Changes in surface roughness on thin silty range sites under time-controlled grazing in northeastern Montana

by Blaine Hanson Macfee Mooers

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Range Science
Montana State University

Abstract:
Slow water infiltration on improperly grazed rangelands has reduced soil moisture and increased runoff and erosion. Since infiltration rates can be improved by increasing surface roughness, I investigated the potential of time-controlled grazing to increase surface roughness.

The objectives of this study were 1) to determine if time-controlled grazing caused significant changes in surface roughness on, thin silty range sites, 2) to assess whether these changes varied with distance from water, and 3) to. examine the effects of season on surface roughness.

Surface roughness was measured within six hours before and after grazing events at 288 permanently marked stations, in three 81 ha pastures. Cattle grazed each pasture for four days in both June and October 1987 at an animal density of 12.25 head/ha and a stocking density of 7.75 animal units/ha. The severe drought of 1988 limited grazing to two days in June at an animal density of 6.63 head/ha and a stock density of 3.35 animal units/ha. Grazing in 1987 did not change surface roughness, but grazing in 1988 increased surface roughness when the surface soil was very dry and plant material was very brittle. Surface roughness changes did not vary with distance from water as hypothesized.

Season had an overriding influence on changes in surface roughness. Surface roughness was greater in nine ungrazed exclosures (p=.0001) in June and October, 1987 and April, 1988 than in June, 1988. Lack of adequate plant cover due to severe drought may have exposed surface roughness to greater weathering. In order for grazing management to influence surface roughness under moister conditions, new methods of creating herd impact, in addition to higher animal densities, are needed.

KEYWORDS: Surface roughness, time-controlled grazing, seasonal influences, distance from water, runoff, erosion, thin silty range sites, northeastern Montana.

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A thesis submitted in partial fulfillment
of the requirements for the degree

of

Master of Science

in

Range Science

MONTANA STATE UNIVERSITY
Bozeman, Montana

June 1989

N378
M776

APPROVAL

of a thesis submitted by

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This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citations, bibliographic style, and consistency, and is ready for submission to the College of Graduate Studies.

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ACKNOWLEDGEMENTS

I thank my major advisor Dr. Clayton Marlow and the members of my committee--Drs. John Lacey, Brian Sindelar, and Tad Weaver--for their valuable suggestions and logistical assistance with this research project. I also thank Gene Foss of the Pothook Ranch for his enthusiasm for this study, his cooperation in allowing this study to be conducted on his ranch, and for managing the large numbers of cattle used in this study. I thank Dr. Gary A. Lehrsch of the USDA Agricultural Research Service in Kimberly, Idaho for sharing computer programs that calculate the surface roughness measures that he developed. For assistance with computer programming, I thank Debbie Rossi, Kathrin Olson-Rutz, and Dr. Richard Lund of MSU. For at least two hundred hours of assistance with data collection and for financial support, I thank my wife Gloria Mooers.

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ABSTRACT

Slow water infiltration on improperly grazed rangelands has reduced soil moisture and increased runoff and erosion. Since infiltration rates can be improved by increasing surface roughness, I investigated the potential of time-controlled grazing to increase surface roughness.

The objectives of this study were 1) to determine if time-controlled grazing caused significant changes in surface roughness on thin silty range sites, 2) to assess whether these changes varied with distance from water, and 3) to examine the effects of season on surface roughness.

Surface roughness was measured within six hours before and after grazing events at 288 permanently marked stations in three 81 ha pastures. Cattle grazed each pasture for four days in both June and October 1987 at an animal density of 12.25 head/ha and a stocking density of 7.75 animal units/ha. The severe drought of 1988 limited grazing to two days in June at an animal density of 6.63 head/ha and a stock density of 3.35 animal units/ha. Grazing in 1987 did not change surface roughness, but grazing in 1988 increased surface roughness when the surface soil was very dry and plant material was very brittle. Surface roughness changes did not vary with distance from water as hypothesized.

Season had an overriding influence on changes in surface roughness. Surface roughness was greater in nine ungrazed exclosures (p=.0001) in June and October, 1987 and April, 1988 than in June, 1988. Lack of adequate plant cover due to severe drought may have exposed surface roughness to greater weathering. In order for grazing management to influence surface roughness under moister conditions, new methods of creating herd impact, in addition to higher animal densities, are needed.

KEYWORDS: Surface roughness, time-controlled grazing, seasonal influences, distance from water, runoff, erosion, thin silty range sites, northeastern Montana.

INTRODUCTION

Since the turn of the century, researchers have reported that severe grazing will reduce soil infiltration rates and increase sediment production (Branson 1984). Nonetheless, the large number of damaged watersheds scattered throughout the western United States reflect a continued lack of understanding of the relationships between livestock grazing and the many physical and biological factors that affect soil infiltration rates and sediment production.

Some advocates of intensive grazing management propose that watershed conditions can be improved by short duration exposure to a high density of hoofed herbivores (Savory 1988). According to this herd impact model, hoof impact breaks water-repellent soil crusts, knocks down dead plant material, and incorporates plant litter into the soil surface. These actions leave the soil surface with a high infiltration rate. In addition, the hoofprints left in both dry and wet soil may increase the amount of surface roughness thereby trapping more overland flow and giving it more time to infiltrate into the soil. High stock densities are thought to encourage uniform distribution of these trampling benefits over a paddock while short grazing periods limit the negative impacts of increased soil bulk density and increased trailing. Long rest intervals between grazing events allow paddocks time to recover from these negative impacts. However, the 30 to 90 day rest periods in most short-duration grazing schemes may be too short for full recovery of the soil surface. Gifford (1986) suggests that six months to ten years of rest may be required for surface soils to recover from high levels of trampling.

The increase in surface roughness predicted by the hoof impact model has not been adequately investigated. Range hydrology studies prior to 1980 were mostly conducted on pastures under season long grazing, and few included measures of soil surface roughness (Blackburn 1984). During the 1980s, increased interest in using intensive grazing management as a tool to improve watershed conditions led to more attempts to quantify the relationships between livestock trampling and various hydrologic parameters, including surface roughness (Knight 1980, Wood and Blackburn 1981, McCalla et al. 1984, Warren et al. 1986a, Warren et al. 1986b, Warren et al. 1986c, Warren et al. 1986d, Weltz and Wood 1986, Pluhar et al. 1987). Most studies found weak to moderate correlations between surface roughness and infiltration rates for two reasons. First, most of these studies simulated rainfall for storms of extremely long return periods (100-150 years). Second, surface roughness was measured parallel to the contour. By measuring surface roughness both parallel and perpendicular to the contour, Sanchez and Wood (1987) recently demonstrated a strong relationship between infiltration rates and surface roughness.

In addition, only researchers in New Mexico and Texas have studied the influence of short duration grazing on surface roughness. Branson (1984) warned against the extrapolation of these results to all of North America's rangelands due to the great variation in hydrological processes from region to region. Consequently, he called for more studies conducted over a much wider geographical range.

This study's goal was to learn more about the relationship between time-controlled grazing and soil surface roughness under natural precipitation. The objectives were (1) to determine the degree of changes in surface roughness caused by time-controlled grazing with cattle on thin silty range sites in northeastern Montana, (2) to determine whether changes in surface roughness varied with distance from water, and (3) to examine effects of seasons on changes in surface roughness on sites protected from grazing.

LITERATURE REVIEW

Definition of Surface Roughness

Surface roughness, microrelief, and microtopography were used interchangeably for the past thirty years in range hydrology research. This caused confusion over what was measured. In an intensive study of tillage effects on surface roughness, Römkens and Wang (1986) identified four types of surface roughness for cropland:

1) Microrelief caused by individual grains, micro-aggregates, or aggregates of soil. Microrelief was on the scale of 0 to 2 mm high and was of great interest to researchers of soil micromorphology.
2) Surface variations due to clods usually caused by the break-up of soil by tillage implements. This variation was on the order of 100 to 200 mm high. It was often referred to as random roughness in surface roughness research on cropland.
3) Systematic differences in elevations caused by farm implements and on the order of 100 - 200 mm high were referred to as oriented roughness.
4) Roughness on a larger topographic level caused by elevation variations at the landscape level.

The first order of roughness (microrelief) may reflect presence or absence of soil crusts induced by raindrop impact. These crusts have less roughness than noncrusted soil due to the packing of a thin layer of silt particles at the surface (Brakensiek and Rawls 1983). Soil crusts have been shown many times to impede infiltration (Osborn 1952).

The second order of roughness on unimproved rangelands often occurs on the scale of 5 to 100 mm rather 100 to 200 mm as on cropland. Still, it may be the most important type of roughness on a broad scale in terms of runoff retention since most rangelands have not had their surface roughness increased through mechanical rangeland improvement practices. This second order of roughness is caused by uneven mulch layers, root crowns of plants, coppice dunes of soil and plant litter around and under the basal portions of grasses and shrubs (Eckert et al. 1986a), eolian deposits (Hennessy et al. 1986), erosion pedestals, rills, wind-scoured depressions, ant disks (small bare areas created by ants), livestock trails, alluvial deposits on the uphill side of perennial plants, depressions in hoofprints, and mounds or ridges on the downhill side of hoofprints (Anderson 1974). This type of roughness should not be called random roughness on unmodified rangelands because it may be dependent on the distribution of plant species which are rarely randomly distributed.

Two types of oriented or nonrandom roughness (the third order of roughness) occur on rangelands: natural and man-made. Examples of naturally occurring nonrandom roughness exist on some North American rangelands. Some soils contain properties that result in the formation of a pattern of microridges and microvalleys or microknolls and microbasins; this type of surface roughness is called gilgai (Soil Survey Staff 1975). The vertical interval ranges from 1 cm to 2 m and the spacing between ridge crests ranges from 1 m to 12 m. Gilgai have occurred in six identifiable patterns (Hallsworth et al. 1955). On the northern Great Plains, it is most frequently found on alluvial fans with soils of high clay content (White and Bonestell 1960). Its influence on surface runoff storage and the spatial variability in wetting depth can be dramatic (Hallsworth et al. 1955).

The second type of oriented roughness on rangelands is created by such rangeland improvement practices as furrowing, root plowing, pitting, ripping, and scalping (Branson et al. 1966). These practices reduce surface runoff and increase water infiltration very effectively (Branson et al. 1966). This type of surface roughness traps a significant amount of surface runoff; contour furrows could store 25 mm of water in eastern Montana (Neff 1973).

The fourth order of surface roughness concerns features identifiable on contour maps. Soil scientists apply the term topography to roughness of this scale during soil surveys (Soil Survey Staff 1951). Topography affects the distribution of runoff not trapped by the lower orders of roughness.

I measured the first two levels of surface roughness in my study for four reasons. First, the third level of roughness was not present on the study area. Second, hoof impact cannot easily change the fourth level of roughness. Third, the first two levels do have the greatest potential for change by the trampling of livestock. Fourth, of the three orders of surface roughness present on this study area (1, 2, and 4), the first two orders control the proportion of precipitation that infiltrates into the soil where it lands as opposed to infiltrating at another site downhill. Since the processes of surface water retention and infiltration may operate together to result in greater soil moisture, I did not attempt to distinguish between the first two orders of roughness. Consequently, both levels are referred to as surface roughness in this study.

Importance of Surface Roughness

Onstad (1984) showed a strong relationship between surface roughness, depressional storage of surface runoff, and slope on cropland. As slope increased or as surface roughness decreased or as both occurred, the depressional storage of overland flow decreased and water infiltration decreased. Although this relationship has not been demonstrated on rangeland, Sanchez and Wood (1987) found a strong relationship between surface roughness, water infiltration, and sediment production on native and reclaimed rangeland in New Mexico. Similarly, Tromble (1976) showed that root-plowed and pitted plots in southeastern Arizona had greater surface roughness and less surface runoff than control plots. As surface roughness increased, sediment production decreased and water infiltration increased. Surface roughness increases the frictional drag on runoff thereby reducing its velocity. This reduces the erosive powers of runoff, and it provides a greater opportunity for the filling of surface depressions with water and sediment. Water trapped in these depressions eventually infiltrates or evaporates (Sanchez and Wood 1987). The fate of this trapped water on rangelands needs more adequate investigation.

Improvements in water infiltration rates are very important in semiarid and arid ecosystems where an estimated 12% of the annual precipitation is available for plant growth. About 66% is lost to evaporation and another 8% is lost as runoff (Keller 1971). While runoff losses may appear small, reductions in surface runoff could be significant for plant growth. For example, using Keller's estimates, a 50% reduction of runoff loss through improved infiltration via increased surface roughness would increase by 30% the water available for plant growth. Similar improvements in soil moisture have been accomplished economically on rangeland by modifying surface roughness with mechanical improvement (Ryerson et al. 1974).

Wilson and Leigh (1964) demonstrated the strong influence of surface roughness on water infiltration in a protected saltbush community dominated by <u>Atriplex</u> and <u>Kochia</u>. They excavated a 15 m long and 60 cm deep transect through one of their study sites following a rainstorm. Although surface roughness had a maximum range of only 30 mm, the wetting front reached 40-60 cm under the low areas but only 10 cm deep under the mounds.

In addition to soil erosion and infiltration, soil surface roughness influences net solar radiation reaching the soil surface. Allmaras et al. (1972) found that fall tilled cornfields had greater winter and spring surface and subsurface soil temperatures than spring tilled fields. They believed this was partially due to the greater direct radiation flux density on the unshaded surfaces. Although Allarmas et al. (1977) found that rough surfaces had proportionally less heat storage, greater air turbulence, greater sensible heat loss, and greater latent heat losses when compared to smoother surfaces, rough surfaces still stored more heat than smooth surfaces. Thus, surface roughness can have a positive influence on the flow of energy, air, and water at the soil surface.

Surface roughness can also greatly influence seedling establishment (Harper 1977). For many seeds of certain morphologies and sizes, rough surfaces improve seed to soil contact and thereby the amount of soil moisture in contact with the seed (Pemadasa 1976, Pemadasa and Amarasinghe 1982, Sterling et. al. 1984, Eckert et al. 1986b, Hamrick and Lee 1987).

High vertical intervals of surface roughness result in greater water storage and infiltration. Coppice dunes, gilgai, and mechanical rangeland improvements have both high vertical intervals and high horizontal intervals. This causes greater variation in wetting depth. Hoofprints often have smaller diameters than these other types of surface roughness features. However, they can have as much vertical relief if made in wet soil. Due to their small diameter, hoofprints can also be more evenly distributed across the landscape. Consequently, evenly distributed hoofprints might reduce the spatial heterogeneity of infiltration rates.

Reductions in the spatial heterogeneity of infiltration rates and wetting depths could result in a more even distribution of soil moisture. This could lead to a more even distribution of individual plants and greater plant density. This in turn may result in greater utilization of the available light, space, mineral, and water resources for plant growth.

The renewal of surface roughness is important because the erosion of the high points of surface roughness and the deposition of sediment in the low points causes reductions in surface roughness over time (Neff 1973). The renewal of the surface roughness of coppice dunes, gilgai, or mechanical rangeland improvements may require several years or large expenditures of money (Hallsworth et al. 1955).

In contrast, hoofprint induced surface roughness is a potentially easy and quick way to renew surface roughness. Grazing management then becomes a means of distributing hoofprints through the pasture. This example of the maintenance of hydrologically desirable surface roughness reflects the goals of most grazing strategies: increases in forage productivity and maintenance of high forage production.

Grazing Terminology

The grazing management terms animal unit, animal-unit equivalent, stocking density, animal density, stocking rate, and grazing pressure are used to describe the grazing studies in the literature reviewed below. The animal unit is the basis for the definition of most grazing terms. An animal unit (AU) has been defined as "one mature 454-kg cow or its equivalent based on an average forage consumption of 12 kg..." dry matter (DM)/day (Society for Range Management 1974). Animal-unit equivalents (AUE) are expressions of the forage demand of animals with consumption rates lower or greater than 12 kg DM/day. AUEs are expressed as proportionate fractions or multiples of one animal unit. They have generally been based on live-weight (Scarnecchia and Kothmann 1982).

The Society for Range Management (1974) defined stocking density as the relationship between the number of animals and the area of land at any instant in time. Stocking density is usually expressed in terms of animal units per acre or hectare. The actual number of individual animals and the total number of animal-unit equivalents in a herd are rarely equal. Consequently, I have used the term animal density to refer to the actual number of individual animals (livestock in this paper) on a unit area of land at any instant in time since the number of animals with hooves is of greater interest in a hoof impact study than the number of animal units.

Stocking rate is an expression of stocking density over time. The Society for Range Management (1974) has defined stocking rate as the number of animal units/unit of land/ unit of time. The time unit can expressed as day, month, or year. The most common expression of stocking rate is animal unit month (AUM)/ac or AUM/ha.

Grazing pressure is the ratio of animals to forage at a given instant (Society for Range Management 1974); its units lack a time dimension. Typical units are AU/kg and AU/ton.

Grazing Methods

The studies reviewed below examined the following grazing methods: yearlong, continuous, season long, deferred rotation, short duration, and high intensity--low frequency. Yearlong grazing occurs on a specific unit of land for the entire year. Continuous grazing by livestock occurs on a specific unit of land throughout the year or throughout that part of the year when grazing is feasible. Consequently, yearlong grazing and continuous grazing are not always synonymous. Season long grazing occurs on a specific unit of land during a specific season for usually one to four months (Society for range Management 1972).

Deferred rotation provides a systematic rotation of deferment among pastures. Deferment is the delay of livestock grazing on a pasture to provide time for plant reproduction, establishment of new plants, or recovery of existing plants (Society for Range Management 1974). One pasture may be deferred while livestock graze the remaining pastures, or livestock graze one pasture while the remaining pastures receive deferment from grazing for various lengths of time.

Short duration grazing is similar to time-controlled grazing in that often a large number of livestock are concentrated in relatively small pastures for short periods of time. This is where the similarity ends. Under short duration grazing, the length of a rotation cycle through a series of pastures is pre-planned. Time-controlled grazing is also planned, but the grazing plan is continuously revised in response to plant growth rates (Savory 1988). The length of time a herd spends in a pasture depends heavily on current plant growth rates; the length of time before the herd returns to that pasture depends upon the plant growth rates that occur during the rest period between grazing events. This frequent readjustment of plans makes experimental testing of time-controlled grazing challenging when measurements are needed at several points in time (Savory 1988). High intensity--low frequency (HILF) grazing is a variant of short duration grazing. Rigid rotation plans are followed, but grazing occurs less frequently (often once every 120+ days) (Knight 1980).

Short Duration Grazing's Influence On Surface Roughness

The influence of time-controlled grazing on surface roughness has not been studied. However, preliminary work has been done under a similar grazing strategy, short duration grazing, using simulated rainfall.

Rangeland hydrology researchers have not concentrated on the effects of short duration grazing on surface roughness. They collected surface roughness data with other parameters including the following: grass standing crop, vegetation cover by species, bare ground cover, shrub-canopy area and interspace area, soil organic matter, soil aggregate size, soil aggregate stability, grass standing crop, soil bulk density, and soil organic matter. Frequently, two to four of these hydrologic parameters explained a large portion of the variation in sediment production and water infiltration (Blackburn 1984). However, the set factors that explained most of the variation in infiltration rates and sediment production changed from site to site and from study to study

(Branson 1984). Consequently, we still lack a complete understanding of the hydrologic importance of surface roughness and of the influence of short duration grazing on surface roughness.

Nine studies collected data about the influence of short duration grazing on surface roughness. Two studies were on the Rolling Plains of Texas (Wood and Blackburn 1981, Pluhar et al. 1987), six studies were on the Edwards Plateau of Texas (Knight 1980, McCalla, et al. 1984, Warren et al. 1986a, Warren et al. 1986b, Warren et al. 1986c, Warren et al. 1986d), and one study had two locations in New Mexico (Weltz and Wood 1986). Because all of these studies were conducted in the southwestern United States, we should not forget Branson's (1984) warning against the extrapolation of results from a narrow geographic area to the rest of North America's rangeland.

Studies on the Texas Rolling Plains

Wood and Blackburn (1981) were the first in North America to collect surface roughness data during an investigation of short duration grazing (actually the variant HILF grazing). Their first objective was to determine infiltration rates under deferred-rotation, HILF grazing, continuous grazing, and grazing exclusion. The second objective was to determine how the different grazing systems affected the various hydrologic parameters that influence infiltration. Apparently changes in surface roughness were not detected because no surface roughness changes were reported.

Pluhar et al. (1987) compared the infiltration rates and sediment production under five grazing treatments. Each treatment had one replicate. They compared single paddocks from a 14-paddock short duration grazing system, from a 42-paddock short duration grazing system, from a 4-pasture 3-herd deferred rotation system, from a yearlong grazing system, and from an ungrazed exclosure. They collected surface roughness data before and after each grazing event in the rotational pastures and once every three months in the continuously grazed pastures. New randomly located plots were used each time data were collected because the harvesting of plant material and the simulated rainfall destroyed the plot's original surface roughness characteristics. This made repeated measures of surface roughness impossible.

When surface roughness was averaged across four seasons for the 14-paddock, 42-paddock, and yearlong grazing, there were no significant differences between treatments. The inability to resample the same location before and after grazing events may have contributed to their inability to detect change in surface roughness. When averaged across treatments, there were significant differences between seasons. Surface roughness was not significantly different between August 1982 and March 1983 and between November 1982 and July 1983, but it was lower on the first set of dates.

Infiltration rates were also lowest in the spring and highest in the fall. The opposite was true for bulk density.

The occurrence of soil bulk density's seasonal peak in the spring and its seasonal low in the fall is contrary to the trend in soil bulk density observed by Laycock and Conrad (1967). They observed an increase in soil bulk density as the growing season progressed in Utah. They attributed this increase to the shrinking of the soil as it became drier towards the end of the summer. They also attributed the low spring bulk density values to frost heaving. Shrinking and swelling during the summer rainy season may be the primary mechanism decreasing soil bulk density. Consequently, seasonal trends in surface roughness observed in Texas may be the opposite of those on rangelands in northern latitudes where frost heaving has a greater influence and where soil moisture content may peak earlier in the growing season.

<u>Studies on the Edwards Plateau</u>

Most studies reporting surface roughness data come from the Texas Agricultural Research Station near Sonora on the Edwards Plateau. Knight (1980) compared the response of surface roughness in shortgrass and midgrass vegetation to heavy continuous grazing, moderate continuous grazing, and HILF grazing over an eighteen month period. Midgrass areas had higher surface roughness than the shortgrass areas. Surface roughness remained similar under the moderate continuous and HILF treatments over the eighteen month period. Surface roughness was lower in the heavy continuously grazed pasture, and it declined during the eighteen month period. Unfortunately, changes in surface roughness between the beginning and the end of the grazing events of the HILF grazing system were not reported.

McCalla et al. (1984) explored the influence of heavy continuous grazing, moderate continuous grazing, short-duration grazing stocked at twice the normal stocking rate, and no grazing on sediment loss. Surface roughness data collected on eleven dates were negatively correlated (r=.-44) with sediment production. However, surface roughness means were not reported.

