Effects of short duration, concentrated livestock grazing on soil density
by Lex Alan Riggle

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Soils
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Abstract:
Disagreement exists among range specialists regarding the effects of high density livestock grazing systems on soil bulk densities (Db). Before managers adopt these types of systems, they should be aware of the impacts on the soil surface layer. The purpose of this study was to quantify seasonal changes in soil surface Db, quantify livestock induced changes in soil surface Db and determine if freeze-thaw cycles or wetting and drying cycles ameliorate livestock induced changes.

Soil bulk densities and percent soil moisture measurements were collected in 3 paddocks of an eight paddock Short Duration Grazing system. The system was stocked with twenty one yearling steers in 1983 and 19 steers in 1984, stock densities were 10 steers/ha, grazing periods were less than 4 days. Seasonal changes in Db were measured in exclosures located within each paddock. Data were collected prior to the first grazing and following each grazing period. Density of three soil layers, 0-5, 0-10, and 0-15 cm was measured using a Troxler model 3411B Surface Moisture Density Gauge. To determine if a particular range in Db was more susceptible to compaction, the data were partitioned and analyzed with a standard T test.

In nearly all cases, the ungrazed treatment Db increased significantly over the summer and decreased significantly over the fall-winter-spring period. In the grazed treatment, Db increases were detected for all observed soil layers, but were not significantly different than the ungrazed treatment at the 0.05 level. In the 0.900 g/cm^3 partitioned data, trampling significantly increased bulk densities in the 0-5 cm layer. Over wintering ameliorated natural and livestock induced changes in bulk densities.

Although some partitioned data reveal a significant change, trampling did not significantly affect the mean DB of each paddock. Since trampling did not significantly increase bulk densities, it is unlikely that infiltration rates or sedimentation rates would be affected.

EFFECTS OF SHORT DURATION, CONCENTRATED LIVESTOCK

GRAZING ON SOIL DENSITY

by

Lex Alan Riggle

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ABSTRACT

Disagreement exists among range specialists regarding the effects of high density livestock grazing systems on soil bulk densities (Db). Before managers adopt these types of systems, they should be aware of the impacts on the soil surface layer. The purpose of this study was to quantify seasonal changes in soil surface Db, quantify livestock induced changes in soil surface Db and determine if freeze-thaw cycles or wetting and drying cycles ameliorate livestock induced changes.

Soil bulk densities and percent soil moisture measurements were collected in 3 paddocks of an eight paddock Short Duration Grazing system. The system was stocked with twenty one yearling steers in 1983 and 19 steers in 1984, stock densities were 10 steers/ha, grazing periods were less than 4 days. Seasonal changes in Db were measured in exclosures located within each paddock. Data were collected prior to the first grazing and following each grazing period. Density of three soil layers, 0-5, 0-10, and 0-15 cm was measured using a Troxler model 3411B Surface Moisture Density Gauge. To determine if a particular range in Db was more susceptible to compaction, the data were partitioned and analyzed with a standard T test.

In nearly all cases, the ungrazed treatment Db increased significantly over the summer and decreased significantly over the fall-winter-spring period. In the grazed treatment, Db increases were detected for all observed soil layers, but were not significantly different than the ungrazed treatment at the 0.05 level. In the 0.900 g/cm^3 partitioned data, trampling significantly increased bulk densities in the 0-5 cm layer. Over wintering ameliorated natural and livestock induced changes in bulk densities.

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INTRODUCTION

Grazing systems which incorporate high stock densities for short time periods have received considerable interest in the livestock industry. This is evident by the increased adoption of high intensity, low-frequency grazing systems during the 1960s and 1970s and the increase in popularity of short duration grazing in the 1970s and 1980s (Welty and Wood, 1986).

Advocates of these systems claim many benefits over more traditional grazing systems. One claim is that improved forage production and plant vigor results from the concentrated hoof effect of high stock densities (Savory and Parsons 1980, Savory, 1988). It is suggested that hoof action causes chipping and breaking of surface crusts which increase water infiltration and soil aeration. Hoof action also incorporates organic matter into the soil, increasing both soil fertility and water holding capacity. Theoretically, all may be occurring, however, little research is available to substantiate these claims.

Many researchers have evaluated the effects of grazing systems which incorporate high stock densities for varying time periods. Most agree that these systems are detrimental to the physical properties of the soil surface layer (Alderfer and Robinson, 1947; Chandler, 1940; Lull, 1959; Van Haveren, 1983; Warren, 1986) and the hydrologic cycle (Abdel-Majid et al., 1987; Blackburn, 1983; Rauzi and Hanson, 1966;

Rhoades, 1964; Welty and Wood, 1986).

As soils dry, bulk densities increase (Larson and Allmaras, 1971). Few grazing studies have documented natural seasonal changes in bulk density (Laycock and Conrad, 1967). There have also been few studies reporting livestock induced soil compaction ameliorated by freeze-thaw cycles.

Before managers adopt these types of grazing systems, they should be aware of the system's impacts on the soil surface layer. Grazing systems should be discouraged if they reduce the soils ability to absorb and store water for future plant production.

This study was initiated in 1983. The overall objectives were to:

(1) quantify seasonal changes in ungrazed soil surface bulk densities,

(2) quantify changes in soil surface bulk densities induced by livestock during two grazing seasons,

(3) determine if freeze-thaw or wetting and drying cycles ameliorate or accentuate livestock induced changes.

LITERATURE REVIEW

Soil Bulk Density

Soil bulk density (Db) is the mass (weight) per unit volume (V) of oven dry soil (Ws) (Brady, 1974; Harris, 1971).

$$Db=\frac{Ws}{V}$$

Since dry soils are composed of both solids and pores, an increase in bulk density would represent a decrease in pore space (Rauzi and Hanson, 1966; Robinson and Alderfer, 1952).

Soil bulk density is a dynamic property which changes seasonally. Laycock and Conrad (1967) documented a seasonal increase in bulk densities resulting from soil drying. Bullock et al. (1988) described how expanding ice crystals enlarged soil pores and decreased soil bulk density. Voorhees (1983), cited shrinking and swelling associated with wetting and drying, as well as fracturing and aggregation caused by plant root growth, as possible agents contributing to fluctuating bulk densities.

Soil Compaction

Tillage practices (Hadas, 1987), mechanical harvesting (Froehlich et al., 1985), livestock grazing (Warren et al., 1986), and recreation activities (Cole, 1985) have all been documented as causing compaction in soils. Soil compaction results when an applied external force exceeds internal soil strength, except when the soil is plastic (high moisture content). Under these conditions, external forces which exceed soil strength will cause the soil to flow. Compaction occurs adjacent to the applied force. The degree of soil compaction can be characterized by bulk density, soil strength, water infiltration and root growth (Meek et al., 1988). Within a soil system, solids and liquids are relatively incompressible and do not undergo appreciable volume change. When loads are applied to the soil mass, the change in degree of compaction depends on movement of either liquid or solids or both.

As force is applied, contact area between soil particles and aggregates increases (Lenhard, 1986), aggregates become somewhat oriented, internal strength increases (Hadas, 1987), and the soil becomes more resistant to further compaction (Benjamin, 1985). Soil compaction lowers total porosity and, especially reduces the number of large pores.

