two important species in the central coast region that commonly grow in proximity, including in mixed stands. Nonetheless, the two species may have different site preferences, suggesting that different approaches to stand evaluation and management may be appropriate. An important step in determining site preferences is to adequately characterize the soils of these ecosystems.

Given the paucity of published information regarding specific soil–plant relations in California oak woodlands, this project was undertaken as a pilot work to identify potential correlations between the occurrence of the two species and soil morphological properties. Sites supporting mature blue oak and coast live oak in northern San Luis Obispo County were chosen for this study.

To improve readability of this paper, soils associated with blue oaks or with coast live oaks may be referred to simply as "blue oak soils" or "coast live oak soils." These designations are not taxonomic names, and they do not imply any distinctive morphological or chemical properties of the soils.

Literature Review

Blue oaks often occur in mosaics of grassland, savannah, and chaparral that may reflect differences in slope, aspect, soil depth, and fire frequency (Barbour 1987). Throughout their range, blue oaks commonly occur on rolling hills of 10 to 30 percent slope (Barbour 1987, Rossi 1980). In southern San Luis Obispo County and northern Santa Barbara County, valley grasslands support scattered, nearly pure stands and individuals of blue oak, whereas upper, higher-elevation slopes are dominated by mosaics of blue oak woodland and chaparral (Borchert and others 1993). In some areas of central California, blue oaks favor southerly-facing slopes (Griffin 1973); in other areas they favor northerly-facing slopes, but they also can be found on easterly, westerly, and southerly-facing aspects (Borchert and others 1993).

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While blue oaks may grow on a wide range of slope positions and aspects, coast live oaks along the central coast seem to be confined more often to drainages and northerly-facing aspects. In the San Luis Obispo area, coast live oaks have been reported on soils derived from diverse parent materials and having a variety of textures, including sand, loamy sand, sandy loam, loam, clay loam, and clay (Wells 1962). Although soil and site characteristics of these stands may be diverse, evidence suggests that in the Chimney Rock Ranch area coast live oaks are found on sandier soils than are neighboring blue oaks (Plumb and Hannah 1991). Soils supporting blue oaks often are characterized by a claypan or an argillic horizon (i.e., clay-rich subsoil layer) (Borchert and others 1993, Hunter 1993, Lytle and Finch 1987).

Blue oaks may occupy droughtier sites and survive severe drought conditions better than coast live oaks (Griffin 1971, Rossi 1980). This hypothesis is supported by the drought-deciduous nature of blue oaks, as well as by studies of plant water relations, root morphology, and root distribution patterns (Callaway 1990, Griffin 1973, Matsuda and McBride 1986, McCreary 1990). Blue oaks have shown higher xylem sap tensions than have coast live oaks under a variety of site conditions, suggesting that of the two species, blue oak may lose more water to transpiration under conditions of mild to moderate stress (Griffin 1973). Under these conditions, sclerophyllous evergreens, such as coast live oak, can more efficiently reduce transpiration rates through stomatal closure than can deciduous species such as blue oak (Chabot and Hicks 1982, Poole and Miller 1975). These transpiration differences have been inferred in comparisons of matched pairs of blue oak and coast live oak (Griffin 1973). Nevertheless, under conditions of severe stress, blue oaks may be better adapted because of their ability to drop their leaves, thus eliminating transpiration losses.

The dominant source of water for the two tree species, whether from vadose soil moisture (i.e., soil water in the unsaturated zone above the water table) or deeper ground water, is unknown, especially for different conditions. In the Sierra Nevada foothills, blue oak and interior live oak (*Q. wislizenii*) can extend their roots more than 20 m deep, allowing them to extract water from below the water table (Lewis and Burgy 1964). Phenotypic similarities between interior live oak and coast live oak suggest the possibility of coast live oak attaining similar rooting depths. Water table penetration may allow some coast live oaks in Monterey County to maintain low xylem sap tensions during severe drought (Griffin 1973).

