



Estimating range production from thickness of mollic epipedon and other soil or site characteristics
by Mary Ellen Cannon

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

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Abstract:

Vegetation production data- are essential to rangeland management. Range production estimates based on harvest data are expensive and time-consuming. Few native range sites in Montana or comparable areas have long-term clipped production data. Objectives of this study were to 1) describe and classify soil pedons on such sites, and 2) to test thickness of mollic epipedon and other readily identifiable site characteristics as predictors of average range production. Mollisols under native range with 6- to 49-year production records were examined at 14 sites in Montana, Wyoming, North Dakota, and Alberta, Canada. Sites ranged in precipitation, elevation, and latitude from 250 to 560 mm/yr, 595 to 2165 m, and 40 to 50°. Soils were described and classified according to standard U.S. soil survey procedures. Mean annual standing crop production ranged from 0.4 Mg/ha on a coarse-loamy, mixed, Aridic Haploboroll to 3 Mg/ha on a fine, montmorillonitic, Argic Cryoboroll. Thickness of mollic epipedon and Munsell color values were recorded for 30 samples per site. Multiple linear regression analysis showed that thickness of mollic epipedon was significantly related to production. Use of both mollic epipedon thickness and mean annual precipitation improved the estimate of production. Separation of sites by vegetation types improved correlations, possibly because it grouped sites climatically. For Stipa/Bouteloua vegetated sites, production (Mg/ha) = $0.32 + 0.02[\text{thickness of mollic epipedon (cm)}]$. Depth to carbonates explained some variation in production, possibly because it may mark the depth that precipitation penetrates the soil.

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MONTANA STATE UNIVERSITY
Bozeman, Montana

June 1983

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APPROVAL

of a thesis submitted by

Mary Ellen Cannon

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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ABSTRACT

Vegetation production data are essential to rangeland management. Range production estimates based on harvest data are expensive and time-consuming. Few native range sites in Montana or comparable areas have long-term clipped production data. Objectives of this study were to 1) describe and classify soil pedons on such sites, and 2) to test thickness of mollic epipedon and other readily identifiable site characteristics as predictors of average range production. Mollisols under native range with 6- to 49-year production records were examined at 14 sites in Montana, Wyoming, North Dakota, and Alberta, Canada. Sites ranged in precipitation, elevation, and latitude from 250 to 560 mm/yr, 595 to 2165 m, and 40 to 50°. Soils were described and classified according to standard U.S. soil survey procedures. Mean annual standing crop production ranged from 0.4 Mg/ha on a coarse-loamy, mixed, Aridic Haploboroll to 3 Mg/ha on a fine, montmorillonitic, Argic Cryoboroll. Thickness of mollic epipedon and Munsell color values were recorded for 30 samples per site. Multiple linear regression analysis showed that thickness of mollic epipedon was significantly related to production. Use of both mollic epipedon thickness and mean annual precipitation improved the estimate of production. Separation of sites by vegetation types improved correlations, possibly because it grouped sites climatically. For Stipa/Bouteloua vegetated sites, production (Mg/ha) = $0.32 + 0.02[\text{thickness of mollic epipedon (cm)}]$. Depth to carbonates explained some variation in production, possibly because it may mark the depth that precipitation penetrates the soil.

INTRODUCTION

Soil influences vegetation and vegetation influences soil. Jenny (1980) called vegetation-soil interactions a "Gordian knot". Alexander the Great was said to have cut the Gordian knot when unable to untie it. This work does not attempt to unravel or cut Gordian knots. Instead it tests the hypothesis that thickness of dark soil (specifically thickness of mollic epipedon) is a "fossil record" of past vegetation production. If climate does not change significantly, thickness of dark soil might be a predictor of average production on native range. Other soil and site properties are also considered for their potential to predict range productivity.

Range productivity models serve to : 1) estimate production, 2) show relationships, and 3) indicate areas for further study. Measurement of range production can be tedious, time consuming, and expensive. Poulton and Tisdale (1961) suggest 5 years of clipped production data to estimate the productivity of a range site. Such data have been collected for only a few sites within Montana or comparable areas. Range production estimates based on parameters other than clip data become attractive if highly correlated to measured production.

Range production measurements or estimates can help determine carrying capacity. Carrying capacity is the maximum number of animals which can graze on a range without producing a downward trend in forage production, forage quality, or soil quality (Stoddart et al.,

1975). Heady (1975) adds that carrying capacity expresses greatest return of combined products (watershed, recreation, animal grazing, etc.) without damage to physical resources.

Available water holding capacity, texture, fertility status, bulk density, depth of solum, and darkness of surface horizon are among soil properties tested by others as production correlates. Munn et al. (1978) suggested thickness of mollic epipedon constitutes a pedologic record of average production in western Montana. In contrast, W.D. Nettleton and B.R. Brasher (unpublished data) found little correlation between thickness of mollic epipedon and aboveground production on native range in Utah. They used general soils information obtained from Soil Conservation Service Soil-5 data files¹ in their study.

Objectives of this study were: 1) to describe and classify soil pedons on well-managed native range sites with long-term production records in Montana or comparable areas, and 2) to test depth of mollic epipedon and other readily identifiable site characteristics as predictors of average range production.

¹Soil-5 data are from official soil series and soil survey interpretations. These data are available through participants in the National Cooperative Soil Survey including USDA Soil Conservation Service, USDA Forest Service, USDI Bureau of Land Management, state agricultural experiment stations, and others.

LITERATURE REVIEW

Shively and Weaver (1939) wrote:

"A remarkable dependence of long standing has existed between soils and their natural vegetation....

...Hence prairie is much more than land covered with grass. It is a slowly evolved highly complex organic entity, centuries old."

Natural resource personnel use the range site concept to apply soil-vegetation interactions in management decisions. The Society for Range Management defines range site as:

"...an area of land having a combination of edaphic, climatic, topographic, and natural biotic factors that is significantly different from adjacent areas. These environmental areas are considered as units for purposes of discussion, investigation, and management.

Change from one site to another represent significant differences in potential forage production and/or differences in management required for proper land use." (Huss, 1964).

Many studies use the above definition. Perhaps more important than any one study is acceptance of soil-vegetation relations as tools for use in range management. Shiftlet (1973) traces the concept of range sites to forest sites and the extrapolation of forest research ideas to rangeland management in the 1930's and 1940's. Hanson and Whitman (1938) classed 36 grassland areas in North Dakota into 9 types differing in botanical composition, topography, thickness of dark

surface soil, depth to effervescence with hydrochloric acid, surface acidity or alkalinity, total concentration of soluble salts, sodium and carbonate contents, soil texture, and colloidal content. Texture differences corresponded to changes in vegetation (Hanson and Whitman, 1938). Olson (1952) recommended using the soil profile to understand range vegetation differences. Poulton and Tisdale (1961) outlined methods of examining soil and vegetation to understand range sites and to classify rangelands. Most correlations between kind of soil and kind of plant community have included soil phase² and soil type³ level of soil classification (Heerwagen and Aandahl, 1961; Anderson, 1968).

Munn et al. (1978) used thickness of mollic epipedon, a readily observed and measured soil characteristic, to predict average production. This constitutes a soil phase level of U.S. soil classification (Soil Survey Staff, 1975).

The mollic epipedon is generally defined as a surface horizon greater than 18 cm thick of soil which is darker than 3.5 moist and 5.5 dry color value; the Soil Survey Staff (1975) gives a precise

²Soil phase is defined as a subdivision of any class in the natural system of soil classification, but it is not itself a category of that system. The basis of any subdivision may be any characteristic or combination of characteristics potentially significant to man's use or management of soils. Before soil type was dropped as a category in U.S. soil classification, soil types were commonly subdivided by soil phases. (Soil Survey Staff, 1951)

³Soil type was dropped as a category of U.S. Classification and is now considered part of the phase name. Soil type distinguished texture within series. Initially texture meant a combination of particle size, structure, and consistence. More recently type designated particle size distribution of the plow layer or its equivalent depth in virgin soil. (Soil Survey Staff, 1975).

definition. Mollic epipedon criteria for classification in Soil Taxonomy (Soil Survey Staff, 1975) groups dark-colored prairie soils of the Great Plains in North America and Europe (Smith and Leamy, 1978; Soil Survey Staff, 1975). Although defined empiracally in terms of morphology, genetic concepts of soil formed under grass influence the mollic epipedon definition. For example, hard and massive horizons are excluded to elimtate some dark but otherwise dissimilar soils in California (Smith and Leamy, 1978).

Under grasslands, organic matter added from decayed vegetation-- mainly roots and rhizomes-- darken soil to form a mollic epipedon. Radiocarbon dating of Black Chernozemic plow layers (mollic epipedons in the U.S. Classification) showed organic matter on upper slopes, midslopes, and depressions to date to 575 years before present (ybp), 270 ybp, and 216 ybp, respectively (Martel and Paul, 1974). Hole and coworkers estimated 400 years was needed to form a mollic epipedon in the prairie (Buol et al., 1980).

Except in the top 6 inches, amount of soil organic matter and roots were linearly correlated in loam and heavy clay loam texture prairie soils (Weaver et al., 1935). Few roots grow in the top centimeter of soil, presumably because of a hostile environment (Weaver, 1982). In Missouri, whole root systems in native prairie turnover in about 4 years and rhizomes turnover at a slower rate (Dahlman and Kucera, 1965). Shamoot et al. (1968) calculated 25-40 grams of organic debris is left in the soil after plant growth for every 100 grams of harvested roots; they used several plant species including Cynodon dactylon and Medicago sativa. Much organic material was

presumed to be incorporated into the soil prior to measurements of organic debris (Shamoot et al., 1968).

Rooting habit changes among plants and with the environment. For example, in situ root studies show Bouteloua gracilis may grow to 2 feet and Stipa comata to 2.5 feet in Sandhill prairie but to 3.3 and 3.5 respectively in the hardlands (Weaver, 1920). In the Great Plains individual plants of many species were excavated and root systems traced (Weaver, 1919; Weaver, 1920). Edaphic characteristics such as porosity, texture, structure, restrictive layers and micro and macro climate affect rooting habit.

Root:shoot ratios vary from 38:1 for an Agropyron smithii stand in eastern Montana (Weaver et al., 1981) to 3:1 in a mixed prairie grassland at Dickinson, North Dakota (Sims et al., 1978). Some difference between data probably results from sampling technique. About 2.5 times as many roots were retained for weighing when washed through a 0.03 mm rather than a 0.2 mm mesh sieve (Caldwell and Fernandez, 1975). Conversely, Bohm (1979) showed few barley roots were lost when washed through a 0.5 mm mesh sieve. Above-ground production data for the Agropyron smithii stand represent standing crop, a minimal production estimate (Singh et al., 1975), whereas the mixed prairie site production data were derived from vegetation harvested every two weeks (Weaver et al., 1981; Sims et al., 1978). The Agropyron smithii stand was mowed annually to simulate large herbivore grazing (Weaver et al., 1981). In contrast the mixed prairie site was ungrazed; on this site, dead shoots comprised 70% of the aboveground standing vegetation (Sims et al., 1978). Studies show root:shoot ratios of

grazed sites increased (Johnston, 1961; Marshall, 1977; Sims et al., 1978) or remained constant (Marshall, 1977; Sims et al., 1978; Lorenz and Rogler, 1967).

Thickness and darkness of mollic epipedon reflect depth of roots, abundance of roots, and climate. The mass of organic matter increases with increasing moisture and decreasing temperature (Jenny, 1930).

Russel and McRuer (1927) said:

"Organic matter has always been considered of high importance as a factor in series differentiating, originally on account of its contribution to soil value... Organic matter (OM) is produced from plant material grown on the soil. The very climatic factors and soil differences which are used in distinguishing series and types determine in considerable extent the nature, rate, and completeness of OM decay, and the amount of its loss by erosion and leaching."

This approach shows in the organization of a reconnaissance soil survey of the Northern Great Plains, according to soil color (Giesecker et al., 1938). Similarly, Thorp (1931) separated soil profiles under different climate and vegetation in northern and northwestern Wyoming chiefly on darkness of A horizon.

Thickness of mollic epipedon integrates soil moisture, temperature, and biomass production; Figure 1 shows typifying soil pedons in the Northern Great Plains with thicker mollic epipedons under moister climates and lusher vegetation. Munn et al. (1978) regressed thickness of mollic epipedon against mean annual production for 27 sites in western Montana and found significant correlation.