Compaction and Soil Water

Water content plays an important role in soil compaction. Because soil water acts as a lubricant (Dr. H Ferguson, personal communication), more force is needed to compact a dry soil than a wet soil (Lull, 1959). Many researchers have demonstrated that under partially saturated conditions, the higher the moisture content of the soil, the more it is compacted by a given pressure (Meek et al., 1988).

Compaction and Particle Size Distribution

Particle size distribution also affects a soil's compactability. Harris (1971) suggested that because of greater area of particle contacts, soils with uniform mixtures of sand, silt and clay-sized particles may initially be more resistant to compaction than soils dominated by one particle size. Although initially more resistant, Burke (1984) and Lull (1959) reported that soils with a broad spectrum of particle sizes have the greatest potential for compaction. This occurs because smaller particles are forced into the voids between larger particles.

Ameliorating Forces

Alternate wetting and drying cycles, freezing and thawing cycles, biotic activity, and tillage can potentially ameliorate compacted soils. Soil water content is important for freeze-thaw cycles to effectively ameliorate compaction. Bullock et al., (1988) found that freezing air-dry aggregates did not significantly affect bulk density. They also determined that ice crystals developing in low water content soils complete their growth in pores before they apply significantly disruptive forces on the soil matrix. Voorhees (1983) observed frost action to be more apparent when the soil was wetter at the time of freeze-up. The increased water content contributes to greater soil displacement by ice expansion which enlarge soil pores and results in decreased bulk density. Kay et al., (1985) reported a silt loam soil to have the greatest frost-action related surface displacement. Wetting and drying cycles can also alleviate compaction (Larson and

Allmaras, 1971). The degree of volume change in response to different water contents depends upon the amount and type of clay, the particle arrangement, exchangeable cations, composition of the soil solution and organic and chemical bonding.

Compaction by Livestock

Soil surface compaction by livestock is a common phenomenon. Lull (1959) calculated the static pressure of a 1,350 pound cow to be 10.9 kg cm^{-2}. Other researchers have used a static loading of 13.6 kg cm^{-2} per cow in artificial trampling studies (Abdel-Magid et al., 1987). Since animals often put their entire weight on one foot during travel, pressures may exceed the above by two to four times.

Contrasting grazed and ungrazed areas, Chandler (1940) attributed higher bulk densities in a woodland soil to the trampling effect of cattle and to a lower organic matter content. Under heavy grazing, which was defined as no available forage greater than 2.5 cm in height following the grazing period, Alderfer and Robinson (1947) reported decreased porosity and increased bulk density in the 0-2.5 cm soil layer. There were no significant differences at greater depths. However in later research Robinson and Alderfer (1952) observed compacted soil and platy structure to depths of 13 cm in grazed sites. These conditions did not exist in ungrazed sites. The researchers attributed the differences to grazing periods which maintained moderate to closely grazed forage.

Under a short-term, high intensity rotation grazing system, Warren et al., (1986b) reported detrimental physical impacts, including soil compaction and reduced soil micro-relief. The effects were observed on a bare, silty clay soil surface at stocking rates twice [8.1 ha/(AU yr)] and three times [2.7 ha/(AU yr)] recommended stocking rates for the site. The results were similar regardless of soil moisture conditions. However, in another study, Abdel-Magid et al., (1987) found no significant bulk density differences among grazing systems or stocking rates for a sandy loam soil. Van Haveren (1983) determined that although bulk densities of fine-textured soils increased with grazing intensity, coarse-textured soils were not affected.

Livestock Use-Hydrologic Interactions

It has been recognized for at least 70 years that heavy continuous grazing accelerates erosion and runoff (Blackburn, 1983). Early livestock grazing/watershed studies by Packer (1953, 1963) and Rauzi and Hanson (1966) indicated that infiltration rates were highly correlated with soil surface bulk density. Wood and Blackburn (1981) identified bulk density as an important variable influencing infiltration rates. McCalla et al., (1984) reported bulk density as one of the most important multiple regression variables influencing runoff. Robinson and Alderfer (1952) reported that as a result of soil compaction by livestock trampling in many permanent pastures, serious runoff losses may be expected during storms of high intensity. A large part of the losses were likely to occur during midsummer when soil moisture is already a serious limiting factor in pasture production.

Increased runoff due to trampling has been observed on a broad range of soil surface textures. Rhoades et al., (1964) reported that water intake rates were inversely proportional to the grazing intensity on a sandy range site in Oklahoma. Rauzi and Hanson (1966) further verified these findings on a sandy loam range site in South Dakota. They concluded that following 20 years of season long grazing, infiltration rates were significantly higher for light and moderately grazed watersheds than heavily grazed sites. On a clayey rangeland in South Dakota, Sharp et al., (1964) observed runoff rates to be 10 times greater on heavily grazed than lightly grazed sites. Abdel-Majid et al., (1987) observed heavy stocking (2.25 ha/steer) to consistently reduce infiltration during the grazing season. Weltz and Wood (1986) reported significantly higher post grazing sediment production for a short duration, high density grazing system (95 ha, 14.0 ha/AU) versus moderate (168 ha, 18.0 ha/AU) and heavily stocked (377 ha, 13.5 ha/AU) continuous grazing. Research by Warren et al., (1986) indicated that following livestock grazing, soil infiltration rates were significantly higher and sediment production significantly lower from plots which were trampled dry than from plots trampled moist.

MATERIALS AND METHODS

Study Site Description

The research was conducted about two kilometers east of Bozeman at Fort Ellis, which is part of the Bozeman unit of the Montana Agricultural Experiment Station. Elevation of the study site is about 1500 meters. The average annual precipitation reported for Montana State University is 473 mm (Joe Caprio, personal communication) of which about one-half occurs during the growing season. Precipitation at Fort Ellis may be slightly higher due to the higher elevation and proximity to the Bridger mountains. The frost free season averages 75 days, ranging from 50 to 90 days.

The surficial geology of the Fort Ellis study site is dissected Tertiary valley fill (Veseth and Montagne, 1980) mantled by loess. Figure 1 illustrates the three physiographic positions found at the research site. The soils are fine-silty, mixed Pachic Argiborolls and are similar to the Bozeman silt loam soil series. The soils at the study site have warmer summer soil temperatures than the Bozeman series and a trace to 10 percent pebbles scattered throughout the profile.

Ross and Hunter (1976) described the climax vegetation of Montana. They classified Fort Ellis as a silty range site receiving 380 to 480 mm of annual precipitation. The species expected on a climax site in this area are listed in Table 1 in order of decreasing dominance (adapted from Ross and Hunter, 1976).

