Relationship between Munsell color value and organic carbon content in Montana soils
by Eva Maria Zelenak

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

Abstract:
Soil color has been successfully used to estimate soil organic carbon content of cultivated surface horizons in several states and countries. Amount of soil organic carbon can influence soil classification, interpretation of soil properties, and pesticide application rates and effectiveness. Soil forming factors vary tremendously in Montana, and weak correlations between Munsell soil color and organic carbon on a statewide basis indicate that other factors may require consideration when attempting to explain variability in organic carbon. Soil organic carbon and Munsell color data sets were analyzed on a statewide basis and at a landscape scale. The relationship between organic carbon and Munsell color, elevation, mean annual precipitation, mean annual soil temperature, and percent clay was evaluated for grassland and cropland soils across the state using multiple regression analysis. Regression models explain approximately 50% of the variation using Munsell color and easily measured climate variables on a statewide basis. Color value alone was sufficient to estimate organic carbon (r2 = 0.90) when the relationship was calibrated for a soil landscape. The regression models provide a feasible means of predicting soil organic carbon from easily measured soil and climate characteristics for Montana cropland and grassland soils.

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

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ABSTRACT

Soil color has been successfully used to estimate soil organic carbon content of cultivated surface horizons in several states and countries. Amount of soil organic carbon can influence soil classification, interpretation of soil properties, and pesticide application rates and effectiveness. Soil forming factors vary tremendously in Montana, and weak correlations between Munsell soil color and organic carbon on a statewide basis indicate that other factors may require consideration when attempting to explain variability in organic carbon. Soil organic carbon and Munsell color data sets were analyzed on a statewide basis and at a landscape scale. The relationship between organic carbon and Munsell color, elevation, mean annual precipitation, mean annual soil temperature, and percent clay was evaluated for grassland and cropland soils across the state using multiple regression analysis. Regression models explain approximately 50% of the variation using Munsell color and easily measured climate variables on a statewide basis. Color value alone was sufficient to estimate organic carbon ($r^2 = 0.90$) when the relationship was calibrated for a soil landscape. The regression models provide a feasible means of predicting soil organic carbon from easily measured soil and climate characteristics for Montana cropland and grassland soils.

CHAPTER 1

INTRODUCTION

Organic matter quantity and quality can greatly affect important soil properties. Organic matter is a source of nutrients for plants, it favorably affects soil structure, drainage and aeration, and it can increase water holding capacity and buffering and exchange capacities of soil. Scientists have devoted much thought to the development of more accurate, rapid, and dynamic methods of characterizing this important soil constituent.

Soil organic matter content influences pesticide effectiveness and fertilizer requirements (Upchurch and Mason, 1962; Page, 1974; Krishnan et al., 1981; Pitts et al., 1986). Generally, the higher the organic matter, the higher the recommended pesticide rate. Further, the adoption of minimum tillage techniques has resulted in a shift towards more dependence on pesticides for weed control (Griffis, 1985). Organic matter content often varies across individual fields, and should be determined at several places so that herbicide application can be adjusted accordingly. Over or under application of pesticides or fertilizers can be costly in terms of crop and environmental damage, poor weed control, and inefficient fertilization. Interest in developing agricultural equipment that can determine soil organic matter levels and adjust application rates on the fly has been widespread (Krishnan et al., 1981; Griffis, 1985; Pitts et al., 1986). Such improvements will require quantification of the relationship between organic matter and other observable soil properties.

Soil color can be reliably associated with important soil properties and is widely used to approximate organic matter content in the field and to judge the presence of diagnostic soil horizons. Generally, the darker the soil color, the higher the organic matter content and the higher the native fertility (Soil Survey Staff, 1975). With publication of standard procedures for determining soil color in the Soil Survey Manual (Soil Survey Staff, 1951) and the adoption of the Munsell color system (Munsell Color Co., 1941), researchers gained a standardized tool for measuring soil color. Many subsequent studies have involved correlations between soil organic carbon and Munsell color value which indicates the total darkness of color. Several researchers have quantified the relationship between soil color and organic carbon content in other states and countries, and have developed field methods and sensors for estimating soil organic carbon from soil color and reflectance characteristics (Alexander, 1969; Page, 1974; Steinhardt and Franzmeier, 1979; Pitts et al., 1986).