At the end of the above study in 1981, a second study at the same location was initiated by Warren et al. (1986a). It ran from late 1982 to late 1984. It was conducted on a 32 ha pasture with a high degree of spatial heterogeneity caused by scattered oak mottes, midgrass interspaces, shortgrass interspaces, and scattered honey mesquite (<u>Prosopis</u> <u>glandulosa</u> Torr. var. <u>glandulosa</u> (Torr.) Cockll.) and ashe juniper (<u>Juniperus</u> <u>asheii</u> Buchh.) trees. This pasture was grazed to simulate a seven pasture short duration grazing system with a 56 day rotation cycle. These researchers sampled this pasture immediately prior to entry by livestock, soon after their removal, and midway between grazing events. However, surface roughness did not differ significantly between the growing season and the dormant season across the two years of this study. Surface roughness was correlated (r=.45) with growing season water infiltration and with dormant season water infiltration (r=.40). It was negatively correlated with growing season sediment production (r=-.30) and dormant season sediment production (r=-.19). Water infiltration recovered partly and sediment production had declined somewhat by the midway point in the rest periods. Apparently, the researchers did not detect the recovery of surface roughness.

A concurrent study at the same location looked at hydrologic responses to different stock densities under a rigid short duration grazing regime (Warren et al. 1986b). Three treatments, each with one replication, were applied: 16 ha pasture grazed for 4 days at a yearlong stocking rate of 4.8 ha/AU/yr with a stocking density of 0.34 ha/au, a 24 ha pasture grazed for 6 days at 4.8 ha/Au /yr and .51 ha/AU stocking density, and a 32 ha pasture grazed for 8 days at 4.8 ha/AU/yr and 0.68 ha/Au stocking density. All three pastures were in good range condition and represented 14, 9, and 7 pasture systems respectively. Cattle, sheep, and goats grazed each pasture. Eight 0.4 m^2 plots in the shortgrass and in the midgrass vegetation types were sampled prior to livestock introduction to the pasture, immediately after their departure, and midway through the rest period. Mean surface roughness values did not vary significantly with stocking density. These workers also reported correlation coefficients of r=.48 and -.33 between surface roughness and water infiltration, and surface roughness and sediment production, respectively. These results were expected because as surface roughness increases, runoff slows, the opportunity for infiltration increases, and sediment settles into depressions rather than moving off-site.

A fifth study at the Texas Agricultural Experiment Station on the Edwards Plateau attempted to resolve whether the impact of hooves on the soil surface or the removal of protective vegetative cover is responsible for the decline in hydrologic condition observed following the use of heavy stocking rates (Warren et al. 1986c). Annual forbs dominated the study site. It had not been grazed for seven years. Plants were killed with 2,4-D prior to the initiation of trampling treatments. The soil was a high shrink-swell silty clay on flat terrain with 4% organic matter and silty clay to a depth of 25 to 50 cm where there was a root-restricting petrocalcic horizon. The researchers evaluated four trampling intensities in twelve paddocks (.011 ha each). The four trampling intensities were: moderate (1 x normal stocking rate) (8.1 ha/AU/yr), double (2x) (4.1 ha/AU/yr), triple (3x) (2.7 ha/AU/yr), and a control. Treatments were applied five times at 30-day intervals from May 20 to September 20. The resulting 30-day rest periods were shorter than rest periods used in other studies at this station. Some soil properties recovered partially during the 30 day intervals, but there was no mention of any change in surface roughness.

Trampling rate had a significant negative correlation with infiltration rate and a significant positive correlation with sediment production. Surface roughness was positively correlated with water infiltration (dry soil r=.28 and wet soil r=.41) and negatively correlated with sediment production (wet r=-.30 and dry r=-.34). In spite of the four relationships described above, surface roughness had no relationship with trampling intensity. This is surprising since studies reviewed above had reported relationships between water infiltration and surface roughness and between sediment production and surface roughness.

Warren et al. (1986d) report more detail on the response of soil bulk density, aggregate stability, aggregate size and surface roughness to the different trampling intensities used in the study just described above. They did not report whether they could detect changes in soil roughness between the beginning and end of each trampling event. However, they did report that surface roughness on dry soil correlated negatively with bulk density (r=-.21). Surface roughness on wet soil correlated positively with aggregate stability (r=.30), with negatively aggregate size (r=-.34), and negatively with bulk density (r=-.29).

Studies in New Mexico

Weltz and Wood (1986) examined the influence of livestock exclusion, continuous grazing, and short duration grazing on infiltration rates at two locations in New Mexico. At the Fort Stanton Experimental Ranch, treatments included a heavily stocked (13.4 ha/AU) continuously grazed 337 ha pasture, a moderately stocked (18 ha/AU) continuously grazed 168 ha pasture, a short duration pasture of 95 ha stocked at (14 ha/AU), and a 7.5 ha exclosure protected since 1952. Potential replicate pastures were too dissimilar to use as replicates in this study. Measurements of hydrological parameters were made in three zones from water: 0.4 km, 0.8 km, and 1.2 km. There were no significant differences in the other hydrological parameters with increasing distance from water. However, surface roughness data were not reported.

At Fort Sumner in the Canadian-Pecos plains area, treatments during July 1982 included a moderately stocked continuously grazed 260 ha pasture (26.6 ha /AU), one paddock of a short duration grazing system 65 ha (13.3 ha/AU) before and after 3 days of grazing, and a 4 ha exclosure protected from grazing since 1900. Methods were the same as those described above. Again, no results concerning surface roughness were reported.

Summary of Studies

Only three of nine studies reported mean values of surface roughness. Knight (1980) found the only documented difference between surface roughness on a short duration pasture and on a pasture under a different type of grazing regime. No data show significant changes in surface roughness between the start and the end of a short duration grazing event. Distance from water may be unimportant under short duration grazing (Weltz and Wood 1986). There were significant differences in surface roughness between vegetation types. Seasons may have a greater affect on surface roughness than animal impact (Pluhar et al. 1987). Surface roughness was positively correlated with infiltration rate and a negatively correlated with sediment production. Differences in infiltration rates, sediment production, and several hydrologic parameters other than surface roughness were demonstrated between short duration grazing and other types of grazing systems. The lack of differences in surface roughness were attributed to no changes occurring, testing short duration grazing over an inadequate range of animal densities, or improper sampling technique.

Surface Roughness Sampling In Short Duration Grazing Studies

All of the researchers mentioned above used very similar methods of collecting surface roughness data. They used 10 or 21-pin relief meters with metal pins spaced 60 mm or 43.5 mm apart, respectively. The relief meter was placed across each infiltration plot at three locations. They collected surface roughness before or after (or both) applying simulated rainfall to infiltration plots. The application of artificial rainfall to simulate storms with a long return frequency (120-150 years) resulted in destructive sampling. Thus, none of these studies were designed to make repeated measurements of surface roughness over a long period of time. If these researchers were concentrating on detecting changes in surface roughness, they either would have used an extremely large number of randomly located plots in order to separate the inherent variability in surface roughness from changes caused by grazing treatments, or they would have established permanent monitoring sites separate from the infiltration plots.

Studies of Other Grazing Systems

New Mexico

Gamaougoun et al. (1984) found significant differences in surface roughness between grazing treatments on a blue grama (Bouteloua gracilis (H.B.K.) Lag.) dominated mesa at Fort Stanton Experimental Ranch in south-central New Mexico. Treatments were one pasture continuously grazed at a heavy stocking rate, one pasture continuously grazed at a moderate stocking rate, two pastures (grazed and rested) from a four-pasture one-herd rotation system stocked at a heavy rate, and an exclosure protected since 1952. Surface roughness values were highest in the exclosure, the heavily stocked continuously grazed pasture, and the rotationally grazed pasture. High values in the exclsoure were attributed to the bunchgrass growth form of its blue grama plants while blue grama plants outside of the exclosure had a flat sodgrass growth form. The high values in the two grazed pastures were attributed to hoof action during wet weather. Means were reported for each treatment and each year. Means were highest in 1981 which was a wet year.

Wood et al. (1986) compared surface roughness of six season-long grazed pastures. These pastures were located at the Fort Stanton Experimental Range. Three pastures were stocked at 2.5 ha/AU with yearling heifers for three to four months, and three fertilized pastures were stocked at 1.2 ha/AU. The researchers found no difference in surface roughness between treatments. They attributed this lack of difference to the increased plant growth on the fertilized area mitigating the impacts of higher livestock numbers. Presumably, trampling by the higher density of livestock in the fertilized pastures was assumed to flatten surface roughness, but this flattening was counteracted by the larger basal crowns of the grass plants resulting from the fertilizer.

Mean surface roughness values were reported by year. The authors generalized that surface roughness may be influenced by the swelling and shrinking of soil from wetting and drying and from freezing and thawing. Surface roughness was lowest in 1980 and highest in 1981. These yearly differences were explained by precipitation differences. While 1980 was characterized by a "dry spring", 1981 had a "wet" spring. They also speculated that livestock increased surface roughness during periods when the soil was wet and livestock decreased surface roughness when the soil was dry.

Idaho

Surface roughness was measured in southern Idaho under a variety of season-long grazing management strategies (Colborg 1972). Data were collected monthly at permanently marked locations over two years in crested wheatgrass pastures on fine sandy loam. Colborg (1972) demonstrated graphically a seasonal trend in surface roughness. Annual maxima occurred in late March and was attributed to frost heaving. Minima occurred in late summer or early fall and was attributed to raindrop impact, shrinking of the soil surface layer during drying, and cattle trampling. Surface roughness often increased in the fall after rainstorms as a result of the soil swelling. Unfortunately, Colborg (1972) did not make statistical comparisons between months or between the grazed areas and the exclosures, and data were not collected immediately before and after cattle grazed each pasture.

England

Davies and Armstrong (1986) monitored changes in the surface roughness of tame pasture in Northumberland, England for three years. They hypothesized reductions in surface roughness resulting from the installation of subterranean drains. On the clay soils studied in this wet part of Great Britain, sward production was reduced by poaching--"...the penetration of the soil surface by the hooves of grazing animals...". When infiltration rates were low and swollen soil limited water flow down soil cracks, the opportunities for puddling increased as excess rainfall ponded rapidly on the soil surface.

Surface roughness was measured at 12 permanently marked 1 m transects once every 3-4 months. These were placed at right angles to the slope. Variability in elevation values were attributed to imprecise relocation of the relief meter, inadequate leveling of the horizontal bar, and genuine soil surface movements. Sheep grazing in the pasture did not appear to walk between the metal markers of the 1 m permanent transects, and they did not affect surface roughness. Changes in surface roughness were also not attributed to shrinking and swelling of the soil. "The belief in surface recovery to a flat surface in the winter after the removal of stock in the fall seemed to be a myth." The undrained plot had the greatest surface roughness initially (standard deviation of 11.2 mm versus 6.8 mm and 9.3 mm for the first two treatments which were two types of subsurface drainage). However, the standard deviations grew closer after three years (8.5 mm for the undrained treatment and 7.1 mm and 8.6 mm for the drained plots) implying that increased surface roughness caused by poaching weathers away after 3 years.

The Effects of Trampling

Process of Soil Deformation

The extent and nature of soil deformation by cattle depends on the rate of treading, the type of soil and its water content. Compression of the soil under the hoof occurs at low to moderate soil moisture conditions. Under high soil moisture conditions plastic flow around the hoof predominates; under prolonged exposure to high moisture levels the soil can become so weakened as to allow severe disruption of the soil surface from treading (known as poaching in Great Britain). Under dry soil conditions, only shallow hoofprints occur and the bulk density of the soil remains near an equilibrium value with the pressure being exerted by the hoof. Under wet soil conditions, trampling produces both poaching of the soil surface and compression in deeper layers because of the uneven distribution of water content within the soil profile (Scholefield et al. 1985).

Scholefield et al. (1985) initiated the approach of using a simulated hoof to examine the process of soil surface deformation. High speed films of walking cattle revealed that hooves contacted the soil surface for .75 seconds while the forelimb pivoted 50 degrees through the vertical. The maximum pressure applied vertically by a walking 530 kg cow on a force plat was 300 kPa, assuming a contact area of 100 cm2. The cow applied this pressure to the ground for 0.6 seconds which was slightly less than contact time. The sum of the maximum forces applied in the other two directions was less than 25% of the maximum vertical force.

The oedometer (the instrument mounted with the simulated hoof and equipped to apply 300 kPa of pressure) caused a compressive deformation of less than 30 mm in a time of less than 0.43 seconds on four grassland soils. The compression of two sandy clay loams increased with increasing water content. The opposite trend was observed in two clay loams. The rapid elastic recovery of all soils increased with increasing water content (from 32 to 56 %). The amount of porosity lost (3 to 6%) from compression was similar to the amount lost by increasing the water tension of uncompressed soil from 1 to 103 kPa (3-6%). In three of the four soils, compression and shrinkage seemed to be independent processes.

Deformation of Surface Roughness

No one has documented the deformation of surface roughness features under controlled levels of trampling by livestock. However, the impact of trampling by human recreationists on native vegetation has been documented (Cole

1985). Curvilinear relationships exist between trampling intensity and vegetation loss and between trampling intensity and soil compaction. A linear relationship exists between mineral soil exposure and trampling intensity (Cole 1985). Similar relationships may or may not exist with livestock, and they probably vary with different ecosystems and soil moisture conditions.

Abdel-Magid et al. (1987b) used an artificial hoof to simulate the trampling that might occur on shortgrass prairie sod under short duration grazing and continuous grazing. Continuous grazed samples were trampled at regular intervals over 32-day periods; the short duration-grazed samples were trampled during the last four days of the 32-day period. The researchers found that water stress had a major impact on detachment of plant material under very high trampling levels (trampled 32 x's in 32 days to simulate continuous grazing or trampled 32 x's in 4 days to simulate short duration grazing). Detachment of plant material doubled when plants were under severe moisture stress. Both live and dead plant material were less brittle when plants were under less moisture stress. When live plant parts had good water relations, the humidity around plants probably enhanced the moisture content of the dead plant material. A more realistic level of trampling (4 x's in 32 days versus 4 x's in 4 days) detached 5% of the living plant material and a larger precentage of the dead material. A greater loss of dead material occurred under the continuous, rather than under the short duration grazing system. Although not quantified, the removal of plant material by high frequencies of trampling could decrease surface roughness by reducing root crown size.

Effects on Bare Soil Crusts

Unprotected bare soil is susceptible to the formation of a surface seal or crust by raindrop impact. This crust impedes water infiltration (Osborn 1952) and reduces saturated conductivity by 75 to 90% (Brakensiek and Rawls 1983). Hoof impact under time-controlled grazing can break this surface crust and thereby improve water infiltration (Savory 1988).

Although this type of surface crust is widespread on semiarid rangelands, it is not universal. Braunack and Walker (1985) found three soils in Australia that did not form crusts. They attributed this lack of crust formation to 1) insufficient silt for packing between sand particles, 2) low surface levels of sodium that would otherwise cause dispersion, 3) high surface organic carbon content, and 4) a surface layer of soil that was more porous than lower layers.

Effects on Cryptogamic Crusts

Cryptogamic crusts are the second type of crusts that form on exposed mineral soil. They consist of liverworts, mosses, lichens, and algae. Since lichens are very slow growing and very sensitive to trampling, the abundance of cryptogamic crust has been considered a sign of over-rest from grazing (Savory 1988). Loope and Gifford (1972) and Brotherson and Rushforth (1983) documented small reductions in infiltration rate due to the presence of cryptogamic crusts. They attributed these reductions to 1) the high silt content often found under cryptogams that swells upon wetting and thereby impedes percolation, 2) the gelatinous filaments of algae that swell when wet thereby blocking downward flow of water, and 3) entrapped air beneath the sealed surface (Brotherson and Rushforth 1983). Consequently, advocates of time-controlled grazing hypothesize that hoof impact breaks up cryptogamic crusts and thereby increases the amount of water entering the soil.

Trampling under season long grazing has been sufficient to reduce most of the cover and the number of species of mosses and lichens in the deserts of the southwestern United States. Filamentous algae were less susceptible to damage by trampling (Anderson et al. 1982, Brotherson et al. 1983).

However, the same crusts that slow infiltration rates have also been noted for their high surface roughness which retained more water than bare surfaces. This high surface roughness slowed surface flow, increased opportunities for infiltration, reduced opportunities for concentration of water into rills, reduced erosive powers, and increased wetting depth (Brotherson and Rushforth 1983). The same three mechanisms which impede water may also reduce evaporation (Brotherson and Rushforth 1983). Unfortunately, there have been no comparisons of the moisture content beneath protected cryptogamic crusts and beneath soil exposed to time-controlled grazing.

Seasonal Changes in Surface Roughness Without Grazing

Arizona

Kincaid and Williams (1966) compared surface roughness from the beginning of the summer of 1964 to the end of the summer. They were interested in the effect of summer rains on a variety of mechanical treatments. They made repeated measures of the same surface roughness profile. They compared surface roughness from the beginning of the summer of 1964 to the end of the summer. No significant change in surface roughness occurred in the control plot, but surface roughness was reduced significantly in several of the pitted treatments. These researchers attributed these reductions in surface roughness to raindrop impact.

Piosphere Concept

The second hypothesis tested in this study concerned whether or not time-controlled grazing caused surface roughness to decrease with increasing distance from water. This hypothesis was based on the piosphere concept as first defined by Lange (1969). Stockwater is at one extreme of this cline of animal impact. Animal impacts on the vegetation and soils declined with increasing distance from water. Lange (1969) showed how sheep trails spread out in almost radial lines from water tanks on flat terrain in Australia. Very few trails cut between the radial trails. Only fences and large patches of impenetrable brush diverted trails from a radial direction. Pickup and Smith (1987) comment that topographic features also influence the patterns of livestock utilization in piospheres.

Lichen frequency decreased with increased grazing pressure and with decreased distance from stockwater (Rogers and Lange 1971). Osborn et al. (1932) and Barker and Lange (1969) found that the impact of sheep grazing on plant population structure and species composition was greatest near stockwater. Andrew and Lange (1986a, 1986b) documented similar effects of livestock grazing on vegetation and soils during the formation of a new piosphere. They found that soil compaction followed a piosphere pattern, but it was largely confined to sheep trails.

Graetz and Ludwig (1978) described vegetation and soil responses to the piosphere phenomenon with the logistic growth curve of population biology. A multiple regression approach to the piosphere concept has also been suggested (Andrew 1988). This strategy would reduce the need for a large number of replicate paddocks stocked at different stocking rates. Replication could be obtained through several radial transects within one piosphere.

METHODS

Study Area

This study was conducted in 1987 and 1988 on the Pothook Ranch 40 km northwest of Sidney, MT (48° 2' 15" N, 104° 36' 30" W). Average annual precipitation is 330 mm and the annual solar thermal unit potential evapotranspiration is 686 mm. The 243 ha study area is on the glaciated plains (Pescado and Brockmann 1980), and it has the hilly topography typical of most rangeland in northeastern Montana. In this region, most sites with gentle topography were put into small grain production in the 1910s and the 1920s. The prominent soils in the study area are Zahill loam, Lambert loam, and Vida loam (Pescado and Brockmann 1980).

The climax vegetation in this region is mixed-grass prairie (Weaver and Albertson 1956). Range sites were generally in fair to excellent range condition, but the thin silty range sites used in this study were in good to excellent range condition. *Schizachryium scoparius* (Michx.) Nash dominated these sites with *Bouteloua curtipendula* (Michx.) Torr. and *Stipa comata* Trin. and Rupr. as codominants and with *Juniperus horizontalis* Moench and *Carex filifolia* Nutt. as subdominants. These species provided 85-95% total canopy cover. Plant names are presented according to GPFA (1986).

These sites were in high condition due to light grazing by cattle in the past. Before 1981, the study area was grazed in the spring and fall as part of a 647 ha pasture. Between 1981 and 1984, the study area was under twice-over deferred rotation management. In 1985, the study area was reduced to a 243 ha pasture, and time-controlled grazing was applied to it.

Treatment

In June 1987, the study area was divided equally into three 81 ha study pastures (Figure 1). Although the pastures in this study differed in outline, they had similar area, grazing history, forage production, range condition, carrying capacity, and representation of range sites, aspects, and topographical features. Each pasture was grazed by herds of mixed breed cows and yearlings under time-controlled grazing in 1987 and 1988. This grazing technique resembles short duration grazing, but it is not the same (Savory 1988). In time-controlled grazing, the length and frequency of grazing events depends on plant growth rates and forage availability instead of calendar dates. This feature makes this grazing method very flexible (Savory 1988).

Treatments consisted of exposure to and exclusion from time-controlled grazing on thin silty range sites located at

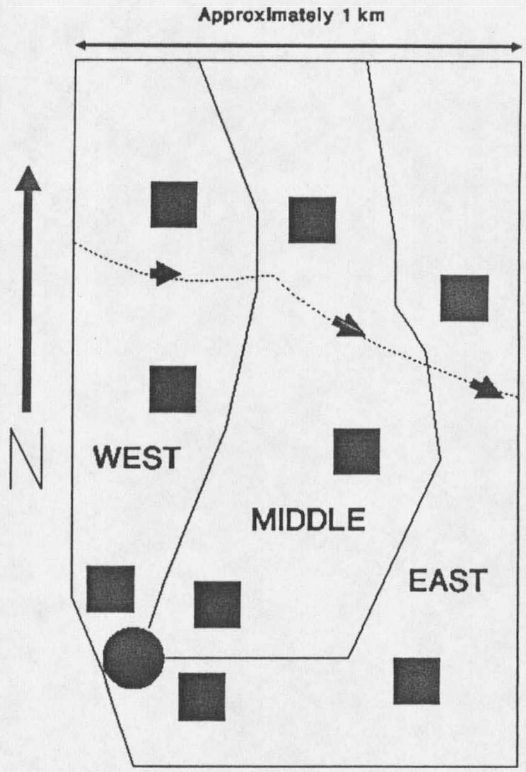

Figure 1. Aerial view of study area showing the three 81 ha pastures on the Pothook Ranch, Richland County, MT. Squares represent plots; cirlce represents stockwater.

three distances from water (100 m, 500 m, and 1000 m) (Figure 2). Since grazing intensity often declines with increasing distance from water (Lange 1969), I collected data at three distances from water to sample three assumed levels of grazing intensity.