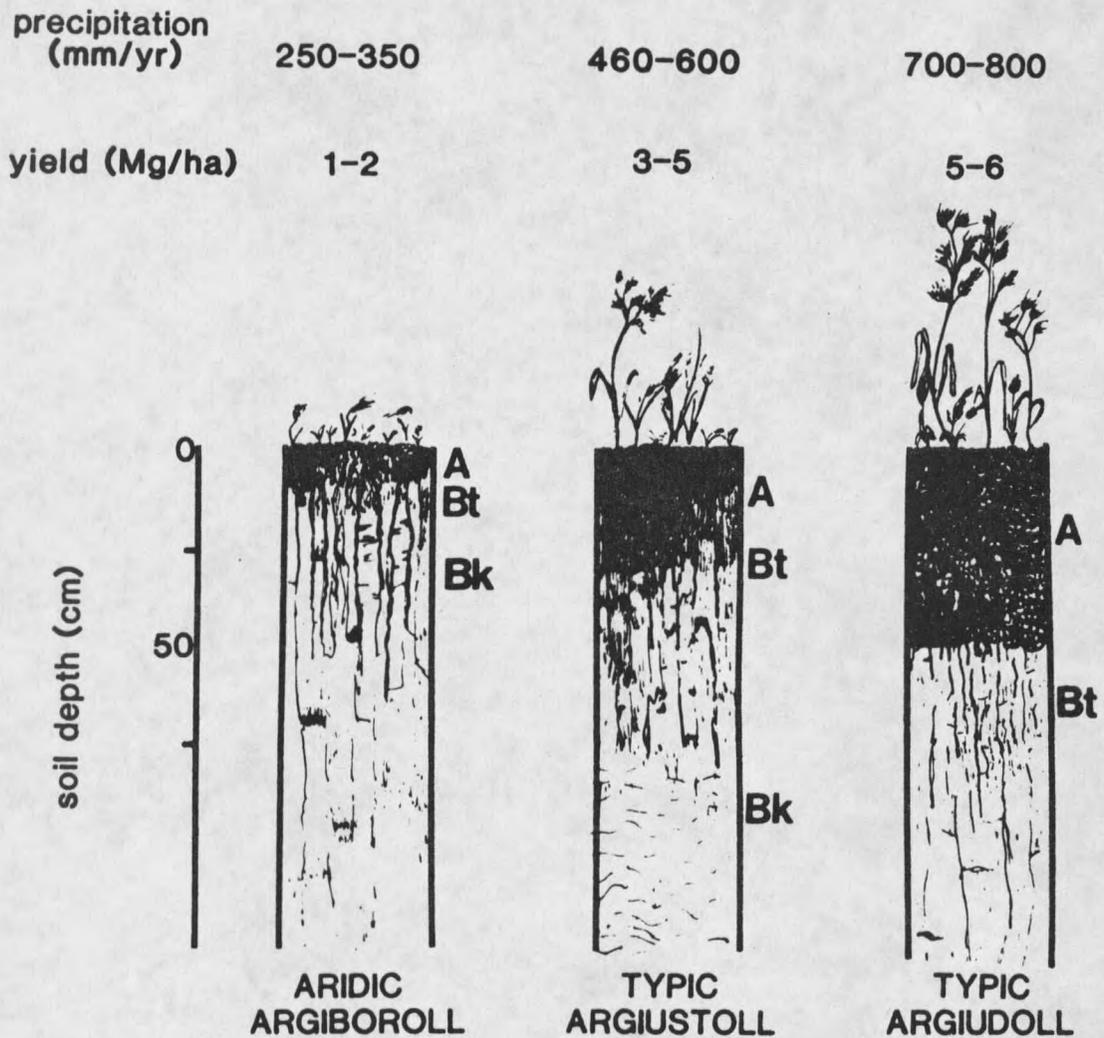


Figure 1. Thickness of Mollic Epipedon for representative pedons in the Northern Great Plains. Scobey, Holdrege, and Sharpsburg soil series are from left to right. Data from Aandahl (1982) and Soil Survey Staff (1980)..OP

MATERIALS AND METHODS

Mollisols under native range with 6- to 49- year records of above-ground vegetation were examined at 14 sites in Montana, North Dakota, Wyoming, and Canada. These are most of the sites with long-term production records for rangelands in Montana and comparable areas. Figure 2 shows site locations. Sites 3 and 6 were moderately grazed; other sites were ungrazed or lightly grazed.

Soil at each site was probed in 30 locations at regular intervals along clipping transects or at random, where production data were from randomly placed clip plots. Thickness of mollic epipedon was measured, and a sample bagged for each spot probed. Mollic epipedon material was defined by a moist Munsell color value of 3.5 or less (Soil Survey Staff, 1975). Under natural sunlight, dry and moist soil colors were later determined for what appeared to be the predominant color. Subsamples were combined, mixed and ground to 2 mm or less for colorimetric organic matter determinations (Sims and Haby, 1971).

Depth of the one-inch diameter coring tube hole minus length of light-colored soil (moist value 3.5) gave thickness of mollic epipedon. Tiling spades were used on moist or very gravelly sites; thickness of mollic epipedon was measured directly and a representative sample was removed with a knife.

One observation pit at least 100 cm deep x 100 cm x 75 cm was dug at most sites. Soils were described and classified according to the

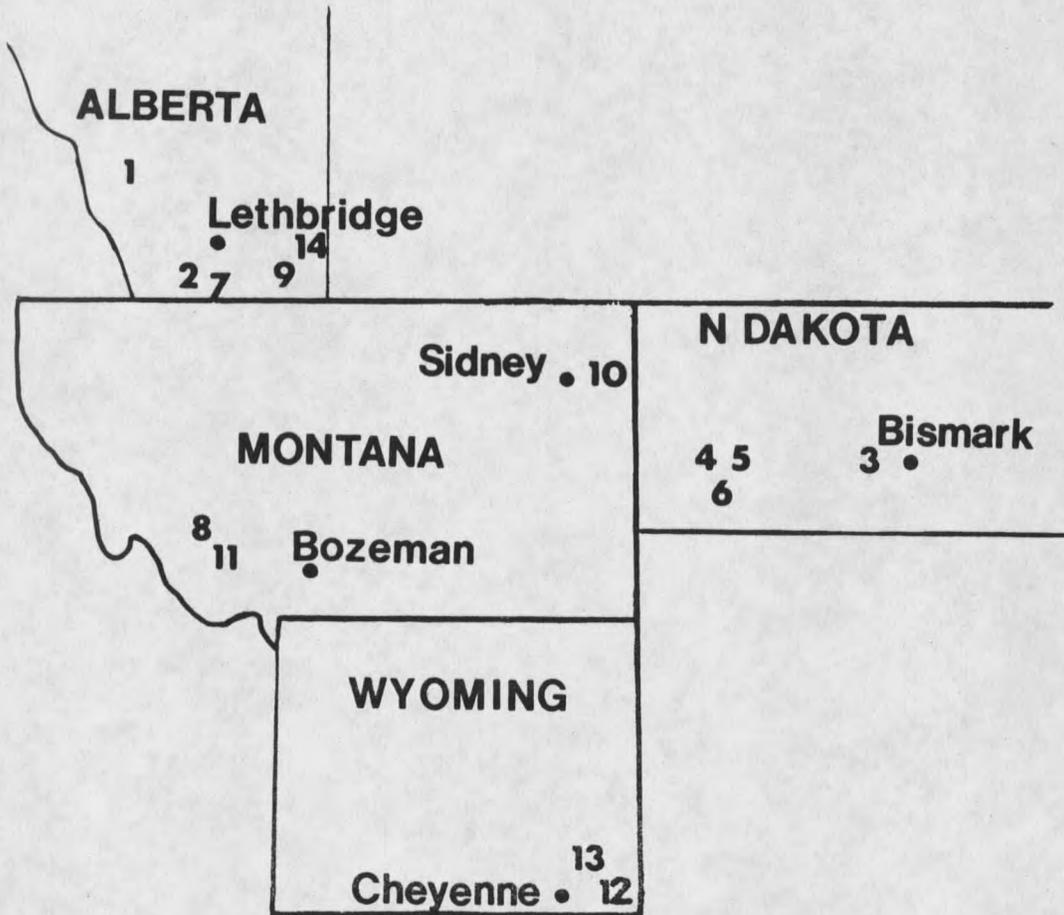


Figure 2. Site Locations. Ordered from 1 (highest) to 14 (lowest) mean annual standing crop production.

Soil Survey Manual (Soil Survey Staff, 1951) and Soil Taxonomy (Soil Survey Staff, 1975). A representative pedon was described and classified earlier for site 10 (Brockman, 1966). Pedons were not described for sites 4-6 in Dickinson ND; soils of the area are described in the Stark County soil survey (Soil Survey Staff and North Dakota State University, 1968). Slides of pedons and sites are in a collection held by the Soils division of the Plant and Soil Science department at Montana State University; Bozeman, MT.

Production data were estimated by clipping all vegetation to ground level near the time of peak standing crop; this provides a minimum estimate of production (Singh et al., 1975). Table 1 in Appendix A lists sources of data. Site 12 data represent grass production only. Forbs and shrubs were reported as a minor (less than 1 %) component of the site (Birch, 1960). Site 3 vegetation was sampled over 100 acres until 1974, then sampled over 40 acres. Production was similar between the 100 and 40 acre pastures; soil was sampled in the 40 acre pasture.

Data were analyzed through a multiple linear regression statistical package (Lund, 1982). Parameters regressed against mean production (maximum standing crop) for 14 sites include mean thickness of mollic epipedon, mean of the predominant dry color value, mean annual precipitation, elevation, latitude, longitude, vegetation (1 Festuca, 2 Stipa/Bouteloua), % organic matter in the mollic epipedon. Data from 9 sites, dominated by Stipa/Bouteloua, and 5 sites dominated, by Festuca spp. were separated and re-analyzed as above. Depth to

strong effervescence with 10% hydrochloric acid was included in regressions for 11 sites with pedon descriptions.

Table 2 in Appendix A shows sources for precipitation data.

Precipitation data for all but sites 8 and 11 came from U.S. and Canadian weather records. Long-term mean annual precipitation values, defined as the mean of 30 years by the U.S. Weather Bureau, were used in regressions. These values may under or over estimate the amount of precipitation a site received in years vegetation was sampled. Mean annual precipitation values from the years vegetation was sampled (short-term mean annual precipitation) were also used in regressions for sites 1 thru 7, 10, 12, and 13. Estimates of mean annual precipitation for sites 8 and 11 were based on the state of Montana average annual precipitation map (USDA, 1977). These estimates were consistent with precipitation data collected on-site for some 40-48 weeks each year over the 10 years sites were clipped for production data (W. Mueggler, personal communication).

RESULTS AND DISCUSSION

Pedon and site descriptions and pedon classification appear in Appendix B. Figure 3 shows pedon classifications, mean annual standing crop production, and thickness of mollic epipedon. Table 3 in Appendix A shows data used in correlations and standard deviations for mean production and thickness of mollic epipedon values. Mean production (maximum standing crop) ranged from about 0.4 Mg/ha at site 14, to 2.9 Mg/ha at site 1. Mean thickness of mollic epipedon ranged from 14 cm at site 14⁴ to 94 cm at site 2. Depth to strong effervescence with 10% HCL ranged from 17 cm at site 14 to 68 cm at site 2. Table 4 in Appendix A shows annual precipitation data and mean annual maximum standing crop production.

Thickness of Mollic Epipedon

Figure 3 shows that most soils with pachic epipedons (>40 cm of mollic epipedon) produced more aboveground vegetation than other sites. Figure 4 shows mean thickness of mollic epipedon is related to mean total production, ($R^2 = .39^*$). Addition of long-term mean annual precipitation to the regression improves the fit of the equation to $R^2 = .72^*$. Table 6 in Appendix A shows regression equations for the above.

⁴Site 14's mean thickness of dark soil (14 cm) does not meet the 18 cm required for mollic epipedons. However, a representative pedon sampled did meet requirements. Site 14 will be discussed as if requirements were met.