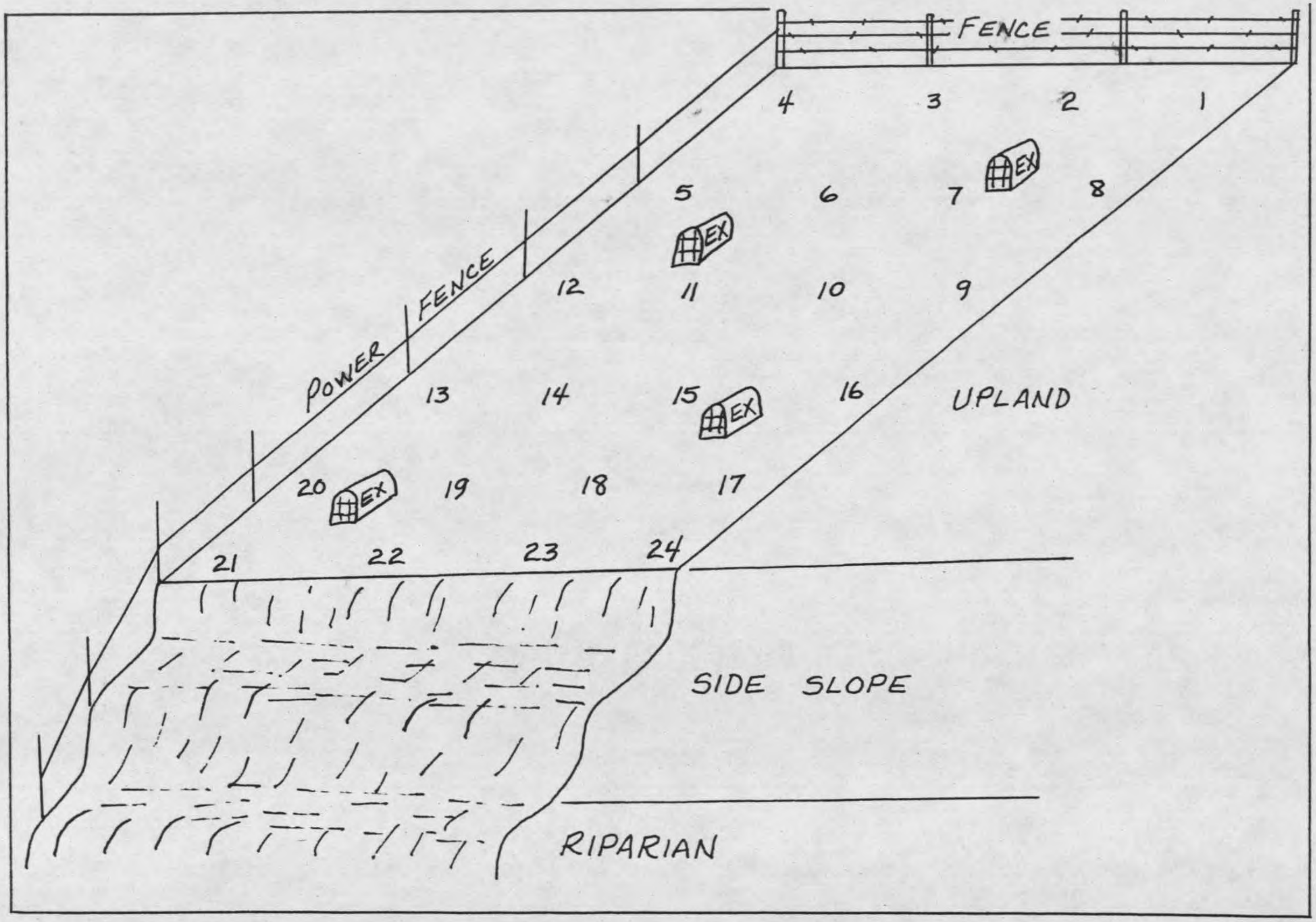

Figure 1. Physiographic positions, sample site locations and exclosures (EX) for each paddock.

Table 1. Component species of climax vegetation of a silty range site in the 380 to 480 mm precipitation zone.

Scientific name	Common Name	Category
Festuca idahoensis	Idaho fescue	increaser
Pseudoregneria spicatum	bluebunch wheatgrass	decreaser
Stipa columbiana	Columbia needlegrass	decreaser
Leymus cinereus	basin wildrye	decreaser
Hesperochloa kingii	spike fescue	decreaser
Danthonia parryi	Parry danthonia	decreaser
Elymus trachycaulus	slender wheatgrass	decreaser
Lupine spp.	lupine	increaser
Geranium viscossisimum	sticky geranium	decreaser
Balsamorhiza sagittata	arrowleaf balsamroot	increaser
Geum triflorum	prairiesmoke	decreaser
Artemisia tridentata	big sagebrush	increaser
Delphinium occidentale	tall larkspur	decreaser
Koeleria cristata	prairie junegrass	increaser
Danthonia intermedia	timber danthonia	increaser
Poa ampla	big bluegrass	decreaser

Adapted from Ross and Hunter, 1976.

The present vegetation at the study site is predominantly crested wheatgrass (Agropyron cristatum), alfalfa (Meticago sativa), Idaho fescue (Festuca idahoensis), needleandthread grass (Stipa comata), Canada bluegrass (Poa compressa), and sedges (Carex spp.). Past management of the site includes the introduction of forage species suitable for hay production. The site has more recently been used for domestic livestock grazing.

The Grazing System

Short Duration Grazing (SDG) utilizes high stock densities, and grazing pressures are reduced by shortening the grazing periods (Kothman, 1984). Researchers consider two to four animal units per hectare as high stock densities (Dr. Clayton Marlow, personal communication). To evaluate the effect of a SDG system on bulk densities of the surface layer, a 7.7 ha pasture was subdivided into eight paddocks, each were 0.97 ha in size. Portable polywire power fencing was used to divide the pasture. Only two charged wires were used to control the livestock. The energizer was manufactured by Gallagher-Snell and powered from a 12 volt car battery. The system was stocked during the 1983 grazing season with 21 yearling angus, hereford and hereford x angus cross steers. The average live weight was about 320 kg. During the 1984 season, 19 yearling steers of the same breeds were used. The grazing periods were lengthened during the 1984 season to replicate the 1983 animal unit days (AUDs) each paddock was exposed to grazing. The steers were rotated through each paddock three times during each year.

Seasonal changes in bulk density were monitored in 1983 and 1984 by measuring bulk densities in ungrazed exclosures within each paddock. In 1983 one 3 m^2 grazing exclosure was constructed on each physiographic position within each paddock. In 1984 data were collected only on the upland positions using four, 1.2 m x 1.8 m utilization cages. The cages were of re-bar construction and covered with page wire. Three sites per cage and a total of 12 sites per paddock were sampled. Utilization cages have been criticized as potentially modifying the microclimate of the sites they are protecting. To reduce the likelihood of such an occurrence, the cages were only in place during the scheduled grazing period. When the steers were rotated from a paddock, the cages were removed.

Prior to measuring bulk densities (Db), the vegetation at all sites was clipped to a 5 mm stubble height. Soil bulk densities were then measured using a Troxler model 3411B Surface Moisture Density Gauge. This instrument is "specifically designed to measure the density and moisture content of soils and soil-stone aggregates" (Troxler, 1980). The density gauge uses cesium-137 as a gamma radiation source to measure density and a neutron source (americium-241: beryllium) to measure soil moisture content.

Before collecting data the instrument was calibrated. The 3411B Gauge requires each sample site to be smooth. To prepare rough surfaces a scraper plate was provided with the instrument. An attempt was made to locate the sample site on a smooth surface, therefore the scraper plate was seldom used. A drill rod was driven into the soil to provide an access hole for the instruments source rod. The source rod was then lowered into the hole and the measurements collected. The measurements represent the mean value between the depth of the source rod and the detectors, which are located on the base of the instrument. An important attribute of the instrument is that it utilizes a non-destructive method. The gauge allows researchers to monitor changes in the same sample population over time as opposed to other methods which destroy the sample and require the comparison of different sample populations before and after treatments. An internal microprocessor provides instantaneous dry bulk density measurements, expressed as g/cm^3. Soil water is also calculated and is expressed as percent by weight.