Root production in blue oaks can exceed that in coast live oaks during the first growing season, because of blue oak's earlier germination and faster root growth (Matsuda and McBride 1986). In response to water stress in the field and greenhouse, blue oaks were observed to significantly increase lateral root growth while coast live oaks did not. In contrast, under conditions of adequate moisture, blue oaks produced few new lateral roots, while coast live oaks produced a moderate amount of new lateral roots. Both species may be able to alter their root systems in response to changing moisture availability. The type and extent of change may be influenced by the presence or absence of mycorrhizae (Callaway 1990). Mycorrhizae increase soil moisture uptake and may enable some plants to obtain water held at otherwise unavailable tensions (Bethlenfalvay and others 1986).

Soils beneath oak canopies have higher organic carbon contents and greater fertility than do adjacent soils (Dahlgren and Singer 1991, Holland 1973, Parker and Muller 1982). Moreover, soil organic matter under evergreen oaks may differ from that under deciduous oaks because of differences in leaf production and retention. In California, the evergreen coast live oak produces about twice as much litter biomass as the deciduous valley oak (Hollinger 1984). In addition, evergreen leaves often have slower rates of decay and mineralization than do deciduous leaves. Contrastingly, in northern temperate forests, evergreen and deciduous species produce similar amounts of litter (Chabot and Hicks 1982).

Site Description

Five sites were selected in northern San Luis Obispo County, California: four at Chimney Rock Ranch, approximately 13 km northwest of Paso Robles, and one at Camp Roberts, about 10 km north of Chimney Rock Ranch. All sites currently are grazed by cattle, with grazing intensity and congregating preferences of the animals varying from site to site. Sites were selected for accessibility and presence of blue oak and/or coast live oak.

The Chimney Rock Ranch sites are blue oak and coast live oak woodlands, in either separate or mixed stands, with understories of herbaceous annuals. The soils, which are dominantly Ultic Haploxeralfs and Ultic Argixerolls, are underlain by calcareous and noncalcareous sandstone and conglomerate, and diatomaceous shale. Aspects vary considerably for both oak species. Slopes range from 5 percent to 40 percent, and elevations are between 335 m and 450 m. Annual rainfall is about 600 mm. At Paso Robles, average air temperatures are as follows: winter average overall is 9 °C, winter average minimum is 1 °C; summer average overall is 21 °C, and summer average maximum is 33 °C (Lindsey 1983). Water well log data at one of the sites indicate that the water table was at 20 m on October 3, 1991.

The Camp Roberts site is open woodland with an annual herbaceous understory. Soils are underlain by soft, calcareous sandstone. The site is limited to blue oaks that grow on north-facing slopes and in drainages. Slopes range from 5 to 30 percent, and elevation is about 275 m. Mean annual maximum air temperature is 24 °C; mean annual minimum temperature is 6 °C, and mean annual rainfall is approximately 180 mm in the Camp Roberts area (Nakata and Associates 1987).

Methods

Soil pedons (i.e., small, three-dimensional soil bodies) were described according to *Soil Survey Manual* guidelines (Soil Survey Division Staff 1993). At Chimney Rock Ranch, 17 pedons (eight blue oak and nine coast live oak) were described in backhoe-dug pits, and at Camp Roberts, three blue oak pedons were described in road cuts and hand-dug pits. The choice of soil pedon locations was limited by safety considerations in backhoe operation. Pedons were chosen to be under the tree canopy or close to it, without regard for aspect or topographic position. The mean distance of soil pits from the nearest tree was similar for each species, but any possible relationship between this distance and soil properties was not evaluated.

Approximately 1 liter of soil was collected from each horizon of each pedon (92 samples total) for laboratory testing. Particle size analyses followed the ASTM (American Society for Testing and Materials) hydrometer method (Gee and Bauder 1986). Gravimetric water contents at -1,500 kPa water potential were determined in a pressure membrane apparatus (Klute 1986). (Although this water potential value is commonly taken as the permanent wilting point, it is an inapplicable designation when applied to most plants other than agricultural row crops. Nonetheless, it is a helpful and commonly used reference point.) Soil reaction (i.e., pH) was measured in a 2:1 0.01M $CaCl_2$ (calcium chloride) solution using a Corning model 420 pH meter. Carbonate content was determined by the acid neutralization method (Allison and Moodie 1965), and organic carbon content was determined by acid dichromate digestion (Allison 1965).