Because adequate visual standards for predicting organic matter are not readily available in every state, few people have developed skill in estimating organic matter content by examining a soil sample. Steinhardt and Franzmeier (1979) reported that a colleague asked 45 agriculturalists to estimate the organic matter content of an Ap horizon in Indiana which contained 6.12% organic matter. Responses ranged from 0.2 to 90%. A prediction equation or color chart could aid in education and enable scientists to have greater accuracy in predicting soil organic matter in field situations.

Thesis Objective

This study aims to quantify the relationship between Munsell color value and soil organic matter for selected soils in Montana. The ultimate goal is to provide a practical field guide and educational method for estimation of organic carbon from soil color and other readily available data for certain Montana soils.

Soil forming factors vary tremendously in Montana, and no strong correlation between Munsell soil color and organic matter has been demonstrated on a statewide basis. In Montana, Decker (1972) reported a coefficient of simple determination (r^2) of 0.45 between Munsell color value determined under moist conditions and soil organic carbon statewide. This correlation indicates that other factors may require consideration when attempting to explain variability in organic matter for Montana soils.

Schulze et al. (1993) and Fernandez et al. (1988) have shown that organic carbon is better correlated with soil color within associated soils in the same landscape rather than soils from a wide geographic region. Because these local relationships are generally not consistent from one climatic region to another (Steinhardt and Franzmeier, 1979), prediction of organic carbon from color alone may not be feasible on a statewide basis.

The hypothesis to be tested is that Munsell soil color, singly or in combination with other soil or climate attributes can be used to predict soil organic carbon in Montana soils. Analyses were conducted to determine at what scale and under what conditions the best relationships were attained. Examining the relationship in different subsets of data, at different scales, and in conjunction with climate and other soil variables may produce a correlation adequate to provide an appropriate field method for estimating organic carbon content from soil color.

Literature Review

Organic Carbon vs. Organic Matter

Organic matter content is usually estimated by multiplying the organic carbon content by 1.72 (Nelson and Sommers, 1982). This assumes that organic matter contains approximately 58% organic carbon. Organic carbon is determined by laboratory analysis. However, Broadbent (1953) concluded after reviewing the literature, that factors of 1.9 and 2.5 would be appropriate for surface soils and subsoils, respectively, and should ideally be experimentally determined for each soil. Because of this problem associated with determining organic matter content, Nelson and Sommers (1982) suggest that investigators determine and report the organic carbon content as a measure of the organic matter in a soil. In this thesis organic carbon content is reported and was used in the analysis. Where research of others is summarized, consistency will be maintained by reporting organic matter or organic carbon as reported by each author.

Methods of Measuring Soil Color

Soil color can be measured with standard color charts or with a number of commercially available spectrophotometers. Discussion will focus on the determination of colors with the Munsell color system, because it is the most practical and economical method for color measurements performed by the Soil Survey Staff and in most field studies.

Munsell Color System

Soil colors are usually determined by visually comparing a soil sample to colored chips in a standard color chart, usually the Munsell Soil Color Charts (Munsell Color Co., 1975). The Munsell soil color system consists of approximately 250 colored chips arranged on hue cards. Adjacent chips represent equal intervals of visual perception. Three coordinates: hue, value, and chroma, describe all the possible colors. Munsell hue, designed to represent cylindrical coordinates, refers to the dominant spectral or rainbow color, with red (R), yellow (Y), green (G), blue (B) and purple (P) comprising the principal hues. Five additional hues; yellow-red (YR), green-yellow (GY), blue-green (BG), purple-blue (PB), and red-purple (RP), represent midpoints between the principal hues. The Munsell hue circle in the Munsell soil color charts usually has 7 hues including 10R, 2.5R, 5YR, 7.5YR, 10YR, 2.5Y, and 5Y (Figure 1). Value indicates the degree of lightness or darkness of a color on a gray scale ranging from black to white. In the Munsell color charts, value ranges from 0 (pure black) to 10 (pure white). Chroma is the purity or saturation of a spectral color. Chroma ranges from 0 (neutral colors) to 8 (strongest color) in the Munsell color system.