Soil bulk densities were systematically sampled in the grazed treatment (Figure 1) and randomly sampled in the exclosures. Mid-way through the first grazing season it became obvious that sampling all eight paddocks was physically impossible because of limited assistance. It was decided to sample only the three northern paddocks. This sampling scheme was continued during the 1984 season. Twenty-four sites were sampled in the grazed portion of paddocks 2 and 3. Twenty sites were sampled in paddock 1. Data were collected at the grazed and ungrazed sites prior to each grazing event and after the final grazing event of 1984. Bulk densities were not measured after the final grazing event of 1983. The pre-grazing sample represents bulk densities following overwintering. Bulk densities for three soil layers were measured at each sample site; 0 to 5 cm, 0 to 10 cm, and 0 to 15 cm.

During the 1984 grazing season, a continuous 24-hour observation period was used to quantify the amount of time the steers were spending on the upland position. The observation period selected was the first 24 hours of each grazing period of paddock 3. Physiographic position and activity were documented for each animal at 30 minute intervals. It was assumed that the activities documented in the first 24 hour period of paddock 3 were representative of the entire grazing period for each paddock.

The data were analyzed using MSUSTAT statistical analysis package, microcomputer version 4.10. The analysis package was developed by Richard E. Lund, Research and Development Institute Inc., Montana State University, Bozeman, MT 59717.

A T-test at the 0.05 significance level was used to evaluate differences between the grazed and ungrazed treatments and to determine if the initial measurements were significantly different. A T-test was also used to document seasonal changes in bulk density. Treatment means for each paddock were tested against the previous measurement from the same paddock. Treatments were analyzed separately.

The 1984 pre-grazing measurements identified an initial difference between the treatment (grazed and ungrazed) means. In all cases, the initial difference was positive (mean Db grazed - mean Db ungrazed = difference). The null hypothesis is that the magnitude of the difference between the treatments remains constant following each grazing period. If the difference between treatment means changes following a grazing period, then the deviation is attributed to livestock grazing. An increase in the difference would indicate that livestock trampling increases bulk densities. A decrease in the difference would substantiate the claims that trampling loosens the soil by chipping and breaking surface crusts.

To determine if a particular range of pre-grazing bulk densities is more or less susceptible to compaction, the 1984 pre-grazing data were partitioned into subsamples. Because of few sample sites for each partition, data from paddocks 2 and 3 were combined into subsamples and analyzed together.

To determine if natural processes ameliorate seasonal changes, pre-grazing bulk density measurements for 1983 and 1984 were compared for statistically significant differences.

RESULTS AND DISCUSSION

Livestock Grazing

Table 2 presents the calendar days and the equivalent number of animal unit days (AUDs) that the steers spent in paddocks 1,2 and 3 during the 1983 and 1984 grazing season.

Table 2. Paddock grazing period and animal unit days (AUDs) for each paddock during 1983 and 1984.

		GRAZING PERIOD					
		1		2		3	
PAD-DOCK	YEAR	DATE	AUD	DATE	AUD	DATE	AUD
1	1983	July 9–10	44	July 30–31	44	Aug 18–19	44
1	1984	July 11–14	47	Aug 3–5	38	Aug 21–23	38
2	1983	June 29 –Jul 8	242*	July 27–29	66	Aug 16–17	44
2	1984	July 8–11	57	July 30 –Aug 1	57	Aug 19–20	38
3	1983	June 24–28	110	July 24–26	66	Aug. 14–15	44
3	1984	June 24–28	110	July 24–26	66	Aug 14–15	44

* The length of this grazing period was determined to be too long and was reduced during the 1984 grazing season.

The calendar days that livestock were in each paddock varied between years. The AUDs that steers were in each paddock and the days of rest between each grazing period were generally consistent between years. Forage availability is responsible for variation in grazing period length for each paddock. Table 3 presents the actual AUDs that the steers occupied each physiographic position during each grazing period. The data were collected during 24 hour observation periods while the steers grazed paddock 3. It is assumed that the data are consistent for all paddocks (Dr. K. Havstad, personal communication).

Table 3. Actual AUDs spent on each physiographic position during each grazing period 1984.

Grazing period	Physiographic Position: Upland	Side slope	Riparian
1	29.2 AUDs	4.2 AUDs	13.6 AUDs
2	33.6 AUDs	2.7 AUDs	1.7 AUDs
3	29.5 AUDs	4.9 AUDs	3.6 AUDs

Table 4 displays the period of rest between each grazing event.

Table 4. Number of days rest between each grazing period.

	Rest Period between Grazing Events					
	1 & 2			2 & 3		
	Paddock					
Year	1	2	3	1	2	3
	Days					
1983	20	19	26	18	18	19
1984	20	19	25	16	18	19

The grazing periods were established prior to the initiation of this study as part of another project. These rest periods are not of adequate duration to maintain the production and vigor of the existing vegetative community (Savory, 1988).

Precipitation

Although climatic data are not collected at the Fort Ellis station, records are available for Montana State University. Precipitation totals for both grazing seasons (as reported by Montana State University) are presented in Table 5.

Table 5. Reported 1983, 1984 and long term* average monthly and total summer precipitation at the Montana State University station.

Year	June	July	Aug.	Total
	Precipitation			
	mm			
1983	70.9	65.8	36.3	175.0
1984	78.2	43.2	46.2	167.6
Long Term Average (1951-80)	73.7	32.5	36.6	142.8

* U.S. Dept. Commerce, 1982.

Total rainfall for both seasons was significantly higher than the long term average. June precipitation was similar in both years compared to the long term average, July rainfall was higher in both years and August precipitation was higher than normal only in 1984.

Seasonal Changes in Bulk Density

The 3 m^2 exclosures built for the 1983 grazing season were constructed with page wire fencing secured on steel posts. A line post was set between corners, braces were not used to reinforce the corners. The steers rubbed the exclosures down and gained access. Due to entry and subsequent trampling, measurements intended to monitor seasonal ungrazed changes in bulk density were lost. Utilization cages used during the 1984 season were successful in excluding livestock.

Table 6 presents the mean bulk density measurements for each layer in paddocks 1, 2 and 3.

Table 6. Mean bulk densities for the grazed and ungrazed treatments for three soil layers.

