

# Factors Influencing Soil-Surface Bulk Density on Oak Savanna Rangeland in the Southern Sierra Nevada Foothills<sup>1</sup>

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## Abstract

The objectives of this study were to compare soil-surface bulk density between rangeland pastures not grazed since 1935, 1975, and 1995 to grazed areas with a 15-year record of light ( $>1,000$  lbs  $\text{ac}^{-1}$  RDM), moderate (600-800 lbs  $\text{ac}^{-1}$  RDM), and heavy ( $<400$  lbs  $\text{ac}^{-1}$  RDM) grazing by beef cattle; and to determine the influence of oak canopy, topographic position, and livestock concentration activities on bulk density. The study was conducted on sandy-loam soils on oak savanna at the San Joaquin Experimental Range in Madera County, CA. A total of 1047 bulk density samples were collected. Soil-surface bulk density was 19 percent lower under oak canopy than in adjacent open grasslands. Livestock grazing at all levels increased bulk density above that in areas excluded from grazing for 5, 25, and 65 years, while there were no significant differences among exclosures. Areas with light grazing had lower bulk density than moderately and heavily grazed sites, which were not different from each other. RDM recommendations at, or above, 800 lbs  $\text{ac}^{-1}$  will likely lead to reduced soil-surface bulk density on these soil series. Livestock-concentration areas were the most compacted sites in the study.

## Introduction

Oak woodlands cover an estimated 3 million ha in the interior valleys and foothills of central California (Griffin 1977), providing forage, firewood, wildlife habitat, open space, and domestic water supplies. The quality of much of California's surface water is dependent on the condition and management of the soils on these watersheds. Blackburn (1984) summarized the general concerns that livestock production practices lead to soil compaction which reduce soil porosity and infiltration capacity, leading to increased surface runoff, soil erosion, and transport of non-point source pollutants.

The most commonly reported measure of soil compaction is soil dry bulk density, expressed as the oven dry mass of soil per volume of soil ( $\text{g cm}^{-3}$ ) (Blake and Hartage 1986). Several rangeland studies have shown that soil bulk density is negatively correlated with infiltration capacity and positively correlated with surface runoff (Liacos 1962; Packer 1953, 1963; Rauzi and Hanson 1966; Spaeth and others

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1996). Liacos (1962) found that the soil-surface bulk density on ungrazed [residual dry matter (RDM)  $\sim 3,400 \text{ lbs ac}^{-1}$ ] Los Osos clay loam soils east of Berkeley averaged  $1.4 \text{ g cm}^{-3}$ ; sites grazed heavily (RDM  $\sim \text{lbs ac}^{-1}$ ) averaged  $1.6 \text{ g cm}^{-3}$ ; and sites that were lightly (RDM  $\sim 1,250 \text{ lbs ac}^{-1}$ ) grazed were intermediate. On coarse sandy loam soils at the San Joaquin Experimental Range (SJER) north of Fresno, Ratliff and Westfall (1971) found that soil-surface bulk density was 24 percent lower within a 36-year ungrazed pasture than on grazed sites. Also at SJER, Assaeed (1982) observed higher bulk densities on grazed swale sites ( $1.38 \text{ g cm}^{-3}$ ) compared to 10 year ungrazed swale sites ( $1.22 \text{ g cm}^{-3}$ ). However, Assaeed (1982) found no difference in bulk density between grazed and ungrazed areas located on hill-slope positions. These studies indicate that grazing in general will increase soil bulk density compared to no grazing, and the authors hint that topographic position may play a role in determining bulk density. The questions of how oak canopy, time since removal of grazing, and grazing intensity affect bulk density are still outstanding, as are the questions of how these factors might interact to determine grazing effects on bulk density. In this paper we present preliminary results of an on-going study to address some of these questions.