Animal numbers and number of days they spend in each pasture varied been 1987 and 1988 due to large differences in annual precipitation (Figure 3). First, near normal precipitation falling in 1987 (292 mm) supported normal forage production (Figure 4). Consequently, cattle grazed each pasture for four days in the spring (June) and again in the

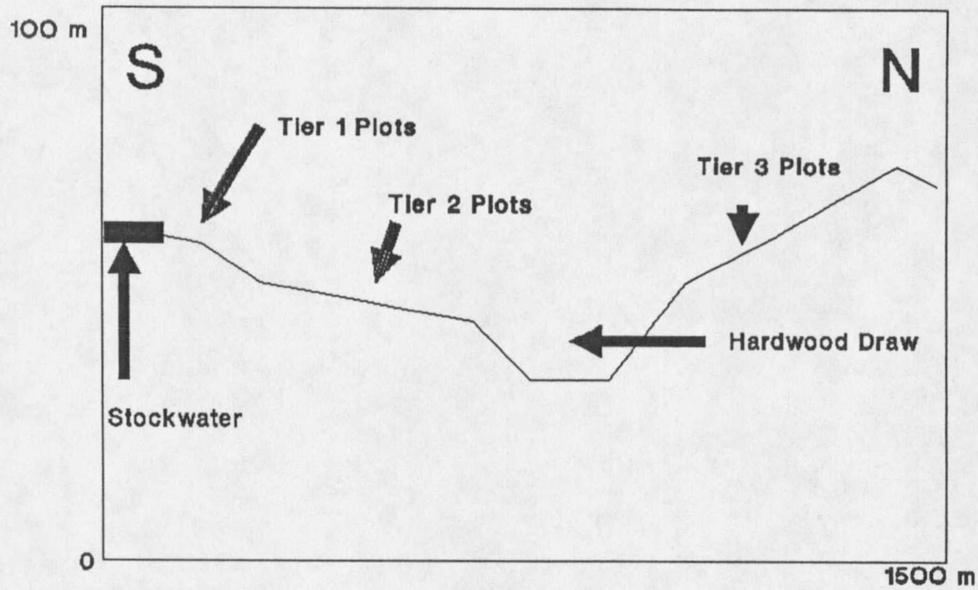

Figure 2. Profile view of middle pasture, surface roughness study area, Pothook Ranch, Richland County, MT.

fall (October). The 90 days of rest between grazing events in 1987 is the recommended length of rest for this region during slow plant growth periods in the summer and fall (Savory 1988). The pastures were grazed with 993 cows, calves, and yearlings at a stocking rate of .96 ha/AUM (2.38 ac/AUM). Animal density was 12.25/ha (4.96/ac) while stocking density was 7.75 AU/ha (3.14 AU/ac).

In the second year (1988), little precipitation fell (168 mm) (Figures 3 and 4). I estimated forage production to be 20% of that which occurred in 1987. Consequently, 537 cows,

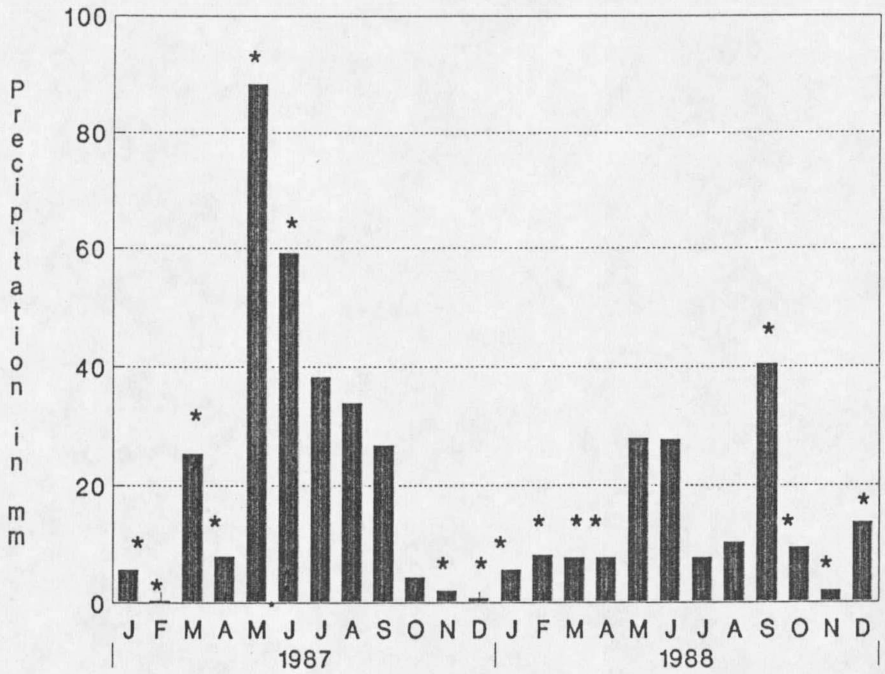

Figure 3. Monthly precipitation collected on or near the study area. Values marked with an asterisk are from Culbertson 10 km north of study area on the Pothook Ranch, Richland County, Montana.

calves, and yearlings grazed each pasture for two days in June at a stocking rate of 4.5 ha/AUM (11.11 ac/AUM--4.7 times less than in 1987). Animal density was 6.63/ha (2.685 individuals/ac) while stocking density was 3.35 AU/ha (1.36 AU/ac). Lack of plant regrowth prevented grazing the pastures a second time.

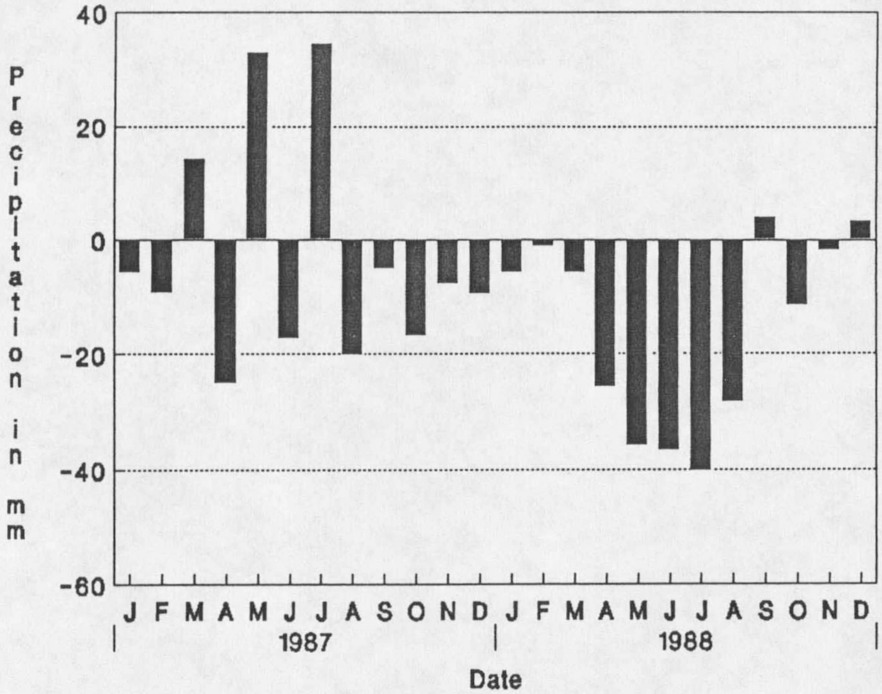

Figure. 4. Monthly precipitation deviations from the long-term average in Culbertson, MT 10 km north of the study area on the Pothook Ranch, Richland County, Montana.

Sampling

Plots

Each pasture had three pairs of plots--ungrazed and grazed. I stratified the plots by distance from water, aspect, and range site (Figures 1 and 2). I established pairs of plots at three distances from the water tanks: 100 m, 500 m, and 1000 m. These distances were referred to as tier 1, tier 2, and tier 3. Plots in tiers 1 and 2 were on north aspects, and plots in tier 3 were on south aspects. All plots were on thin silty range sites in good range condition with 8-19% slopes. Of the paired plots, one, randomly selected, was a treatment plot while the other, enclosed by a fence, was a control plot. Two meters separated each pair of plots to prevent bias caused by cattle travelling along the edge of the exclosure (Figure 5).

Surface roughness data were collected along four permanent transects within each of the eighteen (3 pastures x 3 distances x 2 treatments) 5 m x 10 m plots (Fig. 5). The four transects were randomly selected from 10 potential transects spaced 1 m apart. Each transect was 5 m long and ran perpendicular to the slope. The long side of each plot was parallel with the slope.

Surface roughness was sampled at four randomly located, permanently marked locations along each transect (Figure 5). There were 16 locations (4 transects x 4 locations) on each plot and 288 locations throughout the study area. Both ends of each 0.4 m roughness sampling location were permanently marked with a 60 penny spike driven into the soil through a 19 mm diameter washer. The right side of each location had a washer painted red. This eased the relocation of transect ends. Sampling of transects outside and inside of the

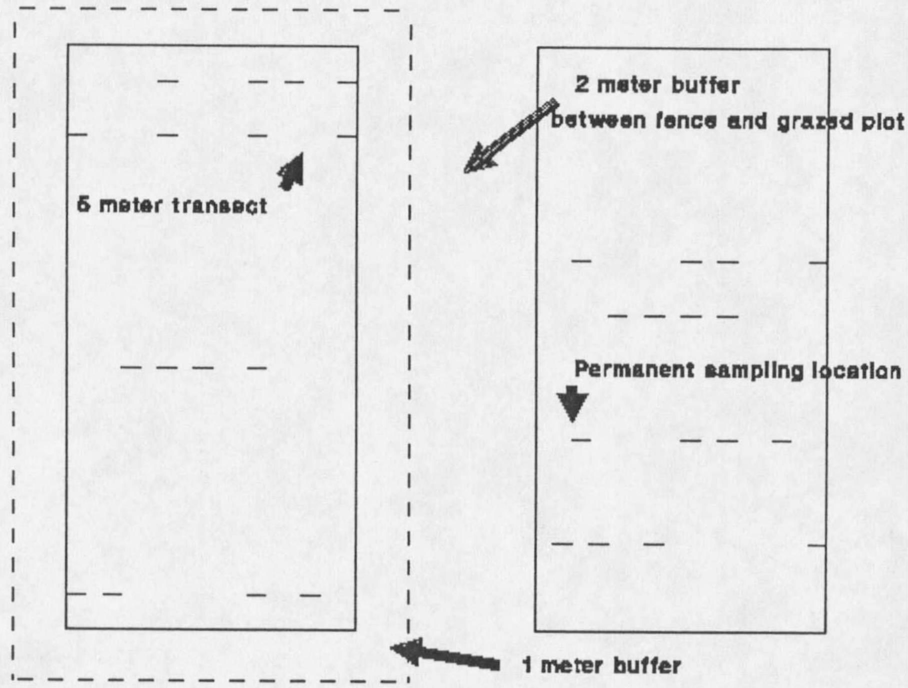

Figure 5. Paired plots located in the first tier of the middle pasture. The left plot was ungrazed, and the right plot was grazed. This pair of plots were from the study area on the Pothook Ranch, Richland County, MT.

exclosures was completed within six hours before and after each grazing event to avoid changes in surface roughness caused by weathering.

Roughness Sampling

A 65-pin point-frame (with pins spaced 6.3 mm apart) was used to measure surface roughness parallel to the contour. (This surface roughness meter was designed by Dr. Clayton Marlow, Animal and Range Sciences Dept., Montana State University). Typical surface roughness meters have pins spaced 43.5 mm or 60 mm apart (Gamougoun et al. 1986, Warren et al. 1986d). Surface roughness was easily, quickly, and accurately recorded on graph paper mounted on a board behind the metal pins and secured with metal clips. The ground surface represented by the position of the pin tops was traced by passing a mechanical pencil over the metal pin tops and along the graph paper.

Dr. Marlow designed the point frame to facilitate exact relocation of pins before and after treatment. The point frame's metal legs were 20 mm wide, and they had two flanges that projected out at 90 degree angles for 10 mm. These flanges made the legs fit snugly around the washers under the heads of the 60 penny (128 mm) spikes. The legs were inserted into the soil 22 mm.

The pin height data on the graph paper was digitized with a Kurta Corporation digitizer and Jandel Corporation's Sigma-Scan software package (Kurta Corporation 1987, Acker and Mitchell 1987). The pin height data from each sampling site were stored in separate data files on micro-computer diskettes. Then these files were linked together into one large data file and organized for reduction into surface roughness measures with a series of programs (Appendix A, Figures 15-22) custom built with a statistical software package (SAS Inc. 1985).

In June 1987, side-slope was isolated by placing the point frame parallel to the side-slope. Later, the point-frame was fitted with a carpenter's level and adjustable legs to permit leveling the point frame. A leveled point frame measured both the surface roughness and the side slope of ground surface. Before the surface roughness measures were obtained, side slope information in the data collected from October 1987, April 1988, and June 1988 were removed because time and resources were too limited to permit its investigation. The side slope effect on pin height was removed by setting the slope of a regression line through the 65 pins to zero. I assumed that the slope of the regression line was a fair reflection of side slope. Since the slopes of the regression lines were very small, adjustments in pin height rarely exceeded two millimeters.

The roughness measures were obtained by using the adjusted data set as input into the SAS program TREG and the Fortran program AREA.FOR (Lehrsch 1985) (Appendix A, Figures 21 and 22). The output data set from AREA.FOR served as input into several programs (Appendix A, Figures 27, 28 and 30) made under the General Linear Models Procedure of the SAS statistical package to accomplish the statistical analysis described below (SAS 1988).

Hoofprint Sampling

To obtain an index of trampling intensity, I collected hoofprint density data from each grazed plot shortly after grazing in the fall of 1987. Prints were counted in ten 20 x 50 cm quadrats placed at 0.5 m intervals along ten 5 m transects in each grazed plot. The quadrats were placed with their long side parallel to the slope. They were placed on the uphill side of the transects to exclude the influence of human traffic which had occurred on the downhill side of the transects during the collection of surface roughness data. Hoofprints that fell on the edge of the quadrat received a value of .5 while hoofprints completely within the quadrat received a value of 1.

Precipitation Sampling

Precipitation measurements were taken with two 70 mm diameter 300 mm long round aluminum Stewart Universal Rain Gages. These gauges were installed in exclosures in the middle and east pastures with the rim of the rain gauge at 500 mm above the soil surface. These gauges contained evaporation baffle float discs. Measurements were made within six hours of each precipitation event. The average of these values plus an estimate of winter precipitation based on data from a NOAA cooperative weather station in Culbertson (10 km north) were used to calculate annual precipitation (NOAA 1987 and 1988).

Surface Roughness

Intuitively, surface roughness recorded parallel to the contour should index the resistance of the surface to the overland flow of water while surface roughness measured perpendicular to the contour should index its surface water storage capacity. However, Sanchez and Wood (1987) found that the magnitude of the positive correlations between "horizontal" surface roughness and infiltration, and between "vertical" surface roughness and infiltration varied with soil moisture content. The sum of surface roughness values measured in both directions had even higher correlations with water infiltration. I measured surface roughness horizontally in this study to facilitate rapid relocation of the large number of surface roughness locations (96 per pasture).

Microrelief Index

Surface roughness meter pin heights for each frame location along a transect were converted into a new surface roughness measure: microrelief index (MI) (Lehrsch et al. 1988b). At least fifteen surface roughness measures have been developed to date (Kuipers 1957, Burwell et al. 1969, Allmaras et al. 1966, Currence and Love 1970, White 1983, Linden and Van Doren 1986, Römkens and Wang 1987, Lehrsch et al. 1988b). Testing all of these parameters for their sensitivity to changes caused by grazing may be one method of selecting a parameter. Since I did not have the time or resources to perform this test, I chose one measure that both reflected soil surface roughness and was easy to comprehend. Over half of the surface roughness measures developed to date involve the combination of two or more surface roughness measures.

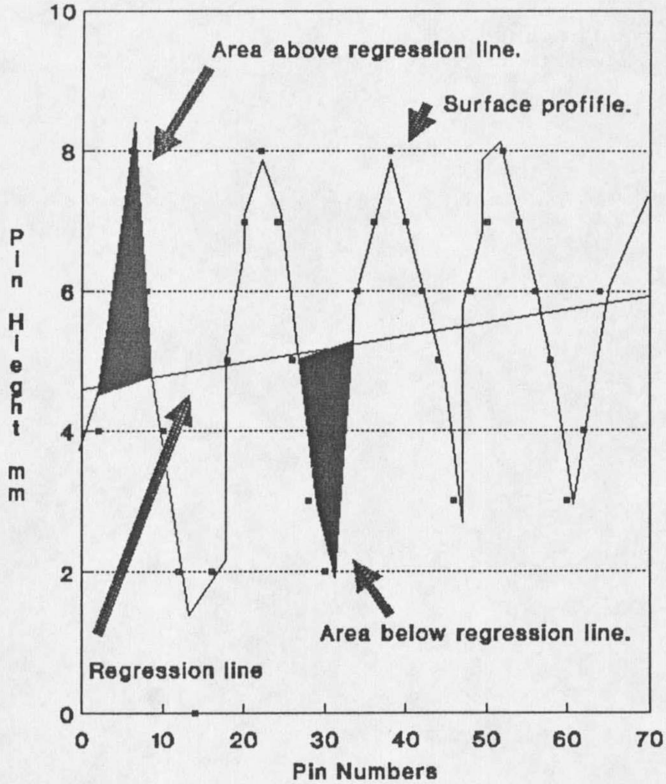

Figure 6. The areas between the surface roughness profile and its regression line were used to derive microrelief index values for the Pothook Ranch, Richland County, MT.

Although these measures may respond well to changes in surface roughness, they can be difficult to interpret.

Microrelief index (MI) is the area between the least-squares regression line and the surface roughness profile (Figure 6). Both areas above and below the regression line were summed and divided by transect length. MI can also be thought of as the average of the absolute value of the residuals. As this index increases, the area above and below the regression line increases and the resistance to surface runoff increases.

Experimental Design

Pretreatment Values

A two-way analysis of variance was conducted with the pre-grazing June 1987 data to determine if there were any antecedent differences in microrelief index (MI) values between the nine paired plot locations. Transect means from both the plot to be grazed and the plot to be protected from grazing were combined since both plots in a pair had yet to be exposed to different grazing influences.

Grazing Effects

To test hypotheses about the effect of time-controlled grazing on changes in surface roughness and about the relationship of these changes with distance from water, I used analysis of variance to compare values collected immediately before and after each grazing event. Since MI data were normally distributed and had equal variance, data transformations were unnecessary. Each year had to be considered a separate experiment due to the difference in stocking rate between years. The experimental design for 1987 was a split-split-plot with four factors: pastures, distance of paired plots from water (tiers), treatment (grazed or ungrazed), and season (Appendix B, Table 8). The experimental design for 1988 was a split-plot with three factors: pastures, distance of paired plots from water, and treatment (Peterson 1985). Time was not a factor in 1988 because the pastures were grazed only once (Appendix B, Table 10).

Seasonal Effects

To evaluate the impact of seasonal effects on surface roughness, data from the exclosures were analyzed with a repeated measures analysis of variance (SAS 1988). The two factors in this model were the season of data collection and plot location (Appendix B, Table 12). Actual surface roughness values were compared in this analysis rather than differences as in the first two analyses. This analysis was used because changes in actual surface roughness between seasons were of interest here rather than differences caused by a grazing event.

Pastures could not serve as replicates as originally planned for two reasons. First, the grazed plot in tier 1 of the west pasture received far more trampling than the other two grazed plots in tier 1. Second, two-way analysis of variance with the June 1987 pregrazing data with pastures and tiers as the main effect showed that all locations did not have the same initial surface roughness. Consequently, transects within plots were used as replicates. Transects were assumed to be spatially independent since they were one or more meters apart. Other investigators of surface roughness rarely found spatial dependence beyond transect intervals of 20 cm (Linden and Van Doren 1986, and Römkens and Wang 1986 and 1987, Lehrsch et al. 1988a).

Statistical Procedures

All analysis of variance procedures were made with type III sum of squares (SAS 1988). For the 1987 data, the error mean square was used in F-tests of the main effect time and its associated interactions, the mean square for {transects [treatment (pasture x tier)]} was the denominator in F-tests of main effect treatment and its associated interactions, and the mean square for [transects (pastures x tiers)] was the denominator in F-tests of the main effects pastures and tiers and their interaction. For the 1987 data, the error mean square was used in F-tests of the main effect treatment and its associated interactions. The mean square for [transects (pastures x tiers)] was the denominator in F-tests of the main effects pasture and tier and their associated interactions.

A significance level of .05 was used to test for differences between means. Single degree of freedom contrasts were used to separate means. When the use of contrasts was not possible, I used Fisher's Least Significant Difference Procedure. In the repeated measures analysis of variance, tests for significant differences among the means were made with Greenhouse and Geisser's adjusted F-test (Greenhouse and

Geisser 1959). This test is more conservative than the common F-test.

RESULTS

Microrelief Index

Pretreatment Values

The interaction between pastures and tiers was not significant, the tier factor (or distance from water) was not significant, and the pasture factor was marginally significant (Table 1). The third tier again had a lower value than the other two tiers, but this value was not significantly different from that values for the first and second tiers (Table 2). Fisher's Protected Least Significant Difference Procedure was used to separate pasture means instead of contrasts because the data had been examined before the development of contrasts. Surface roughness was greater in the middle pasture than in the other pastures (Table 2).

Table 1. ANOVA for test of antecedent differences in microrelief index values between nine paired plot locations on the Pothook Ranch, Richland County, Montana.

Source	DF	Type III SS	F-value	P-value
Pasture	2	6.460441	3.06	.0539
Tier	2	2.392069	1.13	.3284
Pasture * Tier	4	2.093258	0.50	.7388
Error	63	66.483749		

Table 2. Pasture means and tier means of antecedent microrelief index values collected on the Pothook Ranch, Richland County, Montana. Pasture means were compared with the LSD procedure at the α = .05 level.

Grouping	Mean	N	Pasture	Grouping	Mean	N	Tier*
A	5.669mm	24	Middle	A	5.430mm	24	2
B	5.068mm	24	West	A	5.312mm	24	1
B	5.004mm	24	East	A	4.998mm	24	3

Alpha=.05
DF=63
MSE=1.0552992mm
Critical T-value=1.99834
Least Sign. Diff.=0.592608mm

*Tiers: 1=100m, 2=500m, 3=1000m

<u>1987</u>

Changes in microrelief index lacked significant interactions (Appendix B, Table 9) in 1987. The main effects time and pastures were significant ($p \leq .01$, Table 3). Changes that occurred in June were negative when the vegetation was actively growing and thus less brittle. Changes that occurred in October were positive when the vegetation was very brittle

Table 3. Abbreviated ANOVA table for test of changes in microrelief index values before and after two four-day grazing events in 1987 on the Pothook Ranch, Richland County, Montana.