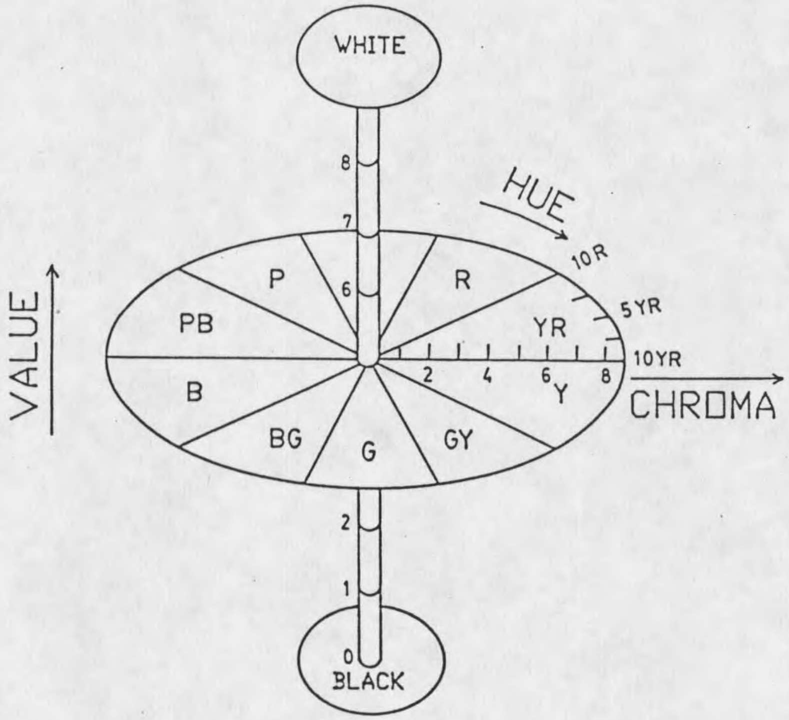

Figure 1. Arrangement of hue, value, and chroma in the Munsell color space (Torrent and Barron, 1993).

In the Munsell color system all chips on a page are of constant hue. Value increases vertically with the darkest colors on the bottom of each page, and chroma increases horizontally with the strongest saturation of colors on the right side of each page. A more detailed description of the Munsell system can be found in the Soil Survey Manual (Soil Survey Staff, 1993).

Many factors can affect the accuracy of a color measurement (Soil Survey Staff, 1993). Quality and intensity of light, roughness of the sample, and moisture content of the sample can affect the amount of reflectance from the soil sample to the eye. Standard conditions of light intensity and quality play an important role in accurately and consistently determining soil color. Incidental light should be as near to a right angle as possible, because roughness of the soil surface can greatly affect the amount of reflectance. Soil color changes with moisture content, (Soil Survey Staff, 1975) therefore it is important that the condition of the sample be recorded. To consistently measure color, two moisture contents can be used: (i) air dry, and (ii) field capacity (Soil Survey Staff, 1975). Field capacity can be sufficiently obtained for color determination by moistening a sample and reading the color as soon as visible moisture films have disappeared (Soil Survey Staff, 1975).

The Soil Survey Staff (1975) report that the probability of perfectly matching any chip in the color chart is less than 100, but that it should be evident which color chip provides the closest match. This, combined with the fact that the ability to sense color differs among people, suggests that there could be uncertainty involved in the reproducibility of consistent colors among different observers. The Soil Survey Staff (1993) suggests that under field conditions, measurements of color are reproducible to within 2.5 units of hue (one page) and 1 unit of value and chroma.

The American Society for Testing and Materials (ASTM, 1993) outlines the procedure for determining Munsell colors for science and industry purposes and describes the limit of precision obtainable using this method. Under controlled conditions they report a precision of 0.5 hue, 0.1 value, and 0.4 chroma. Kelly and Judd (1976) suggest that an experienced observer can visually interpolate reliably to 0.1 value, to 0.25 chroma, and to one hue step. In both cases this level of precision is only attainable in controlled laboratory conditions with consistent illumination and sample preparation, and a complete set of Munsell color charts (Post et al., 1993).

Other researchers have also tried to quantify the confidence with which soil color measurements can be reproduced. Pomerening and Knox (1962) suggested, from the results of one observer, that color measurements were reproducible within 1 unit of hue, and 0.5 unit for both value and chroma. Shields et al. (1966) reported that 12 experienced scientists measuring 20 samples determined Munsell values that varied by between 0.5 to 2 units, with an average discrepancy of 1.0 unit of value. Cooper (1990) evaluated the color measuring ability of students who had competed in the 1988 National Soil Judging Contest. Each student had 3 attempts to match colors to the Munsell color chart with the average percent agreement being 62%, 61%, and 67% for hue, value, and chroma respectively.

