Effect of Grazing on Soil Compaction as Measured by Bulk Density on A High Elevation Cattle Range

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Highlight

Bulk density of the soil in grazed plots was similar to that in ungrazed exclosures both in early summer before grazing and in late summer after grazing. Increases in bulk density during the summer both in grazed and ungrazed areas were attributed to changes in soil moisture. Soils in early summer were moist and swollen and thus weighed less per unit volume than did the dry soils in late summer.

Rotation and rest-rotation grazing systems are now being applied with increasing frequency on the arid rangelands in the West. These systems require heavy concentrations of livestock during one grazing season or portion thereof, followed by complete rest from grazing during the remainder of the season or the following year. Some land managers fear such concentration of animals may cause serious soil compaction that will not be overcome during the rest period.

Relatively few studies have been made to determine how trampling by grazing animals affects the soil. Studies conducted in the more humid eastern or midwestern States have found bulk density is higher in grazed areas than in similar ungrazed areas (Lull, 1959; Reynolds and Packer, 1963; Linnartz, et al., 1966). Studies of soil compaction on arid rangelands, however, have produced somewhat conflicting results. Daubenmire and Colwell (1942) and Meeuwig (1965) found no difference in bulk density between grazed and ungrazed areas. Lodge (1954) and Orr (1960) found bulk densities were higher in grazed areas than in ungrazed areas at some locations but that there were no differences at other locations. Reed and Peterson (1961) and Packer (1963) found that bulk densities in grazed areas were consistently higher than those in ungrazed areas. The conflicts in these findings probably are the result of varying soil, moisture, or other conditions. For example, much more force is

[1] *In this paper the term "significant" will refer to the 5% level of probability and "highly significant" will refer to the 1% level.*

Table 1. Vegetation, topography, and grazing use at sampling locations, Diamond Mountain cattle allotment, Ashley National Forest, Utah.

Sampling unit	Topography	Vegetation	Season and intensity of grazing 1961	1962
1	Swale	Seeded grass[1]	No grazing	Moderate, early summer
	Upland	Seeded grass[2]	No grazing	Heavy, early summer
2	Swale	Seeded grass[1]	Heavy, early summer	No grazing
	Upland	Native sage-brush-grass	Heavy, early summer	No grazing
3	Swale	Native grass	Heavy, late summer	Moderate, midsummer
	Upland	Native sage-brush-grass	Moderate, late summer	Moderate, midsummer
4	Upland	Native sage-brush-grass	No grazing	Light, late summer

[1] These locations had native grass vegetation before seeding.
[2] This location had native sagebrush-grass vegetation before seeding.

Table 2. Average bulk density of soil at various depths in swale and upland locations sampled in early and late summer, 1962 (oven-dry soil g/cc).

Location and depth (inches)	Grazed plots Early	Grazed plots Late	Exclosures Early	Exclosures Late
SWALE				
0-1	0.95	1.03	1.02	1.01
1-2	1.01	1.06	1.04	1.08
2-4	1.07	1.11	1.10	1.12
4-6	1.12	1.14	1.14	1.18
Ave.	1.04	1.08	1.08	1.10
UPLAND				
0-1	1.19	1.22	1.11	1.19
1-2	1.20	1.24	1.12	1.22
2-4	1.20	1.26	1.20	1.24
4-6	1.22	1.24	1.19	1.28
Ave.	1.20	1.24	1.16	1.23

needed to compact a dry soil than to compact the same soil when it is moist (Lull, 1959). Thus, grazing on wet soils often causes soil compaction, but grazing on dry soils does not necessarily have the same effect.

In 1962 a study was conducted on the Diamond Mountain cattle allotment of the Ashley National Forest, Utah, to determine: (1) if grazing causes compaction, as measured by bulk density; and (2) the relation between bulk density and various soil characteristics. This paper presents the results of that study and points out some of the problems and limitations in the use of the bulk density method of measuring soil compaction on rangelands.

Study Area and Procedure

The study area is on the Diamond Mountain Plateau, on the south slope of the Uinta Mountains, 25 mi. north of Vernal, Utah. This area is about 8,000 ft in elevation and receives 20 to 25 inches of precipitation annually. The soils are loams to clay loams derived mostly from sedimentary rocks of the Browns Park and Morgan formations.