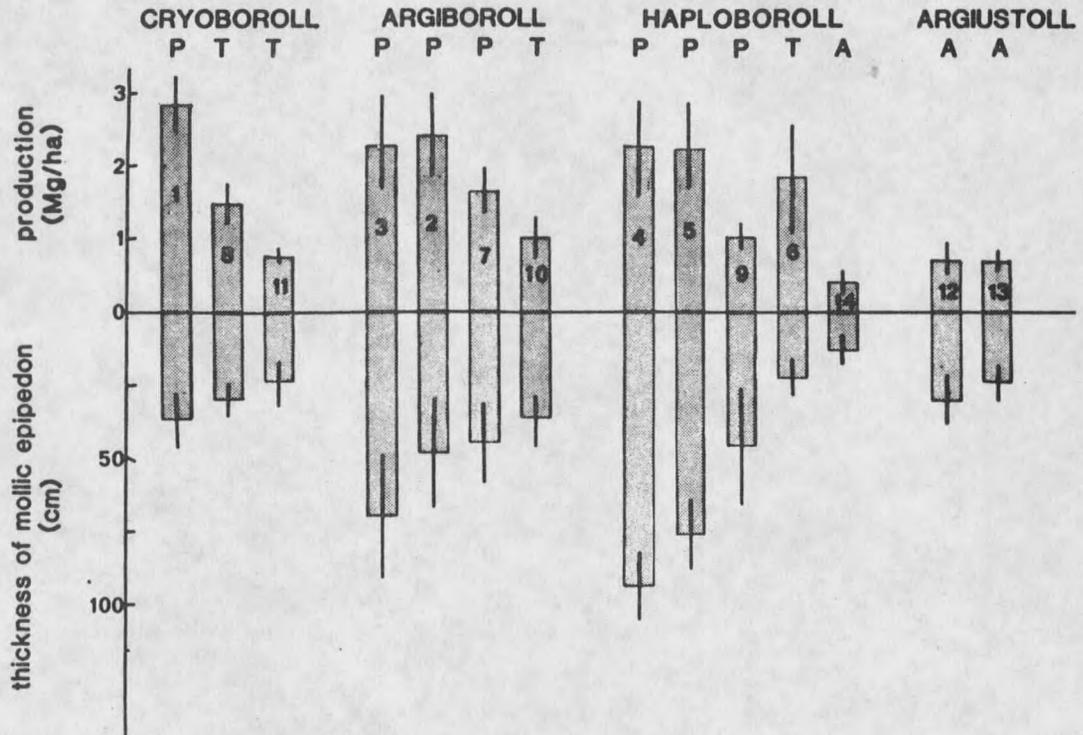


Figure 3. Sites Grouped by Soil Classification. Mean standing crop production (Mg/ha) and mean thickness of mollic epipedon (cm) are shown with corresponding standard deviations.

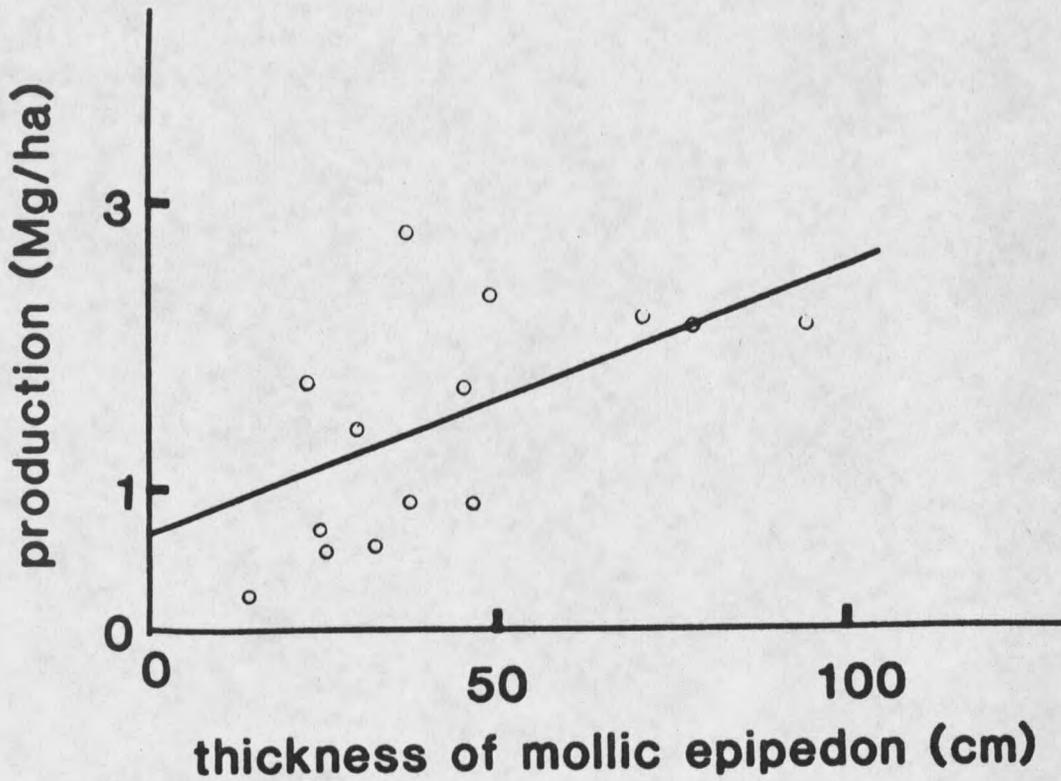


Figure 4. Mean Thickness of Mollic Epipedon Versus Mean Annual Production (Standing Crop). $Production (Mg/ha) = 0.61 + 0.02$ [thickness of mollic epipedon (cm)] $R^2 = .39$, significant at $p=.05$

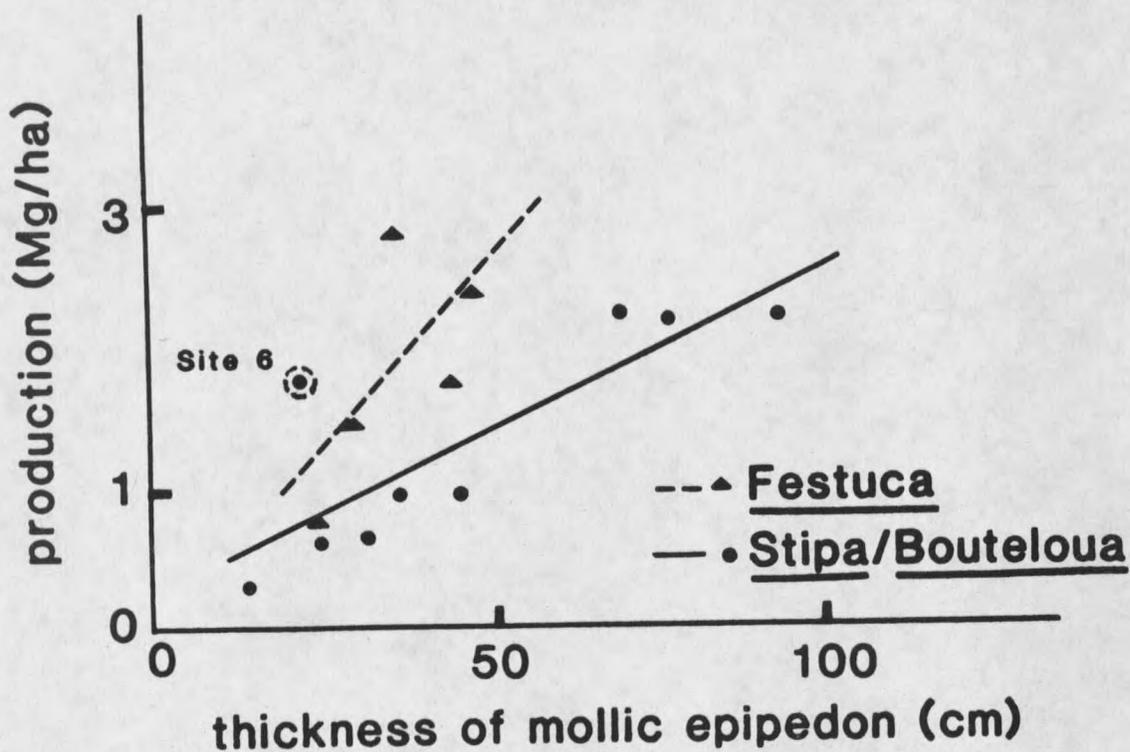


Figure 5. Mean Thickness of Mollic Epipedon Versus Mean Annual Production (Standing Crop) for Stipa/Bouteloua and Festuca sites. Stipa/Bouteloua production (Mg/ha) = $0.315 + 0.023$ [thickness of mollic epipedon (cm)] $R^2 = .66$ Festuca production (Mg/ha) = $-0.11 + 0.053$ [thickness of mollic epipedon (cm)] $R^2 = .42$, * significant at $p = .05$.

Regression of short-term mean annual precipitation with thickness of mollic epipedon showed some improvement over the above ($R^2 = .73^{**}$). I accepted probability values of $\alpha = .20$ as significant. The following discussion reports only long-term mean precipitation as a variable.

Stratification of sites by vegetation improves production estimates, presumably by grouping sites climatically. Stipa comata and Bouteloua gracilis tend to grow in warmer and drier regions than do Festuca scabrella or Festuca idahoensis. Sites dominated by Stipa comata/Bouteloua gracilis vegetation were either at lower latitudes or lower elevations, compared to Festuca sites. Table 7 in Appendix A shows correlation coefficients of sites grouped by vegetation; Stipa/Bouteloua vegetation showed positive correlation between thickness of mollic epipedon and production ($R = .82^*$; $R^2 = .66^*$). Figure 5 shows thickness of mollic epipedon versus mean production for Festuca and Stipa/Bouteloua sites, and includes regression equations. Inclusion of mean annual precipitation as a variable in the Stipa/Bouteloua regression equation results in $R^2 = .79^*$. Mean annual precipitation alone explains more than half of the variation in mean total production ($R^2 = .61^*$). Regression equations for all of the above are shown in table 6 of Appendix A.

Site 6 appears to be "out of line" in Figure 5. The production is relatively high on a soil with a thin mollic epipedon. W. Whitman (personal communication) explained that the site had been grazed heavily by cattle in falls since vegetation harvest trials ended. However, only slight to moderate erosion was observed and it is

assumed that thickness of the mollic epipedon stayed fairly constant since vegetation was first sampled in 1958. Site 6 data may be explained as: 1) part of the normal population and not to be ignored, 2) a high measured mean production value misrepresenting the true mean production, or 3) the result of sandstone residuum parent material forming loamy sand and sandy loam soils which maintain low levels of organic matter.

In the 13 year production record Site 6 produced a mean of about 1.8 Mg/ha above-ground vegetation with as little as 0.9 Mg/ha produced in 1961 and as much as 3.7 Mg/ha in 1962. Site 6 is a Flasher-Vebar soil complex. In normal years Flasher loamy fine sand and Vebar fine sandy loam soils produce 0.9 to 2.0 and 2.4 to 3.2 Mg/ha above-ground vegetation, respectively (Aandahl, 1982). Thus the 1.8 Mg/ha mean production value used in this study appears reasonable. Figure 3 and Table 3, in Appendix A, show that values ranging from 1.1 to 2.6 Mg/ha describe mean production for Site 6.

Generally better aeration and less organo-mineral complexing leads to lower organic matter levels in sandy soils than in finer texture soils. Konova (1966) referred to turn of the century researchers who first showed this trend. Site 14 is also sandy, but its marginal mollic epipedon might be explained by low production as well as by greater aeration and less organo-mineral complexing.

Depth of organic matter, as well as amount, influences thickness of mollic epipedon. Roots in native prairie continually add organic matter to the soil; a four-year turnover rate for whole root systems has been reported in Missouri (Dahlman and Kucera, 1965). Soil

texture, bulk density, restrictive layers, fertility, aeration, and available water affect rooting habit, which also changes with species (Weaver, 1919; Weaver, 1920). Bouteloua gracilis and Stipa comata roots grew to shallower depths in the Sandhills of Nebraska than in other areas, probably because of less available water at depth there (Weaver, 1920).