Additional soil chemical analyses were conducted to test the potential for correlating soil taxonomic classifications published in soil surveys with the distribution and possible site preferences of the two oak species. For the taxonomic purpose of distinguishing Mollisols (which must have base saturation of 50 percent or greater) from Alfisols, base saturation percentages were determined for A horizons in the 14 of 20 pedons that met all other criteria for Mollic epipedon (i.e., the upper layer of soil used for taxonomic classification), and that had pH values between 5.0 and 7.0. Base saturation was calculated as the proportion of the sum of Ca^{2+}, Mg^{2+}, K^{+}, and Na^{+} (analyzed by atomic absorption or atomic emission spectrophotometry) removed from the cation exchange complex, the capacity of which was measured by NH_4OAc (ammonium acetate) saturation (Chapman 1965, Doll and Lucas 1973). Soils having pH greater than 7.0 were assumed to have base saturations greater than 50 percent. Base saturations were not measured in soils that did not meet other Mollisol criteria (i.e., depth, color, structure, or organic carbon content).

Data were analyzed for statistical significance of differences between blue oak and coast live oak sites using the Student's t-test, run on Minitab, version 7.2.

Results and Discussion

Land surfaces were characterized as being dominantly erosional or depositional, depending on whether they tended to lose or accumulate soil. The total sample was composed of 45 percent erosional surfaces and 55 percent depositional surfaces. In the study area, blue oaks more frequently grow on erosional surfaces, and coast live oaks occur more frequently on depositional surfaces. Seven of the 11 (64 percent) blue oak surfaces were erosional, whereas 7 of the 9 (78 percent) coast live oak surfaces were depositional.

Although soil depths could not be measured conclusively, even in backhoe-dug exposures, some observations suggest that on these sites blue oaks may grow in shallower soils than do coast live oaks. At two of the three sites that support both tree species, the proportion of blue oaks is greatest in shallower soils near rock outcrops, and least in deeper soils away from the outcrops. Conversely, coast live oaks increase with increasing distance from outcrops to become pure stands in the deepest soils. In one case, soil depth increases from 90 cm near a rock outcrop to more than 300 cm less than 50 m distant. Both species grow in the shallower soil, but only coast live oak grows in the deeper soil. Moreover, three of the five blue oak pedons at this site have paralithic contacts (i.e., weathered bedrock surfaces) at depths ranging from 90 to 110 cm, while none of the coast live oak pedons have either a paralithic or lithic (i.e., hard rock) contact within 150 cm of the surface. At another site, bedrock appeared to be at about 160 cm under blue oak, but was deeper than 300 cm under coast live oak. Additional observations at this site suggest that the two oak species are growing on different soils, with the blue oaks occupying finer textured, rockier soils than the coast live oaks.

The coast live oak soils generally were richer in organic matter than were blue oak soils, although considerable overlap of properties was noted. Overall, the coast live oak soils exhibited significantly greater frequency of occurrence and thickness ($P = 0.097$) of O horizons (i.e., litter layers), more organic carbon in A horizons ($P = 0.008$), and darker color ($P = 0.047$) as reflected by Munsell values (*table 1*). All organic layers consisted primarily of oak leaf litter, with no significant contribution from grasses and forbs in the understory. In addition, although Munsell color values varied, hues were 10YR (yellow-red) for all A horizons studied.

Somewhat in contrast to the organic matter and color value data, mean thickness of A horizons was not significantly different; nonetheless, the mean thickness of coast live oak A horizons was 6 cm greater than those in blue oak soils. This point suggests that A horizon thickness may depend on the nature of the organic matter and its rate of decomposition, as well as on the organic carbon content. Evergreen leaves tend to be tougher and richer in lignins and other resistant components than are deciduous leaves (Chabot and Hicks 1982). Also, the difference in organic carbon contents found in this study may not be significant when the entire process of A horizon pedogenesis, including nutrient cycling, humus cycling, and bioturbation, is considered.

