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

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[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.

/

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
Bozeman, Montana

June 1983

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.

6-15-83 Gerald A. Nielsen
Date Chairperson, Graduate Committee

Approved for the Major Department

6/15/83 Dwane G Miller
Date Head, Major Department

Approved for the College of Graduate Studies

7-1-83 Michael Malone
Date Graduate Dean

STATEMENT OF PERMISSION TO USE

In presenting this thesis in partial fulfillment of the requirements for a master's degree at Montana State University, I agree that the Library shall make it available to borrowers under rules of the Library. Brief quotations from this thesis are allowable without special permission, provided that accurate acknowledgement of source is made.

Permission for extensive quotation from or reproduction of this thesis may be granted by my major professor, or in his/her absence, by the Director of Libraries when, in the opinion of either, the proposed use of the material is for scholarly purposes. Any copying or use of the material in this thesis for financial gain shall not be allowed without my written permission.

Signature Mary Ellen Cannon

Date June 21, 1983

ACKNOWLEDGEMENTS

Many persons helped me throughout the process of creating this thesis. Dr. Gerald Nielsen gave invaluable encouragement and valuable criticisms. He also helped involve Mr. Clint Mogen and Mr. June Haigh, retired Soil Conservation Service personnel, in the project. Mr. Clint Mogen helped with field work and interpretations for most sites. Our association is a pleasurable memory. Mr. June Haigh assisted with field work for sites in western Montana (8 and 11). Drs. James Bauder and Theodore Weaver shared their time and expertise with me. Dr. Ross Wight directed me to persons with access to long-term production records. Messrs. Phil Bulgin, Bill Siedow, Silvester Smoliak, and Dean Williams and Drs. Harold Goetz, Colin Kaltenbach, Russel Lorenz, Walter Mueggler, Frank Rauzi,Larry White, and Warren Whitman directed me to sites and production data. Dr. James Bauder, and Messrs. Reed Irwin, Rich Macur, and Kurt Swingle helped on different occasions with field work. Drs. Richard Lund and Jack Martin were also of help to me. Financial support for my graduate research was provided by a grant from the Bureau of Land Management and the Montana State Agricultural Experiment Station. Deep appreciation is felt for my family and the friends who gave encouragement.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Figure | Page

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[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 files[1] 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.

---

[1]Soil-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 phase[2] and soil type[3] 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

---

[2]Soil 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)

[3]Soil 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. Inititally 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 elimate 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 herbivoire 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 (Gieseker 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.