Whether Site 6 should be excluded from the data base or not has not been determined. Sandy soils, maintaining lower organic matter levels than other soils offers the best explanation of Site 6's relatively thin mollic epipedon but relatively high production. Conservative judgement calls for inclusion of Site 6 in the data base, with continued thought given to its relationship with other sites sampled. The following regression results if Site 6 is deleted: Production (Mg/ha) = $-0.05 + 0.028[\text{thickness of mollic epipedon (cm)}]$ $R^2 = .92^{**}$

Regression equations, based on Munn et al.'s (1978) research, were developed for the Big Horn National Forest (Nesser, 1979). Regression models gave more accurate predictions for sites with Festuca scabrella and Festuca idahoensis vegetation than for sites with Bouteloua gracilis or alpine vegetation (J. Nesser, personal communication). Separate regression equations for important vegetation types should provide more accurate predictions.

Depth to Carbonates

Depth to carbonates, indicated by strong effervescence, is related to mean production as shown in Figure 6. Depth to carbonates equalled thickness of mollic epipedon in some cases. Use of both

variables in one regression equation to predict production was not helpful because of their correlation with each other.

In some soils depth to carbonates marks the effective depth of penetration by precipitation. Jenny and Leonard (1934) plotted depth of carbonates versus precipitation for soils in the 350 to 1000 mm rainfall zones from Colorado to Kansas. They showed: $D = 0.64(P - 305)$ D is depth to the upper surface of the carbonate horizon, in centimeters. P is mean annual precipitation, in millimeters. Arkley (1963) used a similar technique for California and Nevada soils and showed: $D = 0.16(P - 11)$ $R = .756$ or $R^2 = .57$ with D and P defined as above. Arkley (1963) suggested regional distribution of rainfall (mostly spring rains in Jenny and Leonard's study and winter rains in Arkley's study), soil texture, and amount of precipitation entering the soil affect depth to carbonate.

Depth to carbonates indicating depth of effective precipitation, which in turn is important to plant growth, provides a biologic rationale for its use to predict yield. No significant correlation ($\alpha = .20$) was found between depth to carbonate and precipitation in this study. Possibly heterogeneous soil parent materials, soil textures, ages of soil, and additions of calcareous rich windblown material among sites explain nonsignificant correlations.

Although depth to carbonates has not been used by range managers to predict range production, it has been used to adjust production estimates. Montana Bureau of Land Management personnel use carbonate at or near the surface of a range site to indicate a 10% reduction in potential for production over similar range sites with carbonates at

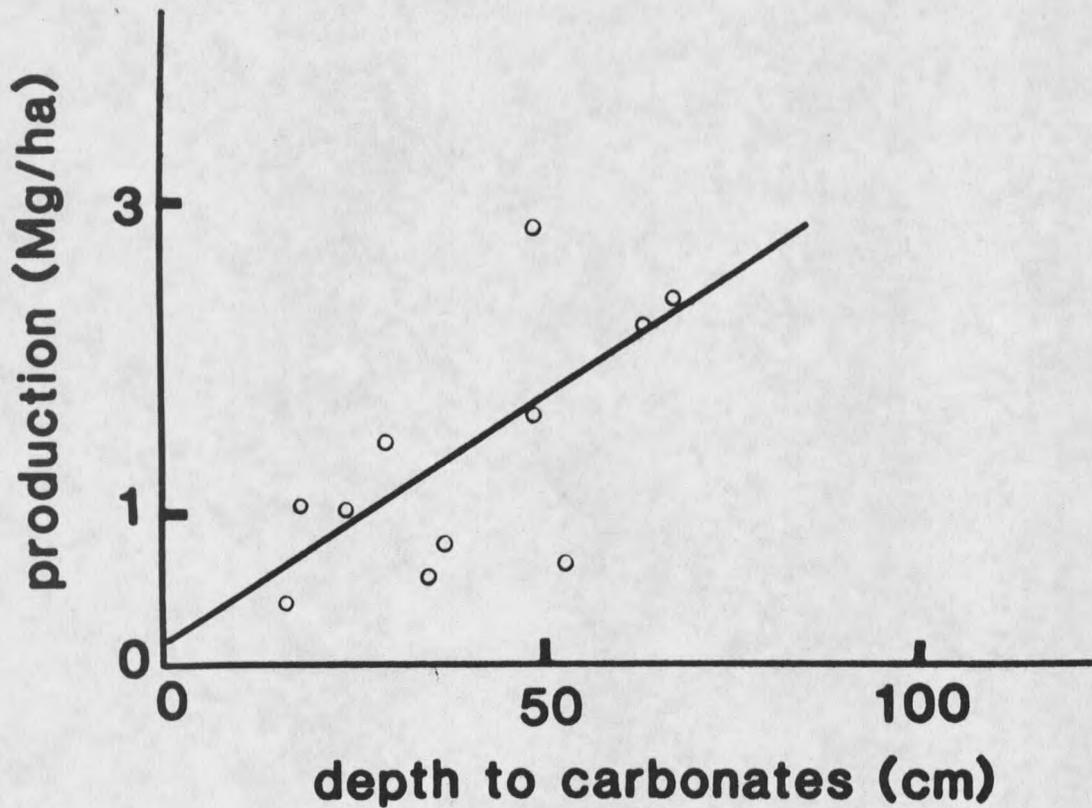


Figure 6. Depth to Carbonates (indicated by strong effervescence) versus Mean Annual Production (Standing Crop). Production (Mg/ha).
 $\text{Production (Mg/ha)} = 0.043 + 0.032[\text{depth to carbonates (cm)}]$ $R^2 = .47$, **, significant at $p = .01$.

greater depths (C. Clark, personal communication). This application of presence of carbonate is a working formula, based on field evidence. The following might explain the field observations: 1) carbonates at shallow depths indicates low precipitation, or 2) abundance of calcium or magnesium associated with carbonates or the typically high pH may result in nutrient imbalances. Lower production results from nutrient imbalance stress. Both reasons may help explain lower production on range sites with carbonates at shallow depths. Extension of depth to carbonates from an adjustor to a predictor of range productivity may be of most value in areas of fairly homogeneous parent material.

Summary

Long-term production data are available on only a few native range sites in Montana and comparable areas. Soil properties and soil classification were determined for 14 such native range sites in Montana; North Dakota; Wyoming; and Alberta, Canada. Pachic versus typic versus aridic soil classification modifiers generally indicate decreasing production. In other words, thick or dark-colored mollic epipedons are correlated with greater production than thin or light-colored mollic epipedons. Use of mean annual precipitation and thickness of mollic epipedon together allows more accurate prediction of mean production than use of either alone. Where precipitation records are unavailable, soil properties alone can provide production estimates. Regression equations, using thickness of mollic epipedon to

predict production might be made more accurate if developed and used for a particular vegetation type. Depth to carbonates, as indicated by strong effervescence, might also help predict site productivity. Principles illustrated here can be integrated into more complex productivity models.

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APPENDICES

APPENDIX A

DATA

Table 1. Sources of Production Data

Site(s)	Source(s)
1,2,7,9,14	Smoliak et al., 1979; and Smoliak, S. 1982 personal communication
3	Lorenz, R. 1982 personal communication
4,5,6	Goetz, H., W. Whitman, and D. Williams. 1982 personal communications; Dickinson Agricultural Experiment Station Annual Reports
8,11	Mueggler, 1971; and Mueggler, W. 1982 personal communication
10	Wight, R. and L. White 1982 personal communications
12	Birch, 1960; Rauzi and Lang, 1967; Lang et al., 1956
13	Rauzi, 1978; Rauzi, 1979

Table 2. Sources of Precipitation Data. †

Site(s)	Station/Source
1	Pekisko, Canada
2	Cardston, Canada
3	Mandan, North Dakota ARS experiment station
4,5,6	Dickinson, North Dakota Agricultural experiment station
7	Milk River Ridge, Canada
8,11	estimated from Mueggler's 40-48 week Forest Service research weather station records and State of Montana Average Annual Precipitation Map (Mueggler, 1982 personal communication; USDA, 1977)
9,14	Manyberries, Canada Agriculture experiment station
10	Sidney, Montana ARS experiment station
12,13	Cheyenne, Wyoming Archer Agriculture experiment station

† Monthly Record Meteorological Observations in Western Canada and U.S. Weather Bureau Climatological Data for Montana, North Dakota, and Wyoming provided data for all but sites 8 and 11.

Table 3. Production Data and Selected Soil and Site Characteristics.

SITE	PRODUCTION [†]			MOLLIC [‡]			PRECIP [§]	EFF [¶]	ELEV [#]	LAT ^{††}	LONG ^{§§}	VEG ^{¶¶}	COLOR ^{###}	OM ^{†††}	
	years	×	sd	range	×	sd	range	×	cm	m					%
	Mg/ha			cm			mm/yr								
1	13	2.87	0.34	2.51-3.77	37	10	21-66	687	50	1000	50	113	F	3.1	7.6
2	12	2.41	0.56	1.51-3.34	48	19	16-17	494	68	1265	49	112	F	3.9	4.8
3	29	2.29	0.61	1.12-3.50	70	21	24-132	403	65	595	47	101	S	3.9	3.0
4	9	2.26	0.62	1.48-3.33	94	12	72-124	388	--	750	47	103	S	4.5	1.6
5	6	2.23	0.60	1.62-3.41	77	12	64-120	388	--	750	47	103	S	3.6	2.3
6	13	1.81	0.74	0.87-3.69	22	6	13-34	388	--	750	47	103	S	5.0	2.1
7	10	1.65	0.30	1.18-2.23	45	13	17-68	304	50	1265	49	111	F	3.3	4.4
8	10	1.47	0.27	0.81-1.79	30	6	20-42	500	32	2165	45	112	F	3.0	10.5
9	13	1.00	0.19	0.71-1.21	46	18	18-76	327	19	930	49	111	S	4.3	2.5
10	13	1.00	0.27	0.45-1.32	37	9	21-55	352	25	640	48	103	S	3.6	2.0
11	10	0.77	0.09	0.66-0.92	24	8	16-53	500	38	2165	45	112	F	3.0	9.6
12	18	0.68	0.20	0.41-1.00	32	9	9-50	371	54	1825	41	104	S	4.8	1.7
13	8	0.66	0.14	0.43-0.87	25	6	17-34	358	35	1825	41	104	S	5.0	2.1
14	49	0.39	0.17	0.10-0.92	14	5	8-26	327	17	930	49	111	S	4.6	1.8

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[†] PRODUCTION = mean annual standing crop (Mg/ha).
[‡] MOLLIC = thickness of mollic epipedon (cm) average of 30 probes.
[§] PRECIP = long-term mean annual precipitation (mm).
[¶] EFF = depth to carbonates in cm (indicated by strong effervescence).
[#] ELEV = elevation (m).
^{††} LAT = latitude (degrees).
^{§§} LONG = longitude (degrees).
^{¶¶} VEG = vegetation (F indicates *Festuca* spp. and S indicates *Stipa/Bouteloua* spp.).
^{###} COLOR = dry Munsell color value of mollic epipedon, average of 30 sample.
^{†††} OM = percent organic matter in mollic epipedon.