Post et al. (1993) distributed sets of soil samples to 36 soil scientists to determine dry and moist Munsell colors using the methods outlined in the Soil Survey Manual (Soil Survey Staff, 1988). Their results probably better represent the precision that can reasonably be expected because they take into account the more realistic uncontrolled measuring conditions that prevail when different scientists measure color. The agreement among the soil scientists was 70, 71, and 72 % for chroma, hue, and value respectively.

To evaluate individual color interpretation skill, Post et al. (1993) also calculated an r^2 that measured the relationship between each scientist's Munsell color measurements and the overall mean of multiple observations on each soil sample. The r^2 results ranged from 0.49 for chroma (moist) to 0.79 for value (moist). When the scientists were asked to interpolate estimates between color chips and were given some guidelines to accomplish the measurements, precision was significantly improved. The r^2 results for value reached 0.90 for dry measurements, and 0.95 for moist measurements. Chroma was determined with less precision, with an r^2 of 0.79 for dry measurements, and 0.70 for moist measurements.

It is clear there are limits on the precision of color measurements, especially when conditions are not controlled and consistent, and when different soil scientists collect data. These limitations, combined with the coarse step nature of the data obtained from visually measuring colors, could place a ceiling on the predictive power Munsell color data may have in relationships between soil color and other soil properties. Procedures outlined in the Soil Survey Manual (Soil Survey Staff, 1993) suggest that soil color measurements be made to the nearest whole unit of value and chroma. The range in color produced by differences in organic carbon can be quite small (Schulze et al., 1993). Therefore, color data sets derived from field descriptions of soils will usually have coarse data resolution for Munsell colors, but should provide knowledge of general relationships when compared with other soil properties such as soil organic carbon.

Instrumental Measurements of Soil Color

Commercial tristimulus colorimeters and spectrophotometers have potential as tools for precisely measuring soil colors in the laboratory (Post et al., 1993). Color can be calculated easily from soil reflectance spectral data measured by these instruments (Shields et al., 1968; Fernandez and Schulze, 1987; Escadafal et al., 1988, 1989; Wutscher and McCollum, 1993). The reflected energy measured by colorimeters can be converted into Commission Internationale de l'Eclairage (CIE, 1931) coordinates. Standard tables (Wyszecki and Stiles, 1982) can be used to convert CIE coordinates into Munsell hue, value, and chroma. These measurements are much more accurate than determinations made by scientists by visually matching soil samples to the color standards in the Munsell color book.

Post et al. (1993) reported that the repeatability of measuring soil colors with a chroma meter is very good. The mean standard deviation for hue, value, and chroma color measurements in their study of 10 different soils was only 0.08. Shields et al. (1966) reported a precision of 0.1 unit for Munsell value and chroma when a spectrophotometer was used to measure the spectral reflectance of 20 samples.

Although instrumental measurements of color can be extremely precise and accurate because the potential errors associated with inconsistent lighting conditions and observer differences can be eliminated, accuracy can still be influenced by improper sample preparation. Spectrophotometric color is mostly determined for dry samples because the preparation necessary for moist samples is more complicated. Excess moisture can cause unwanted specular reflection, and evaporation can influence measurements (Torrent and Barron, 1993). New methods are being developed and tested to overcome these difficulties. Grinding a soil sample can dramatically change its color (Torrent and Barron, 1993). Because the longer a sample is ground, the lighter its color will become, standardized grinding procedures are required if results are to be realistically compared.

Color-Organic Carbon Studies

Alexander (1969) developed a color chart for estimating organic matter content in the surface of cultivated soil in Illinois. The chart was developed by comparing Munsell soil color to organic matter levels determined by lab analysis for over 300 surface soils. Five color chips corresponded to organic matter ranges of 1 to 2%, 1.5 to 2.5%, 2 to 3%, 2.5 to 4%, and 3.5 to 7%. As long as the chart is used with moist soil in cultivated surface soils of medium to fine textures, it claims 95% accuracy in predicting soil organic matter content within these classes in Illinois or other areas of similar climate and geology. Alexander (1969) suggests that the chart can be used to "estimate organic matter well enough to determine application rates of herbicides." Unfortunately, the data used to develop the color chart have not been published and the methods cannot be examined.