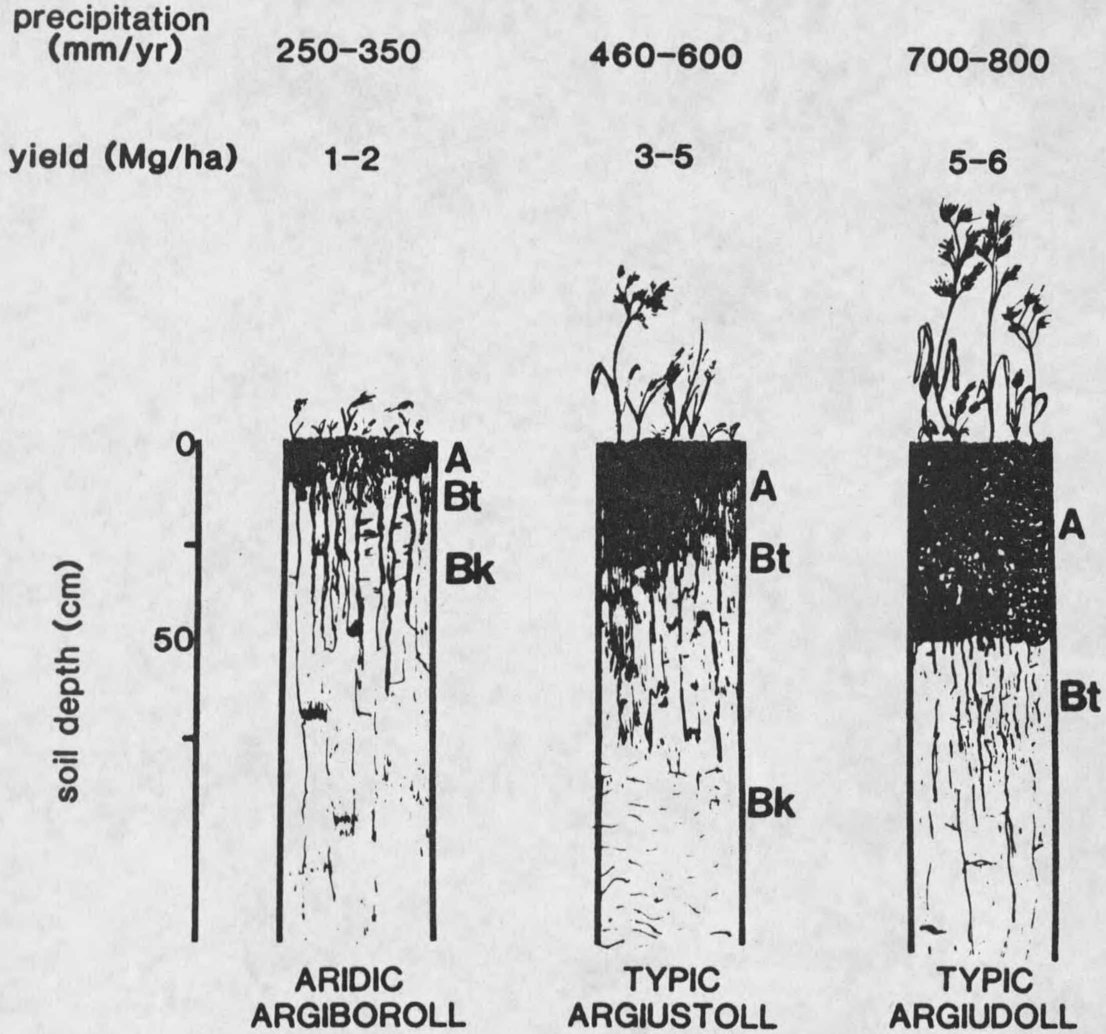

Figure 1. Thickness of Mollic Epipedon for representative pedons in the Northern Great Plains. Scobey, Holdrege, and Sharpsburg soil series are from left to right. Data from Aandahl (1982) and Soil Survey Staff (1980)..OP