Source	DF	F-value	P-value	F-test MSE
Season	1	6.90	.0112	.6806376
Pasture	2	15.74	.0001	.5531804

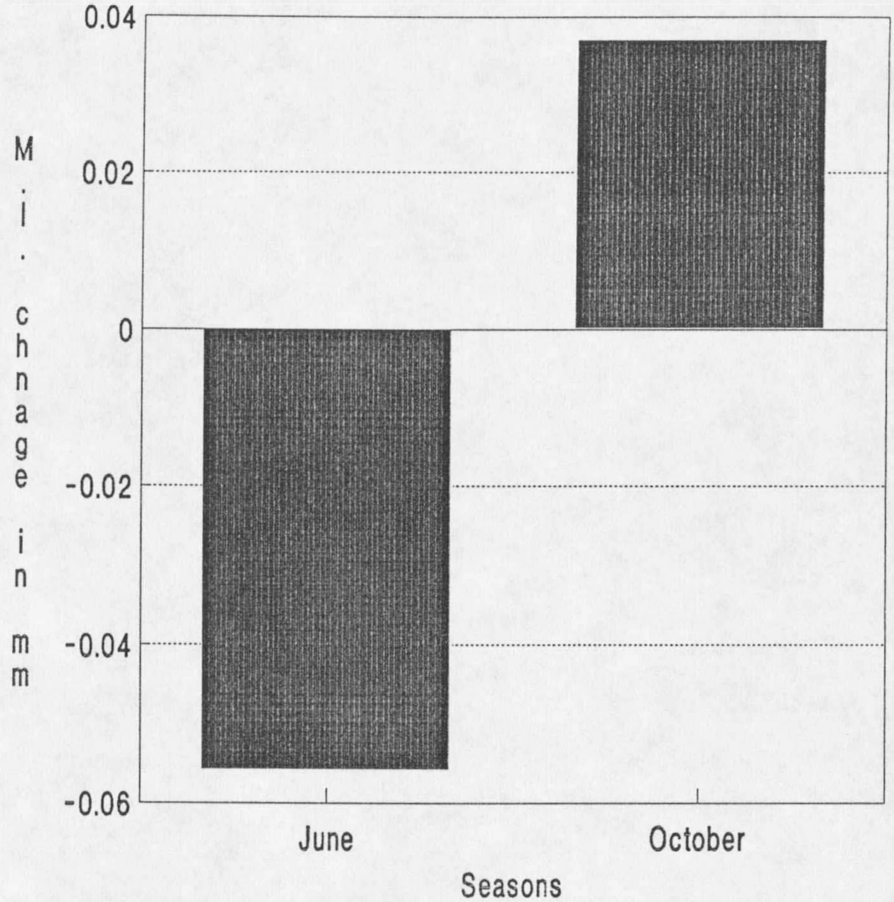

Figure 7. Change in microrelief index means from June 1987 and October 1987 on the Pothook Ranch, Richland County, Montana.

(Figure 7). Change in microrelief index in the west pasture differed significantly from the average of the changes that occurred in both the middle and east pastures; changes that occurred in the east pasture did not differ significantly from those that occurred in the middle pasture (Table 4).

Table 4. Pasture main effect orthogonal contrasts for changes in microrelief index values occurring during two four-day grazing events in 1987 on the Pothook Ranch, Richland County, Montana.

Means: west: .45 middle: -.36 east: -.17

	W	M	E	Contrast	SE contrast	S.S.	T (DF=27)	P-value
C1:	2	-1	-1	1.438	.2454	16.54	5.861	.0000
C2:	0	1	-1	-.190	.1417	.8664	-1.341	.1910

1988

In 1988 treatment and pastures interacted significantly (p .05, Table 5). The pasture factor was marginally significant (Table 5). The grazed plots in the west pasture experienced greater increases in surface roughness during grazing than the middle and east pastures (Table 6).

The treatment factor had a p-value of a lower order of magnitude (p .01) than the treatment*pasture interaction. Consequently, the treatment factor had greater significance than the treatment*pasture interaction. The mean change in microrelief index values for the ungrazed plots was -.13 mm while it was +.22 mm for the grazed plots. Changes in microrelief index in all grazed plots except one had greater positive values or lower negative values than the values in the exclosures (Figure 8).

Table 5. Abbreviated ANOVA table for test of changes in microrelief index values before and after one two-day grazing event in 1988 on the Pothook Ranch, Richland County, Montana.

Source	DF	F-value	P-value	F-test MSE
Pasture	2	3.60	.0413	.0952139
Treatment	1	10.45	.0032	.4665072
Treatment* Pasture	2	4.02	.0297	.4665072

Table 6. Pasture*treatment interaction single-degree of freedom orthogonal contrasts of changes in microrelief index values before and after one two-day grazing event in 1988 on the Pothook Ranch, Richland County, Montana.

	W Excl.	W Grazed	M Excl.	M Grazed	E Excl.	E Grazed
Mean	-.194	.598	.056	.138	-.265	-.073
C1:	0	2	0	-1	0	-1
C2:	2	0	-1	0	-1	0

	Contrast	SE contrast	S.S.	T (DF=27)	P-value
C1:	1.131	.2403	2.559	4.707	.0000
C2:	-.177	.2403	.063	-.737	.7373

<u>Seasons</u>

Changes in microrelief index values caused by grazing during the severe drought of 1988 occurred due to the extremely dry and brittle condition of the soil and vegetation. The main effect seasons was extremely significant ($p \leq .0001$, Table 7) when microrelief index values from the

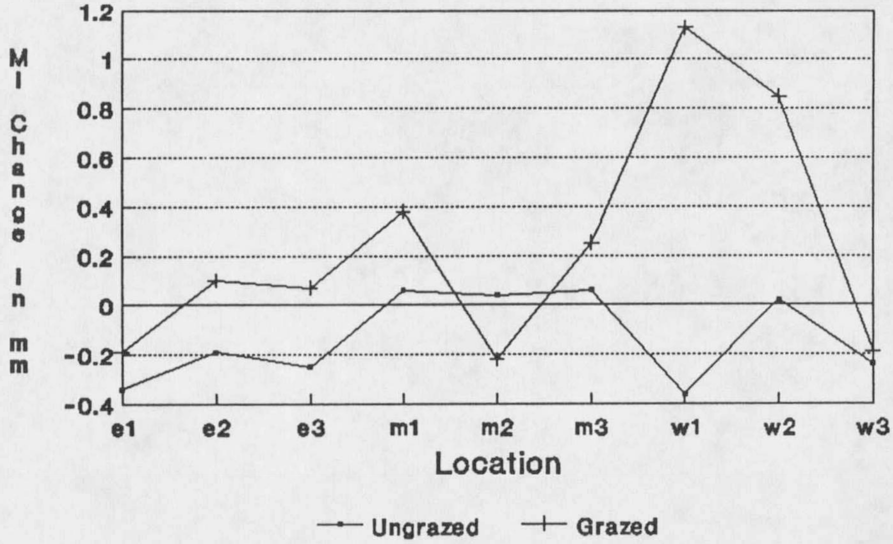

Figure 8. Mean change in microrelief index by plot on the Pothook Ranch, Richland County, Montana.

exclosures were compared across four dates. Microrelief index values were significantly lower in June 1988 than in June 1987 or April 1988 (Figure 9). Severe drought conditions in the spring of 1988 had caused appreciable weathering of surface roughness between April and June. The weathering of surface roughness between June 1987 and October 1987 had been of a smaller magnitude. Frost heaving observed during the winter of 1987-1988 increased surface roughness.

A marginally significant three-way interaction occurred between time, distance from water, and pastures when the microrelief index data from the exclosures were compared

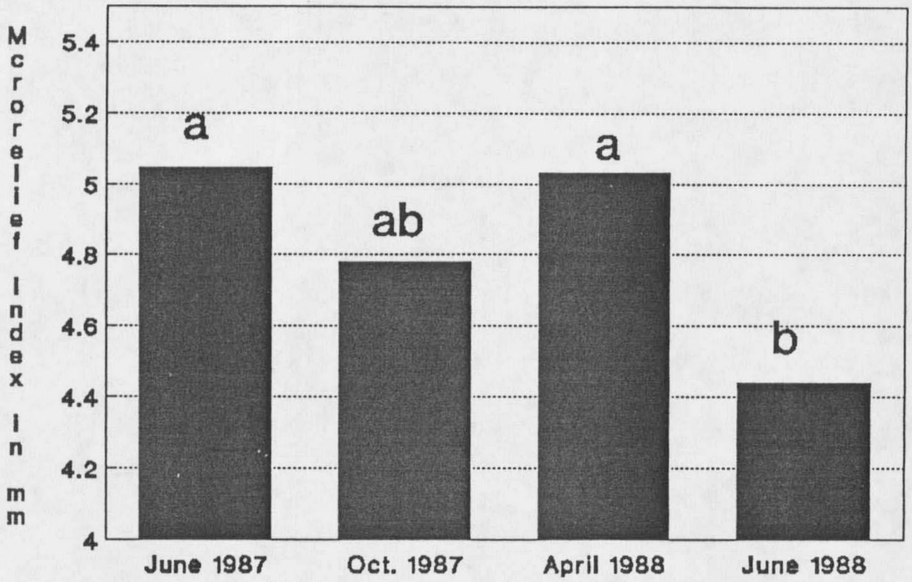

Figure 9. Season means for exclosure microrelief index values on the Pothook Ranch, Richland County, MT. Means separated with LSD procedure at α = .05.

between four seasons (p≤.05, Appendix B, Table 13). This complex interaction of thirty-six treatment combination means was examined with eight single degree of freedom tests (Appendix B, Table 14). Pairs of contrasts were made at each factor level of time. The first contrast of the pair was made between the west pasture and the average of the east and middle pastures. The second contrast was made between the average of the first two tiers and the third tier.

In the pasture comparison for June 1987, the average MI values of both the east and middle pastures was greater than

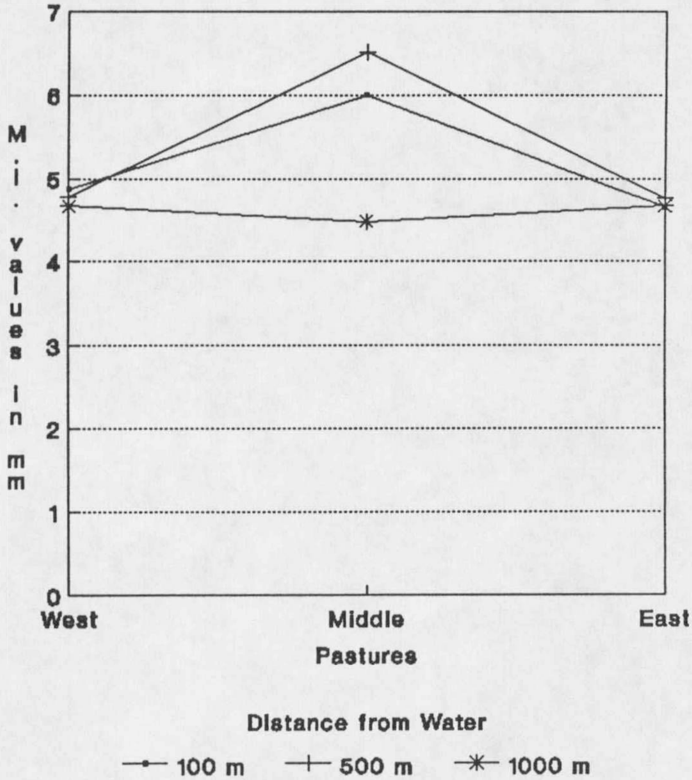

Figure. 10. Mean exclosure microrelief index values from June 1987 show the interaction between pasture and distance from water. Collected from the Pothook Ranch, Richland County, Montana.

that of the west pasture due to the high values in the middle pasture (Figure 10). This contrast was not significant for the other three dates.

When MI was compared by distance from water, the average microrelief index values of tiers one and two was greater than the mean MI value of the third tier during June 1987, October 1987, and April 1988. This contrast was not significant during June of 1988. Again, the higher than experiment-wide average microrelief index values in the first two tiers of the

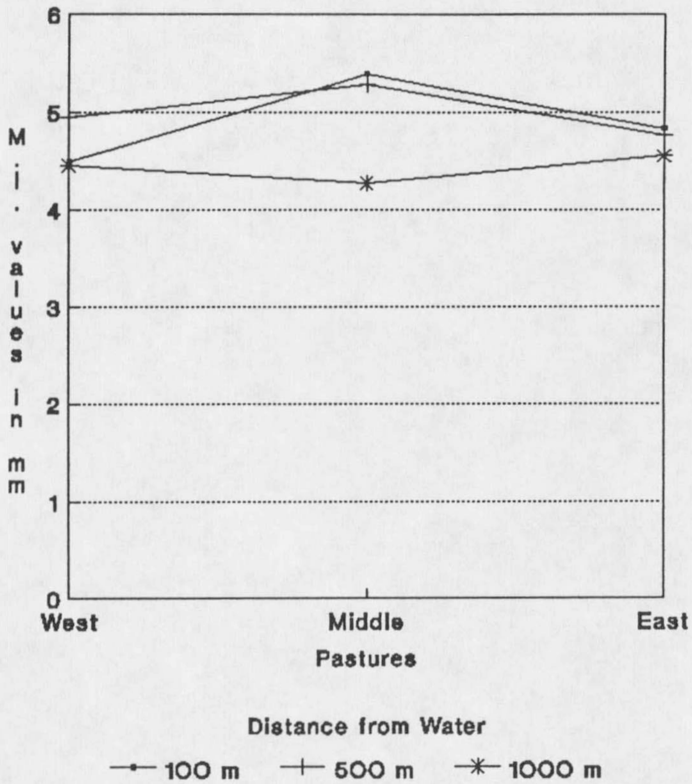

Figure 11. Mean exclosure values from October 1987 which show the interaction between distance from water and pastures. Collected on the Pothook Ranch, Richland County, Montana.

middle pasture explain the significance of the first three contrasts (Figures 10, 11, and 12), and they are responsible for the significant pasture*tier interaction.

The microrelief index values in the exclosures of the east and west pastures did not vary greatly between different distances at any time period. The means were at their lowest in June 1988 after two months of extremely dry weather and very little plant growth to provide the soil with protective

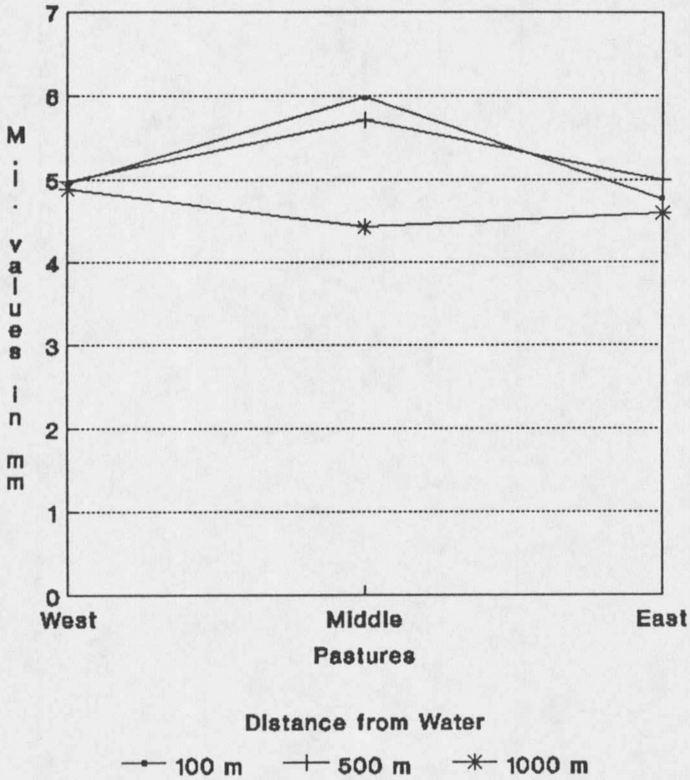

Figure 12. Mean exclosure microrelief index values from April 1988 show the interaction between pastures and distance from water. Collected from the Pothook Ranch, Richland County, Montana.

cover from wind and water erosion (Figure 13). The microrelief index values in the middle pasture second tier had finally decreased to near those of the other plots while the microrelief index values of the middle pasture first tier continued to have higher than average values.

In summary, the pastures varied at the start of the study with the middle pasture having and retaining the highest surface roughness (Table 7). Seasonal effects probably caused the different in directions surface roughness change between

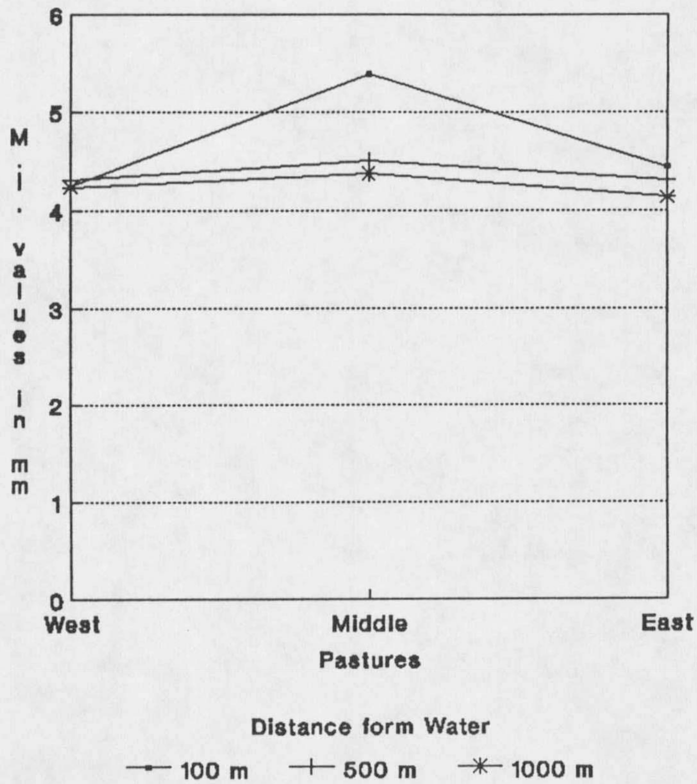

Figure 13. Mean exclosure microrelief index values from June 1988 show the interaction between pastures and distance from water. Collected from the Pothook Ranch, Richland County, Montana.

June and October 1987. Seasonal effects had a strong influence on the surface roughness in the ungrazed plots, and seasonal effects were responsible for the brittle environment in June 1988 that was easily affected by time-controlled grazing.

Table 7. Summary of significant factors and interactions from tables 1, 3, 5 and 13. From analysis of microrelief index values from the Pothook Ranch, Richland County, Montana.

	DF	Type III SS	F-test	P-value
Pretreatment				
Pasture	2	6.460441	3.06	.0539
1987				
Season	1	1.007697	6.90	.0112
Pasture	2	5.488206	15.74	.0001
1988				
Pasture	2	0.554003	3.60	.0413
Treatment	1	0.716638	10.45	.0032
Treatment*Pasture	2	0.551211	4.02	.0297
Seasons				
Seasons	3	2.743801	21.40	.0001
Seasons*Pasture*Tier	12	1.038260	2.02	.0380

Hoofprint Density

The relationship between hoofprint density and distance from water varied from pasture to pasture (Figure 13). In the east and west pasture, hoofprint density followed the hypothesized relationship of declining density with increasing distance from water. Although this relationship varied in magnitude between the east and west plots, it was still a negative relationship. Not so in the middle pasture where hoofprint density was lower in the first tier than in the second tier. This different response was due to the livestock concentrating their travel from the stockwater tanks in a different direction than predicted during the establishment of the pastures and the plots. Travel behavior of the cattle after the establishment of the three study pastures differed from travel behavior before the creation of the three pastures. Consequently, travel behavior after pasture establishment could not be used to explain the differences in surface roughness between exclosures since these differences existed before pasture establishment.

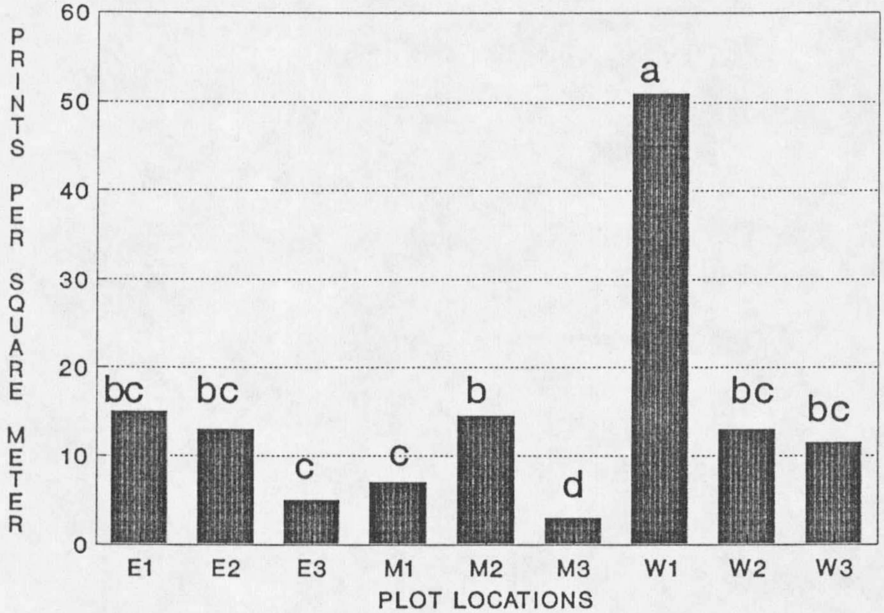

Figure 14. Hoofprint density collected in October 1987 from the surface roughness study area on the Pothook Ranch, Richland County, Montana. Means separated with LSD Procedure at the α =.05 level.

DISCUSSION

Grazing Effects on Surface Roughness

One of three time-controlled grazing events changed surface roughness. Surface roughness increased during the third grazing event with 54% of the animal numbers used in the first two events, and it occurred with a grazing period of only two days rather than four days. These changes occurred during the severe drought of 1988 when the soil was very dry, the plant litter on the ground was very brittle, and aboveground plant growth was extremely reduced (ocularly estimated to be 20% of the aboveground growth of 1987). These three conditions of the surface in June 1988 made it very susceptible to changes in surface roughness caused by grazing and weathering. Consequently, drought had an overriding influence on changes in surface roughness created by time-controlled grazing in 1988. Distance from water did not have an equally important influence on changes in surface roughness in the grazed plots. The magnitude of change in surface roughness in the grazed plots varied between pastures due to confounding topographical and pasture configuration influences.

Of all of the studies of short duration grazing systems, none have detected changes in surface roughness attributable to a single grazing event (Wood and Blackburn 1981, McCalla et al. 1984, Warren et al. 1986a, Warren et al. 1986b, Warren et al. 1986c, Warren et al. 1986d, Weltz and Wood 1986, Pluhar et al. 1987). None have had the combination of severe drought conditions and the ability to make repeated measures on surface roughness of the same plots. Consequently, none have reported changes in surface roughness similar to those found in this study.

Explanations for No Change in 1987

I advance five hypotheses for the failure of this study and studies of short duration grazing to detect changes in surface roughness attributable to a single grazing event during "normal" years for plant growth and soil moisture. First, it may take many years for change in surface roughness to become detectable. Second, the stock densities used in this and other studies may have been too low to cause significant changes in surface roughness. Third, the sampling technique used may have been insensitive to changes in surface roughness. Fourth, cattle never cause significant changes in surface roughness under short duration grazing during normal years. Fifth, seasonal factors may over-ride changes in surface roughness caused by hoof impact.