The mean and range of soil pH values suggested stronger acidity, by about one-half pH unit, in coast live oak soils than in blue oak soils (*table 2*). Differences were not statistically significant between A horizons ($P = 0.13$), but they were significant between subsoils ($P = 0.038$) and between pedons taken as a whole ($P = 0.026$). Subsoils and whole pedons showed similar pH values. Although statistically significant, differences in mean pH values between soils of the two species may be of no importance to reproduction and growth of the trees, because both species clearly thrive within a similar range of pH values.

No consistent patterns of pH change with soil depth emerged under either species, although pH consistently decreased with increasing depth under oaks in an earlier central coast study (Borchert and others 1993). The lack of consistent decrease in pH with increasing soil depth probably is due to the calcareous parent materials in several pedons. In addition, no correlation between pH and organic carbon content was found in the A horizons.

Soils ranged from weakly developed Entisols to well-developed Alfisols for each species, a range similar to that noted in an earlier study of blue oaks in southern San Luis Obispo and northern Santa Barbara Counties (Borchert and others 1993). Ten of the 14 sites that were analyzed for taxonomic purposes had base saturations between 45 percent and 55 percent. The base saturations were only weakly correlated with pH, with the correlation being slightly stronger under coast live oaks than under blue oaks. The average base saturation of A horizons was significantly ($P = 0.051$) less, and the range of values was wider in coast live oak soils than in blue oak soils (*table 2*). Nonetheless, tree species distribution is unrelated to the base saturation distinction between Mollisols and Alfisols.

Blue oak soils tended to be more finely textured than coast live oak soils (*table 3*), with blue oak soils having more silt near the surface, and more clay and

Table 1—Organic matter-related characteristics of soils associated with blue oak and coast live oak

			A Horizons						
	O Horizons		Thickness		Organic carbon concentration		Munsell color value[1]		
Species	No./No. of pedons	Mean thickness	Mean	Range	Mean	Range	2 (darker)	3	4 (lighter)
		cm	*cm*	*cm*	*pct*	*pct*			
Blue oak	4/11 (36 *pct*)	2.00	36	20-75	2.35	1.09-3.56	0	8 (40 *pct*)	3 (15 *pct*)
Coast live oak	8/9 (89 *pct*)	3.63	42	10-99	3.55	2.20-4.67	1 (5 *pct*)	8 (40 *pct*)	0

[1]Data beneath Munsell color values are numbers of pedons in which that color was observed.

Table 2—pH and base saturation values for soils associated with blue oak and coast live oak

Species and associated soil	pH		Base saturation percentage	
	Mean	Range	Mean	Range
Blue oak				
A horizons	6.0	5.1–7.5	49.7	44.9-53.6
Subsoils	5.8	3.9–7.9	NA	NA
Coast live oak				
A horizons	5.5	4.3–6.4	38.5	14.1-53.8
Subsoils	5.2	3.7–7.8	NA	NA

Table 3—Soil particle size percentages and levels of statistically significant differences for blue oak soils and coast live oak soils

Species	Sand		Silt		Clay		
	Mean	Range	Mean	Range	Mean	Range	Increase with depth
Blue oak	53.9	8–88	24.9	6–52	21.4	6–64	19.3
Coast live oak	64.2	20–87	18.9	3–48	16.8	5–35	6.89
	P = 0.030		P = 0.030		P = 0.089		P = 0.047

less sand at depth. Although argillic horizons, which were identified by the presence of clay films as well as by clay increase with depth, were present in 16 of the 20 (80 percent) pedons described, they were slightly more common and more strongly developed under blue oaks than under coast live oaks, suggesting somewhat stronger leaching of clay in the blue oak soils. These differences led to soil taxonomic distinctions at the family level, but not at the higher (i.e., broader) levels in the taxonomy. While all coast live oak pedons were classified in the coarse-loamy particle size class, only about half of the blue oak pedons fell into this class. The remaining blue oak pedons (5 of 11) fell into the fine-loamy, fine, or very fine classes.