The objectives of this study were to compare soil-surface bulk density between rangeland pastures not grazed since 1935, 1975, and 1995 to grazed areas with a 15-year record of light ( $>1,000 \text{ lbs ac}^{-1}$  RDM), moderate ( $600\text{--}800 \text{ lbs ac}^{-1}$  RDM), and heavy ( $<400 \text{ lbs ac}^{-1}$  RDM) grazing by beef cattle; and to determine the influence of oak canopy (blue oak, live oak, open), topographic position (swale, hill-slope, ridge), and livestock concentration activity (none, trails, corrals, supplement sites, water tanks) on soil-surface bulk density.

## Methods

### Study Site

The study was conducted on the 1,772 ha San Joaquin Experimental Range (SJER) in Madera County, CA. SJER has been operated by the USDA Forest Service as a rangeland research station since 1932. SJER is grazed year around with a commercial type beef cattle herd. Elevation ranges from 213 m to 518 m. Climate at SJER is Mediterranean with 485 mm average annual precipitation falling almost entirely during November to May as rainfall. Soil type is uniform across SJER with the Ahwahnee Series (coarse-loamy, mixed, thermic Mollic Haploxeralf) in upland (hill-slope and ridge) positions and the Visalia Series (coarse-loamy, mixed, thermic Pachic Haploxeralf) in swale positions. Soil depth in the uplands ranges from 0.5 to 1.0 m. Soil depth in swales can range from 1.0 to 3.0 m.

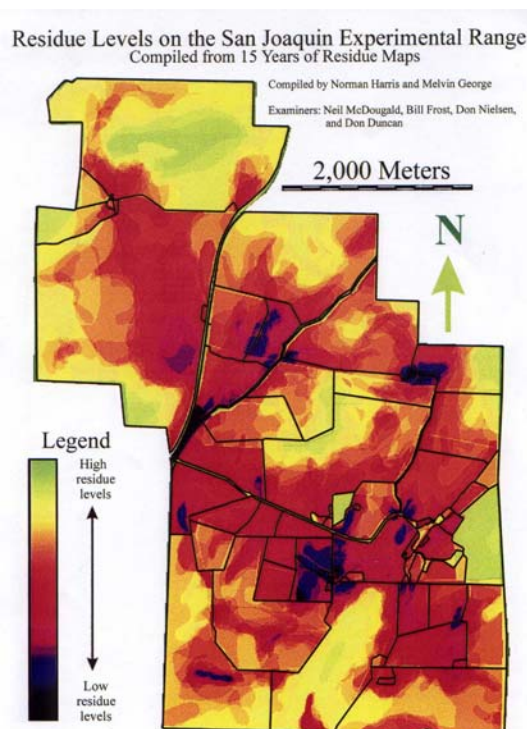
Swales on SJER are intermittent wetlands which become saturated during the rainfall season, gradually drying as the rainfall season ends. As a result, swales produce green forage later into the summer months than adjacent uplands, making swales a preferred site for livestock. Vegetation is oak woodland/savanna with annual grassland understory. Blue oak (*Quercus douglasii* Hook and Arn.) and interior live oak (*Quercus wislizeni* A.DC.) dominate the overstory, while wild oats (*Avena fatua* L.), ripgut brome (*Bromus diandrus* Roth), soft chess (*Bromus rubens* L.), and redstem filaree (*Erodium cicutarium* (L.) L'Her) dominate the open grassland and understory.

Over the course of years numerous livestock exclosures have been constructed and maintained on SJER for various research related purposes. The size of these

exclosures varies from 160 to 0.5 acres. Livestock exclosures constructed in 1935 (~160 ac), 1975 (~20 ac), and 1995 (~15 ac) were selected for use in this study because they span a significant window of livestock exclosure and provide adequate areas for replicated sampling. Annual fall residual dry matter (RDM) mapping has been conducted across SJER since 1985, providing a total of 15 years of grazing intensity history as measured by RDM. GIS technology was utilized to generate a composite RDM map from these 15 years (*fig. 1*).