Number of Grazing Events

The number of time-controlled grazing events required to cause detectable change in surface roughness during normal years remains unknown. Changes in surface roughness are brought about both by changing plant growth-form and by breaking up the soil surface in the interspaces between plants. Grass plants that are not overgrazed often have clumped growth that increases surface roughness (Gamougoun et al. 1984). Such plants are also taller and thereby more capable of intercepting precipitation and channelling it into the soil through stemflow (Ndawula-Senyimba et al.1971). If time-controlled grazing can bring about this hydrologically more favorable growth form through infrequent grazing events, long lasting improvements in surface roughness will result.

If time-controlled grazing induced changes in surface roughness of plant interspaces must accumulate over several grazing periods to become detectable, these changes in surface roughness must survive the seasonal influences of raindrop impact, wind erosion, frost heaving, soil shrinking, and soil swelling that occur between grazing events. This investigation and other studies found that seasonal influences can change surface roughness (Schumm 1964, Colborg 1972, Gamougoun et al. 1984, Wood et al. 1986, Pluhar et al. 1987). Large reductions in surface roughness can occur in only three years (Davies and Armstrong 1986).

Stocking Density

A lack of significant change in surface roughness during normal years may be related to stocking density. The highest stocking densities used in most studies of short duration grazing have been about 10 animal units per hectare (au/ha) (Knight 1980, Wood and Blackburn 1981, McCalla et al. 1984, Wood and Blackburn 1981, Knight 1980, Warren et al. 1986a, Warren et al. 1986b, Warren et al. 1986c, Warren et al. 1986d, Weltz and Wood 1986, Pluhar et al. 1987). These densities have not satisfactorily simulated the herd effect as proposed by Savory (1988). Livestock should not trail and should not be selective about where they step when causing herd effect. Walker and Heitschmidt (1986) showed that cow densities of 3 cows/ha and of 10 cows/ha resulted in the formation of a higher density of trails than existed in pastures under less intensive management. Balph and Malecheck (1985) found that cattle avoided stepping on crested wheatgrass plants at a stocking density of 10.6 AU/ha.

The designers of this and previous studies assumed that high stocking densities should yield at least some of the results of herd impact. Savory (1988) has recently acknowledged that high animal densities alone will not cause herd effect. He suggests that high densities of animals need to be excited in some fashion in order to cause them to become less careful about where they step. When this happens, more plant material is knocked down, and the soil surface is more uniformly disturbed. In unaltered ecosystems, predators provide the excitement that causes herbivores to gather in tight groups and ignore where they step. Since predation is an unacceptable method of producing herd effect with livestock, Savory (1988) has suggested using small quantities of granulated salt to cause animal excitement on small areas for short periods of time.

Yet, there may still be a positive relationship between change in surface roughness and high stocking densities without management practices that create animal excitement. Further exploration of this relationship requires experimenting with higher animal densities than have been used in past studies. Such experimentation might also find the stocking densities at which livestock are not selective about the placement of their hooves and are no longer willing to trail.

Savory (1988) developed his herd effect model from his observations of wildlife herds in Africa, and he has assumed that bison in North America behaved in a similar manner prior to their demise at the end of the last century. Unfortunately, the changes in hydrologic characteristics caused after the passage of one of these African herds over a tract of African savannah has not been published. In addition, the scientific literature has yet to contain an account of the complete simulation of the hypothesized herd effect through high stock densities in North America.

However, some supporting evidence does exist. Sithamparanathan et al. (1986) found fivefold increases in grass seedling establishment in New Zealand hill pasture where up to 1200 sheep/ha were grazed for one day. Their study area had been oversown with grass and legume seed, and it had been sprayed with herbicide to kill the existing plants. In addition, low-resolution modelling has shown that maximum livestock production per area and per head can be accomplished through many paddocks with very short stays. However, high forage availability must be maintained (Senft and Malechek 1985).

Sampling Adequacy

The third explanation for a lack of detectable change in surface roughness during the normal year of 1987 in this study could be due to the use of an insensitive sampling technique. If the average sized cattle hoof has an area of 0.0085 m2 (Abdel-Magid et al. 1987a), the plot with lowest hoofprint density in this study had 1.275 m^2 (2.5%) of a possible 50 m^2 covered with hoofprints. The plot with the highest hoofprint density had 21.675 m^2 (43%) of a possible 50 m^2 covered with hoofprints while the median plot had 5.525m^2 (11%) covered with hoofprints. It seems likely that sixteen randomly located 42 cm long transects would have been able to detect changes in surface roughness at least at the median densities of hoofprints. In addition, the surface roughness meter used in this study was very precise since the analysis was able to detect least significant differences in changes in surface roughness of less than 0.2 mm. Consequently, I am confident that real changes in surface roughness in this study's plots in 1987 would have been detected with the plot sampling method used.

<u>No Change Possible</u>

The fourth explanation for the lack of improvement in surface roughness has yet to be fully tested. It may eventually be proven that short duration grazing can cause significant changes in surface roughness during normal years if stocking densities of 20 or more AU/ha are used, or if other methods of simulating the herd effect are practiced. Or, perhaps it may be shown that time-controlled grazing is more effective in changing the surface roughness of rangeland in low seral stages that have large amounts of flat and exposed soil. Perhaps high stock densities become ineffective at modifying roughness below a certain percentage of exposed bare soil and above certain moisture levels in the plants, litter, and soil. The surface roughness of a wide variety of range sites in various successional stages needs to be characterized, and the stocking densities and grazing period lengths necessary to increase surface roughness under different seasonal conditions need to be determined.

Overriding Seasonal Influences

The fifth explanation that seasonal influences can be overriding was true in this study. The extreme drought conditions made the landscape in this study less resistant to changes in surface roughness. Abdel-Magid et al. (1987b) found that simulated trampling of prairie sod detached more dead plant material and live leaves under high moisture stress than under low moisture stress. Future researchers need to determine the threshold moisture levels of live plants, plant litter, and soil below which changes in surface roughness by time-controlled grazing become possible.

Differences with Distance from Water

In this study, actual values of microrelief index in the exclosures varied with distance from water. This variation was attributed to antecedent differences in surface roughness between the plots that may or may not have been influenced by grazing that occurred prior to this study. Plots in the third tier had the lowest values, perhaps due to their presence on a southern exposure where weathering mechanisms may have been more influential. Otherwise, surface roughness and hoofprint density did not change consistently with increasing distance from water.

Weltz and Wood (1986) stratified their infiltration plots into three zones extending from water in their study of short duration grazing. They found no relationship between changes in surface roughness and increasing distance from water as demonstrated in Australia (Andrew 1988). All other investigators of the hydrological impacts of short duration grazing in North America failed to stratify their sampling by distance from water. Rather, they have either stratified their samples by vegetation type, or they have located their samples randomly. Consequently, these researchers have been assigning variation in surface roughness to their error terms rather than to a distance from water factor. This may have reduced their ability to detect differences in surface roughness between treatments and dates.

I offer two hypotheses for the lack of a consistent piosphere relationship between pastures. First, the experimental material prevented the establishment of a large number of small paired plots randomly located within each zone of increasing distance from water; the pastures had a wide variety of exposures and range sites that would have made the random location of numerous small plots on the same range site and aspect very difficult. Second, rough terrain may have also prevented the strong expression of this relationship because cattle tended to seek the most level routes.

Ideally, a large number of small plots may have more adequately sampled the spatial variation of animal traffic within each zone. Eight pairs of randomly located surface roughness sampling sites with one of the pair exposed to grazing while the other location was protected by a small cage could have more adequately sampled this variation than the approach taken in my study.

Seasonal Effects on Surface Roughness

In this study, season had a strong influence on surface roughness with frost heaving during the winter causing a renewal in surface roughness and weathering during the summer causing reductions in surface roughness. The same seasonal trend was found by Colborg (1972) during a two year study in southern Idaho. Extreme drought conditions in 1988 created a very brittle environment that enabled time-controlled grazing to cause increases in surface roughness. However, it is difficult to make inferences about seasonal trends in surface roughness for other years because this was only data collected from one twelve month period. Wood et al. (1986) found year to year variation in surface roughness over a three year period. They attributed this variation in surface roughness to differences in precipitation patterns between years. On the Edwards Plateau, no difference was found in surface roughness between the growing season and the dormant season by Warren et al. (1986a). However, Pluhar et al. (1987) found significant differences in surface roughness over a two year period on the Rolling Plains of Texas. Surface roughness reached its minimum in the early spring, and it approached its maximum in the fall.

The relationship of surface roughness and the freeze-thaw cycle in the northern Great Plains still needs a more in depth investigation. In a four year study, Smith (1987) documented diurnal increases in surface roughness elevation of 10 mm and seasonal increases of 23 to 45 mm per year on bare soil. In contrast, on this study area seasonal heaving increased surface roughness by 0.5 mm.

Yet, seasonal influences were able to override hoof-impact on pastures with cattle densities below 12.25 head/ha in 1987. Severe drought conditions created an environment that was so brittle that only 6.63 head/ha could increase surface roughness.

CONCLUSIONS

1. Grazing by cattle at an animal density of 12.25 head/ha failed to change surface roughness during two four-day grazing events in the normal precipitation year of 1987. However, grazing by cattle at an animal density of 6.63 head/ha did change surface roughness during one two-day grazing event in the severe drought year of 1988. The extreme aridity of the surface microrenvironment in 1988 made it very brittle. Consequently, it was very susceptible to changes in surface roughness.

2. There was not a clear relationship between distance from water, surface roughness of grazed plots, and an index of grazing intensity. Cattle were more uniformly distributed within each pasture than hypothesized. However, their distribution varied between pastures.

3. Seasonal effects had a strong influence on surface roughness. Frost heaving activity, dramatic changes in protective plant cover, and differences in soil moisture content were responsible for the seasonal changes in surface roughness.

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APPENDICES

APPENDIX A: COMPUTER PROGRAMS

Appendix A is included to assist future researchers of surface roughness who will be using similar methods of collecting and handling surface roughness data. An example of the data file obtained from the Sigma-Scan digitizing software program is followed by sixteen computer programs. The first seven programs reduce the data into surface roughness measures. The last nine programs do the statistical tests described in the text.

x-axis	y-axis
0.9024	17.2085
2.0117	17.9018
2.9193	18.1057
4.0488	18.1057
5.0774	19.0843
6.1463	17.4940
7.1346	17.8610
8.1431	16.8823
9.1112	16.3522
10.1802	17.4940
11.1483	16.6784
12.1568	16.3930
13.1047	16.3522
14.0729	16.0667
15.1822	15.7405
16.1503	16.2298
17.1184	17.2085
18.1269	16.8415
19.2563	17.1270
20.2043	17.4124
21.1926	17.6163
22.1607	18.0649
23.2498	18.2280
24.2381	16.3114
25.2668	17.2493
26.2147	17.8202
27.1828	17.4532
28.1711	16.1891
29.2199	16.2298
30.2687	16.1483
31.1965	14.2725
32.1646	14.6395
33.1126	15.1696
34.1614	13.9462
35.1496	16.2706
36.1581	13.1307
37.1464	15.6182
38.0943	13.1715
39.1431	14.1501
40.1919	13.7016
41.0995	14.4764
42.1282	15.2512
43.0761	13.6200
44.1653	14.6395

Figure 15. A Sigma-Scan data file called E10ac\tr1fr1.PRN. It is from the first location along the first transect in tier 1 of the east pasture. X-axis values are in 1/4-inch increments while the Y-axis values are in 1/8-inch increments.

45.1132	14.0686
46.1217	15.4958
47.1503	13.4569
48.0781	12.7637
49.1672	13.0899
50.0748	14.3133
51.1034	14.3540
52.1321	14.3540
53.0599	14.3540
54.1288	14.2317
55.0768	15.0065
56.0651	13.2122
57.0534	14.6803
57.9610	14.8026
58.9694	16.2298
60.0586	12.9268
61.1275	12.3967
62.2570	11.9481
63.1646	11.5811
64.1126	11.0102
65.0202	11.0918

Figure 15--<u>Continued</u>

```
*  PROGRAM:  E10.SAS
*
*  PROGRAMMER:  BLAINE MOOERS WITH ASSISTANCE FROM DEBBIE
*               ROSSI
*
*  DATE:  12-11-88
*
*  PURPOSE:  TO LINK TOGETHER DATA FROM SEVEN DATES AND
*            SIXTEEN SURFACE ROUGHNESS METERS OR FRAMES FOR
*            THE PLOT IN THE EXCLSOURE AT 100 METERS FROM
*            WATER IN THE EAST PASTURE.  THE RESULTING
*            DATASET WAS CALLED FLOPPY1.DAT.  SIMILAR
*            PROGRAMS WERE DEVELOPED FOR EACH REMAINING
*            PLOT.;

DATA Z; DO N=1 TO 65 BY 1; OUTPUT; END; RUN;

DATA A1; INFILE 'tr1fr11.PRN' MISSOVER; INPUT X Y1; DROP X;
RUN;
DATA A2; INFILE 'tr1fr12.PRN' MISSOVER; INPUT X Y2; DROP X;
RUN;
DATA A3; INFILE 'tr1fr13.PRN' MISSOVER; INPUT X Y3; DROP X;
RUN;
DATA A4; INFILE 'tr1fr14.PRN' MISSOVER; INPUT X Y4; DROP X;
RUN;
DATA A5; INFILE 'tr1fr15.PRN' MISSOVER; INPUT X Y5; DROP X;
RUN;
DATA A6; INFILE 'tr1fr16.PRN' MISSOVER; INPUT X Y6; DROP X;
RUN;
DATA A7; INFILE 'tr1fr17.PRN' MISSOVER; INPUT X Y7; DROP X;
RUN;
DATA A; MERGE Z A1 A2 A3 A4 A5 A6 A7; TRTSTR = '1 1 0 1 1';
RUN;

DATA A1; INFILE 'tr1fr21.PRN' MISSOVER; INPUT X Y1; DROP X;
RUN;
DATA A2; INFILE 'tr1fr22.PRN' MISSOVER; INPUT X Y2; DROP X;
RUN;
DATA A3; INFILE 'tr1fr23.PRN' MISSOVER; INPUT X Y3; DROP X;
RUN;
DATA A4; INFILE 'tr1fr24.PRN' MISSOVER; INPUT X Y4; DROP X;
RUN;
DATA A5; INFILE 'tr1fr25.PRN' MISSOVER; INPUT X Y5; DROP X;
RUN;
DATA A6; INFILE 'tr1fr26.PRN' MISSOVER; INPUT X Y6; DROP X;
RUN;
DATA A7; INFILE 'tr1fr27.PRN' MISSOVER; INPUT X Y7; DROP X;
```

Figure 16. SAS program E10.sas was used to link together all Sigma-Scan files for plot E10 into a floppy.dat output file. Similar programs were developed for each plot.

```
RUN;
DATA B; MERGE Z A1 A2 A3 A4 A5 A6 A7; TRTSTR = '1 1 0 1 2';
RUN;


DATA A1; INFILE 'tr1fr31.PRN' MISSOVER; INPUT X Y1; DROP X;
RUN;
DATA A2; INFILE 'tr1fr32.PRN' MISSOVER; INPUT X Y2; DROP X;
RUN;
DATA A3; INFILE 'tr1fr33.PRN' MISSOVER; INPUT X Y3; DROP X;
RUN;
DATA A4; INFILE 'tr1fr34.PRN' MISSOVER; INPUT X Y4; DROP X;
RUN;
DATA A5; INFILE 'tr1fr35.PRN' MISSOVER; INPUT X Y5; DROP X;
RUN;
DATA A6; INFILE 'tr1fr36.PRN' MISSOVER; INPUT X Y6; DROP X;
RUN;
DATA A7; INFILE 'tr1fr37.PRN' MISSOVER; INPUT X Y7; DROP X;
RUN;
DATA C; MERGE Z A1 A2 A3 A4 A5 A6 A7; TRTSTR = '1 1 0 1 3';
RUN;

DATA A1; INFILE 'tr1fr41.PRN' MISSOVER; INPUT X Y1; DROP X;
RUN;
DATA A2; INFILE 'tr1fr42.PRN' MISSOVER; INPUT X Y2; DROP X;
RUN;
DATA A3; INFILE 'tr1fr43.PRN' MISSOVER; INPUT X Y3; DROP X;
RUN;
DATA A4; INFILE 'tr1fr44.PRN' MISSOVER; INPUT X Y4; DROP X;
RUN;
DATA A5; INFILE 'tr1fr45.PRN' MISSOVER; INPUT X Y5; DROP X;
RUN;
DATA A6; INFILE 'tr1fr46.PRN' MISSOVER; INPUT X Y6; DROP X;
RUN;
DATA A7; INFILE 'tr1fr47.PRN' MISSOVER; INPUT X Y7; DROP X;
RUN;
DATA D; MERGE Z A1 A2 A3 A4 A5 A6 A7; TRTSTR = '1 1 0 1 4';
RUN;

DATA A1; INFILE 'tr2fr11.PRN' MISSOVER; INPUT X Y1; DROP X;
RUN;
DATA A2; INFILE 'tr2fr12.PRN' MISSOVER; INPUT X Y2; DROP X;
RUN;
```

Figure 16.--<u>Continued</u>

```
DATA A3; INFILE 'tr2fr13.PRN' MISSOVER; INPUT X Y3; DROP X;
RUN;
DATA A4; INFILE 'tr2fr14.PRN' MISSOVER; INPUT X Y4; DROP X;
RUN;
DATA A5; INFILE 'tr2fr15.PRN' MISSOVER; INPUT X Y5; DROP X;
RUN;
DATA A6; INFILE 'tr2fr16.PRN' MISSOVER; INPUT X Y6; DROP X;
RUN;
DATA A7; INFILE 'tr2fr17.PRN' MISSOVER; INPUT X Y7; DROP X;
RUN;
DATA E; MERGE Z A1 A2 A3 A4 A5 A6 A7; TRTSTR = '1 1 0 2 1';
RUN;

DATA A1; INFILE 'tr2fr21.PRN' MISSOVER; INPUT X Y1; DROP X;
RUN;
DATA A2; INFILE 'tr2fr22.PRN' MISSOVER; INPUT X Y2; DROP X;
RUN;
DATA A3; INFILE 'tr2fr23.PRN' MISSOVER; INPUT X Y3; DROP X;
RUN;
DATA A4; INFILE 'tr2fr24.PRN' MISSOVER; INPUT X Y4; DROP X;
RUN;
DATA A5; INFILE 'tr2fr25.PRN' MISSOVER; INPUT X Y5; DROP X;
RUN;
DATA A6; INFILE 'tr2fr26.PRN' MISSOVER; INPUT X Y6; DROP X;
RUN;
DATA A7; INFILE 'tr2fr27.PRN' MISSOVER; INPUT X Y7; DROP X;
RUN;
DATA F; MERGE Z A1 A2 A3 A4 A5 A6 A7; TRTSTR = '1 1 0 2 2';
RUN;

DATA A1; INFILE 'tr2fr31.PRN' MISSOVER; INPUT X Y1; DROP X;
RUN;
DATA A2; INFILE 'tr2fr32.PRN' MISSOVER; INPUT X Y2; DROP X;
RUN;
DATA A3; INFILE 'tr2fr33.PRN' MISSOVER; INPUT X Y3; DROP X;
RUN;
DATA A4; INFILE 'tr2fr34.PRN' MISSOVER; INPUT X Y4; DROP X;
RUN;
DATA A5; INFILE 'tr2fr35.PRN' MISSOVER; INPUT X Y5; DROP X;
RUN;
DATA A6; INFILE 'tr2fr36.PRN' MISSOVER; INPUT X Y6; DROP X;
RUN;
DATA A7; INFILE 'tr2fr37.PRN' MISSOVER; INPUT X Y7; DROP X;
RUN;
DATA G; MERGE Z A1 A2 A3 A4 A5 A6 A7; TRTSTR = '1 1 0 2 3';
RUN;
```

Figure 16.--Continued.

```
DATA A1; INFILE 'tr2fr41.PRN' MISSOVER; INPUT X Y1; DROP X;
RUN;
DATA A2; INFILE 'tr2fr42.PRN' MISSOVER; INPUT X Y2; DROP X;
RUN;
DATA A3; INFILE 'tr2fr43.PRN' MISSOVER; INPUT X Y3; DROP X;
RUN;
DATA A4; INFILE 'tr2fr44.PRN' MISSOVER; INPUT X Y4; DROP X;
RUN;
DATA A5; INFILE 'tr2fr45.PRN' MISSOVER; INPUT X Y5; DROP X;
RUN;
DATA A6; INFILE 'tr2fr46.PRN' MISSOVER; INPUT X Y6; DROP X;
RUN;
DATA A7; INFILE 'tr2fr47.PRN' MISSOVER; INPUT X Y7; DROP X;
RUN;
DATA H; MERGE Z A1 A2 A3 A4 A5 A6 A7; TRTSTR = '1 1 0 2 4';
RUN;

DATA A1; INFILE 'tr3fr11.PRN' MISSOVER; INPUT X Y1; DROP X;
RUN;
DATA A2; INFILE 'tr3fr12.PRN' MISSOVER; INPUT X Y2; DROP X;
RUN;
DATA A3; INFILE 'tr3fr13.PRN' MISSOVER; INPUT X Y3; DROP X;
RUN;
DATA A4; INFILE 'tr3fr14.PRN' MISSOVER; INPUT X Y4; DROP X;
RUN;
DATA A5; INFILE 'tr3fr15.PRN' MISSOVER; INPUT X Y5; DROP X;
RUN;
DATA A6; INFILE 'tr3fr16.PRN' MISSOVER; INPUT X Y6; DROP X;
RUN;
DATA A7; INFILE 'tr3fr17.PRN' MISSOVER; INPUT X Y7; DROP X;
RUN;
DATA I; MERGE Z A1 A2 A3 A4 A5 A6 A7; TRTSTR = '1 1 0 3 1';
RUN;

DATA A1; INFILE 'tr3fr21.PRN' MISSOVER; INPUT X Y1; DROP X;
RUN;
DATA A2; INFILE 'tr3fr22.PRN' MISSOVER; INPUT X Y2; DROP X;
RUN;
DATA A3; INFILE 'tr3fr23.PRN' MISSOVER; INPUT X Y3; DROP X;
RUN;
DATA A4; INFILE 'tr3fr24.PRN' MISSOVER; INPUT X Y4; DROP X;
RUN;
DATA A5; INFILE 'tr3fr25.PRN' MISSOVER; INPUT X Y5; DROP X;
RUN;
DATA A6; INFILE 'tr3fr26.PRN' MISSOVER; INPUT X Y6; DROP X;
RUN;
DATA A7; INFILE 'tr3fr27.PRN' MISSOVER; INPUT X Y7; DROP X;
RUN;
```