Page (1974) measured soil reflectance with a color-difference meter for 96 Ap horizon samples from the Coastal Plain region of South Carolina. The reflectance values were highly correlated with soil organic matter ($r^2 = 0.89$). Page concluded that, for those soils, organic matter could be more quickly and more economically predicted by reflectance methods than by laboratory determinations.

Steinhardt and Franzmeier (1979) reported a semi-quantitative relationship between organic matter content and Munsell color for cultivated silt loam soils of Indiana. Their system divides the samples analyzed (n = 262) into 3 categories: (i) samples with Munsell color of 10YR 2/1 contained > 5% organic matter, (ii) samples with Munsell colors of 10YR 2/2, 3/1, 3/2, and 3/3 contained 3-5% organic matter, and (iii) all other 10YR colors contained <3% organic matter. The categories seemed broad, and the data points showed considerable scatter, but they suggest that the system is 90% accurate within these classes and could be used to assist in field problem diagnosis and education.

Franzmeier (1988) grouped 1268 Indiana samples from Ap horizons with hues of 10YR into 5 larger texture classes to quantify the relationship between organic carbon and Munsell color. The 5 regression equations developed for coarse, moderately coarse, medium, moderately fine, and fine texture groups produced r^2 values ranging from 0.31 to 0.47. Both value and chroma were important in predicting organic carbon in these groupings. The authors concluded that soil organic carbon content of the Ap horizons increased with increasing clay content, decreasing color value, and decreasing color chroma. For darker soil colors (10YR 2/2, 3/1, 3/2), poorly drained soils consistently contained more organic carbon than well drained soils with the same colors.

Bingham et al. (1993) studied the relation between Munsell color value and organic carbon content for cultivated surface horizons from two land resource areas in Ohio. They reported a poor correlation for all of the samples combined, but a better relationship for samples within soil landscapes that had similar soil textures.

Several researchers have explored the hypothesis that soil color and organic matter would be more closely related in soil of similar textures within the same soil landscapes. Fernandez et al. (1988) found a strong correlation ($r^2 = 0.94$) between Munsell color value (calculated from reflectance spectra) and organic matter for moist samples in two toposequences of soils in Indiana. They suggest that systems which measure soil color as an estimate of organic matter content might be more successful if they can be "calibrated on a field by field basis" (Fernandez et al. 1988). Schulze et al. (1993) determined that the relationship between soil color and organic matter was poor ($r^2 = 0.31$) for Indiana soils analyzed statewide, but predictable ($r^2 = 0.90$) within soil landscapes with relatively uniform textures. It was also shown that different soil landscapes often had different relationships.

Qian et al. (1993) studied the relationship between Munsell color value and nitrogen in forest mineral soils in British Columbia. Color is used in site classification by foresters to estimate ecological quality and soil nutrient levels. The best regression model ($r^2 = 0.70$) used color value, climate, soil moisture, and soil texture as variables, and climate accounted for the majority of the variation in both mineralizable and total nitrogen.

In Montana, Decker (1972) reported a correlation ($r^2 = 0.45$) between Munsell color value and soil organic carbon on a statewide basis for color determined for crushed peds under moist conditions (n=164). Dry color value (n=132) explained only 34% of the variability in organic carbon content. Colors determined for crushed peds were more highly correlated to organic carbon than colors measured on the interior or exterior of peds

Several researchers have analyzed soil reflectance data obtained from Landsat Thematic Mapper (TM) images and airborne optical scanners in an attempt to correlate remotely sensed spectral data with organic carbon content (Baumgardner et al., 1970; Escadafal et al., 1989; Bhatti et al, 1991; Wilson et al., 1994). Al-Abbas et al. (1972) quantified the correlation between spectral response bands (obtained with an airborne optical-mechanical scanner) and organic matter for a 25 hectare field in Indiana. Five spectral bands combined to predict 0.57% of the variation in organic matter. Wilcox et al. (1994) analyzed digital TM data from 2 field sites in the Palouse region of eastern Washington state. Regression analysis showed a strong linear relationship for both field sites (r^2 = 0.88 and 0.77).