## Design

This study was a cross-sectional survey of soil-surface (0-7.5 cm) bulk density across all available combinations of four factors across SJER. The four factors were grazing history (excluded 1935, 1975, 1995; light, moderate, heavy grazing), canopy (no canopy, blue oak, live oak), topographic position (swale, hill-slope, ridge), and livestock concentration activities (none, supplement station, stock trail, water tank, corral). Bulk density sampling was conducted within the three livestock exclosures as well as within multiple areas with a clear 15-year record of light ( $>1,000$  lbs  $\text{ac}^{-1}$  RDM), moderate (600-800 lbs  $\text{ac}^{-1}$  RDM), and heavy ( $<400$  lbs  $\text{ac}^{-1}$  RDM) grazing (*fig. 1*). Random sampling of available canopy, topographic position and livestock concentration activities combinations was conducted within each grazing history. Where there was oak canopy, trunk diameter at breast height (DBH) was measured. At this point in time, most, but not all, possible combinations of grazing history, topographic position, and canopy have been sampled within the 1935 exclosure, light, moderate and heavy grazing sites. The 1975 and 1995 exclosures do not contain certain combinations involving canopy and topography. For instance, the 1995 exclosure does not contain a canopy by swale combination, and the exclosures do not contain livestock concentration activity.



**Figure 1**—Fifteen-year composite end of season (October) residual dry matter map of SJER.

### **Soil Dry Bulk Density**

Soil-surface bulk density ( $\text{g cm}^{-3}$ ) was determined via the core method (Blake and Hartage 1986) using a 7.62 cm long by 4.78 cm diameter cylindrical metal core. Samples were dried at 105 C for 24 hours in a forced-air oven, weighed and bulk density calculated as sample dry weight (g) divided by sample volume ( $136.74 \text{ cm}^3$ ). A total of 1047 bulk density samples were collected across SJER during the fall and early winter of 2000, prior to soil saturation.

### **Analysis**

Data were analyzed via backward stepwise general linear model procedures in Systat V.10 (SPSS, Inc. 1996). Independent variables included in the original model were grazing history (excluded 1935, 1975, 1995; light, moderate, heavy grazing intensity); topographic position (swale, hillslope, ridge); canopy (open, blue oak, live oak); and livestock concentration activity (none, supplement station, stock trail, water tank, corral). Soil-surface bulk density was the dependent variable. Evaluation of interactions between main factors is not reported in this preliminary paper due to insufficient sampling of all possible main effect combinations. On-going sampling will allow this analysis prior to final publication in an appropriate journal. Test criteria for inclusion in the final model was  $p < 0.05$ . Mean separation for significant factors was accomplished using pair-wise contrasts ( $p < 0.05$ ). Finally, possible relationships between oak tree size and soil-surface bulk density were evaluated with simple linear regression with soil bulk density as the dependent and DBH as the independent variable.