Table 4. Annual Precipitation and Mean Standing Crop Production.

year	precip	prod	year	precip	prod
	site 1			site 3 (cont)	
1969	792	2.72	1967	338 ^e	2.56
1970	737	3.77	1968	457	3.00
1971	721	2.95	1969	358	3.50
1972	776	2.90	1970	436	2.67
1973	584	2.51	1971	408	2.28
1974	751	2.55	1972	381	2.86
1975	811	3.01	1973	247	1.12
1976	624	2.67	1974	361	1.43
1977	587	2.58	1975	484	2.17
1978	843	3.04	1976	324	2.99
1979	635	2.85	1977	483	1.34
1980	M	2.89	1978	397	2.60
1981	M	2.52	1979	379	1.78
	site 2			site 4	
1969	339	2.63	1970	512	2.19
1970	402	1.88	1971	533	1.81
1971	657	2.87	1972	527	3.33
1972	678	3.34	1973	344	1.87
1973	267	1.93	1974	360	2.59
1974	619	1.51	1975	450	2.74
1975	860	2.21	1976	322	1.62
1976	526	2.13	1977	587	1.48
1977	580	2.84	1978	448	2.69
1978	962	3.08		site 5	
1979	362	1.98	1971	533	2.28
1980	M	2.53	1972	527	3.82
	site 3		1973	344	2.54
1951	515	2.12	1974	360	2.61
1952	261	1.61	1975	450	2.59
1953	553	2.40	1976	322	1.82
1954	512	2.09		site 6	
1955	463	2.29	1958	309	1.37
1956	425	1.90	1959	342 ^e	0.94
1957	389 ^e	2.88	1960	260	1.48
1958	321	2.50	1961	353	0.87
1959	301	2.00	1962	466	3.69
1960	384	1.82	1966	424	2.40
1961	308	1.36	1967	362	1.50
1962	390	2.52	1968	400	1.79
1963	464	2.78	1969	416	1.53
1964	376	2.78			
1965	593	3.07			
1966	395	3.40			

Table 4. Annual Precipitation and Mean Standing Crop Production (continued)

site 6 (cont)			site 10		
1970	512	2.10	1967	210	1.20
1971	533	2.50	1968	158	0.74
1972	527	1.72	1969	338	1.24
1973	344	1.65	1970	218	1.20
			1971	141	0.72
			1972	206	1.22
			1973	232	0.76
			1974	179	0.93
			1975	208	1.32
			1976	193	1.10
			1977	91	0.45
			1978	220	1.25
			1979	277	0.82
			site 11		
			1964	*	0.81
			1965	*	0.92
			1966	*	0.69
			1967	*	0.87
			1968	*	0.78
			1969	*	0.70
			1970	*	0.66
			1971	*	0.86
			1972	*	0.72
			1973	*	0.66
			site 12		
			1947	486	0.96
			1948	275	0.47
			1949	516	0.68
			1950	322	0.41
			1951	463	0.58
			1952	332	0.66
			1953	396	0.82
			1954	264	0.42
			1955	467	1.01
			1956	402	0.48
			1957	519	1.01
			1958	363	0.74
			1959	313	0.53
			1960	209	0.51
			1961	432	0.88
			1962	371	0.81
			1963	378	0.73
			1964	151	0.58
site 7					
1971	257	1.59			
1972	294	1.69			
1973	180	1.35			
1974	228	1.18			
1975	524	1.56			
1976	255	1.76			
1977	327	1.82			
1978	570	2.23			
1979	M	1.41			
1980	M	1.89			
site 8					
1964	*	0.81			
1965	*	1.58			
1966	*	1.36			
1967	*	1.79			
1968	*	1.49			
1969	*	1.46			
1970	*	1.48			
1971	*	1.77			
1972	*	1.39			
1973	*	1.56			
site 9					
1969	243	1.20			
1970	352	1.05			
1971	316	1.04			
1972	334	0.78			
1973	219	0.77			
1974	382	1.11			
1975	572	0.97			
1976	300	1.21			
1977	286	1.21			
1978	513	1.19			
1979	341	1.02			
1980	339	0.74			
1981	308	0.71			

Table 4. Mean Annual Precipitation and Mean Standing Crop Production (continued)

site 13			site 14 cont		
1970	391	0.64	1953	**	0.55
1971	333	0.74	1954	**	0.57
1972	376	0.56	1955	**	0.69
1973	470	0.80	1956	**	0.55
1974	295	0.87	1957	**	0.43
1975	289	0.43	1958	**	0.42
1976	289	0.58	1959	**	0.28
1977	417	0.68	1960	**	0.27
			1961	**	0.10
			1962	**	0.21
			1963	**	0.27
			1964	**	0.28
			1965	**	0.74
			1966	**	0.56
			1967	**	0.52
			1968	**	0.52
			1969	**	0.31
			1970	**	0.36
			1971	**	0.35
			1972	**	0.30
			1973	**	0.19
			1974	**	0.48
			1975	**	0.59
			1976	**	0.44
			1977	**	0.26
			1978	**	0.71
			1979	**	0.56
			1980	**	0.22
			1981	**	0.36
			1982	**	0.44

M denotes missing precipitation values

e denotes precipitation values wholly or partially estimated for weather station records

* mean annual precipitation is estimated to be 500 mm from State of Montana precipitation map (USDA, 1977) and checked against 10 years of 40-48 week on-site weather station data collected by W. Mueggler (personal communication)

**long-term mean annual precipitation of 303 mm should represent precipitation for the 49 year production record

Table 5. Correlation Matrix, including all sites (right side of diagonal line), and Correlation Matrix including only sites with depth to Carbonates data included (left side of the line).

Variables [†]	PROD	ME	PRECIP	EFF	ELEV	LAT	LONG	VEG	MCV	%OM
PROD		.66	.64	.69	-.33	.50	.20	.52	.50	.34
ME	.62		-.01	.61	-.52	.31	-.30	.02	-.15	.14
PRECIP	.53	.08		.35	.20	.15	.40	-.63	-.56	.72
EFF	--	--	--		-.00	-.05	-.14	-.35	-.14	.10
ELEV	.44	-.49	.24	--		-.69	.26	-.40	-.10	.55
LAT	.48	.21	.14	--	-.64		.49	-.28	-.43	.34
LONG	.04	-.41	.41	--	.42	.39		-.75	-.50	.61
VEG	-.29	.21	-.63	--	-.50	-.24	-.79		.79	-.84
MCV	-.32	-.08	-.53	--	-.21	-.36	-.52	.75		-.82
%OM	.15	-.27	.71	--	.62	.05	.67	-.86	-.79	

[†] PROD = mean annual standing crop (Mg/ha); ME = thickness of mollic epipedon, mean of 30 probes (cm); PRECIP = mean annual precipitation (mm); EFF = depth to carbonates in cm (indicated by strong effervescence) ELEV = elevation (m); LAT = latitude (degrees); LONG = longitude (degrees); VEG = vegetation (1 = Festuca, 2 = Stipa/Bouteloua); MCV = mean color value; %OM = percent organic matter in the mollic epipedon.

Table 6. Selected Regression Equations

dependent variable [†]	R ²	n
PROD = 0.61 + 0.02[thickness of mollic epipedon (cm)]	.39 *	n =14
PROD = -1.34 + 0.02[thickness of mollic epipedon (cm)] +0.005[mean annual precipitation (mm)]	.72 *	n =14
STCO/BOGR PROD = 0.32 + 0.023[thickness of mollic epipedon (cm)]	.66 *	n =9
STCO/BOGR PROD = -2.71 + 0.13[thickness of mollic epipedon(cm)] + 0.009[mean annual precipitation(mm)]	.79 *	n =9
FEID PROD = -0.11 + 0.053[thickness of mollic epipedon (cm)]	.42	n =5
PROD = 0.043 + 0.032[depth to carbonates (cm)]	.47 *	n =11
PROD = -0.18 + 0.004[mean annual precipitation (cm)]	.28	n =14
PROD = 0.12 + 0.025[thickness of mollic epipedon(cm)] 0.09(% OM)	.49 *	n =14
PROD = 1.6 + 0.024[thickness of mollic epipedon (cm)] + -0.70(vegetation type, 1= <u>Festuca</u> , 2= <u>Stipa/Bouteloua</u>)	.57 **	n =14
PROD = -4.1 + 0.019[thickness of mollic epipedon(cm)] 0.103[latitude (degrees)]	.52 *	n =14
PROD = 1.04 + 0.019[thickness of mollic epipedon(cm)] + -0.025[elevation (cm)]	.41	n =14
PROD = 1.83 + 0.021[thickness of mollic epipedon(cm)] + -0.30(mean color value)	.46 *	n =14
PROD = 2.86 + 0.016[thickness of mollic epipedon(cm)] + 0.00004[elevation (m)] + -0.38(mean color value)	.52	n =14
PROD = -1.64 + 0.023[thickness of mollic epipedon(cm)] + 0.0005[mean annual precipitation (cm)] + 0.053(mean color value)	.72 **	n =14

Table 6. Selected Regression Equations (continued)

Dependent variable [†]	R ²	n
PROD = 1.53 + 0.016[thickness of mollic epipedon(cm)] + 0.00009[mean annual precipitation (mm)] + -0.0003[elevation (cm)] + -0.40[latitude (degrees)] + 0.077[longitude (degrees)] + -1.9(vegetation, 1 = Festuca, 2 = Stipa/Bouteloua) + 0.50(mean color value) + 0.18(% OM)	.96 **	14
STCO/BOGR PROD = 0.069 + 0.023[thickness of mollic epipedon (cm)] + 0.051(mean color value)	.67 *	9
STCO/BOGR PROD = 8.01 + 0.019[(thickness of mollic epipedon(cm)] + -0.072[longitude (degrees)]	.76 *	9
FEID PROD = 0.11 + 0.053[thickness of mollic epipedon (cm)] + 0.0047[mean annual precipitation (mm)]	.96 *	9

[†] PROD = mean annual standing crop production (Mg/ha); STCO/BOGR
 PROD = PROD from only Stipa/Bouteloua vegetated sites; FEID PROD =
 PROD from only Festuca vegetated sites. *, significant at .05 level
 **, significant at .01 level

Table 7. Correlation Matrix for Stipa/Bouteloua and Festuca vegetated sites. Left of the line presents correlation coefficients for 9 sites with Stipa/Bouteloua vegetation. Right of the line shows correlation coefficients for the 5 sites with Festuca vegetation.

Variables [†]	PROD	ME	PRECIP	EFF	ELEV	LAT	LONG	MCV	%OM
PROD		.64	.51	.65	-.86	.85	.70	.46	-.47
ME	.82		-.30	.86	-.80	-.81	.01	.83	-.94
PRECIP	.78	.54		-.02	-.15	.13	.78	-.20	.44
EFF	--	--	--		-.7	.77	.10	.92	-.85
ELEV	-.62	-.44	-.12	--		-.99	-.58	-.51	.53
LAT	.28	.20	-.32	--	-.89		.56	.53	-.79
LONG	.63	-.43	-.91	--	.10	.36		-.24	.05
MCV	-.40	-.52	-.06	--	.62	-.50	.21		-.77
%OM	.38	.21	.23	--	-.35	.25	-.14	-.43	

[†] PROD = mean annual standing crop (Mg/ha); ME = thickness of mollic epipedon, mean of 30 probes (cm); PRECIP = mean annual precipitation (mm); EFF = depth to carbonates in cm (indicated by strong effervescence); ELEV = elevation (m); LAT = latitude (degrees); LONG = longitude (degrees); MCV = mean color value; %OM = percent organic matter in the mollic epipedon

APPENDIX B
SITE/SOIL DESCRIPTIONS

Site/Soil Description---Site 1

Date sampled: June 21, 1982
 Area: Stavely Research Substation
 Location: NE 1/4 Sec 22 T14 R29 W4 th 11 miles west and 2 miles
 north of Stavely, Canada
 Mean production (13 years 1969-1981): 2865 kg/ha
 Mean depth of mollic epipedon (30 probes): 37 cm
 Pedon classification: Argic Cryoboroll fine, montmorillonitic
 (Orthic Black Chernozemic, fine-clayey, montmorillonitic)
 Vegetation: Festuca scabrella with some Danthonia parryi
 Climate: 687 mm annual precipitation (mean of 10 years) soil
 temperature 9 C at 50 cm,
 Parent material: glacial till
 Physiography: upland
 Relief: complex
 Elevation: 1000 m
 Slope: 4%
 Aspect: SW
 Erosion: slight
 Permeability: moderate
 Drainage: well drained
 Ground water: not reached
 Salt or alkali: not observed
 Stoniness: class 0
 Root distribution: deep, abundant
 Moisture: moist
 % coarse fragments: 5
 Pedon described by: Mary Ellen Cannon, Clinton Mogen
 Notes: Tongues of 10YR 2/2 (moist) in A extend from surface to depths
 ranging from as little as 10 cm to as much as 38cm. Organic
 staining in Bt horizon as part of tongues and in patches.
 Gradual wavy mollic epipedon boundary. Lime appears in soft
 threads and precipitated on rock bottoms in Bk horizon. Distinct
 thick clay skins in Bt horizon. Disintegrating sandstone and
 shale in Bt horizon and below causes color varigations. Pit dug
 to 100+ cm.

0 2-0 cm. dead grass and grass roots

A 0-12 cm. Very dark grayish brown (10YR 3/2) loam, black
 (10YR 2/1) moist; moderate fine granular structure; soft (dry),
 friable (moist), nonsticky and nonplastic (wet); noncalcareous;
 many fine and very fine, few medium roots; many fine and very
 fine tubular pores; 5% coarse fragments; abrupt irregular
 boundary.