Many agricultural engineers have attempted to correlate spectral properties with soil organic carbon in efforts to develop light reflectance organic carbon sensors for agricultural equipment (Krishnan et al. 1981; Griffis, 1985; Pitts et al, 1986). A practical sensor would be useful for prescription applications of soil-applied chemicals. Recently, Shonk et al. (1991) developed and field tested a prototype real-time soil organic carbon sensor. Preliminary field tests were successful (r^2 = 0.83) and the sensor is being further developed and tested.

<u>Relation of Organic Carbon to Soil Properties and Climate</u>

The total amount of soil organic carbon depends on the balance of biomass production and decomposition, and on the soil's capacity to store organic carbon. Therefore, accumulation of organic carbon is sensitive to climatic factors such as precipitation, and soil temperature (Jenny, 1941; Kononova, 1966; Anderson and Coleman, 1985, Burke et al., 1989). In general, soil organic carbon increases along gradients of increasing precipitation and decreasing temperature. Landscape position, through its influence on microclimate, also affects the accumulation of organic carbon (Schimel et al., 1985; Yonker et al., 1988).

Soil texture, which is related to parent material, exerts some control over the accumulation of soil organic carbon. A higher proportion of plant material is stabilized into soil organic carbon in fine textured soils than in coarse soils (Parton et al., 1987; Schimel et al., 1985). Texture is related to water holding capacity which also influences inputs to organic carbon by affecting plant biomass productivity. In the central and southern Great Plains states, clay content is positively and significantly correlated with soil organic carbon (Nichols, 1984; Burke et al., 1989). Sims and Nielsen (1986) reported that in a study of 130 A horizons from Montana soil pedons, clay percentage was not significantly correlated to soil carbon. In multiple regression analysis elevation and precipitation better predicted carbon content ($R = 0.80$).

CHAPTER 2

MATERIALS AND METHODS

Soil organic carbon and Munsell color data sets were analyzed to quantify the relationships between color and organic carbon for the state of Montana and for a small soil landscape. Two experiments will be described separately in this section and in the results and discussion section: (i) organic carbon relationships on a statewide basis, and (ii) organic carbon relationships in a soil landscape.

Organic Carbon Relationships for Montana Soils

Munsell color and soil organic carbon data from grassland and cropland surface horizons were compared on a statewide basis to examine the possibility that a general relationship may exist. Correlations were expected to be poor in very large areas because of the tremendous variability in Montana soils and climate, and the correlations obtained by Decker (1972) in a statewide analysis. Sample sets were narrowed to smaller subsets to determine at what scale and under what conditions the best relationship existed. Other factors that may account for some of the variation in soil organic carbon were added in multiple regressions or used to further divide and stratify the data. These include soil texture, status of sample (moist or dry), effervescence (as an indicator of $CaCO_3$), and climate.

The Montana Soil Pedon Database (MSPD) (Jersey and Nielsen, 1992) comprised the primary source of data for the statewide analysis. The MSPD is composed of site and horizon description data and chemical and physical laboratory data for 1189 horizons of soil pedons sampled throughout Montana. Results from previously published studies were used to select variables that are easily measured and are among soil and climate properties tested by others to be correlates of organic carbon (Table 1).

Table 1. Independent variables selected for stepwise multiple regression analysis on a statewide basis.

Independent Variables	
Munsell value	Elevation (m)
Munsell chroma	Mean annual precipitation (cm)
Clay percent	Mean annual soil temperature (°C)

Organic carbon content, Munsell color, particle size analysis, elevation, and mean annual precipitation data for 95 grassland A horizons and 60 cropland Ap horizons were obtained from the MSPD (Figure 2). Colors determined for crushed peds were used whenever possible, but in many cases the ped condition was unspecified. Organic carbon percentages were determined by the acid dichromate digestion method. Mean annual soil temperature data were obtained from MAPS Atlas (Caprio et al., 1994), a Montana Geographical Information System (GIS) that provides estimates of 150 land and climate attributes for Montana.