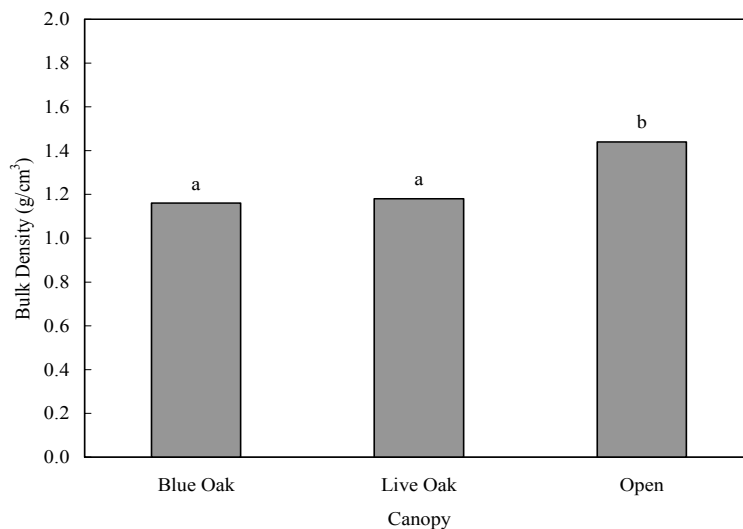
### **Results and Discussion**

General linear models analysis produced a final statistical model ( $p < 0.001$ , multiple  $R^2 = 0.58$ ,  $n = 1,047$ ) showing canopy, grazing history, and livestock concentration activity as highly significant factors determining soil-surface bulk density ( $p < 0.001$ ). Topographic position was not a significant factor in this model ( $p = 0.62$ ). This potentially conflicts with findings by Assaeed (1982) that while swale site bulk density was higher in grazed compared to 10-year exclosures, hillslope bulk density was not significantly different between grazed and ungrazed. Our analysis did allow us to examine the effect of topography with the effect of grazing already accounted for statistically, which we are not certain Assaeed did. It is also possible, in fact likely, that some grazing history by topographic position interactions exist, which our continued data collections will allow us to test.

### **Canopy**

While bulk density was significantly lower ( $p < 0.001$ ) under both blue and live oak compared to open areas, there was no significant difference ( $p = 0.64$ ) between live or blue oak canopy (*fig. 2*). Oak trees play an important role in determining soil bulk density on oak woodlands. This result is in agreement with work conducted by others illustrating that oaks create islands of enhanced fertility beneath their canopy through organic matter incorporation and nutrient cycling, leading to elevated soil quality relative to adjacent grasslands (Kay 1987, Jackson and others 1990, Dahlgren and others 1997). Low soil-surface bulk density is one component of high soil quality. While the presence or absence of oak canopy was a significant factor

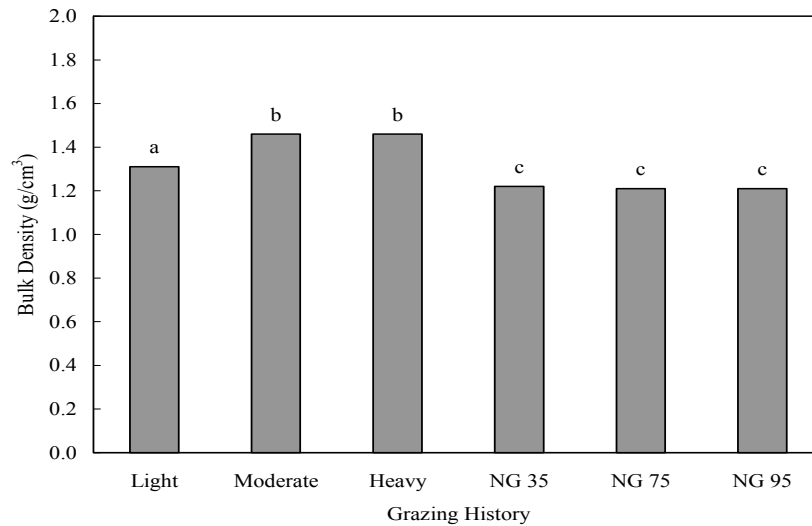
determining bulk density, tree DBH (reflecting age) was not a significant predictor of bulk density under either blue (multiple  $R^2 = 0.017$ ) or live (multiple  $R^2 < 0.001$ ) oak canopy.



**Figure 2**—Mean soil-surface bulk density for blue oak, live oak, and open canopy sites at SJER (columns with different letters are significantly different [ $P \leq .05$ ] by pairwise contrasts).