Site/Soil Description---Site 1 (continued)

Bt 12-58 cm. Brown (10YR 5/3) clay loam, dark yellowish brown (10YR 3.5/4,4/4) to yellowish brown (10YR 5/4) moist; moderate fine prismatic structure breaking to strong fine angular blocky structure; hard (dry), friable (moist), sticky and plastic (wet); many fine and very fine, few medium roots, many fine and very fine tubular pores; 5% coarse fragments; clear wavy boundary.

Bk 58+ cm. Light gray (10YR 7/2) with white (10YR 8/1) lime streaks loam, brown (10YR 5/3) with light gray (10YR 7/2) lime streaks moist; strong fine platy structure breaking to strong very fine angular blocky structure; (dry), friable (moist), slightly sticky and slightly plastic (wet); violently effervescent; common fine and very fine roots; many fine and very fine tubular pores; 5% coarse fragments.

Site/Soil Description---Site 2

Date sampled: June 24, 1982
 Area: enclosure near Owendale, Canada
 Location: E 1/2 Sec 13 T2 R22
 Mean production (12 years 1969-1980): 2.41 Mg/ha
 Mean depth of mollic epipedon (30 probes): 48 cm
 Pedon classification: Typic Argiboroll, fine, montmorillonitic
 (Orthic Dark Brown Chernozemic, fine-clayey, montmorillonitic)
 Vegetation: Festuca scabrella with some Festuca idahoensis, Carex
 and Agropyron spp.
 Climate: 687 mm annual precipitation (10 year mean), soil temperature
 13 C at 50 cm
 Parent material: glacial till
 Physiography: upland
 Relief: complex, subdued
 Elevation: 1000 meters
 Slope: 3%
 Aspect:
 Erosion: slight
 Permeability: moderate
 Drainage: well drained
 Ground water: not reached
 Salt or alkali: not observed
 Stoniness: class 0
 Root distribution: deep, abundant
 Moisture: moist
 % coarse fragments: 5-10
 Pedon described by: Mary Ellen Cannon and Clint Mogen

Notes: A lot of holes in field. Krotovina between 27 to 37 cm.
 Texture of material in krotivina finer than surface texture,
 colors are the same. Hole was probably filled in long ago.
 Tongues of A reach into Bt horizon. Secondary lime on bottoms of
 rock and threads of lime in Bk horizons. Thick clay films in Bt1
 and Bt2 horizon with some clay films in krotivina material.

O 2-0 cm. dead grass

A 0-10 cm. Very dark grayish brown (10YR 3/2) loam, black (10YR
 2/1) moist; moderate fine granular structure; soft (dry), friable
 (moist), non-sticky and non-plastic (wet); noncalcareous; many fine
 and very fine, few medium roots; many fine tubular pores; 5% coarse
 fragments; abrupt irregular boundary.

Bt1 10-27 cm. Dark brown to brown (10YR 4/3) clay loam, dark brown
 (10YR 3/3) moist; moderate medium prismatic structure; soft (dry),
 friable (moist), slightly sticky and plastic (wet); noncalcareous;
 many fine and very fine and few medium roots; many fine tubular pores;
 10% coarse fragments; abrupt irregular boundary.

Site/Soil Description---Site 2 (continued)

Bth 27-37 cm. Very dark grayish brown (10YR 3/2) loam, black (10YR 2/1) moist; strong fine prismatic structure; soft (dry), friable (moist), slightly sticky and plastic (wet); noncalcareous; many fine and very fine, few medium roots; many fine and very fine tubular pores; 5% coarse fragments; abrupt irregular boundary.

Bt2 37-68 cm. Brown (10YR 5/3) clay loam, brown (10YR 5/3) moist; strong medium prismatic structure; slightly hard (dry), friable (moist), slightly sticky and plastic (wet); noncalcareous; many fine and very fine, few medium roots; many fine and very fine tubular pores; 5% coarse fragments; clear smooth boundary.

Bk1 68-91 cm. Light brownish gray (2.5Y 6/2) clay, dark grayish brown (2.5Y 4/2) moist; moderate fine prismatic structure; hard (dry), friable (moist), sticky and plastic (wet); violently effervescent in spots; many fine and very fine and few medium roots; many fine and very fine tubular pores; 5% coarse fragments; clear smooth boundary.

Bk2 91+ cm. Brown (10YR 5/3) with white (10YR 8/0) lime streaks clay, brown (10YR 5/3) with light gray (10YR 7/2) lime streaks moist; weak thick platy structure almost massive; hard (dry), firm (moist), sticky and plastic (wet); violently effervescent; common fine and very fine, few medium roots; many fine and very fine tubular pores; 10% coarse fragments; boundary not reached.

Site/Soil Description---Site 3

Date sampled: May 7 and 8, 1982

Area: Mandan, North Dakota

Location: Forty acre moderately grazed long-term pasture on ARS experiment station. Pit is 60 feet east of southeast corner of enclosure.

Mean production (29 years, 1951-1979,1981): 2.29 Mg/ha

Mean depth of mollic epipedon (30 probes): 70 cm

Pedon classification: Typic Argiboroll, fine-silty, mixed

Vegetation: *Bouteloua gracilis*, *stipa comata*

Climate: 403 mm annual precipitation (mean of 29 years), soil temperature 9 C at 50 cm on May 8, 1982

Parent material: loess over glacial till

Physiography: upland

Relief: complex

Elevation: 595 meters

Slope: 2% near pit

Erosion: slight

Permeability: moderate

Drainage: well drained

Ground water: not reached

Salt or alkali: not observed

Stoniness: class 0

Root distribution: deep, abundant

Moisture: moist to 65 cm, dry, then moist below 120 cm

% coarse fragments: 5

Pedon described by: Mary Ellen Cannon and Clinton Mogen

Notes: Vegetation was clipped over a 100 acre area for production data until 1974. Then pasture was cut in half and production data is from the 40 acres sampled. Russel Lorenz (personal communication, 1982) says production for both areas is similar and pooling production data should pose few problems. Randomly sampled thickness of mollic epipedon and described pedon within the 40 acres.

Prisms are more coarse at the bottom of the Bt horizon. One could split the Bt into two horizons. Soft, white calcium carbonate nodules 1 cm in diameter were observed; each lime segregation has an end to it. Calcium carbonate cast deposited on underside of rounded rocks near Bt/2Bk boundary. Organic matter stains show in Bt horizon, and clay films cover outside of coarse prisms. Clay movement continues into Bk horizon coating lime particles and matrix.

Site/Soil Description--Site 3 (continued)

A 0-18 cm. Very dark grayish brown (10YR 3/2) silt loam, very dark grayish brown (10 YR 3/2) moist; moderate fine granular and moderate medium subangular blocky structure; slightly hard (dry), friable (moist), slightly sticky and nonplastic (wet); abundant fine and very fine roots; many very fine tubular pores; noneffervescent; pH 7 (Truog testing kit); no coarse fragments; clear smooth boundary.

AB 18-29 cm. Very dark brown to brown (10YR 4/3) silt loam, dark brown (10YR 3/3) moist; moderate fine prismatic structure; slightly hard (dry), friable (moist), slightly sticky and plastic (wet); many fine and very fine roots, common medium roots; many very fine tubular pores; noneffervescent; pH 7 (Truog testing kit); no coarse fragments; clear irregular boundary.

Bt 29-65 cm. Brown (10YR 5/3) silty clay loam, yellowish brown (10YR 5/4) moist; moderate medium prismatic structure; slightly hard (dry), friable (moist), nonsticky and plastic (wet); common very fine, fine, and medium roots; many very fine tubular pores; noneffervescent; 5% coarse fragments; abrupt irregular boundary.

2Bk 65+ cm. Pale brown (10YR 6/3) with white (10YR 8/1) streaks clay loam, dark grayish brown (10YR 4/2) with white (10YR 8/1) streaks moist; moderate coarse prismatic structure; slightly hard (dry), firm (moist), slightly sticky and plastic (wet); common fine and very fine roots; many very fine tubular pores; violently effervescent; 5% coarse fragments; clay skins coat prism faces; boundary not reached.

Site/Soil Description---site 4

Date sampled: May 6, 1982

Area: Dickinson Agricultural Experiment Station, North Dakota
State University

Location: SW 1/4 SW 1/4 Sec 23 T 140N R 97W, Dickinson fertilizer
trial check plots (Goetz fertility plots)

Mean production (9 years 1970-1978): 2257 kg/ha

Mean depth of mollic epipedon (30 probes): 94 cm

Soil Classification: Pachic Haploboroll, fine-loamy, mixed

Vegetation: Stipa comata, Bouteloua gracilis

Climate: 388 mm mean annual precipitation

Parent material: alluvium

Physiography: upland

Relief: slight undulating

Elevation: 750 m

Erosion: slight

Stoniness: class 0

Site/Soil Description---Site 5

Date sampled: May 6, 1982
Area: Dickinson Agricultural Experiment Station, North Dakota
State University
Location: SW 1/4 SW 1/4 Sec 23 T 140N R 97W, Dickinson
interseeding trial check plots
Mean production (6 years 1971-1976): 2230 kg/ha
Mean depth of mollic epipedon (30 probes): 77 cm
Soil classification: Pachic Haploboroll, fine-loamy, mixed
Vegetation: Stipa comata, Bouteloua gracilis
Climate: 388 mm mean annual precipitation
Parent material: alluvium
Physiography: upland
Relief: slight undulating
Elevation: 750 m
Erosion: slight
Stoniness: class 0

Site/Soil Description--Site 6

Date sampled: May 6, 1982
Area: Dickinson Agricultural Experiment Station, North Dakota
State University
Location: SE 40 NE 1/4 Sec 2 T 140N R 96W, Dickinson
light fall grazing site US/IBP site similar
Mean production (13 years 1958-1962, 1966-1973): 1811 kg/ha
Mean depth of mollic epipedon (30 probes): 22 cm
Soil classification: Typic Ustipsamment, mixed, frigid, shallow and
Typic Haploboroll, coarse-loamy, mixed (Flasher-Vebar
complex)

Vegetation: Stipa comata, Bouteloua gracilis
Climate: 388 mm mean annual precipitation
Parent material: residual sandstone
Physiography: upland
Relief: convex
Elevation: 750 m
Erosion: slight
Stoniness: class 0

Site/Soil Description---Site 7

Date sampled: June 23, 1982
 Area: Twin River Grazing Reserve; near Del Bonita, Canada
 Location: E 1/2 Sec 9 & 4 T1 R18 W4 th
 Mean production (10 years 1971-1980): 1.65 Mg/ha
 Mean depth of mollic epipedon (30 probes): 45 cm
 Pedon classification: Typic Argiboroll, fine, montmorillonitic
 (Dark Brown Chernozemic, fine, montmorillonitic)
 Vegetation: Festuca idahoensis
 Climate: 304 mm annual precipitation (mean of 10 years) soil
 temperature 15 C at 50 cm,
 Parent material: glacial till
 Physiography: upland
 Relief: complex, subdued
 Elevation: 1265 m
 Slope: 2%
 Aspect:
 Erosion: slight
 Permeability: moderate
 Drainage: well drained
 Ground water: not reached
 Salt or alkali: not observed (probably natric soils below by pond
 but vegetation was clipped on upland)
 Stoniness: class 0
 Root distribution: deep, abundant
 Moisture: moist
 % coarse fragments: 5
 Pedon described by: Mary Ellen Cannon, and Clinton Mogen
 Notes: Mollic to 36 cm gradual boundary between mollic and not
 mollic. 10YR 3/2 color of A horizon tongues into Bt horizon.
 Lime threads and films plus lime casts on rocks in Bk1 and Bk2
 horizons. Bk2 structure appears massive but does break into
 thick plates. Limestone, sandstone, and possibly green quartzite
 were observed in the pit. Pit dug to 100+ cm.

O 2-0 cm. dead grass

A 0-10 cm. Very dark grayish brown (10YR 3/2) loam, very dark brown (10YR 2/2) moist; moderate fine granular structure; soft (dry), friable (moist), non-sticky and non-plastic (wet); noncalcareous; many fine and very fine and common medium roots; many fine and very fine tubular pores; 5% coarse fragments; abrupt irregular boundary.

Bt 10-50 cm. Brown (10YR 5/3) clay loam, very dark grayish brown (10YR 3/2) and very dark brown (10YR 2/2) with coatings of dark brown-brown (10YR 4/3) moist; strong medium prismatic structure breaking to strong coarse angular blocky; slightly hard (dry), friable (moist), slightly sticky and plastic (wet); noncalcareous; many fine and very fine and few medium roots; many fine and very fine tubular pores; 5% coarse fragments; clear smooth boundary.