The Diamond Mountain allotment covers about 11,000 acres and is grazed by 510 cattle from June 1 through September 30. The allotment is fenced into range units, some of which have native sagebrush-grass vegetation on upland sites and native grass in swales. Parts of other units were seeded to introduced grasses in the early 1950's.

In 1959, several small exclosures (33 x 33 ft) were constructed in each unit to exclude grazing. These exclosures and the adjacent grazed range were excellent study locations for determining the effect of grazing on soil compaction.

Four of the allotment's range units were used in this study. In three of these units (1, 2, and 3), soil samples were taken from both upland and swale areas from exclosures and adjacent grazed plots. In the fourth unit (4), however, soil samples could only be taken in an upland area because no exclosures had been constructed in a swale area within this unit. The characteristics of each location sampled, along with the season and intensity of grazing use each received in 1961 and 1962, are shown in Table 1.

We did not know whether 3 years' protection from grazing was long enough to overcome soil compaction that might have occurred before the exclosures were established. Therefore, in early summer we sampled areas inside and outside an old exclosure that had been protected from grazing about 15 years. The data from this sampling were not included in any of the comparisons or analyses.

A hand-driven core sampler was used to take the samples, which were 3 inches in diameter. Samples were taken at depths of 0-1, 1-2, 2-4, and 4-6 inches in early summer before grazing began and again in late summer near the end of the grazing season. Four to six samples were taken from each of the upper three depths and two samples were taken from the 4 to 6-inch depth inside and outside the exclosures at every location.

Each sample was placed in a can, weighed within 8 hr., oven-dried for 48 hr. at 105 C, and re-weighed. Bulk density was ex-

Table 3. Change in average bulk density during the summer of 1962 (g/cc).[1]

Sampling unit	Grazing period	Change during summer Grazed	Excl.	Ave.
SWALE				
1	Early sum.	+0.06	+0.08	+0.07
2	None	+ .13	+ .03	+ .08
3	Midsum.	− .05	− .04	− .04
Ave.		+ .04	+ .02	+ .03
UPLAND				
1	Early sum.	+ .16	+ .18	+ .17
2	None	− .01	+ .08	+ .03
3	Midsum.	− .05	+ .08	+ .02
4	Late sum.	+ .06	− .02	+ .02
Ave.		+ .04	+ .08	+ .06
Ave. all locations		+ .04	+ .06	+ .05

[1]Each figure is an average of the four sampling depths.

Table 4. Analysis of variance of change in bulk density between early and late summer.

Source	D. F.	M. S.	"F"
Location	6	0.0370	**10.0
Depth	3	.0008	[1]N.S.
Error a	18	.0037	
Treatment[2]	1	.0018	[1]N.S.
Treat. X depth	3	.0027	[1]N.S.
Treat. X loc.	6	.0134	** 4.5
Error b	18	.0030	
Total	55		

**Significant at the 1% level of probability.
[1]Not significant at the 5% level of probability.
[2]Grazed plots vs exclosures.

pressed as grams of ovendry soil per cubic centimeter. The samples taken in early summer were screened to determine percentage of gravel (rock particles over 2 mm.). Amounts of sand, silt, and clay in the gravel-free proportion were determined by the hydrometer method (Bouyoucos, 1937). A modification of the wet combustion method described by Walkley and Black (1934) was used to determine amount of organic matter.

Bulk densities were averaged for each depth at all locations (Table 2). The change in bulk density was then computed by subtracting the average bulk density obtained in early summer from that for late summer. The average changes for all depths combined at each location were then determined (Table 3).

To compare actual bulk density among different depths and sampling locations, the average bulk density was computed for each depth at every sampling location. The early and late bulk densities from both the grazed and ungrazed plots for each depth were pooled in figuring these averages.

Results

At most locations, bulk densities of the soil samples were similar in the grazed plots and exclosures, both in early and late summer (Table 2). The average bulk density in the grazed plots was less than .01 gram per cubic centimeter higher than that in the exclosures. This difference was not significant.[1] In early summer bulk densities inside the old exclosure that had been protected from grazing for 15 years were essentially the same as in the grazed plot outside the exclosure.

Bulk densities increased during the summer at almost every location—inside and outside the exclosures both in grazed and ungrazed units (Table 2). The average increase (0.5 g/cc) was highly significant.