Overall, blue oak soils and coast live oak soils showed no significant differences in water content at –1,500 kPa among the five sites; nonetheless, values were significantly higher in blue oak soils than in coast live oak soils on two of the three sites that supported both species (*table 4*). The differences at these two sites are attributed to higher clay content in the blue oak soils than in the coast live oak soils. Soils on one of these sites exhibited –1,500 kPa water content that was approximately three times greater than that of other sites (*table 4*). This difference appears to be a function of soil parent material, which is derived from diatomaceous shale on the site that retains more water, and from sandstone and conglomerate on the two sites that retain less water.

Table 4—Gravimetric water content (pct) at -1,500 kPa in blue oak and coast live oak soils

	All sites		Site 1*		Site 2*		Site 4*	
Species	Mean	Range	Mean	Range	Mean	Range	Mean	Range
Blue oak	12.8	4.5-39.3	10.8	4.5-23.0	7.6	4.5-16.1	36.6	32.4-39.3
Coast live oak	12.3	2.0-34.5	6.1	2.0-15.4	8.0	5.7-9.6	31.6	29.3-34.5
	$P = 0.83$		$P = 0.001$		$P = 0.72$		$P = 0.04$	

*Soils of sites 1 and 2 are derived from sandstone and conglomerate; soil of site 4 is derived from diatomaceous shale. Site numbers correspond to those presented in Downie (1996).

Field moisture contents for three soils (two blue oak and one coast live oak) sampled in mid-September 1992 were close to the –1,500 kPa values obtained in the laboratory, indicating that at that time soils were at or near the so-called permanent wilting point. No rain had fallen since the previous spring, and rainfall that year was close to average. In contrast, soil water potentials at the Sierra Foothill Range Field Station in Yuba County, California, ranged from –3,600 kPa at the soil surface to –1,800 kPa at 40 cm depth in August 1986 (Gordon and others 1991). Removal of the litter layer may partially account for the low potentials in the Yuba County study. In our study, the presence of depositional surfaces (including a flood plain), which are likely to accumulate litter as well as soil, and the presence of diatomaceous parent materials at some sites may have helped maintain higher moisture concentrations in the fall.

Macropores and casts attributed to earthworms often were noted in pedon descriptions, but their significance was not assessed. Future studies of oak woodland soils should consider the role of earthworms, which often are abundant in California oak soils and can significantly affect soil physical and chemical properties (Graham and others 1995, Wood and James 1993).

Conclusions and Recommendations

Even though considerable overlap of site and soil characteristics was found, this study reveals significant microsite differences between blue oak and coast live oak. These differences further suggest that the two species have different site adaptations or preferences, each of which should be more fully investigated, with larger data sets, on a scale that covers the full geographic range of each species.

Virtually none of the differences noted are revealed by soil taxonomic classifications, except for taxonomic criteria related to soil texture and depth. Although using soil taxonomy to differentiate site preferences at this time would be dubious, additional work with large data sets might reveal soil taxonomic differences between soils associated with the two species.

Given the differences in litter layers, organic carbon contents, and pH between soils of the two species, additional differences in soil cation exchange capacity and fertility are possible. The effects of these on seed germination and seedling growth deserve attention.

Soils from the two sites having widest textural differences also exhibited significant differences in –1,500 kPa water content. Likewise, soils having no significant differences in texture showed no significant differences in –1,500 kPa water content. Overall, the relationships noted among soil texture, water potential, water content, and oak species distribution are inconclusive. Nonetheless, given that weak relationships were noted, and that blue oaks tended to favor finer soils than did coast live oaks, soil water potential through the year may be an important site discriminator on a broader scale than was covered in this study. This possibility merits further investigation.

The final point is clear: the soil component in oak ecosystems must be much more intensively and extensively investigated if these systems are to be understood, enhanced, and managed efficiently and effectively.

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