	Grazing Period						
Depth of Soil Layer	1983			1984			
	Pre-Grazing	Post 1st	Post 2nd	Pre-Grazing	Post 1st	Post 2nd	Post 3rd
	g/cm^3						
Paddock 1							
0-5 cm							
Grazed	0.983a[1]	1.077b	1.068b	1.015a	0.995a	1.024a	1.041a
Ungrazed	*	*	*	*	0.939a	0.935a	0.977a
0-10 cm							
Grazed	1.061a	1.143b	1.127b	1.121a	1.083a	1.132b	1.136b
Ungrazed	*	*	*	*	1.037a	1.060a	1.092a
0-15 cm							
Grazed	1.083a	1.176b	1.151b	1.155a	1.114a	1.170b	1.165b
Ungrazed	*	*	*	*	1.073a	1.110a	1.117a
Paddock 2							
0-5 cm							
Grazed	1.020a	1.041a	1.064a	0.978a	1.034b	1.098b	1.073b
Ungrazed	*	*	*	0.922a	0.975a,b	1.013b	0.969a,b
0-10 cm							
Grazed	1.111a	1.146a	1.145a	1.113a	1.098a	1.187b	1.166b
Ungrazed	*	*	*	1.044a	1.057a	1.136b	1.102a,b
0-15 cm							
Grazed	1.128a	1.198b	1.181b	1.170a	1.121b	1.226b,c	1.202c
Ungrazed	*	*	*	1.096a	1.109a	1.181b	1.151b
Paddock 3							
0-5 cm							
Grazed	0.973a	1.064b	1.082b	0.917a	1.017b	1.023b	1.25b
Ungrazed	0.960	*	*	0.822a	0.894b	0.891b	0.908b
0-10 cm							
Grazed	1.045a	1.152b	1.155b	1.051a	1.128b	1.126b	1.139b
Ungrazed	1.053	*	*	0.964a	1.028b	1.025b	1.052b

Table 6. (Cont'd)

Depth of Soil Layer	Grazing Period 1983 Pre-Grazing	Post 1st	Post 2nd	1984 Pre-Grazing	Post 1st	Post 2nd	Post 3rd
	glem[3]						
0-15 cm							
Grazed	1.047a	1.192b	1.179b	1.096a	1.162b	1.170b	1.177b
Ungrazed	1.037	*	*	1.036a	1.097b	1.078b	1.102b

[1] Means followed by the same letter within a row and year are not significantly different ($P \leq 0.05$).
* Missing data.

Regardless of treatment, pre-grazing bulk densities were always lower than the final measurement of the season. The bulk densities nearly always increased significantly ($P \leq 0.05$) as the season progressed. Bulk densities declined significantly over winter. The most likely explanation would involve the development of ice crystals in the soil pores. Soil water content must be high enough to contribute adequate quantities of water to ice crystal growth. The expanding crystals fill the pore spaces and eventually exert pressures against and can shatter the soil matrix. Macro-pores remain after the ice melts (Bullock et al., 1988; Voorhees, 1983).

The ungrazed treatment data represent natural seasonal changes. The seasonal increase in Db represents the cumulative effect of the soil drying (Table 7) and supports the results of Laycock and Conrad.

Table 7. Mean percent water for three soil layers.

	1983 Pre-Grazing	1983 Post Grazing	1984 Pre-Grazing	1984 Post Grazing
	% water g/g			
GRAZED				
0-5 cm	31.7	20.1	26.9	14.3
0-10 cm	24.9	18.6	23.8	12.5
0-15 cm	25.5	17.8	22.5	12.0
UNGRAZED				
0-5 cm	32.8	*	31.7	20.1
0-10 cm	31.4	*	24.9	18.6
0-15 cm	34.6	*	25.5	17.8

* Missing data.

(1967). As soil dries, water layers surrounding soil particles become thinner and interparticle forces pull soil particles together (Larson and Allmaras, 1971). The grazed treatment also includes seasonal changes as well as the effects of trampling. In nearly all cases, pre-grazing bulk densities (Table 6) were significantly different ($P \leq 0.05$) than subsequent measurements. Table 6 presents seasonal change in bulk densities of the grazed and ungrazed sites. Because of the similarities between years for the grazed treatments, had the 1983 exclosure data not been lost, the same relationship would exist.

Also presented in Table 6 is the relationship between seasonal change in bulk density and soil depth. These changes represent both seasonal changes and the effects of livestock trampling for the grazed treatment and seasonal changes for the ungrazed treatment.

Grazing Induced Changes in Bulk Density

Table 8 presents the change in the difference between treatment means following each grazing event.

Table 8. Mean change in the difference between treatment means following each grazing period.

Soil Layer	Post 1st	Post 2nd	Post 3rd
		g/cm3	
Paddock 2			
0 to 5 cm	0.003	0.021	0.006
0 to 10 cm	-0.029	0.010	0.013
0 to 15 cm	-0.062	0.033	0.006
Paddock 3			
0 to 5 cm	0.029	0.009	0.013
0 to 10 cm	0.012	0.001	-0.001
0 to 15 cm	0.050	-0.045	0.010

If higher soil water content contributes to soil compactability then the above values should decrease after each grazing period. This pattern occurs for some soil layers, but is not consistent for others.

This study was not designed to adequately document the effect of soil water content on soil compactability. Although the time spent by livestock on each physiographic position is known (Table 3), the distance traveled consuming forage is not. Forage availability prior to each grazing event is also unknown. Although earlier in the grazing season the soil compactability was greater due to higher moisture content, forage availability was also greater. Livestock did not need to travel as far to satisfy their metabolic requirements. Hence, reduced livestock travel may decrease the likelihood of detecting larger Db changes earlier in the grazing season.

Mean bulk densities for both treatments in each measured paddock have been identified (Table 6). The data presented in Table 9 for paddocks 2 and 3 reveal that yearling steers, grazing forage produced on silt loam soils, did not significantly compact the soil between the 0 and 15 cm depths.

Table 9. T and P values for three soil layers in paddocks 2 and 3.

Soil Layer		Grazing Event: Post 1st Grazing	Post 2nd Grazing	Post 3rd Grazing
Paddock 2				
0-5 cm.				
	T	0.081	0.654	1.377
	P	0.936	0.518	0.178
0-10 cm				
	T	-0.929	-0.658	-0.201
	P	1.640	1.485	1.158
0-15 cm				
	T	-2.319	-1.065	-0.933
	P	1.973	1.706	1.643
Paddock 3				
0 to 5 cm				
	T	1.213	1.712	1.027
	P	0.233	0.096	0.312
0 to 10 cm				
	T	0.526	0.568	0.00
	P	0.602	0.574	1.00
0 to 15 cm				
	T	0.281	1.795	0.774
	P	0.780	0.082	0.444

The increasing T values between the first and second grazing periods indicate that the bulk densities of the grazed treatments are increasing at larger increments than the ungrazed. Because the P values are much larger than 0.05 the differences are not statistically significant at the 0.05 level. Surface litter and high root content within the surface layer may have cushioned the soil from hoof impact. This may partially explain why significant increases were not detected. Researchers have reported on the relationship between bulk density and infiltration rates (Wood and Blackburn, 1981) and sedimentation rates (McCalla et al., 1984). Since trampling did not significantly increase bulk densities, it is unlikely that the Db component of infiltration rates or sedimentation rates would be affected.

The following discussion provides a more detailed presentation of the study results. Readers not interested in greater specifics are encouraged to advance to the Partitioned Data section.

Results Paddock 1

The 1984 pregrazing bulk density measurements for the ungrazed treatment were inadvertently omitted. Because of this oversite, further discussion of paddock 1 data will be limited to those observations which do not require the 1984 pregrazing data.

Results Paddock 2

Table 10 presents mean bulk densities for both treatments and pregrazing treatment mean differences used in the hypothesis testing.

Table 10. 1984 pre-grazing treatment mean Db and differences.

	0-5 cm	0-10 cm	0-15 cm
	g/cm3		
$\bar{X}$ Db grazed	0.978a	1.113a	1.170a
$\bar{X}$ Db ungrazed	0.922b	1.044b	1.096b
$\bar{X}$ Difference	0.056	0.069	0.074

Means followed by the same letter in the same column are not significantly different ($P \leq 0.05$).