Bulk densities increased slightly more in the unit grazed in early summer than in those grazed in mid and late summer (Table 3). However, grazing evidently was not responsible for these increases because bulk densities increased as much in the exclosures as in the grazed plots.

An analysis of variance indicated that changes in bulk density were highly significantly different among locations but not significantly different between treatments (grazed plots vs. exclosures) nor among the four depths (Table 4). The "Treatment X location" interaction was significant. Further analysis revealed that bulk density increased significantly more in the exclosures than in the grazed plots in the upland locations.

In the analysis discussed above, changes in bulk density were used. In an analysis of variance using average bulk density for each location, the difference among locations was highly significant (Table 5). Most of the variation between locations was accounted for by the comparison between swale and upland locations; average bulk density in the uplands (1.21) was significantly higher than in the swales (1.07). These differences in bulk density are related to basic soil characteristics such as moisture, texture, and organic matter, and not to differences in livestock trampling.

Average bulk density at the different depths was:

0-1″	1-2″	2-4″	4-6″
1.10	1.13	1.17	1.20

The increase with depth was also highly significant (Table 5). However, the increase was linear within the range sampled, and no further comparisons could be made between measured depths because the significance would be affected by the interval between the depths.

Correlation Between Bulk Density and Soil Characteristics

Some factors other than trampling by livestock evidently were responsible for the increase in bulk density during the summer because density increased in ungrazed areas as well as in those grazed. The correlation coefficients between bulk density and some of the measured soil factors are shown below:

Soil factor	Correl. coef.
% soil moisture	−.60
% organic matter	−.72
% clay	−.25

Table 5. Analysis of variance of average bulk density at different sampling locations and depths.

Source	Degrees of freedom	Mean square	"F"
Location	6	0.0331	**20.7
Depth	3	.0121	** 7.6
Error	18	.0016	
Total	27		

**Significant at 1-percent level of probability.

The coefficients for soil moisture and organic matter are highly significant.

Soil Moisture. — Soil moisture decreased from early to late summer (Table 6). This probably caused the increase in bulk density. Moist soils dried in sampling cylinders decreased in volume but no quantitative measure of amount was obtained. Soils in early summer were moist and swollen at the time of sampling. Therefore, these samples contained less soil mass and weighed less per unit volume than the dry soil samples taken in late summer.

Swelling and shrinking of the soil in response to different moisture conditions evidently occurs in almost all soils (Perrier, et al., 1959) especially those containing montmorillonite clays. Much of the research in this field has been on heavy clay soils in which relatively large changes in volume are common (Holmes, 1955; Fox, 1964). However, research by Haines (1923), Lauritzen and Stewart (1941), and Lauritzen (1948) indicates that swelling is also common in soils that contain less clay. The volume change depends on texture, type of clay, and amount of moisture. Volume changes are greatest in a moisture range between field capacity and wilting point (Haines, 1923).

The high correlation between bulk density and soil moisture suggested the use of covariance analysis to separate the effects of soil moisture and grazing or trampling on bulk density. The relation between bulk density and soil moisture is not entirely linear, however. In addition, bulk density is also highly correlated with other soil factors, such as texture and organic matter. The lack of linearity and the interrelations with other soil factors preclude the use of simple covariance for evaluating or adjusting bulk density data.

Table 6. Average percentage of soil moisture, organic matter, gravel, clay, silt, and sand in the soil of swale and upland locations.

Depth (inches)	Moisture content: Early summer	Moisture content: Late summer	Organic content	Gravel	Soil separates[1]: Clay	Soil separates[1]: Silt	Soil separates[1]: Sand
SWALE							
0-1	26.4	9.0	8.1	4.2	23.7	36.6	39.7
1-2	23.1	10.2	7.6	6.3	24.8	37.1	38.1
2-4	22.8	11.9	6.4	4.5	27.0	37.3	35.7
4-6	22.4	12.8	5.2	3.6	31.5	32.3	36.2
Ave.	23.7	11.0	6.8	4.7	26.8	35.8	37.4
UPLAND							
0-1	12.9	4.5	5.6	8.8	19.6	36.4	44.0
1-2	11.5	5.8	4.8	9.4	22.0	34.7	43.3
2-4	11.4	6.6	4.4	9.6	23.4	33.0	43.6
4-6	10.8	7.8	3.8	10.2	24.9	30.4	44.7
Ave.	11.7	6.2	4.6	9.5	22.5	33.6	43.9

[1]Clay, silt, and sand are expressed as a percentage of the gravel-free portion of soil.