Site/Soil Description---Site 7 (continued)

Bk1 50-64 cm. Light brownish gray (2.5Y 6/2) clay loam, dark grayish brown (2.5Y 4/2) with streaks of white (2.5Y 8/2) moist; strong medium prismatic structure; hard (dry), friable (moist), slightly sticky and plastic (wet); violently effervescent; many fine and very fine and few medium roots; many fine and very fine tubular pores; 5% coarse fragments; clear smooth boundary.

Bk2 64+ cm. Light gray (10YR 7/2) clay loam, dark brown to brown (10YR 4/3) moist; weak thick platy; hard (dry), firm (moist), slightly sticky and plastic (wet); violently effervescent; many fine and very fine roots to 75 cm then common fine and very fine roots; many fine and very fine tubular pores; 5% coarse fragments; boundary not reached.

Site/Soil Description---Site 8

Date sampled: June 17, 1982

Area: Gravelly Mountain Range Montana

Location: NE 1/4 Sec 11 T 8S R 2W. North facing slope of Mueggler's 10-year weather station within the Beaverhead National Forest off of Call Road.

Mean production (10 years 1964-1974): 1.47 Mg/ha

Pedon classification: Typic Cryoboroll, fine-loamy, skeletal

Vegetation: Festuca idahoensis/Agropyron spicatum habitat type

Climate: cryic (personal communication June Haigh, 1982), 500 mm precipitation (estimated from Mueggler's weather records and State of Montana Precipitation map); soil temperature 5° C at 50 cm.

Parent material: limestone residuum

Physiography: upland

Relief: complex

Elevation: 2165 meters

Slope: 8%

Aspect: N-NW 330

Erosion: slight

Permeability: moderate

Drainage: well drained

Ground water: not reached

Salt or alkali: not observed

Stoniness: none

Root distribution: many to 48 cm, common to 74 cm, few below 74 cm

Moisture: moist

% coarse fragments: 30

Notes: The site sampled is the 7100 feet elevation site on a north-facing slope described by Mueggler (1971). Mueggler W.F. 1971. Weather variations on a mountain grassland in southwestern Montana. USDA Forest Service Research Paper INT-99. Intermountain Forest and Range Experiment Station. Ogden, Utah 84401. 25 pages.

North-facing slope has some *Artemisia tridentata*, but south-facing slope has none. Bk2 identified by difference in texture and root abundance but not sampled separately. In Bw (32-48 cm) clay films on soil by rock.

A 0-32 cm. Very dark grayish brown (10YR 3/2) loam, black (10YR 2/1) moist; moderate fine granular structure; soft (dry), friable (moist), nonsticky and nonplastic (wet); many fine and very fine, few medium roots; many fine and very fine pores; noneffervescent; 5-10% coarse fragments; abrupt smooth.

Bw 32-48 cm. Brown (10YR 5/3) channery loam, dark brown to brown. (10YR 4/3) moist; moderate medium angular blocky structure; slightly

Site/Soil Description---Site 8 (continued)

hard (dry), friable (moist); slightly sticky and plastic (wet); many fine and very fine roots, few medium roots; many fine and very fine pores; strongly effervescent; 20% channers; clear wavy boundary.

Bk1 48-74 cm. White (10YR 8/1) channery loam, very pale brown (10YR 7/3) moist; weak fine platy structure; slightly hard (dry), friable (moist); slightly sticky and nonplastic (wet); common fine and very fine roots; many fine and very fine pores; violently effervescent; 25-30% channers; gradual wavy boundary.

Bk2 74+ cm. White (10YR 8/1) channery and gravelly loam, very pale brown (10YR 7/3) moist; weak medium platy breaking to moderate very fine angular blocky structure; slightly hard (dry); friable (moist), slightly sticky and nonplastic (wet); few fine and very fine roots; many fine and very fine pores; violently effervescent; about 80% channers; boundary not reached.

Site/Soil Description---Site 9

Date sampled: June 26, 1982

Area: Pinhorn grazing association near Comrey.

Location: N 1/4 Sec 18 T2 R6 W 4th Vegetation sampling covered a quarter section.

Mean production (13 years 1969-1981): 1001 kg/ha

Mean depth of mollic epipedon (30 probes): 46 cm

Pedon classification: Typic Haploboroll, loamy mixed

Vegetation: Stipa comata, Koeleria cristata

Climate: 327 mm annual precipitation (mean of 10 years), soil temperature 15 C at 50 cm,

Parent material: aeolian silt & sand

Physiography: upland

Relief: convex

Elevation: 930 m

Slope: 1% by pit

Aspect:

Erosion: slight

Permeability: moderate

Drainage: well drained

Ground water: not reached

Salt or alkali: not observed (natric complex observed 1/2 mile to north)

Stoniness: class 0

Root distribution: throughout

Moisture: dry at surface moist otherwise

% coarse fragments: 0

Pedon described by: Mary Ellen Cannon and Clint Mogen

Notes: Pit dug to 120 + cm. Mollic to 35 cm. Krotovina at 50 to 64 cm, 2.5Y 3/2 color, oval shaped. Krotovina tongues downward. Faint, thin threads of calcium carbonate in Bk horizons.

A 0-19 cm. Olive-light olive brown (2.5Y 4.5/2) loam, very dark grayish brown (2.5Y 3/2) moist; weak fine granular structure; soft (dry), very friable (moist), nonsticky and nonplastic (wet); noncalcareous; many fine and very fine roots; many fine pores; gradual wavy boundary.

Bw 19-34 cm. Olive-light olive brown (2.5Y 4.5/2) loam, very dark grayish brown (2.5Y 3/2) moist; weak coarse prismatic structure; soft (dry), very friable (moist), nonsticky and nonplastic (wet); violently effervescent; many fine and very fine roots; many fine tubular pores; clear wavy boundary.

Bk1 34-72 cm. Light olive brown (2.5Y 5/4) fine sandy loam, olive brown (2.5Y 4/2) moist; massive structure falling into single grain when broken; soft (dry), loose (moist), nonsticky and nonplastic (wet); violently effervescent; many fine and very fine roots; many fine pores; gradual wavy boundary.

Site/Soil Description---Site 9 (continued)

Bk2 72-120+ cm. Pale yellow (2.5Y 7/4) fine sandy loam, light olive brown (2.5Y 5/4) moist; massive structure falling into single grain when broken; soft (dry), loose (moist), nonsticky and nonplastic (wet); violently effervescent; common fine and very fine roots; many fine pores; boundary not reached.

Site/Soil Description--Site 10

Date sampled: December 29, 1966 by Lester C. Brockmann, Richland County SCS

Area: ARS Experiment Station Sidney Montana

Location: NE 1/4 Sec 25 T 23 N R 58E. profile described from pits in which hydraulic lysimeter was installed

Mean production (13 years 1967-1979): 1.0 Mg/ha

Mean depth of mollic epipedon (30 probes): 37 cm

Pedon classification: fine-loamy,

Vegetation: Western wheatgrass, needleandthread, threadleaf sedge

Climate: 352 mm annual precipitation (mean of 13 years) semiarid

Parent material: friable clay loam till

Physiography: slightly convex area on till mantled terrace

Relief: complex

Elevation: 640 m

Slope: 1%

Aspect: SW

Erosion: none to slight

Permeability: moderate

Drainage: well drained

Ground water: very deep

Salt or alkali: not observed

Stoniness: few scattered stones (class 0 stoniness)

Root distribution: abundant to 10 inches, plentiful to 18 inches, few below

Moisture: moist to 12 inches

% coarse fragments:

Notes: Called a Sprole loam when sampled in 1966. Name changed to Williams loam. Dr. Larry White located site for us on May 5, 1982.

A1 (A) 0-4 1/2 in. (0-11 cm) Grayish brown (10YR 5/2) loam, very dark grayish brown (10YR 2.5/2) moist; moderate fine crumb (granular) structure; slightly hard (dry), very friable (moist), slightly sticky and slightly plastic (wet); noncalcareous, clear boundary.

B2t (Bt) 4 1/2-10 in. (11-25 cm) Brown (10YR 5/3) heavy clay loam; dark brown (10 YR 3/3 moist); moderate medium prismatic breaking to moderate medium blocky structure with continuous clay film; hard (dry), friable (moist); slightly sticky and plastic (wet); noncalcareous; few small gravels; clear wavy boundary.

B3 (BC or CB) 10-14 in. (25-36 cm) Light brownish gray (2.5Y 6/2) clay loam; moderate medium prismatic structure with few patches of clay films; hard (dry), friable (moist), sticky and plastic (wet); strongly calcareous; few small gravels lime coated on underside; gradual boundary.

Site/Soil Description---Site 10 (continued)

C1ca (Ck1) 14-18 in. (36-46 cm) Light gray (2.5Y 7/2 with mottles of 8/0) clay loam; light olive brown (2.5Y 5/3) moist; weak coarse prismatic structure; hard (dry), friable (moist); sticky and plastic (wet); very strongly calcareous with many films and common soft nodules of lime; a few small gravels.

C2ca (Ck2) 18-30 in. (46-76 cm) Light brownish gray (2.5Y 6.5/2) clay loam, olive brown (2.5Y 4.5/2) moist; massive; hard (dry), friable (moist), sticky and plastic (wet); strongly calcareous with common films and a few soft nodules of lime; common small lime coated gravels; gradual boundary.

C3 30-36 in. (76-91 cm) Light yellowish brown (2.5Y 6/3) clay loam, olive brown (2.5Y 4/3) moist; massive; hard (dry), friable (moist), sticky and plastic (wet); strongly calcareous with a few films and nodules of lime; a few small gravels; gradual boundary.

C4 36-47 in. (91-119 cm) Pale olive (5Y 6/3) light clay loam, olive (5Y 4/3) moist; massive; hard (dry), friable (moist), sticky and plastic (wet); strongly calcareous; a few small gravels; gradual boundary.

Site/Soil Description---Site 11

Date sampled: June 18, 1982

Area: Gravelly Mountain Range Montana

Location: NE 1/4 Sec 11 T 8S R 3E. South facing slope of Mueggler's 10-year weather station within the Beaverhead National Forest off of Call Road.

Mean production (10 years 1964-1974): 0.77 Mg/ha

Pedon classification: Typic Cryoboroll, fine-loamy, mixed

Vegetation: Festuca idahoensis/Agropyron spicatum habitat type

Climate: cryic (personal communication June Haigh, 1982), 500 mm annual precipitation (estimated from Mueggler's weather records and State of Montana Precipitation map), soil temperature 10° C at 50 cm.

Parent material: limestone residuum

Physiography: sloping upland

Relief: plain

Elevation: 2165 meters

Slope: 6%

Aspect: 210 SW

Erosion: slight

Permeability: moderate

Drainage: well drained

Ground water: not reached

Salt or alkali: not observed

Stoniness: few

Root distribution: normal

Moisture: throughout

% coarse fragments: 15-25

Notes: The site sampled is the 7100 feet elevation site on a south-facing slope described by Mueggler (1971). See soil/ site description---site 8 note.

Most of the 30 mollic epipedon samples had more coarse fragments than this pedon (approximately 5% gravels and 10-15% angular cobbles). No *Artemisia tridentata* on the south-facing slope, but there is some on the north-facing slope.

A 0-22 cm. Very dark grayish brown (10YR 3/2) silt loam, very dark grayish brown (10 YR 3/2) moist; moderate very fine granular structure; soft (dry), very friable (moist), slightly sticky and slightly plastic (wet); many fine and very fine roots; noneffervescent to 10 cm, slightly effervescent 10 to 22 cm; 5% gravels and 5% cobbles; clear smooth boundary.

Bw 22-38 cm. Brown (10YR 5/3) gravelly loam, dark brown to brown (10YR 3/2) moist; moderate fine angular blocky structure; slightly hard (dry), friable (moist), slightly sticky and slightly plastic (wet); many fine and very fine roots; strongly effervescent; 5% gravels and 10% cobbles; clear wavy boundary.

Site/Soil Description---Site 11 (continued)

Bk 38-65 cm. White (10YR 8/2) gravelly loam, light gray (10YR 7/2) moist; weak medium angular blocky; hard (dry), firm (moist), slightly sticky and slightly plastic (wet); few fine and very fine roots; violently effervescent; 10% gravels and 5% cobbles; clear smooth boundary.