Because of the initial difference, the null hypothesis tested is that the pregrazing difference remains constant after each grazing event.

0 to 5 cm

The tested hypothesis is:

Ho: $\bar{X}$ Db grazed - $\bar{X}$ Db ungrazed $\neq$ 0.056

Ha: $\bar{X}$ Db grazed - $\bar{X}$ Db ungrazed $\neq$ 0.056

Table 9 identifies T and P values for the tested hypothesis. The increasing T values across grazing periods indicate that grazed Db's are increasing at larger increments than the ungrazed. These data indicate that trampling is increasing bulk densities. However, the P values greater than 0.05 indicate that the differences are not statistically significant at the 0.05 level.

0 to 10 cm

The tested hypothesis is:

Ho: $\bar{X}$ Db grazed - $\bar{X}$ Db ungrazed $\neq$ 0.069

Ha: $\bar{X}$ Db grazed - $\bar{X}$ Db ungrazed $\neq$ 0.069

The increasing T values (Table 9) identify livestock trampling as contributing to increasing grazed Db. The P values larger than 0.05 denote the differences as not statistically significant ($P \leq 0.05$).

0 to 15 cm

The tested hypothesis is:

$$Ho: \bar{\bar{X}}\ Db\ grazed - \bar{X}\ Db\ ungrazed \neq 0.074$$

$$Ha: \bar{X}\ Db\ grazed - \bar{X}\ Db\ ungrazed \neq 0.074$$

The results are similar to those above. The T values (Table 9) detect trampling as a factor contributing to increasing bulk densities. Because the P values are larger than 0.05 the changes are not significant ($P \leq 0.05$).

Results Paddock 3

Table 6 presents the pre-grazing bulk densities for both treatments for each observed layer. Table 11 displays the pre-grazing mean bulk densities for both treatments and the difference between treatment means.

Table 11. 1984 Mean Db and differences for each depth.

	0-5 cm	5-10 cm	10-15 cm
		g/cm3	
$\bar{X}$ Db grazed	0.917a	1.051a	1.096a
$\bar{X}$ Db ungrazed	0.822b	0.964b	1.036b
$\bar{X}$ Difference	0.095	0.087	0.060

Means followed by the same letter in the same column are not significantly different ($P \leq 0.05$).

0 to 5 cm

The tested hypothesis is:

Ho: $\bar{X}$ Db grazed - $\bar{X}$ Db ungrazed $\neq$ 0.095

Ha: $\bar{X}$ Db grazed - $\bar{X}$ Db ungrazed $\neq$ 0.095

The T and P values for the tested hypothesis are presented in Table 9. The P values larger than 0.05 indicate that trampling induced changes in bulk densities are not significant ($P \leq 0.05$).

0 to 10 cm

The tested hypothesis is:

Ho: $\bar{X}$ Db grazed - $\bar{X}$ Db ungrazed $\neq$ 0.087

Ha: $\bar{X}$ Db grazed - $\bar{X}$ Db ungrazed $\neq$ 0.087

Again, T values indicate trampling is contributing to the increased Db of the grazed treatment. The P values larger than 0.05 indicate that trampling effects are not significant at the 0.05 level.

0 to 15 cm

The tested hypothesis is:

Ho: $\bar{X}$ Db grazed - $\bar{X}$ Db ungrazed $\neq$ 0.022

Ha: $\bar{X}$ Db grazed - $\bar{X}$ Db ungrazed $\neq$ 0.022

The P values (Table 9) indicate that trampling was not significantly ($P \leq 0.05$) increasing bulk densities at the 0 to 15 cm depth.

Partitioned Data

Combined data from paddocks 2 and 3 were partitioned into narrower ranges of bulk density to determine if a particular range in bulk density was more sensitive to trampling. Table 12 presents the ranges in bulk density and the sample site numbers for each partition.

Table 12. Bulk density subsamples and sample site numbers for each depth and treatment.

	Bulk Density (c/cm^3) Subsamples							
Depth of Soil Layer	<0.900		0.900 - <1.00		1.00 - 1.100		>1.100	
	Grazed Site	Ungrazed Site	Grazed Site	Ungrazed Site	Grazed Site	Ungrazed Site	Grazed Site	Ungrazed Site
0-5 cm	Cell 2 2,4,5,7, 18,24	Cell 2 32,37,38,39 40,41,42	Cell 2 1,3,6,11, 12,14,15, 17	Cell 2 31,33	Cell 2 8,9,10, 16,20,21, 22,23	Cell 2 35,36	Cell 2 13,19	Cell 2 34
	Cell 3 3,6,9,10, 12,14,18, 24	Cell 3 31,32,33,34, 35,38,39,40, 41,42	Cell 3 2,4,5,11, 13,15,16, 17,19,21,22	Cell 3 36,37	Cell 3 1,7,8,20, 23	Cell 3	Cell 3	Cell 3
	<1.000		1.000 - <1.100		1.100 - <1.200		>1.200	
	Grazed Site	Ungrazed Site	Grazed Site	Ungrazed Site	Grazed Site	Ungrazed Site	Grazed Site	Ungrazed Site
0-10 cm	Cell 2 4,24	Cell 2 32,38,40	Cell 2 2,3,5,6, 7,11,12, 14,15,17, 18	Cell 2 33,36,37, 39,41,42	Cell 2 1,8,10, 13,16,20	Cell 2 31,34,35	Cell 2 9,19,21, 22,23	
	Cell 3 10,12,14, 18	Cell 3	Cell 3 1,2,3,4,5, 6,9,11,13, 15,16,17,19, 24	Cell 3	Cell 3 7	Cell 3	Cell 3	

Table 12. (Cont'd)

	<1.000		1.000 - <1.100		1.00 - <1.200		>1.200	
	Grazed Site	Ungrazed Site	Grazed Site	Ungrazed Site	Grazed Site	Ungrazed Site	Grazed Site	Ungrazed Site
	Cell 2	Cell 2	Cell 2 4,7,11,15	Cell 2 32,33,37, 38,39,40	Cell 2 1,2,3,5, 6,10,12, 14,16,17, 18,24	Cell 2 31,34,35, 36,41,42	Cell 2 8,9,13,19, 20,21,22	Cell 2
	Cell 3 14	Cell 3 40,41	Cell 3 3,6,7,9, 10,18,19, 21	Cell 3 32,33,35,36, 37,38,39,42	Cell 3 1,2,4,5, 8,11,13, 15,16,17, 20,23,24	Cell 3 31,34	Cell 3 22	Cell 3

A sample site was categorized into a particular partition based on its 1984 pre-grazing bulk density. Table 13 identifies the partitioned mean bulk densities for each depth.

Table 13. Mean bulk densities of partitions at each soil layer.