The following tabulation of soil moisture percentages reveals some interesting soil moisture relations in grazed plots and exclosures:

	Grazed plots	Exclosures
EARLY SUMMER		
Swale	22.0	25.4
Upland	11.3	12.0
LATE SUMMER		
Swale	11.7	10.3
Upland	6.4	6.0

These figures include only locations where the grazed plots and exclosures were sampled on the same or successive days. At the time of snowmelt, the soils inside and outside the exclosures undoubtedly were saturated and had the same moisture content. However, the exclosures have more litter and live plant cover than the adjacent grazed plots. Such cover may retard evaporation and retain moisture in the soil in the exclosures longer in early summer. By late summer evapotranspiration had reduced soil moisture to about the same low level inside and outside of most exclosures.

Organic matter.—The soil in swales contained more organic matter at all depths than that in the uplands (Table 6). This probably is part of the reason that bulk density is lower in the swales than in the uplands. Organic matter decreased with depth. This decrease probably is partly responsible for the increase in bulk density with depth because the correlation between organic matter and bulk density (-.72) was highly significant.

Soil texture.—The swale soils contained more silt and clay and less sand than the upland soils (Table 6). The amount of sand and the combined amount of silt and clay were similar for all depths but the amount of clay generally increased with depth, whereas silt decreased. The correlation between clay and bulk density (-.25) was not significant at the 5% level, but was significant at the 10% level of confidence. The correlation between gravel content and bulk density was quite low and computation of bulk density on a gravel-free basis did not appear to be justified.

Conclusions

Bulk density should not be used to compare the effects of grazing on soil compaction unless soil moisture conditions are approximately the same in the areas compared, or unless comparative data are taken on both grazed and ungrazed areas, because bulk density varies with amount of soil moisture. Differences in bulk density caused by differences in soil moisture could be mistakenly attributed to other causes. For example, if only grazed areas had been sampled in this study, an erroneous conclusion could have been reached that grazing caused a significant increase in bulk density when in fact no measurable compaction was caused by grazing.

Trampling can influence soil characteristics other than bulk density—structure, amount and distribution of pores, and rate of infiltration of water (Lull, 1959; Reynolds and Packer, 1963). However, amount of total pore space and rate of infiltration are highly correlated with bulk density (Packer, 1953; 1963) so the precautions mentioned in the preceding paragraph probably should also be observed when making comparisons using any of these types of data.

Further studies are now being made on the Diamond Mountain cattle allotment to better define the relation between bulk density and soil moisture, pore space, and infiltration rate and to determine how time of sampling as well as grazing treatment affects all of these characteristics. The results should provide a better basis for measuring the effect grazing has on the soil in future studies.

Summary

In 1962, soils in exclosures and on the adjacent grazed range on the Diamond Mountain cattle allotment, Ashley National Forest, Utah, were sampled to determine: (1) difference in compaction, as measured by bulk density, on grazed and ungrazed areas, and (2) the relation between bulk density and various soil characteristics. Samples were taken at 0-1, 1-2, 2-4, and 4-6 inch depths in early summer before grazing began and again in late summer near the end of the grazing season.

The upland soils had higher average bulk density than the swale soils. Bulk densities in the grazed plots were similar to those in the exclosures both in early and late summer. However, bulk density increased significantly during the summer in both grazed and ungrazed areas.

Bulk density was significantly correlated with percentage of soil moisture and organic matter. Of these factors, only moisture changed during the summer. Soils were moist in early summer and dry in late summer. These soils swelled when wetted and shrank when dried, giving different bulk density values.

Evidently almost all soils swell and shrink in response to different moisture conditions. Because of this, bulk density should not be used to compare effects of treatments on soil compaction unless soil moisture conditions at the time of sampling are approximately the same in the areas compared. Difference in bulk density resulting from difference in soil moisture could be attributed mistakenly to other causes.

Studies are now being made to better define the relation between bulk density and soil moisture and to determine how time of sampling affects bulk density, pore space, and infiltration of water into the soil. The results should provide a better basis for measuring the effect of grazing on the soil.

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