Figure 16.--Continued

```
DATA J; MERGE Z A1 A2 A3 A4 A5 A6 A7; TRTSTR = '1 1 0 3 2';
RUN;

DATA A1; INFILE 'tr3fr31.PRN' MISSOVER; INPUT X Y1; DROP X;
RUN;
DATA A2; INFILE 'tr3fr32.PRN' MISSOVER; INPUT X Y2; DROP X;
RUN;
DATA A3; INFILE 'tr3fr33.PRN' MISSOVER; INPUT X Y3; DROP X;
RUN;
DATA A4; INFILE 'tr3fr34.PRN' MISSOVER; INPUT X Y4; DROP X;
RUN;
DATA A5; INFILE 'tr3fr35.PRN' MISSOVER; INPUT X Y5; DROP X;
RUN;
DATA A6; INFILE 'tr3fr36.PRN' MISSOVER; INPUT X Y6; DROP X;
RUN;
DATA A7; INFILE 'tr3fr37.PRN' MISSOVER; INPUT X Y7; DROP X;
RUN;
DATA K; MERGE Z A1 A2 A3 A4 A5 A6 A7; TRTSTR = '1 1 0 3 3';
RUN;

DATA A1; INFILE 'tr3fr41.PRN' MISSOVER; INPUT X Y1; DROP X;
RUN;
DATA A2; INFILE 'tr3fr42.PRN' MISSOVER; INPUT X Y2; DROP X;
RUN;
DATA A3; INFILE 'tr3fr43.PRN' MISSOVER; INPUT X Y3; DROP X;
RUN;
DATA A4; INFILE 'tr3fr44.PRN' MISSOVER; INPUT X Y4; DROP X;
RUN;
DATA A5; INFILE 'tr3fr45.PRN' MISSOVER; INPUT X Y5; DROP X;
RUN;
DATA A6; INFILE 'tr3fr46.PRN' MISSOVER; INPUT X Y6; DROP X;
RUN;
DATA A7; INFILE 'tr3fr47.PRN' MISSOVER; INPUT X Y7; DROP X;
RUN;
DATA L; MERGE Z A1 A2 A3 A4 A5 A6 A7; TRTSTR = '1 1 0 3 4';
RUN;

DATA A1; INFILE 'tr4fr11.PRN' MISSOVER; INPUT X Y1; DROP X;
RUN;
DATA A2; INFILE 'tr4fr12.PRN' MISSOVER; INPUT X Y2; DROP X;
RUN;
DATA A3; INFILE 'tr4fr13.PRN' MISSOVER; INPUT X Y3; DROP X;
RUN;
DATA A4; INFILE 'tr4fr14.PRN' MISSOVER; INPUT X Y4; DROP X;
RUN;
DATA A5; INFILE 'tr4fr15.PRN' MISSOVER; INPUT X Y5; DROP X;
RUN;
```

Figure 16.--Continued

```
DATA A6; INFILE 'tr4fr16.PRN' MISSOVER; INPUT X Y6; DROP X;
RUN;
DATA A7; INFILE 'tr4fr17.PRN' MISSOVER; INPUT X Y7; DROP X;
RUN;
DATA M; MERGE Z A1 A2 A3 A4 A5 A6 A7; TRTSTR = '1 1 0 4 1';
RUN;

DATA A1; INFILE 'tr4fr21.PRN' MISSOVER; INPUT X Y1; DROP X;
RUN;
DATA A2; INFILE 'tr4fr22.PRN' MISSOVER; INPUT X Y2; DROP X;
RUN;
DATA A3; INFILE 'tr4fr23.PRN' MISSOVER; INPUT X Y3; DROP X;
RUN;
DATA A4; INFILE 'tr4fr24.PRN' MISSOVER; INPUT X Y4; DROP X;
RUN;
DATA A5; INFILE 'tr4fr25.PRN' MISSOVER; INPUT X Y5; DROP X;
RUN;
DATA A6; INFILE 'tr4fr26.PRN' MISSOVER; INPUT X Y6; DROP X;
RUN;
DATA A7; INFILE 'tr4fr27.PRN' MISSOVER; INPUT X Y7; DROP X;
RUN;
DATA N; MERGE Z A1 A2 A3 A4 A5 A6 A7; TRTSTR = '1 1 0 4 2';
RUN;

DATA A1; INFILE 'tr4fr31.PRN' MISSOVER; INPUT X Y1; DROP X;
RUN;
DATA A2; INFILE 'tr4fr32.PRN' MISSOVER; INPUT X Y2; DROP X;
RUN;
DATA A3; INFILE 'tr4fr33.PRN' MISSOVER; INPUT X Y3; DROP X;
RUN;
DATA A4; INFILE 'tr4fr34.PRN' MISSOVER; INPUT X Y4; DROP X;
RUN;
DATA A5; INFILE 'tr4fr35.PRN' MISSOVER; INPUT X Y5; DROP X;
RUN;
DATA A6; INFILE 'tr4fr36.PRN' MISSOVER; INPUT X Y6; DROP X;
RUN;
DATA A7; INFILE 'tr4fr37.PRN' MISSOVER; INPUT X Y7; DROP X;
RUN;
DATA O; MERGE Z A1 A2 A3 A4 A5 A6 A7; TRTSTR = '1 1 0 4 3';
RUN;

DATA A1; INFILE 'tr4fr41.PRN' MISSOVER; INPUT X Y1; DROP X;
RUN;
DATA A2; INFILE 'tr4fr42.PRN' MISSOVER; INPUT X Y2; DROP X;
RUN;
DATA A3; INFILE 'tr4fr43.PRN' MISSOVER; INPUT X Y3; DROP X;
RUN;
```

Figure 16.--Continued

```
DATA A4; INFILE 'tr4fr44.PRN' MISSOVER; INPUT X Y4; DROP X;
RUN;
DATA A5; INFILE 'tr4fr45.PRN' MISSOVER; INPUT X Y5; DROP X;
RUN;
DATA A6; INFILE 'tr4fr46.PRN' MISSOVER; INPUT X Y6; DROP X;
RUN;
DATA A7; INFILE 'tr4fr47.PRN' MISSOVER; INPUT X Y7; DROP X;
RUN;
DATA P; MERGE Z A1 A2 A3 A4 A5 A6 A7; TRTSTR = '1 1 0 4 4';
RUN;


DATA STACK;
  SET A B C D E F G H I J K L M N O P;
  FILE 'FLOPPY1.DAT';
  PUT (TRTSTR N Y1-Y7)
      ($9. +1 2. +1 6.2 +1 6.2 +1 6.2 +1 6.2 +1 6.2 +1 6.2 +1
6.2);
RUN;
ENDSAS;
```

Figure 16--<u>Continued</u>

```
*     PROGRAM:  COMBINE.SAS
*
*     PROGRAMMER:  DEBBIE ROSSI
*
*     DATE:  12-13-88
*
*     PURPOSE:  To link together 21 floppy.dat files which
*               each of which contain pin height data for all
*               1040 pin locations in a particular plot over
*               the seven data collection periods;

DATA Z; DO N=1 TO 65 BY 1; OUTPUT; END; RUN;

DATA A1; INFILE 'FLOPPY1.DAT' MISSOVER; INPUT T1-T5 N Y1-Y7;
RUN;
DATA A2; INFILE 'FLOPPY2.DAT' MISSOVER; INPUT T1-T5 N Y1-Y7;
RUN;
DATA A3; INFILE 'FLOPPY3.DAT' MISSOVER; INPUT T1-T5 N Y1-Y7;
RUN;
DATA A4; INFILE 'FLOPPY4.DAT' MISSOVER; INPUT T1-T5 N Y1-Y7;
RUN;
DATA A5; INFILE 'FLOPPY5.DAT' MISSOVER; INPUT T1-T5 N Y1-Y7;
RUN;
DATA A6; INFILE 'FLOPPY6.DAT' MISSOVER; INPUT T1-T5 N Y1-Y7;
RUN;
DATA A7; INFILE 'FLOPPY7.DAT' MISSOVER; INPUT T1-T5 N Y1-Y7;
RUN;
DATA A8; INFILE 'FLOPPY8.DAT' MISSOVER; INPUT T1-T5 N Y1-Y7;
RUN;
DATA A9; INFILE 'FLOPPY9.DAT' MISSOVER; INPUT T1-T5 N Y1-Y7;
RUN;
DATA A10; INFILE 'FLOPPY10.DAT' MISSOVER; INPUT T1-T5 N Y1-Y7;
RUN;
DATA A11; INFILE 'FLOPPY11.DAT' MISSOVER; INPUT T1-T5 N Y1-Y7;
RUN;
DATA A12; INFILE 'FLOPPY12.DAT' MISSOVER; INPUT T1-T5 N Y1-Y7;
RUN;
DATA A13; INFILE 'FLOPPY13.DAT' MISSOVER; INPUT T1-T5 N Y1-Y7;
RUN;
DATA A14; INFILE 'FLOPPY14.DAT' MISSOVER; INPUT T1-T5 N Y1-Y7;
RUN;
DATA A15; INFILE 'FLOPPY15.DAT' MISSOVER; INPUT T1-T5 N Y1-Y7;
RUN;
DATA A16; INFILE 'FLOPPY16.DAT' MISSOVER; INPUT T1-T5 N Y1-Y7;
RUN;
DATA A17; INFILE 'FLOPPY17.DAT' MISSOVER; INPUT T1-T5 N Y1-Y7;
RUN;
```

Figure 17. The Sas program Combine.sas linked together all floppy.dat files into one file called All.dat.

```
DATA A18; INFILE 'FLOPPY18.DAT' MISSOVER; INPUT T1-T5 N Y1-Y7;
RUN;
DATA A19; INFILE 'FLOPPY19.DAT' MISSOVER; INPUT T1-T5 N Y1-Y7;
RUN;
DATA A20; INFILE 'FLOPPY20.DAT' MISSOVER; INPUT T1-T5 N Y1-Y7;
RUN;
DATA A21; INFILE 'FLOPPY21.DAT' MISSOVER; INPUT T1-T5 N Y1-Y7;
RUN;
DATA ALL; SET A1 A2 A3 A4 A5 A6 A7 A8 A9 A10 A11 A12 A13 A14
A15 A16 A17 A18 A19 A20 A21;
FILE 'ALL.DAT'
PUT (T1-T5 N Y1-Y7)
      (1. +1 1. +1 1. +1 1. +1 1. +1 2. +1 6.2 +1 6.2 +1 6.2
+1 6.2 +1 6.2 +1 6.2 +1 6.2);
RUN;
Endsas;
```

Figure 17--Continued

```
*    PROGRAM TREGY37.SAS   MODIFIED FOR BLAINE MOOERS
*      ON 1-5-89.
*    PROGRAMMER: GARY A. LEHRSCH
*    DATE: MAY 20, 1985
*
*    PURPOSE: TO CALCULATE AND OUTPUT THE LEAST-SQUARES
*             REFERENCE LINE (DATUM) THROUGH ALL THE
*             MEASURED POINTS OF THE TRANSECT;
LIBNAME C 'D:\BLAINE';
OPTIONS PS=56 LS=80;
DATA C.TRANS;
 INFILE 'ALL2XCR.DAT' MISSOVER;
 INPUT TRTSTR $ 1-9 X 11-13 Y3 15-19 Y4 21-25 Y5 27-31 Y6
33-37 Y7 39-43;
RUN;
PROC SORT DATA=C.TRANS;
     BY TRTSTR;
RUN;
*Do a regression on Y3-Y7;
PROC REG DATA=C.TRANS OUTEST=EST32;
        MODEL Y3=X / NOPRINT;
     BY TRTSTR;
PROC REG DATA=C.TRANS OUTEST=EST42;
        MODEL Y4=X / NOPRINT;
     BY TRTSTR;
PROC REG DATA=C.TRANS OUTEST=EST52;
        MODEL Y5=X / NOPRINT;
     BY TRTSTR;
PROC REG DATA=C.TRANS OUTEST=EST62;
        MODEL Y6=X / NOPRINT;
     BY TRTSTR;
PROC REG DATA=C.TRANS OUTEST=EST72;
        MODEL Y7=X / NOPRINT;
     BY TRTSTR;
RUN;
DATA A3;
   SET EST32;
   FILE 'ESTY32.DAT';
   PUT @ 2 TRTSTR
           @ 22 INTERCEP 6.3 @ 30 X 6.3;
RUN;
DATA A4;
   SET EST42;
   FILE 'ESTY42.DAT';
   PUT @ 2 TRTSTR
           @ 22 INTERCEP 6.3 @ 30 X 6.3;
RUN;
```

Figure 18.--SAS program Tregy37.sas was used to calculate the regression coefficients for the last five data collection dates.

```
DATA A5;
   SET EST52;
   FILE 'ESTY52.DAT';
   PUT @ 2 TRTSTR
           @ 22 INTERCEP 6.3 @ 30 X 6.3;
RUN;
DATA A6;
   SET EST62;
   FILE 'ESTY62.DAT';
   PUT @ 2 TRTSTR
           @ 22 INTERCEP 6.3 @ 30 X 6.3;
RUN;
DATA A7;
   SET EST72;
   FILE 'ESTY72.DAT';
   PUT @ 2 TRTSTR
           @ 22 INTERCEP 6.3 @ 30 X 6.3;
RUN;
*ESTY3-7 are data files of past tier trt trans frm intercept
*and slope for y3-7;
ENDSAS;
```

Figure 18--<u>Continued</u>

```
*     PROGRAM:  Y37MOD.SAS
*
*     PROGRAMMER:  DEBBIE ROSSI
*
*     DATE:  12-13-88
*
*     PURPOSE:  TO MAKE CORRECTIONS IN Y3 THROUGH Y7 VALUES
*               DUE TO THE BASELINE OF THE FRAME USED TO
*               COLLECT THESE VALUES BEING PERPENDICULAR TO
*               THE GROUND SURFACE WHILE THE FRAMES USED TO
*               COLLECT THE VALUES FOR Y1-Y2 WERE LEVEL WITH
*               THE TRUE HORIZONTAL PLANE.  TO ACCOMPLISH
*               THESE TASKS, THE SLOPE OF THE Y3-Y7 REGRESSION
*               LINES WILL BE USED TO DERIVE A TANGENT FUNCTION
*               FOR EACH FRAME (OBSERVATION UNIT) USED IN THE
*               COLLECTION OF THE Y3 THROUGH Y7 ELEVATIONS.
*               THE THE ARCTANGENT OF THIS SLOPE WILL BE USED
*               TO PRODUCE A RADIAN VALUE THAT THE COSINE
*               FUNCTION CAN USE TO CALCULATE THE NEW Y-VALUE.;
*
LIBNAME C 'D:\BLAINE';
OPTIONS PS=56 LS=80;
DATA C.ALLB;
  INFILE 'D:\BLAINE\ALLB.DAT';
*ALLB.DAT contains the slope of the regression line for each
*surface roughness profile.
  INPUT TRTSTR $ 1-9 B3 25-30 B4 32-37 B5 39-44 B6 46-51 B7
      53-58;
DATA;
SET C.ALLB;
RUN;
PROC SORT;
         BY TRTSTR;
RUN;
*THE TANGENT FUNCTION=SLOPE--THAT IS RISE OVER RUN--IS EQUAL
*TO OPPOSITE OVER ADJACENT WITH A LINE OF ZERO SLOPE SERVING
*AS THE REFERNECE LINE.  FIND F WHICH IS EQUAL TO THE NEW Y-
*VALUE;
DATA;
SET C.B;
  INFILE 'ALL.DAT';
 INPUT TRTSTR $ 1-9 N 11-12 Y3 29-33 Y4 36-40 Y5 43-47 Y6
50-54 Y7 57-61;
   PROC SORT; BY TRTSTR N;
RUN;
```

Figure 19. SAS program Y37mod.sas removed side slope effect from data collected during the last five data collection dates.

```
DATA C;
   MERGE C.ALLB C.B; BY TRTSTR; RUN;
DATA D; SET C;
 IF B3>O THEN Q3=65-N;
 IF B3<O THEN Q3=N;
  A3=TANB3*Q3;
  F3=Y3+A3;

 IF B4>O THEN Q4=65-N;
 IF B4<O THEN Q4=65;
  A4=TAN(B4)*Q4;
  F4=Y4+A4;

 IF B5>O THEN Q5=65-N;
 IF B5<O THEN Q5=65;
  A5=TAN(B5)*Q5;
  F5=Y5+A5;

 IF B6>O THEN Q6=65-N;
 IF B6<O THEN Q5=N;
  A6=TAN(B6)*Q6;
  F6=Y6+A6;

 IF B7>O THEN Q7=65-N;
 IF B7<O THEN Q7=N;
  A7=TAN(B7)*Q7;
  F7=Y7+A7;

DATA;
SET D;
*WILL BE ALLC.DAT;
FILENAME F21C 'D:\BLAINE\F21C.DAT';
FILE F21C NOTITLE;
  PUT (TRTSTR N F3 F4 F5 F6 F7)
     ($9. +1 2. +1 5.2 +1 5.2 +1 5.2 +1 5.2 +1 5.2);
RUN;
ENDSAS;
```

Figure 19.--<u>Continued</u>

```
*   PROGRAM TREG   MODIFIED FOR BLAINE MOOERS
*
*   PROGRAMMER: GARY A. LEHRSCH
*   DATE: MAY 20, 1985
*
*   PURPOSE: TO CALCULATE AND OUTPUT THE LEAST-SQUARES
*            REFERENCE LINE (DATUM) THROUGH ALL THE
*            MEASURED POINTS OF THE TRANSECT;
LIBNAME C 'D:\BLAINE';
OPTIONS PS=56 LS=80;
DATA C.TRANS;
 INFILE 'ALL.DAT' MISSOVER;
 INPUT PAST TIER TRT TRANS FRM X Y1-Y7;
RUN;
PROC SORT DATA=C.TRANS;
     BY PAST TIER TRT TRANS FRM;
RUN;
*Do a regression on Y1-Y7;
PROC REG DATA=C.TRANS OUTEST=EST1;
        MODEL Y1=X;
     BY PAST TIER TRT TRANS FRM;
PROC REG DATA=C.TRANS OUTEST=EST2;
        MODEL Y2=X;
     BY PAST TIER TRT TRANS FRM;
PROC REG DATA=C.TRANS OUTEST=EST3;
        MODEL Y3=X;
     BY PAST TIER TRT TRANS FRM;
PROC REG DATA=C.TRANS OUTEST=EST4;
        MODEL Y4=X;
     BY PAST TIER TRT TRANS FRM;
PROC REG DATA=C.TRANS OUTEST=EST5;
        MODEL Y5=X;
     BY PAST TIER TRT TRANS FRM;
PROC REG DATA=C.TRANS OUTEST=EST6;
        MODEL Y6=X;
     BY PAST TIER TRT TRANS FRM;
PROC REG DATA=C.TRANS OUTEST=EST7;
        MODEL Y7=X;
     BY PAST TIER TRT TRANS FRM;
RUN;
DATA E1; SET EST1; RENAME INTERCEP=INT1 X=B1; RUN;
PROC SORT; BY PAST TIER TRT TRANS FRM;

DATA E2; SET EST2; RENAME INTERCEP=INT2 X=B2; RUN;
PROC SORT; BY PAST TIER TRT TRANS FRM;

DATA E3; SET EST3; RENAME INTERCEP=INT3 X=B3; RUN;
PROC SORT; BY PAST TIER TRT TRANS FRM;
```

Figure 20. Program Treg.sas produced regression coefficients for entire data set.

```
DATA E4; SET EST4; RENAME INTERCEP=INT4 X=B4; RUN;
PROC SORT; BY PAST TIER TRT TRANS FRM;

DATA E5; SET EST5; RENAME INTERCEP=INT5 X=B5; RUN;
PROC SORT; BY PAST TIER TRT TRANS FRM;

DATA E6; SET EST6; RENAME INTERCEP=INT6 X=B6; RUN;
PROC SORT; BY PAST TIER TRT TRANS FRM;

DATA E7; SET EST7; RENAME INTERCEP=INT7 X=B7; RUN;
PROC SORT; BY PAST TIER TRT TRANS FRM;

DATA ALLEST;
  MERGE E1 E2 E3 E4 E5 E6 E7;
  BY PAST TIER TRT TRANS FRM;
  FILE 'ALLINT.DAT';
  PUT (PAST TIER TRT TRANS FRM INT1-INT7)
      (1. +1 1. +1 1. +1 1. +1 1. +1 4.1 +1 4.1 +1 4.1 +1
    4.1 +1 4.1 +1 4.1 +1 4.1);
  FILE 'ALLB.DAT';
  PUT (PAST TIER TRT TRANS FRM B1-B7)
      (1. +1 1. +1 1. +1 1. +1 1. +1 6.4 +1 6.4 +1 6.4 +1
    6.4 +1 6.4 +1 6.4 +1 6.4);
RUN;

ENDSAS;
```

Figure 20.--<u>Continued</u>

```
C    (last modified 01/06/89 for Blaine Mooers by Richard
C     Lund)
C
************************************************************
C
C          PROGRAM:  AREANEW.FOR (A FORTRAN PROGRAM)
C
C          PROGRAMMER:  UNKNOWN
C          INSTITUTION: U.S.D.A. SEDIMENTATION LABORATORY
C                       P.O. BOX 1157
C                       OXFORD, MS 38655
C          DATE: 1984
C
C          MODIFIED BY: GARY A. LEHRSCH
C          INSTITUTION: DEPARTMENT OF AGRONOMY
C                       MISSISSIPPI STATE UNIVERSITY
C                       P.O. BOX 5248
C                       MISSISSIPPI STATE, MS 39762
C          DATE: MAY 20, 1985
C
C          PURPOSE:  TO CALCULATE AREAS ABOVE AND BELOW THE
C                    REFERENCE LINE AND TO CALCULATE THE NINE
C                    ROUGHNESS PARAMETERS
C
C          VARIABLES:
C              ITA      TAPE NUMBER
C              ITMT     TREATMENT NUMBER
C              IREP     REPLICATION NUMBER
C              ICOND    CONDITION OF THE PLOT
C              AA       Y-INTERCEPT OF THE REFERENCE LINE
C              BB       SLOPE OF THE REFERENCE LINE
C       ! AA AND BB WERE OBTAINED USING THE PROGRAM TREG.SAS
C              AREA     AREA ABOVE THE REFERENCE LINE AND BELOW
C                       THE MEASURED POSITIONS OF THE TRANSECT
C              BREA     AREA BELOW THE REFERENCE LINE AND ABOVE
C                       THE MEASURED POSITIONS OF THE TRANSECT
C              PKHT     MAXIMUM PEAK HEIGHT (MM)
C              DEDEP    MAXIMUM DEPRESSION DEPTH (MM)
C              PKS      NUMBER OF PEAKS MEASURED FOR THE
C                       TRANSECT
C              SL       INDICATOR VARIABLE FOR THE SLOPE, EQUAL
C                       TO 1.0 IF THE SLOPE IS POSITIVE
C              Z        TRANSECT NUMBER
C              TRLEN    TRANSECT LENGTH (MM)
C              REINDEX  MICRORELIEF INDEX ((MM**2)/MM)
```