Db Partition	Pre-Grazing	Post 1st Grazing	Post 2nd Grazing	Post 3rd Grazing
0-5 cm.				
$\leq$ 0.900 g/cm^3				
Grazed	0.895	0.948	0.978	0.976
Ungrazed	0.812	0.896	0.910	0.901
0.90-$\leq$1.00 g/cm^3				
Grazed	0.947	0.992	1.035	1.028
Ungrazed	0.973	0.988	1.011	1.002
0-10 cm				
$\leq$ 1.00 g/cm^3				
Grazed	0.955	0.948	0.981	0.966
Ungrazed	0.833	0.864	0.911	0.877
1.00-$\leq$1.10 g/cm^3				
Grazed	1.056	1.076	1.116	1.119
Ungrazed	1.042	1.079	1.106	1.088
1.10-$\leq$1.20 g/cm^3				
Grazed	1.136	1.178	1.230	1.212
Ungrazed	1.118	1.105	1.205	1.168
0-15 cm				
1.00-$\leq$1.10 g/cm^3				
Grazed	1.058	1.121	1.153	1.156
Ungrazed	1.046	1.091	1.112	1.102
1.10-$\leq$1.20 g/cm^3				
Grazed	1.137	1.127	1.187	1.181
Ungrazed	1.138	1.143	1.189	1.164

Table 14 presents the T values for each partition and for each soil layer. An increasing value after each grazing period indicates that grazing increased bulk density.

Table 14. Partitioned data T values for three soil layers.

	BD Partition (g/cm^3)	Pre-Grazing	Post 1st Grazing	Post 2nd Grazing	Post 3rd Grazing
0-5 cm	$\leq$0.900	0.6491	1.440	2.259	2.648
	0.90-$\leq$1.00	3.311	-0.430	-0.032	-0.020
0-10 cm	$\leq$1.00	-1.759	0.218	0.011	0.020
	1.00-$\leq$1.10	1.581	-1.262	-0.385	0.903
	1.10-$\leq$1.20	1.117	1.165	0.302	0.697
0-15 cm	1.00-$\leq$1.10	1.003	0.732	1.625	1.822
	1.10-$\leq$1.20	-0.081	-1.434	-0.597	0.297

The P values presented in Table 15 reveal that only soils with pre-grazing bulk densities less than 0.900 g/cm^3 have values less than 0.05.

Table 15. Partitioned data P values for three soil layers.

	BD Partition (g/cm^3)	Post 1st Grazing	Post 2nd Grazing	Post 3rd Grazing
0-5 cm	$\leq$0.900	0.161	0.032	0.013
	0.90-$\leq$1.00	1.328	1.025	0.984
0-10 cm	$\leq$1.00	8.834	0.992	0.985
	1.10-$\leq$1.10	0.471	0.117	0.081
	1.10-$\leq$1.20	1.838	1.144	0.768
0-15 cm	1.00-$\leq$1.10	1.784	1.297	0.373
	1.10-$\leq$1.20	0.267	0.768	0.499

These soils have significantly increased bulk densities at the 0.05 level. Two grazing periods were required for the bulk densities to be significantly greater than those of the ungrazed treatments. Trampling induced compaction of these soils may actually improve plant growing conditions by reducing pore sizes. This would increase the capillary rise potential of the soil. Compaction would also improve the soils seedbed characteristics by increasing mineral soil/seed contact.

A more detailed discussion of the partitioned data, hypothesis testing and results follows. Readers not interested in specific details should advance to the Results of Overwintering section.

0 to 5 cm

The tested hypothesis for the partitioned data with 1984 pre-grazing bulk densities ≤ 0.900 g/cm^3 is:

Ho: $\bar{X}$ Db grazed - $\bar{X}$ Db ungrazed $\neq$ 0.014

Ha: $\bar{X}$ Db grazed - $\bar{X}$ Db ungrazed $\neq$ 0.014

The mean bulk densities increased as the season progressed. The increasing T values (Table 14) reveal that the differences between the treatment means also increased. The data indicate that livestock trampling was contributing to increased bulk densities. The trampling induced changes are significant ($P \leq 0.05$) after the second grazing period (Table 15).

The tested hypothesis for the 0.90-$\leq$ 1.00 g/cm^3 partition data set is:

Ho: $\bar{X}$ Db grazed - $\bar{X}$ Db ungrazed $\neq$ 0.226

Ha: $\bar{X}$ Db grazed - $\bar{X}$ Db ungrazed $\neq$ 0.226

The interpretation of the data is similar to the previous data set. The mean bulk densities are increasing as the season progresses. However, the difference between the treatment means is not changing significantly ($P \leq 0.05$) after each grazing event.

0 to 10 cm

The hypothesis tested for the partitioned data set Db less than 1.00 g/cm^3 is:

Ho: $\bar{X}$ Db grazed - $\bar{X}$ Db ungrazed $\neq$ 0.069

Ha: $\bar{X}$ Db grazed - $\bar{X}$ Db ungrazed $\neq$ 0.069

Generally, the mean bulk densities increase during the grazing season. Table 15 indicates that the mean difference between treatments does not change significantly ($P \leq 0.05$) during the season.

The data reveals that trampling associated with grazing does not affect soils with bulk densities less than 1.00 g/cm^3 at these depths. However, because of the small sample sizes a significant difference was not detected.

The tested hypothesis for the 1.00 - $\leq$1.10 g/cm^3 data set was:

Ho: $\bar{X}$ Db grazed - $\bar{X}$ Db ungrazed $\neq$ 0.016

Ha: $\bar{X}$ Db grazed - $\bar{X}$ Db ungrazed $\neq$ 0.016

The mean Db's increase as the season progresses. The T values (Table 14) indicate that the grazed treatment bulk densities increased more than the ungrazed treatment. This is evident by the decreasing T values. Although the Db for grazed areas are increasing at a greater rate than for ungrazed, the P values greater than 0.05 indicate that the mean difference between the treatments are not significantly different at the 0.05 level.

The tested hypothesis for the partitioned data set 1.10 - $\leq$ 1.20 g/cm^3 was:

Ho: $\bar{X}$ Db grazed - $\bar{X}$ Db ungrazed $\neq$ 0.024

Ha: $\bar{X}$ Db grazed - $\bar{X}$ Db ungrazed $\neq$ 0.024

A similar pattern occurs with this data set as with the previous set. The difference between the treatment means does not change significantly during the grazing season.

10 to 15 cm

The tested hypothesis for both partitioned data sets was:

Ho: $\bar{X}$ Db grazed - $\bar{X}$ Db ungrazed $\neq$ 0.011

Ha: $\bar{X}$ Db grazed - $\bar{X}$ Db ungrazed $\neq$ 0.011

The mean bulk densities generally increase during the season. Both partitioned subsample T values also increased following each grazing event. This indicates that trampling is contributing to an increase in the difference between the treatment means. However, the differences are not significant at the 0.05 level (Table 15).

Results of Overwintering

The previous data demonstrate that soil bulk densities increase as the season progresses (Table 6). In most cases the bulk densities at the end of the grazing season are significantly ($P \leq 0.05$) different than pre-grazing densities. The processes responsible for this pattern are the seasonal drying of the soil (Table 7) and the trampling effect of livestock in the grazed areas.

The following data will show that natural processes that occur during the non-grazing season ameliorate trampling induced compaction and natural increases in bulk density. Table 16 presents pre-grazing bulk densities for the 1983 and 1984 grazing seasons.

Table 16. Pre-grazing mean bulk densities for 1983 and 1984.