Ck 65+ cm. White (10YR 8/2) gravelly loam, pale brown (10YR 6/3) about 10% light gray (10YR 7/2) lime; weak fine platy breaking to moderate very fine angular blocky structure; hard (dry), firm (moist), sticky and plastic (wet); violently effervescent; 10% gravels and 5% cobbles; boundary not reached.

Site/Soil Description---Site 12

Date sampled: June 13, 1982

Area: Archer Substation Wyoming Agricultural Experiment Station
10 miles east of Cheyenne, Wyoming on U.S. Interstate 80.

Location: SW 1/4 NW 1/4 Sec 27 T 14N R 65W Pasture 4 of Grazing
Intensity Study north end of upland. Pit is in line with
white house with green roof last of group of buildings 4
pastures away.

Mean production (18 years, 1947-1964): 0.68 Mg/ha

Mean depth of mollic epipedon (30 probes): 32 cm

Pedon classification: Aridic Argiustoll, fine, mixed, mesic

Vegetation: Bouteloua gracilis, Agropyron smithii

Climate: 371 mm annual precipitation, soil temperature
16° C at 50 cm

Parent material: Sherman granite pedisements

Physiography: upland

Relief: subdued complex

Elevation: 1825 m

Slope: 2%

Aspect: SE

Erosion: moderate some evidence of wind-caused deflation in pasture

Permeability: moderate

Drainage: well drained

Ground water: not reached

Salt or alkali: not observed

Stoniness: class 0

Root distribution: deep, abundant

Moisture: moist

% coarse fragments: 5

Pedon described by: Mary Ellen Cannon and Clint Mogen

Notes: 25-30% cicada cast holes in Bt horizon. Very dark gray (10YR
3/1) and dark grayish brown (10YR 3/2) material in holes in Bt.
Threads of soft lime in Bk1 and Bk2 horizons.

A 0-10 cm. Dark brown to brown (10YR 4/3) loam, dark brown (10YR
3/3) moist; weak fine granular structure; soft (dry), friable (moist),
slightly sticky and slightly plastic (wet); noncalcareous; many fine
and very fine roots; many fine and very fine pores; 5% coarse frag-
ments; abrupt smooth boundary.

AB 10-18 cm. Dark brown to brown (10YR 4/3) clay loam, dark brown
(10YR 3/3) moist; weak fine prismatic structure breaking to strong
fine angular blocky structure; hard (dry), friable (moist), slightly
sticky and plastic (wet); noncalcareous; many fine and very fine
roots; many fine and very fine pores; 5% coarse fragments; abrupt
smooth boundary.

Site/Soil Description---Site 12 (continued)

Bt1 18-38 cm. Dark brown to brown (10YR 4/3) clay, dark brown (10YR 3/3) moist; weak fine prismatic structure breaking to strong fine blocky structure; very hard (dry), friable (moist), sticky and plastic (wet); noncalcareous; many fine and very fine roots between peds and worm casts sometimes through peds or casts; many fine and very fine pores; 5% coarse fragments; clear smooth boundary.

Bt2 38-54 cm. Brown (10YR 5/3) clay, dark brown to brown (10YR 4/3) moist; weak coarse prismatic structure breaking to strong fine blocky structure; very hard (dry), friable (moist), sticky and plastic (wet); noncalcareous; many fine and very fine roots between peds and in cast holes, common fine and very fine roots throughout; many fine and very fine pores; 5% coarse fragments; abrupt wavy boundary.

Bk1 54-64 cm. Light yellowish brown (10YR 6/4) sandy clay loam, brown (10YR 5/3) moist; weak coarse prismatic structure breaking to strong fine blocky structure; very hard (dry), friable (moist), sticky and plastic (wet); strongly effervescent; many fine and very fine roots between peds and in cast holes, common fine and very fine roots throughout; many fine and very fine pores; 5% coarse fragments; clear wavy boundary.

Bk2 64-97 cm. Light yellowish brown (10YR 6/4) sandy clay loam, brown (10YR 5/3) moist; massive structure; hard (dry), friable (moist), sticky and plastic (wet); violently effervescent; many fine and very fine roots throughout; many fine and very fine pores; clear wavy boundary.

Bk3 97-107 cm. Light yellowish brown (10YR 6/4) sandy clay loam, yellowish brown (10YR 5/4) moist; massive structure; soft (dry), very friable (moist), slightly sticky and slightly plastic (wet); violently effervescent; common fine and very fine roots throughout; many fine and very fine pores; 15% coarse fragments (Sherman granite, quartz); abrupt wavy boundary.

Bk4 107 + cm. White (10YR 8/1,8/2) sandy loam, very pale brown (10YR 7/4) moist; massive structure; soft (dry), very friable (moist), slightly sticky and nonplastic (wet); violently effervescent; common fine and very fine roots; many fine and very fine pores; 15% coarse fragments; boundary not reached.

Site/Soil Description---Site 13

Date sampled: June 13, 1982

Area: Archer Substation Wyoming Agricultural Experiment Station
10 miles east of Cheyenne, Wyoming on U.S. Interstate 80.

Location: NW 1/4 SW 1/4 Sec 27 T 14N R 65W Nitrogen fertilizer
check plots Frank Rauzi's experiment

Mean production (8 years, 1970-1977): 0.66 Mg/ha

Mean depth of mollic epipedon (30 probes): 25 cm

Pedon classification: Aridic Argiustoll, clayey over sandy,
mixed, mesic

Vegetation: Bouteloua gracilis, Agropyron smithii

Climate: 377 mm annual precipitation

Parent material: pediment surface materials eroded from Sherman
granite pedisediments

Physiography: upland

Relief: subdued

Elevation: 1825 m

Slope: 0-1%

Erosion: slight to moderate

Permeability: moderately slow

Drainage: well drained

Ground water: not reached

Salt or alkali: not observed

Stoniness: class 0

Root distribution: deep, abundant

Moisture: moist

% coarse fragments: 5

Pedon described by: Mary Ellen Cannon and Clint Mogen

Notes: Mollic Bt1 tongues into Bt2 and Btk horizons particularly
along prism faces. Clay films also follow prism faces. 20-25%
cicada cast holes in Bk horizon. Cicada casts are less numerous
in other horizons. Bt2 has spots of calcareous materials perhaps
caused by cicada mixing. Threads of soft lime appear in Btk, Bk,
2Bk1, and 2Bk2 horizons. Lime is precipitated on coarse fragments
in Bk, 2Bk1, 2Bk2, and 3Bk horizons.

A 0-8 cm. Brown (10YR 5/3) loam, dark brown (10YR 3/3) moist;
moderate medium fine granular structure; soft (dry), friable (moist),
slightly sticky and slightly plastic (wet); noncalcareous; many fine
and very fine roots; many fine and very fine pores; 0% coarse frag-
ments; abrupt smooth boundary.

Bt 18-23 cm. Brown (10YR 5/3) clay, dark brown (10YR 3/3) moist;
moderate medium prismatic structure; soft (dry), friable (moist),
slightly sticky and plastic (wet); noncalcareous; many fine and very
fine roots; many fine and very fine tubular pores; 0% coarse frag-
ments; clear irregular boundary.

Site/Soil Description---Site 13 (continued)

Bt2 23-35 cm. Brown (10YR 5/3) clay, dark brown to brown (10YR 4/3) moist; moderate fine prismatic structure breaking to strong medium angular blocky structure; soft (dry), friable (moist), slightly sticky and plastic (wet); strong effervescence in spots; many fine and very fine roots; many fine and very fine pores; 0% coarse fragments; clear irregular boundary.

Btk 35-44 cm. Pale brown (10YR 6/3) clay, brown (10YR 5/3) moist; weak fine prismatic structure breaking to strong medium blocky structure; soft (dry), friable (moist), slightly sticky and plastic (wet); violently effervescent; many fine and very fine roots; many fine and very fine pores; 0% coarse fragments; clear broken boundary.

Bk 44-57 cm. Very pale brown (10YR 7/3) clay loam, brown (10YR 5/3) moist; massive structure; very hard (dry), friable (moist), slightly sticky and plastic (wet); violently effervescent; many fine and very fine roots along fractures and cicada holes; many fine and very fine pores; 5% coarse fragments; abrupt smooth boundary.

2Bk1 57-84 cm. Very pale brown (10YR 7/3) clay loam, brown (10YR 5/3) moist; massive structure; very hard (dry), friable (moist), slightly sticky and plastic (wet); violently effervescent; common fine and very fine roots throughout; many fine and very fine pores; 15% coarse fragments; abrupt smooth boundary.

2Bk2 84-108 cm. Very pale brown (10YR 7/4) with white (10YR 8/2) streaks sandy clay loam with pockets of loamy sand or sandy loam material, brown (10YR 5/3) with very pale brown (10YR 7/3) streaks moist; massive structure; very hard (dry), friable (moist), nonsticky and nonplastic (wet); violently effervescent; common fine and very fine roots throughout; many fine and very fine pores; 45% coarse fragments; abrupt smooth boundary.

3Bk 108-134+ cm. Reddish yellow (7.5YR 6/6) very gravelly loamy sand, dark brown to brown (7.5YR 4/4) moist; single grain structure; loose (dry), very friable (moist), nonsticky and nonplastic (wet); violently effervescent; few fine and very fine roots; can not distinguish pores; 85% coarse fragments; boundary not reached.

Site/Soil Description---Site 14

Date sampled: June 25, 1982

Area: Many berries Agricultural Experiment Station long-term production plot maintained by S. Smoliak

Location: NE 1/4 Sec 16 T 2 N R 4 W 4th East of complex beyond windbreak and northwest of shack by about 150 yards.

Mean production (49 years 1930-1940, 1942, 1943, 1947-1982):
0.34 Mg/ha

Mean depth of mollic epipedon (30 probes): 14 cm

Pedon classification: Aridic Haploboroll, loamy, mixed
(Calcareous Brown Chernozemic, loamy, mixed)

Vegetation: Stipa comata, Koeleria cristata, Selaginella densa

Climate: 327 mm annual precipitation (mean of 10 years) soil temperature 20°C at 50 cm,

Parent material: glacial outwash

Physiography: esker upland

Relief: convex

Elevation: 930 m

Slope: 3%

Aspect: S

Erosion: slight

Permeability: moderately rapid

Drainage: well drained

Ground water: not reached

Salt or alkali: not observed

Stoniness: class 0

Root distribution: deep, abundant (very profuse throughout top few roots below layer of coarse fragment)

Moisture: dry

% coarse fragments: 10

Pedon described by: Clint Mogen and Mary Ellen Cannon

Notes: Pit dug to 110 + cm. Thick mat of roots at top and many throughout. Lenses of calcium carbonate in C horizon near bottom. Hardened white material. Calcium carbonate cast on gravel.

A 0-17 cm. Pale brown (10YR 5/3) sandy loam, dark brown (10YR 3/3) moist; weak fine granular structure; soft (dry), very friable (moist), slightly sticky and nonplastic (wet); noncalcareous; many fine and very fine roots throughout; many fine pores; 10% coarse fragments; abrupt smooth boundary.

Bk 17-65 cm. Light gray (10YR 7/2) sandy loam, brown (10YR 5/3) moist; weak fine granular structure; soft (dry), very friable (moist), slightly sticky and nonplastic (wet); violently effervescent; many fine and very fine roots throughout; many fine pores; 10% coarse fragments; diffused lime throughout; abrupt smooth boundary.

2Bk 65-78 cm. Light gray (10YR 7/2) sandy loam, brown (10YR 5/3); massive structure; soft (dry), very friable (moist), slightly sticky and nonplastic (wet); violently effervescent; many fine and very fine roots; many tubular pores; 65% coarse fragments; calcium carbonate coats bottom of rocks; threads of soft lime; abrupt wavy boundary.

Site/Soil Description---Site 14 (continued)

3Bk 78+ cm. Light gray (10YR 7/2) loamy sand, brown (10YR 5/3) moist; single grained structure; loose (dry), nonsticky and nonplastic (wet); violently effervescent; few fine and very fine roots; 15% coarse fragments; lenses of hardened calcium carbonate; soft calcium carbonate casts on gravels; boundary not reached.



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of Mollic Epipedon and
other soil or site ...

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