Figure 21. Fortran program Area.for calculated nine roughness measures including microrelief index.

```
C             HTDPTL   (PEAK HEIGHT +DEPRESSION DEPTH)
C                      /TRANSECT LENGTH
C                      (UNITLESS)
C             FREQ     PEAK FREQUENCY (PEAKS/MM)
C             FHT      PEAK FREQUENCY/MAXIMUM PEAK HEIGHT
C                      (PEAKS/(MM**2))
C             MIHT     MICRORELIEF INDEX/MAXIMUM PEAK HEIGHT
C                      (UNITLESS)
C             MIOF     MICRORELIEF INDEX/PEAK FREQUENCY
C                      ((MM**2)/PEAK)
C             MIF      MICRORELIEF INDEX*PEAK FREQUENCY
C                      (PEAKS)
C
C         UNIT ASSIGNMENTS:
C              3         OUTPUT FILE (LONG VERSION, GIVING THE
C                      INCREMENTAL CHANGES MADE TO AREA AND
C                      BREA)
C             4        INPUT DATA FILE (TR1.DAT)
C             5        TERMINAL (FOR OUTPUT)
C             6        OUTPUT FILE (SHORT VERSION, GIVING ONLY
C                      THE REGRESSION LINE AND ROUGHNESS
C                             PARAMETERS)
C              7         OUTPUT FILE CONTAINING THE CALCULATED
C                      ROUGHNESS
C                      PARAMETERS THAT WILL BE ADDED TO A FILE
C                      CONTAINING PARAMETERS CALCULATED FOR
C                      THE OTHER TRANSECTS
C             9        TERMINAL (FOR INPUT)
C
C
*******************************************************
C
 DIMENSION X(65),Y(65),Z(65),XX(65),YY(65),YYY(65),A(65)
 DIMENSION C(65),D(65),AA(7),BB(7),YIN(7),IDENT1(5),
          IDENT2(5)
 REAL MIHT,MIOF,MIF
C
C
CX    WRITE (0,71)
CX 71 FORMAT(1X,'ENTER IN ORDER THE TAPE #, TREATMENT #,',
CX       &' REPLICATION  #,',/,1X,'AND  CONDITION  CX
(BARE=1,VEG=2).')
CX    READ (0,*) ITA,ITMT,IREP,ICOND
CX    WRITE (0,72)
CX 72 FORMAT (1X,'ENTER IN ORDER THE Y-INTERCEPT AND SLOPE',
```

Figure 21.--Continued

```
CX    &'FOR THE REGRESSION LINE.')
C
      DO 998 IY=1,7
  888 READ (11,13,END=997) IDENT1,(AA(LLL),BB(LLL),LLL=1,7)

   13 FORMAT(I1,4I2,7(F5.1,F7.4))
C
CX    WRITE (3,13) ITA,ITMT,IREP,ICOND,AA,BB
CX 13 FORMAT(1X,'TAPE # ',I3,', TREATMENT # ',I3,
CX   &', REPLICATION # ',I3,', CONDITION ',I3,
CX   &' (1=BARE, 2=VEG).',
CX   &/,'O','THE Y-INTERCEPT IS ',F11.6,' AND THE SLOPE ',
CX   &'IS',F12.8,/,1X,/,'O',5X,
'AREA',6X,'BREA',5X,'X(I)',6X,
CX   &'Y(I)',7X,'C(I)',6X,'D(I)',/,1X)
CX    WRITE (6,14) ITA,ITMT,IREP,ICOND,AA,BB
CX 14 FORMAT(1X,'TAPE # ',I3,', TREATMENT # ',I3,
CX   &', REPLICATION # ',I3,', CONDITION ',I3,
CX   &' (1=BARE, 2=VEG).',
CX   &/,'0','THE Y-INTERCEPT IS ',F11.6,' AND THE SLOPE ',
CX   &'IS ',F12.8,/,1X)
      DO 100 I=1,65
      Z(I)=99.9
      READ (4,10,END=999) IDENT2,XIN,YIN
   10 FORMAT(I1,4I2,F4.0,7F6.2)
      X(I)=XIN
      Y(I)=YIN(IY)
C
      DO 98 LL=1,5
         IF (IDENT1(LL).NE.IDENT2(LL)) THEN
            WRITE(0) ' IDENT MIS-MATCH'
            GOTO 999
            ENDIF
   98 CONTINUE
C
  100 CONTINUE
  80  ND=I-1
C
C     INSURE THAT THE DATA ARE ORDERED SUCH THAT
C     THE X-COORDINATE INCREASES
C
      IF (X(1).LT.X(5)) GO TO 73
      DO 1 I=1,ND
      J=ND+1-I
      XX(J)=X(I)
      YY(J)=Y(I)
```

Figure 21.--<u>Continued</u>

```
    1 CONTINUE
      DO 2 I=1,ND
      X(I)=XX(I)
      Y(I)=YY(I)
    2 CONTINUE
C
C     DETERMINE THE ELEVATION OF THE REFERENCE LINE
C     AT EACH X-COORDINATE
C
   73 DO 3 I=1,ND
    3 YYY(I)=AA(IY)+BB(IY)*X(I)
C
C     INITIALIZATION
C
      AREA=0.
      BREA=0.
      K=ND-1
      PKHT=0.0
      DEDEP=0.0
      DO 11 I=1,ND
      C(I)=Y(I)-YYY(I)
      IF(C(I).GT.PKHT) PKHT=C(I)
      IF(C(I).LT.DEDEP) DEDEP=C(I)
   11 CONTINUE
      DEDEP=ABS(DEDEP)
      DO 20 I=1,K
   20 D(I)=X(I+1)-X(I)
      DO 40 I=1,K
C
C     IF THE ELEVATION IS ABOVE THE REFERENCE LINE
C     THEN INCREMENT AREA
C
      IF (C(I+1).GE.O.AND.C(I).GE.O) GO TO 7
C
C     IF THE ELEVATION IS BELOW THE REFERENCE LINE
C     THEN INCREMENT BREA
C
      IF (C(I+1).LE.O.AND.C(I).LE.O) GO TO 8
      X1=ABS(C(I))*D(I)/(ABS(C(I))+ABS(C(I+1)))
      X2=ABS(C(I+1))*D(I)/(ABS(C(I))+ABS(C(I+1)))
C
C     IF THE ELEVATION HAS CROSSED THE REFERENCE LINE
C     THEN INCREMENT AREA AND BREA EQUALLY
C
      IF (C(I+1).GE.O.AND.C(I).LE.O) GO TO 9
```

Figure 21.--Continued

```
      AREA=AREA+(X1*C(I)/2.)
      BREA=BREA+(X2*ABS(C(I+1))/2.)
      GO TO 4
    7 AREA=AREA+(D(I)*(C(I+1)+C(I))/2.)
      GO TO 4
    8 BREA=BREA+(D(I)*(ABS(C(I+1))+ABS(C(I)))/2.)
      GO TO 4
    9 AREA=AREA+(X2*C(I+1)/2.)
      BREA=BREA+(X1*ABS(C(I))/2.)
    4 CONTINUE
C
C     AT EACH ITERATION OUTPUT THE CHANGES
C     MADE TO AREA AND BREA
C
CX    WRITE (3,50) AREA,BREA,X(I),Y(I),C(I),D(I)
CX 50 FORMAT (1X,2F10.4,2F10.5,2F10.4)
   40 CONTINUE
CX    WRITE (3,51) X(ND),Y(ND)
CX 51 FORMAT (21X,2F10.5,/,1X)
C
C     DETERMINE THE NUMBER OF PEAKS
C     MEASURED FOR THE TRANSECT
C
      PKS=0.0
      SL=0.0
      DO 41 I=2,ND
      DIFF=Y(I)-Y(I-1)
      IF(DIFF.GT.0.0) SL=1.0
      IF(DIFF.EQ.0.0) GO TO 41
      IF(DIFF.LT.0.0) THEN
       IF(SL.EQ.0.0) GO TO 41
       PKS=PKS+1.0
       SL=0.0
      END IF
   41 CONTINUE
CX    WRITE (3,14) ITA,ITMT,IREP,ICOND,AA,BB
CX    WRITE (3,18) Z(1)
CX    WRITE (6,18) Z(1)
CX 18 FORMAT(1X,'THE TRANSECT NUMBER IS ',F6.0,/,1X)
C
C     CALCULATE THE TRANSECT LENGTH
C
      TRLEN=X(ND)
C
C     CALCULATE THE NINE ROUGHNESS PARAMETERS
C
```

Figure 21.--Continued

```
      REINDEX=((AREA+BREA)/TRLEN)*100.0
      PKHT=PKHT*10.0
      DEDEP=DEDEP*10.0
      HTDPTL=(PKHT+DEDEP)/TRLEN
      FREQ=PKS/TRLEN
CCC
      FHT=0.0
      MIHT=0.0
      IF (PKHT.GT.0.0) THEN
         FHT=FREQ/PKHT
         MIHT=REINDEX/PKHT
         ENDIF
C
      MIOF=0.0
      IF (FREQ.GT.0.0) MIOF=REINDEX/FREQ
      MIF=REINDEX*FREQ
CCCC
C
C     OUTPUT
C
CX    WRITE (3,15) PKHT,DEDEP,HTDPTL,FREQ,FHT
CX    WRITE (6,15) PKHT,DEDEP,HTDPTL,FREQ,FHT
CX 15 FORMAT(1X,' MAXIMUM PEAK HEIGHT: ',F5.2,' MM',/,'0',
CX   &' MAXIMUM DEPRESSION DEPTH: ',F5.2,' MM',
CX      &/,'0',' (MAXIMUM PEAK HEIGHT+MAXIMUM DEPRESSION
DEPTH)/',
CX   &'TRANSECT LENGTH: ',F6.4,
CX   &/,'0',' PEAK FREQUENCY: ',F8.6,' PEAKS/MM',
CX      &/,'0',' PEAK FREQUENCY/MAX. PEAK HT.: ',F8.6,'
PEAKS/(MM**2)')
CX    WRITE (3,5) AREA,BREA
CX    WRITE (6,5) AREA,BREA
CX  5 FORMAT ('0',' AREA ABOVE AVE. LINE:',2X,F10.5,' CM**2',
CX   &/,2X,'AREA BELOW AVE. LINE:',2X,F10.5,' CM**2')
CX    WRITE (3,52) TRLEN,REINDEX
CX    WRITE (6,52) TRLEN,REINDEX
CX 52 FORMAT('0',' TRANSECT LENGTH:  ',F6.0,' MM',/,1X,/,'0',
CX   &' MICRORELIEF INDEX:',F7.4,' (MM**2)/MM')
CX    WRITE (3,16) MIHT,MIOF,MIF
CX    WRITE (6,16) MIHT,MIOF,MIF
CX 16 FORMAT('0',' MICRORELIEF INDEX/MAX. PEAK HT.: ',F8.4,

CX    &/,'0',' MICRORELIEF INDEX/PEAK FREQUENCY: ',F6.2,' CX
     (MM**2)/PEAK',
```

Figure 21.--Continued

```
CX    &/,'O',' MICRORELIEF INDEX*PEAK FREQUENCY: CX
',F6.4,'PEAKS')
      IZ=IFIX(Z(1))
C
C     OUTPUT THE CALCULATED ROUGHNESS PARAMETERS
C     TO A SEPARATE FILE
C
      WRITE (7,17) IDENT1,IY,PKHT,DEDEP,
     &HTDPTL,FREQ,FHT,REINDEX,MIHT,MIOF,MIF
   17 FORMAT(6I2,2(1X,F6.2),1X,F6.4,1X,F7.5,1X,F8.6,1X,
     &F8.4,1X,F8.4,1X,F8.2,1X,F8.4)
C
      GOTO 888
C
  997 REWIND 4
      REWIND 11
  998 CONTINUE
 999  STOP
      END
```

Figure 21.--<u>Continued</u>

```
*PROGRAM:   FINADJ3.DAT
*
*DATE:   1-8-89
*
*PROGRAMMER:   BLAINE MOOERS
*
*PURPOSE:   THIS PROGRAM SHIFTED THE DECIMAL POINT TO THE
*           PROPER LOCATION IN THE OUTPUT DATA; THE DATA ARE
*           ARRANGED BY COLLECTION DATE;
LIBNAME C 'C:\SAS';
OPTIONS PS=56 LS=80;
DATA C.FINAL;
INFILE 'FINAL.DAT';
INPUT IDEN1 $ 2-10 IY 12 PKHT 14-19 DEDEP 21-26 HTDPTL 28-33
FREQ 36-41
 FHT 44-50 REINDEX 52-59 MIHT 63-68 MIOF 71-77 MIF 80-86;
PROC SORT;
BY IY IDEN1;
DATA C.FINADJ3;
SET C.FINAL;
A=PKHT/10;
B=DEDEP/10;
C=HTDPTL/10;
D=FREQ;
E=FHT*10;
F=REINDEX/100;
G=MIHT/10;
H=MIOF/100;
I=MIF/100;
FILENAME FINADJ3 'C:\SAS\FINADJ3.DAT';
FILE FINADJ3 NOTITLE;
PUT (IDEN1 IY A B C D E F G H I)
   ($9. +1 1. +1 5.2 +1 5.2 +1 6.5 +1 6.5 +1 7.6 +1 8.6 +1
6.5 +1 7.4 +1 7.6);
RUN;
ENDSAS;
```

Figure 22. SAS program Finadj3.dat shifted decimal points of roughness measures to their proper position.

```
*    PROGRAM:  MEAN.SAS
*
*    PROGRAMMER:  BLAINE MOOERS
*
*    DATE:  1-27-89
*
*    PURPOSE:   TO FIND ALL OF THE TREATMENT COMBINATION
*               MEANS;

options ps=58 ls=110;
libname c  'D:\BLAINE';
PROC SUMMARY DATA=C.MEAN88A;
CLASS PAST TIER TRTMT;
VAR V1-V9;
OUTPUT OUT=C.SUM88 MEAN=M1-M9;
RUN;
PROC PRINT DATA=C.SUM88;
RUN;
data a;
set c.sum88;
file 'mean88.sum';
put (obs time past tier trtmt _freq_ m1 m2 m3 m4 m5 m6 m7 m8
    m9)
(2. +1 1. +1 1. +1 1. +1 1. +1 3. +1 8.5 +1 8.5 +1 10.7 +1
10.7 +1 10.7 +1 9.5 +1 9.6 +1 8.5 +1 9.6);
run;
ENDSAS;
```

Figure 23. SAS program Mean.sas calculated all treatment combination means.

```
*    PROGRAM:   PAIRDIFF.SAS
*
*    PROGRAMMER:   BLAINE MOOERS
*
*    DATE:   1-20-89
*
*    PURPOSE:   TO CALCULATE THE DIFFERENCE BETWEEN THE
*               POST AND PRE-GRAZING SURFACE ROUGHNESS
*               MEASURES.  THESE DIFFERENCES ARE TO USED
*               IN THE CALCULATION OF THE TRANSECT MEAN
*               DIFFERENCE IN THE MEANDIFF.SAS PROGRAM.;


LIBNAME C 'D:\BLAINE';
OPTIONS PS=56 LS=85;
DATA PRE;
  SET C.FINADJ3;
    IF IY=1 OR IY=3 OR IY=6;
     RENAME     PKHT=PRPKHT      DEDEP=PRDEDEP      HTDPTL=PRHTDP
     FREQ=PRFREQ    FHT=PRFHT    REINDEX=PRREIND    MIHT=PRMIHT
     MIOF=PRMIOF MIF=PRMIF;
RUN;
DATA POST;
  SET C.FINADJ3;
  IF IY=2 OR IY=4 OR IY=7;
  IF IY=2 THEN IY=1;
  IF IY=4 THEN IY=3;
  IF IY=7 THEN IY=6;
RUN;
 PROC SORT DATA=PRE;
  BY IY IDEN TR FR;
 PROC SORT DATA=POST;
  BY IY IDEN TR FR;
RUN;
DATA PREPOST;
MERGE PRE POST;
  BY IY IDEN TR FR;
  DIFF1=PKHT-PRPKHT;
  DIFF2=DEDEP-PRDEDEP;
  DIFF3=HTDPTL-PRHTDP;
  DIFF4=FREQ-PRFREQ;
  DIFF5=FHT-PRFHT;
  DIFF6=REINDEX-PRREIND;
  DIFF7=MIHT-PRMIHT;
  DIFF8=MIOF-PRMIOF;
  DIFF9=MIF-PRMIF;
```

Figure 24. SAS program Pairdiff.sas calculated the difference between the post and pre-grazing surface roughness measures.

```
DATA C.DIFF87;
  SET PREPOST;
  IF IY=1 OR IY=3;
  RENAME IY=TIME;
  RUN;
DATA C.DIFF88;
  SET PREPOST;
  IF IY=6;
  RUN;
ENDSAS;
```

Figure 24.--Continued

```
*     PROGRAM:  DIFFMEAN.SAS
*
*     PROGRAMMER:  BLAINE MOOERS
*
*     DATE:  1-20-89
*
*     PURPOSE:  TO PRODUCE TRANSECT MEANS OF SURFACE
*                ROUGHNESS MEASUSRES.  THESE MEANS WILL SERVE
*               AS INPUT INTO THE ANALYSIS OF VARIANCES OF
*                DIFFERENCES IN SURFACE ROUGHNESS IN 1987 AND
*               1988.;
LIBNAME C 'D:\BLAINE';
OPTIONS PS=56 LS=110;

 DATA MEAN87;
SET C.DIFF87;
PROC UNIVARIATE;
VAR DIFF1 DIFF2 DIFF3 DIFF4 DIFF5 DIFF6 DIFF7 DIFF8 DIFF9;
BY TIME IDEN TR;
OUTPUT  OUT=C.MEAN87  MEAN=DF1MEAN  DF2MEAN  DF3MEAN  DF4MEAN
     DF5MEAN DF6MEAN DF7MEAN DF8MEAN DF9MEAN;
RUN;
DATA A1;
  SET C.MEAN87;
   FILE 'MEAN87.DAT';
  PUT  (TIME IDEN TR DF1MEAN DF2MEAN DF3MEAN DF4MEAN
    DF5MEAN DF6MEAN DF7MEAN DF8MEAN DF9MEAN)
(1. +1 3. +1 1. +1 6.3 +1 6.3 +1 10.8 +1 10.8 +1 10.8 +1 12.8
+1 10.7 +1 12.7 +1 10.7);
RUN;
DATA C.M;
  INFILE 'MEAN87.DAT';
    INPUT TIME 1 PASTURE 3 TIER 4 TRMT 5 TR 7 DF1MEAN 9-14
   DF2MEAN 16-25 DF3MEAN 27-36 DF4MEAN 38-47 DF5MEAN 49-58
   DF6MEAN  60-71  DF7MEAN  73-82  DF8MEAN  84-97
DF9MEAN99-108;
PROC SORT DATA=C.M;
BY TIME PASTURE TIER TRMT TR;
RUN;
DATA MM;
SET C.M;
FILE 'MEAN87A.DAT';
  PUT (TIME PASTURE TIER TRMT TR DF1MEAN DF2MEAN DF3MEAN
DF4MEAN DF5MEAN DF6MEAN DF7MEAN DF8MEAN DF9MEAN)
   (1. +1 1. +1 1. +1 1. +1 1. +1 6.3 +1 6.3 +1 10.8 +1 10.8
+1 10.8 +1 12.8 +1 10.7 +1 12.7 +1 10.7);
RUN;
```

Figure 25. SAS program Diffmean.sas produced transect means.

```
DATA C.MEAN88; SET C.DIFF88;
PROC UNIVARIATE;
VAR DIFF1 DIFF2 DIFF3 DIFF4 DIFF5 DIFF6 DIFF7 DIFF8 DIFF9;
BY IY IDEN TR;
OUTPUT  OUT=C.MEAN88  MEAN=DF1MEAN  DF2MEAN  DF3MEAN  DF4MEAN
     DF5MEAN DF6MEAN DF7MEAN DF8MEAN DF9MEAN;
RUN;
DATA B1;
  SET C.MEAN88;
   FILE 'MEAN88.DAT';
  PUT  (IY IDEN TR DF1MEAN DF2MEAN DF3MEAN DF4MEAN
    DF5MEAN DF6MEAN DF7MEAN DF8MEAN DF9MEAN)
(1. +1 3. +1 1. +1 6.3 +1 6.3 +1 10.8 +1 10.8 +1 10.8 +1 12.8
+1 10.7 +1 12.7 +1 10.7);
RUN;
DATA C.P;
  INFILE 'MEAN88.DAT';
    INPUT TIME 1 PASTURE 3 TIER 4 TRMT 5 TR 7 DF1MEAN 9-14
     DF2MEAN 16-25 DF3MEAN 27-36 DF4MEAN 38-47 DF5MEAN 49-58
     DF6MEAN  60-71  DF7MEAN  73-82  DF8MEAN  84-97
DF9MEAN99-108;
PROC SORT DATA=C.P;
BY TIME PASTURE TIER TRMT TR;
RUN;
DATA PP;
SET C.P;
FILE 'MEAN88A.DAT';
  PUT (TIME  PASTURE  TIER  TRMT  TR  DF1MEAN  DF2MEAN  DF3MEAN
DF4MEAN
    DF5MEAN DF6MEAN DF7MEAN DF8MEAN DF9MEAN)
   (1. +1 1. +1 1. +1 1. +1 1. +1 6.3 +1 6.3 +1 10.8 +1 10.8
+1 10.8 +1 12.8 +1 10.7 +1 12.7 +1 10.7);
RUN;
ENDSAS;
```

Figure 25.--Continued

```
*     PROGRAM:  GLM87.SAS
*
*     PROGRAMMER:  DEBBIE ROSSI
*
*     DATE:  1-20-87
*
*     PURPOSE:  TO DO ANALYSIS OF VARIANCE WITH THE
*               1987 DIFFERENCE DATA.  THE EXPERIMENTAL
*               DESIGN WAS A SPLIT SPLIT-PLOT.  THIS PROGRAM
*               ALSO PLOTS THE RESIDUALS VERSUS THE PREDICTED
*               VALUES.;

libname c 'd:\blaine';
proc glm data=c.mean87a;
  classes time past tier trtmt trans;
  model v1-v9 = past tier past*tier trans(past tier)
                trtmt past*trtmt tier*trtmt past*tier*trtmt
                trans*trtmt(past tier)
                time time*past time*tier time*past*tier
                time*trtmt time*past*trtmt time*tier*trtmt
                time*past*tier*trtmt / ss3;
TEST H=PAST TIER PAST*TIER E=TRANS(PAST*TIER) / HTYPE=3
     ETYPE=3;
TEST   H=TRTMT   PAST*TRMTMT   TIER*TRTMT   PAST*TIER*TRTMT
     E=TRANS*TRTMT(PAST*TIER) / HTYPE=3 ETYPE=3;
  output out=new87 r=r1-r9 p=p1-p9;
run;
proc plot data=new87;
  plot r1*p1  r2*p2  r3*p3  r4*p4  r5*p5  r6*p6  r7*p7  r8*p8
r9*p9/vref=0;
run;
ENDSAS;
```