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

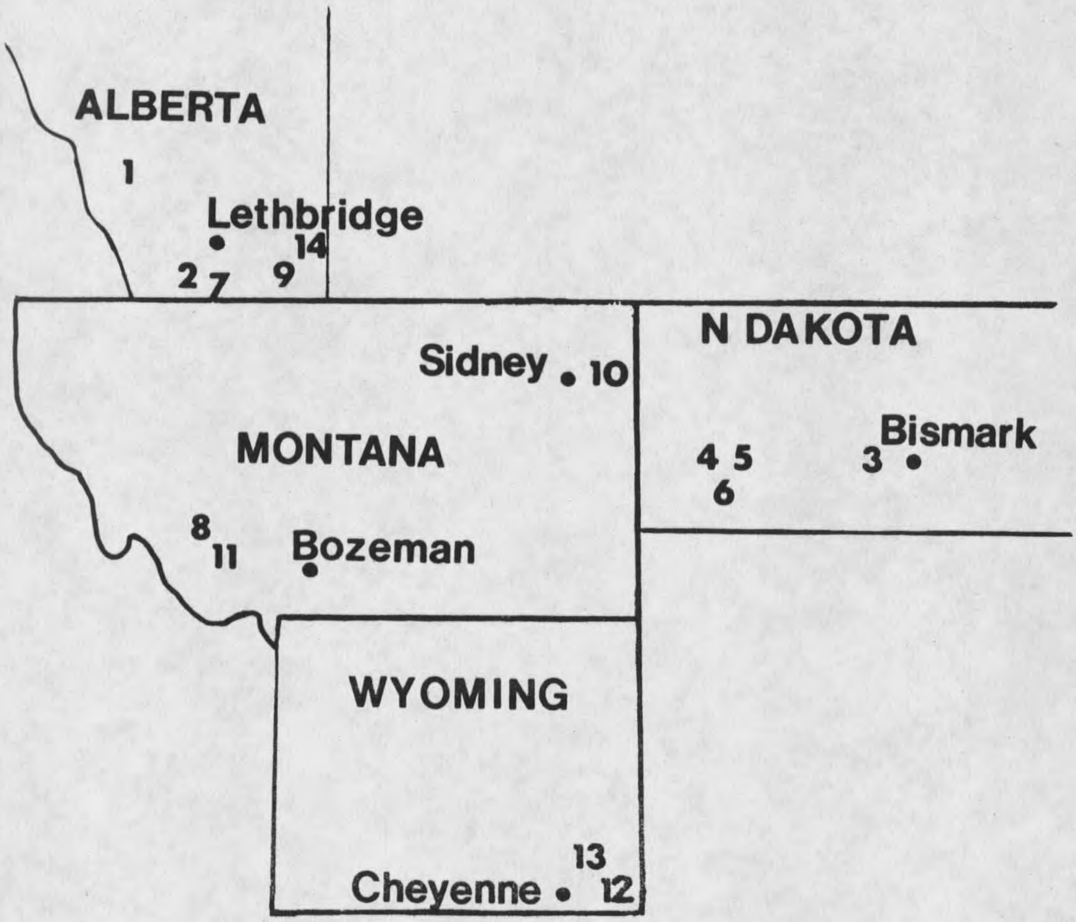

Figure 2. Site Locations. Ordered from 1 (highest) to 14 (lowest) mean annual standing crop production.

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 DISCUSION

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 14[4] 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.

---

[4]Site 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.