	Grazed			Ungrazed		
	Soil Layer (cm)					
	0-5	0-10	0-15	0-5	0-10	0-15
	g/cm^3					
Paddock 1						
1983	0.983a[1]	1.061a	1.083a	*	*	*
1984	1.015b	1.121a	1.155a	*	*	*
Paddock 2						
1983	1.020a	1.111a	1.128a	*	*	*
1984	0.978b	1.113b	1.170a	0.922	1.044	1.096
Paddock 3						
1983	0.973a	1.045a	1.047a	0.960a	1.053a	1.037a
1984	0.917a	1.051b	1.096a	0.822b	0.964b	1.036a

* Missing data

[1] Means followed by the same letter within the same column and same paddock are not significantly different ($P \leq 0.05$).

In some cases, the pre-grazing mean bulk densities were not significantly different between years. In other cases the pre-grazing mean bulk densities were significantly different between years. Of the samples with differences, the 1984 pre-grazing Db was less than the 1983 measurement 50 percent of the time. The samples that had larger 1984 pre-grazing Db values were the 0-5 cm sample in Paddock 1 and the 0-10 cm samples in Paddocks 2 and 3. Neither of these samples were significantly affected by livestock trampling during the 1984 season (Table 9). Since the pattern of seasonal change is similar for both years, the differences between the pre-grazing measurements are not residual livestock induced changes from the 1983 grazing season.

Bulk densities were highest when measured soil moisture was the lowest. This relationship was expected because during water loss soil particles are pulled together. Table 17 presents a comparison of soil water content and Db for the three samples, paddock 1, 0-5 cm; paddocks 2 and 3, 0-10 cm layers.

Table 17. Pre-grazing bulk densities and soil water contents for selected samples

Sample		Bulk Density (g/cm^3)	Percent soil water (g/g)
Paddock 1, 0-5 cm			
	1983	0.983a	25.7a
	1984	1.015b	19.3b
Paddock 2, 0-10 cm			
	1983	1.111a	17.5a
	1984	1.113a	20.3b
Paddock 3, 0-10 cm			
	1983	1.045a	33.7a
	1984	1.051b	34.0a

Means followed by a different letter in the same column for the same paddock are significantly different at the 0.05 level.

The difference between years is apparently a function of the percent soil water at the time of sampling. The higher water contents have thicker films of water surrounding the soil particles. Since water is incompressible the soil particles are forced apart to accommodate higher water contents. This reduces the total soil particles per unit volume soil.

The return to near pre-grazing bulk densities demonstrates that natural processes ameliorate seasonal increases in bulk densities.

Although not specifically documented, freeze-thaw cycles, capillary rise of water to freezing zones, elongation of ice crystals and resultant expansion of soil pores are probably the major forces reducing bulk densities. To a lesser extent, the expansion associated with wetting of soils and flocculation and aggregation associated with drying cycles also contribute to reducing soil bulk densities.

Management Implications

This is based on the fact that no significant differences between treatments were detected when the paddocks were analyzed separately, and that other researchers identified bulk density as an important variable influencing infiltration (Wood and Blackburn, 1981) and runoff (McCalla et al., 1984). This type of grazing system does not adversely affect the infiltration or sedimentation. In addition, soil aeration and resistance to root penetration should not be significantly different between the treatments.

If the vegetative community is managed for improved vigor and production by allowing adequate rest between grazing periods, then the grazed sites can at least be as productive as the ungrazed sites.

By grazing these sites livestock are mechanically knocking vegetation to the soil surface. Once on the surface this vegetation is in an environment that is conducive to decomposition by microorganisms. The metabolic by-products and waste produced by grazing livestock accelerates mineral cycling. Because of the increased availability of plant nutrients, plant production on the grazed sites could exceed that of ungrazed sites.

SUMMARY AND CONCLUSIONS

Soil bulk densities were measured to determine effects of a short duration grazing system on a silt loam soil at depths of 0 to 5 , 0 to 10, 0 to 15 cm. Soil bulk density and moisture contents of grazed and ungrazed sites were measured prior to the first grazing period and immediately following each period. These measurements represented seasonal changes for each treatment and also effects of grazing/trampling. The 1984 data identified a difference between the grazed and ungrazed mean bulk densities. The tested hypothesis was:

Ho: $\bar{X}$ Db grazed - $\bar{X}$ Db ungrazed ≠ pre-grazing difference

Ha: $\bar{X}$ Db grazed - $\bar{X}$ Db ungrazed ≠ pre-grazing difference

The difference between the treatment means was used to quantify grazing induced changes in bulk density. An increase, identified after any grazing period, demonstrated that cattle were compacting soil. A decrease in the difference betweeen treatment means supports claims that cattle loosen the soil surface layer by chipping and breaking soil crusts.

Seasonal change in soil bulk density was quantified during the 1983 and 1984 grazing season (Table 6). Soil bulk densities increased as the soil water content decreased and final measurements were usually significantly different from the pre-grazing measurements. This occurred regardless of whether the site was grazed or ungrazed. The effect of wetting and drying cycles during the grazing season was not specifically addressed in this study. Although precipitation events and drying occurred between the first and second, and the second and third grazing events, bulk densities continued to increase in both grazed and ungrazed treatments. These data support earlier research by Laycock and Conrad (1967). The implication is that regardless of the number of precipitation events during summer months, the driving force of seasonal bulk density change is soil drying. This was evident during two summer seasons with above normal precipitation. As the thickness of water layers surrounding individual soil particles decrease, the interparticle forces pulled the soil particles together. Similar results would be expected during periods of normal or below normal precipitation. The only difference would be a more rapid and/or a greater change in bulk density when fewer precipitation events occur.

Summer precipitation of June, July and August 1983 and 1984 was above normal and it is presumed that soil moisture contents were also above normal. Under these conditions, trampling associated with a short duration grazing system which incorporates stock densities of 10, 320 kg yearling steers per hectare for periods of up to 4 days, significantly increased the bulk densities of soils that had pre-grazing values less than 0.900 g/cm^3. These soils were more vulnerable to compactive forces because of their high volume of large pore space and relatively few interparticle or interaggregate contacts. Once these soils became more dense and had a greater total area of aggregate or particle contact, their resistance to further compaction increased. This would explain why the soil partitions with greater bulk density did not show significant livestock induced change in bulk density. Deformation forces exerted by the livestock did not exceed internal soil strength.

Evidence of livestock induced compaction was measured in all layers. However, only the soils with pre-grazing values less than 0.900 g/cm^3 were statistically significant at the 0.05 level. Trampling induced compaction may actually improve plant growing conditions by reducing pore sizes. This would increase the capillary rise potential of the soil layer, allowing deeper soil moisture to be wicked to germinating seeds and improving the likelihood of seedling establishment. Caution should be used when extending these results to grazing systems for mature cattle. Live body weights can be between 450 and 680 kg. These animals would exert greater pressures than yearling steers. Consequently, soil compaction could occur over a broader range of bulk densities.

Although bulk densities increased seasonally as soil dried, the 1984 pre-grazing bulk densities demonstrated reductions during the previous autumn, winter or spring. These observations support other work which documents the amelioration of compacted soils by freeze-thaw activity (Larson and Allmaras, 1971) and the disruptive forces exerted by expanding ice crystal within the pores of a wet soil (Bullock et al., 1988).

Although ice crystals were not directly observed in the soil surface layer, local climatic conditions would suggest that freeze-thaw activity was responsible for reducing soil bulk density.

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