### Grazing History

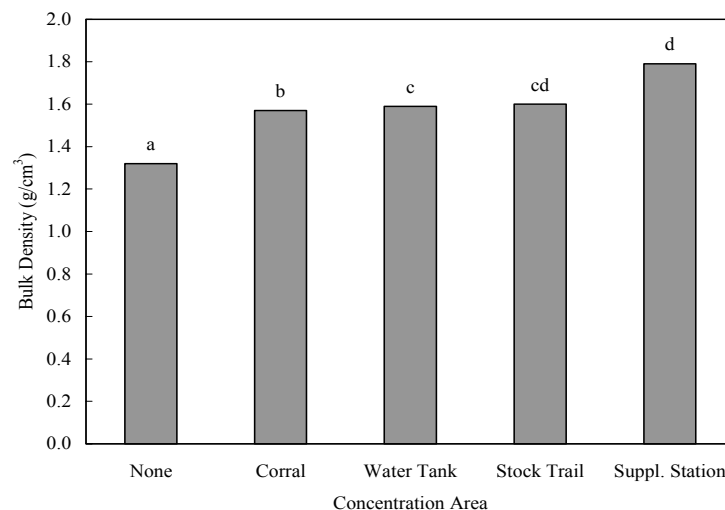
There was no significant difference in bulk density between the three livestock exclosures; however, all currently grazed sites (light, moderate, heavy) had significantly higher bulk density compared to exclosures (*fig. 3*). Sites with light grazing had significantly lower ( $p < 0.05$ ) bulk density than moderate and heavily grazed sites. There was no significant difference between moderate and heavy grazing sites ( $p = 0.21$ ). These results compare well with previous work documenting the reduction in bulk density with livestock exclosure (Assaeed 1982, Liacos 1962, Ratliff and Westfall 1971) conducted on California hardwood rangeland. Our results do imply that there is no apparent improvement in soil bulk density past 5 years of livestock exclosure, indicating that the reversal of soil compaction from grazing on these low clay-silt, high sand content, soil types is relatively rapid. One potential mechanism is an increase in activity of burrowing mammals within exclosures, which was our casual observation. Another mechanism could be increased soil organic matter and development of a deeper and more porous O horizon within the exclosures. Samples are currently being analyzed for organic matter and organic carbon content.



**Figure 3**—Mean soil-surface bulk density for 15-year light, moderate, heavy grazed as well as pastures excluded from grazing since 1935 (NG35), 1975 (NG75), and 1995 (NG95) at SJER (columns with different letters are significantly different [ $P \leq .05$ ] by pairwise contrasts).

### Livestock Concentration Activities

Any form of livestock concentration activity significantly increased soil bulk density (*fig. 4*), with supplemental feeding stations being the most compacted sites found in this study. These results reconfirm the importance of keeping livestock concentration sites as far from water bodies as possible to reduce the risk of elevated runoff levels from these sites reaching surface water.



**Figure 4**—Mean soil-surface bulk density for areas without livestock concentration (none), corrals, water tanks, stock trails, and supplemental feeding stations at SJER (columns with different letters are significantly different [ $P \leq .05$ ] by pairwise contrasts).

## Conclusions

We found the presence or absence of oak tree canopy, grazing history, and livestock concentration areas significantly affect soil-surface bulk density on oak savanna rangelands at SJER. Soil-surface bulk density was 19 percent lower under oak canopy than in adjacent open grasslands. Livestock grazing at all levels found on SJER increased bulk density above areas excluded from grazing for 5, 25, and 65 years. There was no significant difference among the three exclosures, indicating that reversal of soil compaction from grazing on these sites occurs within 5 years. Areas with 15 years of light grazing ( $> 1,000 \text{ lb ac}^{-1}$  RDM) had significantly lower bulk density than moderately ( $800\text{--}600 \text{ lb ac}^{-1}$  RDM) and heavily ( $<400 \text{ lb ac}^{-1}$ ) grazed sites, which were not significantly different from each other. RDM recommendations at, or above,  $800 \text{ lb ac}^{-1}$  will likely lead to elevated soil-surface bulk density on these soil series. However, these results for soil-surface bulk density may not translate into an identical response in surface runoff to grazing history given the inherently high infiltration capacity of these sandy soils (Tate and others 2000). Further data collection will continue at SJER, enabling us to test for potential interactions between the effects of grazing history, canopy, and topographic position on bulk density.

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