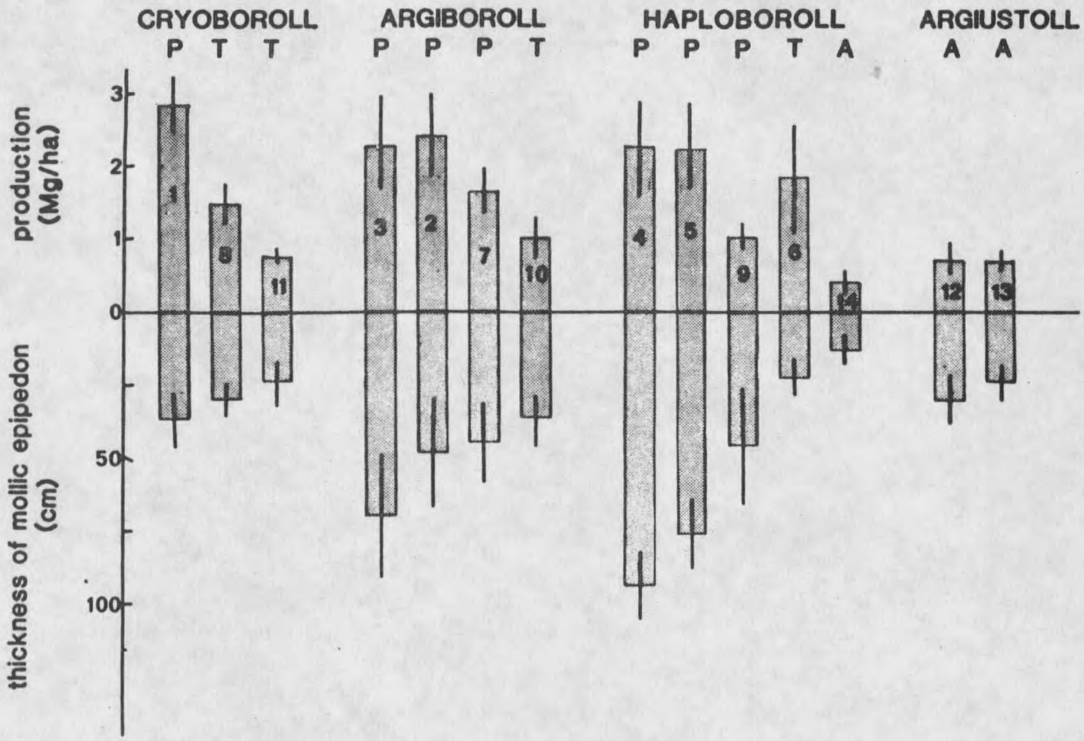

Figure 3. Sites Grouped by Soil Classification. Mean standing crop production (Mg/ha) and mean thickness of mollic epipedon (cm) are shown with corresponding standard deviations.

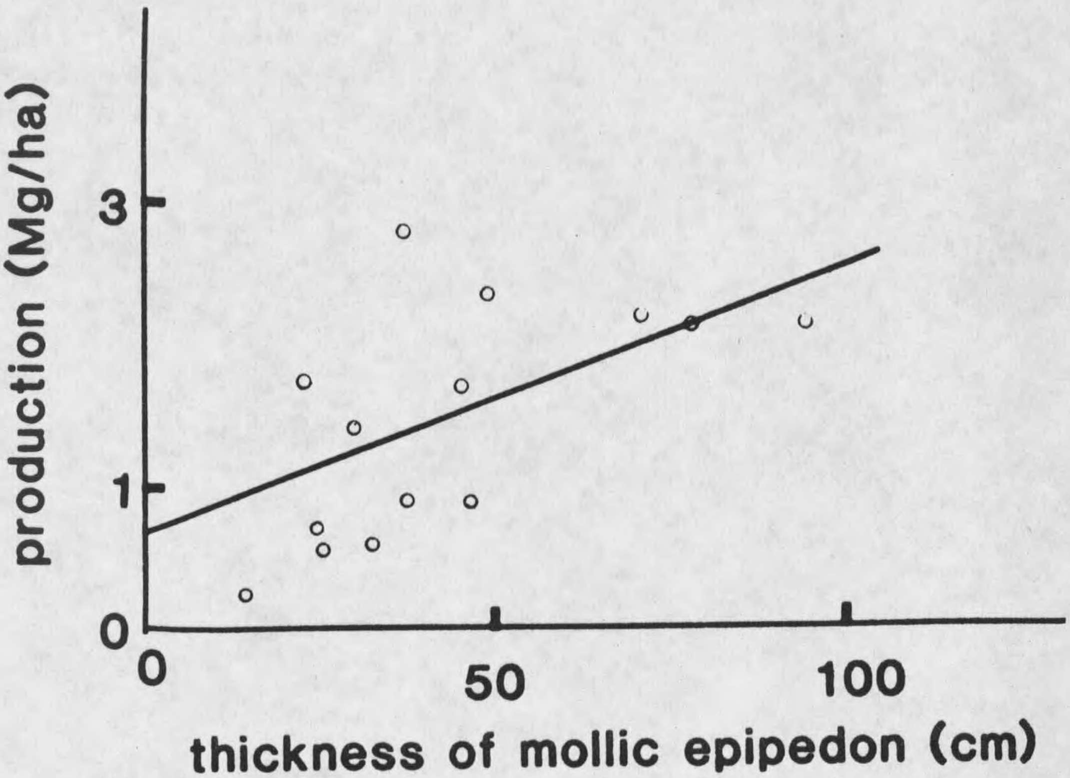

Figure 4. Mean Thickness of Mollic Epipedon Versus Mean Annual Production (Standing Crop). Production (Mg/ha) = 0.61 + 0.02 [thickness of mollic epipedon (cm)] R^2 =.39*, significant at p=.05