Figure 26. SAS program Glm87.sas did analysis of variance with the 1987 difference data. See Table 8 in Appendix B for more details.

```
*    PROGRAM:  GLM88.SAS
*
*    PROGRAMMER:  DEBBIE ROSSI
*
*    DATE:  1-26-89
*
*    PURPOSE:  TO DO ANALYSIS OF VARIANCE OF THE DIFFERENCES
*              IN SURFACE ROUGHNESS MEASURES IN 1988.  THE
*              DESIGN WAS A SPLIT-PLOT DESIGN.  SEE APPENDIX
*              B FOR MORE DETAILS.
*
options ls=78 ps=58;
libname c 'd:\blaine';
data c.mean88_1;
  infile 'mean88a.dat' ls=104 missover;
  input time 1 past 3 tier 5 trtmt 7 trans 9 v1 10-16 .3 v2
      17-23 .3 v3 24-34 .8 v4 35-45 .8 v5 46-56 .8 v6 57-69
      .8 v7 70-80 .7 v8 81-93 .7 v9 94-104 .7;
  if trtmt=2 and tier=1 then delete;
run;
proc glm data=c.mean88_1;
  classes past tier trtmt trans;
  model v1-v9 = past tier past*tier trans(past tier)
                trtmt past*trtmt tier*trtmt past*tier*trtmt;

  test h=past tier past*tier e=trans(past tier);
  output out=new88 r=r1-r9 p=p1-p9;
run;
proc plot data=new88;
  plot r1*p1  r2*p2  r3*p3  r4*p4  r5*p5  r6*p6  r7*p7  r8*p8
r9*p9/vref=0;
run;
proc univariate data=new88 normal plot;
  var r1-r9;
run;
endsas;
```

Figure 27. SAS program Glm88.sas did analysis of variance of differences in surface roughness measures in 1988. See Table 10 in Appendix B for more details.

```
*    PROGRAM:  EXSUM.SAS
*
*    PROGRAMMER:  BLAINE MOOERS
*
*    DATE:  1-20-89;
*
*    PURPOSE:  TO PRODUCE THE MEANS OF THE SURFACE ROUGHNESS
*               MEASURES FOR EACH TRANSECT IN THE
*                EXCLOSURES.  THIS MEANS ARE USED IN THE
*               SEAS***.SAS REPEATED MEASURES ANALYSIS OF
*              VARIANCE PROGRAMS;
LIBNAME C 'D:\BLAINE';
OPTIONS PS=56 LS=110;
DATA C.SUMDAT;
  INFILE 'EXTIME.DAT';
  INPUT PASTURE 1 TIER 3 TRMT 5 TR 7 FR 9 TIME 11 PKHT 13-18
DEDEP 20-25
 HTDPTL 27-36 FREQ 38-47 FHT 49-58 REINDEX 60-71 MIHT 73-82
MIOF 84-95
MIF 97-106;
 RUN;
DATA C.R;
SET C.SUMDAT;
PROC UNIVARIATE;
VAR PKHT DEDEP HTDPTL FREQ FHT REINDEX MIHT MIOF MIF;
BY TIME PASTURE TIER TRMT TR;
ID FR;
OUTPUT  OUT=C.EXMEAN  MEAN=PKMEAN  DEMEAN  HTDPMEAN  FREQMEAN
FHTMEAN
  REINMEAN MIHTMEAN MIOFMEAN MIFMEAN;
RUN;
DATA A1;
  SET C.EXMEAN;
   FILE 'EXMEAN.DAT';
  PUT  (TIME PASTURE TIER TRMT TR PKMEAN DEMEAN HTDPMEAN
 FREQMEAN FHTMEAN REINMEAN MIHTMEAN MIOFMEAN MIFMEAN)
 (1. +1 1. +1 1. +1 1. +1 1. +1 6.3 +1 6.3 +1 10.8 +1 10.8 +1
10.8 +1 12.8 +1 10.7 +1 12.7 +1 10.7);
RUN;
ENDSAS;
```

Figure 28. SAS program Exsum.sas produced transect means of surface roughness measures from each exclosure.

```
*    PROGRAM:  SEASDP.SAS
*
*    PROGRAMMER:  DEBBIE ROSSI
*
*    DATE:  1-26-89
*
*    PURPOSE:  TO DO REPEATED MEASURES ANALYSIS OF VARIANCE
*              ON PRE-GRAZING SURFACE ROUGHNESS MEASURES
*              FROM THE EXCLOSURES IN ORDER TO TEST
*              HYPOTHESES CONCERNING DIFFERENCES IN SURFACE
*              ROUGHNESS OVER TIME.  THIS PROGRAM CAN ONLY
*             HANDLE ONE SURFACE ROUGHNESS MEASURE AT A TIME.
*              IT HAD TO BE RUN NINE TIMES.  IT TRANSPOSES
*              PART OF THE DATA PRIOR TO THE ANALYSIS OF
*              VARIANCE.  AFTER THE ANALYSIS OF VARIANCE, IT
*             PLOTS THE RESIDUALS AND PROVIDE A LARGE NUMBER
*             OF UNIVARIATE STATISTICS INCLUDING MEASURES OF
*              NORMALITY.

title 'REPEATED MEASURES RUN FOR deMEAN OVER SEASONS';
libname c 'd:\blaine';
options ps=58 ls=78;
data c.DEmean;
 inFILE 'EXMEAN.DAT';
 inPUT  TIME 1 PASTURE 3 TIER 5 TRMT 7 TR 9 DEMEAN 18-23;
proc sort data=c.DEmean;
  by pasture tier trmt tr time;
run;
proc transpose data=c.DEmean out=new;
  var v2;
  by pasture tier trmt tr;
run;
proc print data=new;
run;
proc glm data=new;
  classes pasture tier;
  model col1-col4 = pasture tier pasture*tier / nouni;
  repeated time 4 (1 3 5 7) polynomial / short summary;
  output out=newout r=resid p=yhat;
run;
proc plot data=newout;
  plot resid*yhat / vref=0;
run;
proc univariate normal plot;  var resid;  run;
ENDSAS;
```

Figure 29. SAS program Seasdp.sas did repeated analysis of variance on pre-grazing surface roughness measures from the exclosures to test for seasonal effects. See Table 12 in Appendix B for more details.

```
*     PROGRAM:  MMAG.SAS
*
*     PROGRAMMER:  BLAINE MOOERS
*
*     DATE:  4-4-89
*
*     PURPOSE:  TO OBTAIN MEANS OF THE ABSOLUTE SURFACE
*               ROUGHNESS VALUES RATHER THAN THEIR
*               DIFFERENCES.  THIS DATA WILL BE USED IN
*               STATPLOT.SAS TO TEST TO FOR DIFFERENCES
*               BETWEEN PLOT LOCATIONS THAT EXISTED PRIOR TO
*               THE INITITATION OF THIS STUDY.

LIBNAME C 'magnit';
OPTIONS PS=56 LS=110;
DATA A;
INFILE 'FINADJ3.DAT';
INPUT PASTURE 1 TIER 2 TRMT 3 TR 5 FR 7 DATE 9 PK 11-15 DEP
17-21
      HDL 23-28 FRQ 30-35 FHT 37-43 REX 45-52 MIH 54-59
      MOF 61-67 MIF 69-75;
PROC SORT;
BY DATE PASTURE TIER TRMT TR FR;
RUN;

DATA B;
SET A;
PROC UNIVARIATE;
VAR PK DEP HDL FRQ FHT REX MIH MOF MIF;
BY DATE PASTURE TIER TRMT tr;
OUTPUT OUT=MEAN MEAN=PKMEAN DEPMEAN HDLMEAN FRQMEAN FHTMEAN
     REXMEAN MIHMEAN MOFMEAN MIFMEAN;
RUN;

DATA C;
SET MEAN;
FILE 'MAGMEAN.DAT';
 PUT (DATE PASTURE TIER TRMT TR PKMEAN DEPMEAN HDLMEAN
FRQMEAN FHTMEAN REXMEAN MIHMEAN MOFMEAN MIFMEAN)
(1. +1 1. +1 1. +1 1. +1 1. +1 6.3 +1 6.3 +1 10.8 +1 10.8 +1
     10.8 +1 12.8 +1 10.7 +1 12.7 +1 10.7);
RUN;
ENDSAS;
```

Figure 30. SAS program Mmag.sas obtained transect means of absolute surface roughness values from all plots.

```
*     PROGRAM:  GLMPRE87.SAS
*
*     PROGRAMMER:  DEBBIE ROSSI, MODIFIED BY BALINE MOOERS
*
*     DATE:  4-11-89
*
*     PURPOSE:  TO DO ANALYSIS OF VARIANCE OF THE PREGRAZING
*               JUNE  1988  DATA  TO  TEST  FOR  ANTECEDANT
*               DIFFERENCES IN SURFACE ROUGHNESS BETWEEN PLOT
*               LOCATIONS.

libname c '[uascmbm]';
DATA A;
INFILE 'Magmean.DAT' LS=110 MISSOVER;
INPUT TIME 1 PAST 3 TIER 5 TRTMT 7 TRANS 9 V1 11-16 .3  V2
18-23.3 V3 25-34 .8 V4 36-45 .8 V5 47-56 .8 V6 58-69 .8 V7
71-80 .7 V8 82-93 .7 V9 95-104;
run;
data aa;
set a;
if time= '1';
proc sort;
by past tier trtmt trans;
run;
data aa;
proc glm data=aa;
  classes past tier trtmt trans;
  model v1-v9 = past tier past*tier/SS3;
  output out=B r=r1-r9 p=p1-p9;
run;
proc plot data=b;
  plot  r1*p1  r2*p2  r3*p3  r4*p4  r5*p5  r6*p6  r7*p7  r8*p8
r9*p9/vref=0;
run;
PROC UNIVARIATE DATA=Aa NORMAL PLOT;
VAR r1-r9;
run;
ENDSAS;
```

Figure 31. SAS program Glmpre87.sas did two-way analysis of variance to test for antecedent differences between plots.

```
*    PROGRAM:  STATPLOT.SAS
*
*    PROGRAMMER:  BLAINE MOOERS
*
*    DATE:  4-12-1989
*
*    PURPOSE:  TO PRODUCE SEVERAL STATISTICS OF PIN HEIGHT
*              THAT HAVE BEEN USED OCCASSIONALLY AS MEASURES
*              OF SURFACE ROUGHNESS.  THE VALUES USED IN
*              THIS PROGRAM COME FROM POST-GRAZING JUNE
*             1988.  THESE CHOSEN TO SERVE AS REPRESENTATIVES
*              OF THIN SILTY RANGE SITES UNDER AND NOT UNDER
*              TIME-CONTROLLED GRAZING.  THE RESULTS CAN BE
*              FOUND IN APPENDIX C.;

libname c '[uascmbm]';
options ps=56 ls=80;
data a;
infile 'all2x.dat';
input past 1 tier 3 trtmt 5 tr 7 fr 9 n 11-13 y7 57-62;
* yl 15-20 y2 22-27 y3 29-34
* y4 36-41 y5 43-48 y6 50-55 y7 57-62;
proc sort;
by past tier trtmt;
run;
proc means data=a noprint;
var y7;
 by past tier trtmt;
 output out=b mean=y7mean var=y7var std=y7std range=y7range
min=y7min
        max=y7max stderr=y7stderr;
run;
data c;
set b;
file 'statplot';
 put (past tier trtmt y7mean y7var y7std y7range y7min y7max
y7stderr)
 (1. +1 1. +1 1. +1 9.6 +1 9.5 +1 9.5 +1 8.5 +1 8.5 +1 8.5 +1
8.5);
run;
endsas;
```

Figure 32. SAS program Statplot.sas produced common statistics of pin heights.

APPENDIX B: ANOVA TABLES AND CONTRASTS

Appendix B contains keys to complex ANOVA tables referred to in the text. Each key is followed by the complete ANOVA table. The last table contains eight large contrasts referred to in the text.

Table 8. Key to ANOVA table used to test for 1987 changes in microrelief index values. See text for more information.

1987 Surface Roughness Change ANOVA Key

Source of Variation	df	df from	MS	Test Stat.
Treatments	8	pi-1	MSTR	MSTR/MSW
(Pasture)	(3)	p-1	MSP	MSP/MSW
(Tier)	(3)	i-1	MSI	MSI/MSW
(Pasture*Tier)	(4)	(p-1)(i-1)	MSPI	MSPI/MSW
Error(W)	27	pl(r-1)	MSW	
Error(W)=transect(pasture*tier)				
Grazing	1	g-1	MSG	MSG/MSSP
Grazing*Pasture	2	(g-1)(p-1)	MSGP	MSPI/MSSP
Grazing*Tier	2	(g-1)(i-1)	MSGT	MSGT/MSSP
Error(SP)	27	pi(r-1)(g-1)	MSSP	
Error(SP)=transect*grazing(pasture*tier)				
Time	1	t-1	MST	MST/MSSSP
Time*Pasture	2	(t-1)(p-1)	MSTP	MSTP/MSSSP
Time*Tier	2	(t-1)(i-1)	MSTI	MSTI/MSSSP
Time*Pasture*Tier	4	(t-1)(pi-1)	MSTPI	MSTPI/MSSSP
Time*Grazing	1	(t-1)(g-1)	MSTG	MSTG/MSSSP
Time*Pasture*Grazing	2	(t-1)(p-1)(g-1)	MSTPG	MSTPG/MSSSP
Time*Tier*Grazing	2	(t-1)(i-1)(g-1)	MSTIG	MSTIG/MSSSP
Time*Pasture* Tier*Grazing	4	(t-1)(pi-1)(g-1)	MSTPTG	MSTPIG/MSSSP
Error(SSP)	54	pig(r-1)(t-1)	MSSSP	
Error(SSP)=overall error sum of square				
Total	143	pigtr		

KEY: treatments=plot pair location p=pastures i=tiers g=grazing or no grazing t=time (June or October 1987)

Table 9. ANOVA table used to test for 1987 changes in microrelief index values. See text for more information.

1987 Microrelief Index Change ANOVA

Source of Variation	df	Type III SS	F-value	PR > F
Pasture	2	5.4882057	18.79	.0001
Tier	2	0.8009707	2.30	.1199
Pasture*Tier	4	0.1175329	1.70	.1800
Transect(Pasture*Tier)	27	4.7080525		
Grazing	1	0.000499682	0.00	.9508
Grazing*Pasture	2	0.653517	2.53	.0983
Grazing*Tier	2	0.448436	1.74	.1951
Grazing*Pasture*Tier	4	0.7070332	1.37	.2707
Transect*Grazing*(Pasture*Tier)	27	3.4852376		
Time	1	1.0076971	6.90	.0112
Time*Pasture	2	0.653517	2.22	.1181
Time*Tier	2	0.448436	2.34	.1060
Time*Pasture*Tier	4	0.7070332	1.19	.3269
Time*Treatment	1	0.3186622	2.18	.1454
Time*Pasture*Treatment	2	0.1137421	0.39	.6793
Time*Tier*Treatment	2	0.1598192	0.55	.5817
Time*Pasture*Tier*Treatment	4	0.2460013	0.42	.7927

Table 10. Key to ANOVA table used to test for 1988 changes in microrelief index values. See text for more information.

<u>1988 Surface Roughness Change ANOVA Key</u>

Source of Variation	df	df form	MS	Stat. Test
Treatments	8	pi-1	MSTR	MSTR/MSW
(Pasture)	(3)	p-1	MSP	MSP/MSW
(Tier)	(3)	i-1	MSI	MSI/MSW
(Pasture*Tier)	(4)	(p-1)(i-1)	MSPI	MSPI/MSW
Error(W)	27	pi(r-1)	MSW	

Error(W)=transect(pasture*tier)

Source of Variation	df	df form	MS	Stat. Test
Grazing	1	g-1	MSG	MSG/MSW
Grazing*Pasture	2	(g-1)(p-1)	MSGP	MSGP/MSW
Grazing*Tier	2	(g-1)(i-1)	MSGT	MSGT/MSW
Grazing*Pasture*Tier	4	(pi-1)(g-1)	MSGPT	MSGPT/MSW
Error(SP)	27	pi(r-1)(g-1)	MSSP	

Error(SP)=overall error sum of squares

Total	71	pigr		

KEY: treatments=plot pair location p=pastures i=tiers g=grazing or no grazing t=time (June or October 1987)

Table 11. ANOVA table used to test for 1988 changes in microrelief index values. See text for more information.

<u>1988 Microrelief Index Change ANOVA</u>

Source of Variation	df	Type III SS	F-value	PR > F
Treatments	8			
(Pasture)	(2)	0.554003	3.60	.0413
(Tier)	(2)	0.1031859	0.67	.5201
(Pasture*Tier)	(4)	0.7258644	2.36	.0790
Error (W)	27	2.079963		
Grazing	1	0.7166382	10.45	.0032
Grazing*Pasture	2	0.5512108	4.02	.0297
Grazing*Tier	2	0.2571200	1.87	.1729
Grazing*Pasture*Tier	4	0.5307781	1.93	.1335
Error (SP)	27	1.8522148		

Table 12. Key to repeated measures analysis of variance table used in testing season effects on the ungrazed plots.

Surface Roughness Over Seasons

Repeated Measures Analysis of Variance Key

Source of Variation	df	df form	MS	Test Stat.
Locations	8	L-1	MSL	MSL/MSW
(Pasture)	(2)	p-1	MSP	MSP/MSW
(Tier)	(2)	i-1	MSI	MSI/MSW
(Pasture*Tier)	(4)	(p-1)(i-1)	MSPI	MSPI/MSW
Error (W)	27	l(r-1)		
Error (W) from tests for between subject effects				
Seasons	3	s-1	MSS	MSS/MSSP
Seasons*Pasture	6	(s-1)(p-1)	MSPS	MSPS/MSSP
Seasons*Tier	6	(s-1)(i-1)	MSTS	MSTS/MSSP
Seasons*Pasture*Tier	12	(s-1)(L-1)	MSSPT	MSSPT/MSSP
Error (Time)	81	L(s-1)(r-1)	MSSP	
Error (Time) from univariate tests for within subject effects				
Total	143	Lsr		

KEY: L=exclosure location s=season p=pasture i=tier

Table 13. Repeated measures analysis of variance table used in testing season effects on the ungrazed plots.

Microrelief Index Over Seasons

Repeated Measures Analysis of Variance

Source of Variation	df	Type III SS	F-value	PR > F
Locations	8			
(Pasture)	(2)	3.1216718	2.68	.0870
(Tier)	(2)	2.6959287	2.31	.1184
(Pasture*Tier)	(4)	2.5444984	1.09	.3810
Error (W)	27	15.747688		
Error (W) from tests for between subject effects				
Seasons	3	2.7438008	21.40	.0001
Seasons*Pasture	6	0.5958546	2.32	.0463
Seasons*Tier	6	0.4704694	1.83	.1104
Seasons*Pasture*Tier	12	1.0382605	2.02	.0380
Error (Time)	81	3.4613128		
Error (Time) from univariate tests for within subject effects				
Total	143	Lsr		

Table 14. Eight orthogonal contrasts for the season*pasture*tier interaction of microrelief index season data referred to in the text.

Eight Contrasts at Four Season Factor Levels

Treatment Comb.	Means	A	B	C	D	E	F	G	H
111	4.6580 mm	+1	0	0	0	-1	0	0	0
112	4.7718	+1	0	0	0	-1	0	0	0
113	4.6681	+1	0	0	0	-2	0	0	0
121	5.9993	+1	0	0	0	-1	0	0	0
122	6.5196	+1	0	0	0	-1	0	0	0
123	4.4833	+1	0	0	0	+2	0	0	0
131	4.8799	-2	0	0	0	-1	0	0	0
132	4.7819	-2	0	0	0	-1	0	0	0
133	4.6697	-2	0	0	0	+2	0	0	0
211	4.8356	0	+1	0	0	-1	0	0	0
212	4.7738	0	+1	0	0	-1	0	0	0
213	4.5545	0	+1	0	0	+2	0	0	0
221	5.3987	0	+1	0	0	-1	0	0	0
222	5.2839	0	+1	0	0	-1	0	0	0
223	4.2733	0	+1	0	0	+2	0	0	0
231	4.4965	0	-2	0	0	-1	0	0	0
232	4.9475	0	-2	0	0	-1	0	0	0
233	4.4550	0	-2	0	0	-1	0	0	0
311	4.7690	0	0	+1	0	0	-1	0	0
312	4.9913	0	0	+1	0	0	-1	0	0
313	4.5963	0	0	+1	0	0	+2	0	0
321	5.9791	0	0	+1	0	0	-1	0	0
322	5.7107	0	0	+1	0	0	-1	0	0
323	4.4260	0	0	+1	0	0	+2	0	0
331	4.9454	0	0	-2	0	0	-1	0	0
332	4.9849	0	0	-2	0	0	-1	0	0
333	4.8873	0	0	-2	0	0	+2	0	0
411	4.4489	0	0	0	+1	0	0	0	-1
412	4.3176	0	0	0	+1	0	0	0	-1
413	4.1391	0	0	0	+1	0	0	0	+2
421	5.3933	0	0	0	+1	0	0	0	-1
422	4.5055	0	0	0	+1	0	0	0	-1
423	4.3786	0	0	0	+1	0	0	0	+2
431	4.2431	0	0	0	+1	0	0	0	+2

*Key to three digit code:
First digit--seasons: 1=June, 2=Oct., 3=April, 4=June'88
Second digit--pastures: 1=west, 2=middle, 3=east
Third digit--tier: 1=100 m, 2=500 m, 3=1000 m

Table 14.--Continued

	Contrast	SE contrast	Sum of Squares	T (df=81)	p-value
CA:	2.4371	1.3568	1.1880	1.7962	.0381
CB:	1.3220	"	0.3495	0.9743	.1664
CC:	0.8371	"	0.1401	0.6169	.1401
CD:	1.6025	"	0.6778	1.1810	.1205
CE:	3.9683	"	3.1495	2.9247	.0022
CF:	3.1699	"	2.0097	2.3363	.0110
CG:	3.5612	"	2.5364	2.6247	.0052
CH:	1.7051	"	0.5815	1.2567	.1062

CA: (June'87 East + Middle Pastures)/2 vs. (Ju'87 West Past.)
CB: (Oct. East + Middle Pastures)/2 vs. (Oct. West Pasture)
CC: (April East + Middle Pastures)/2 vs. (April West Pasture)
CD: (June'88 East + Middle Pastures)/2 vs. (Ju'88 West Past.)

CE: (June '87 Tier 1 + Tier 2)/2 vs. (June '87 Tier 3)
CF: (October Tier 1 + Tier 2)/2 vs. (October Tier 3)
CG: (April Tier 1 + Tier 2)/2 vs. (April Tier 3)
CH: (June '88 Tier 1 + Tier 2)/2 vs. (June '88 Tier 3)