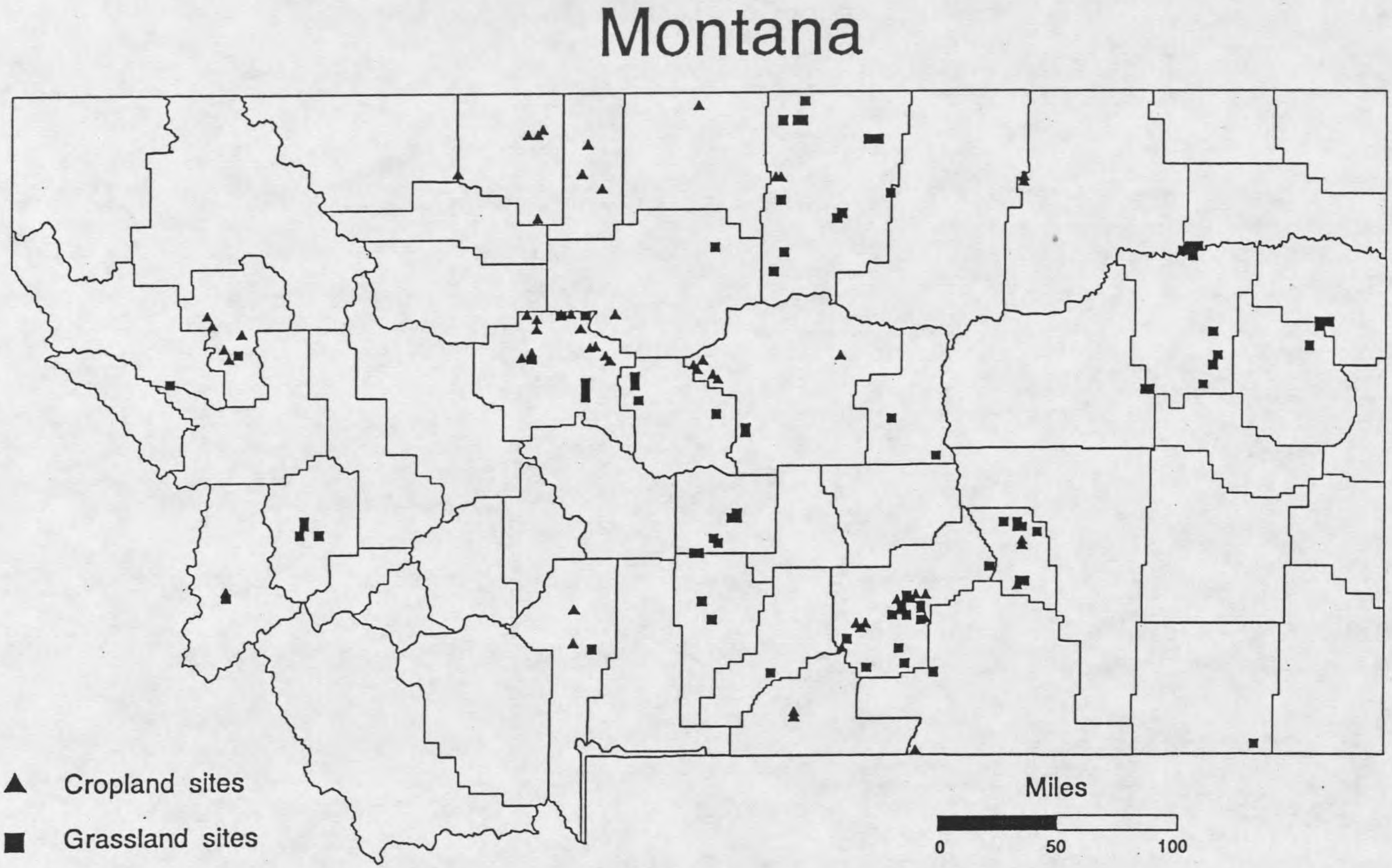

Figure 2. Locations of cropland and grassland sample sites from the Montana Soil Pedon Database that were used in the multiple regression analysis.

The soil and climate attributes that were examined in this study were entered into database files in dBase III+. Files were then exported to SAS (SAS Institute, Inc., 1988), where correlation and regression analyses were performed. A complete list of the data that were analyzed is presented in Appendix A. Stepwise forward regression analysis was used for variable selection and model creation. Dependent variables were considered one-by-one for addition to the regression model. The F-level for entry or deletion of a variable was set to the 0.05 level of significance. The significance of each independent variable was determined by a T-test, and overall significance of the regression model was determined by an F-test. No cases with missing data were included in the analysis.

Residual analysis for the models presented in the results and discussion section were also performed. Residuals of the independent variables were visually examined in scattergrams and probability plots to ensure that the homoscedasticity and normality criteria for multiple linear regression were met. Scatter plots of each independent variable vs. organic carbon were also examined to ensure that the assumption of linearity was met.

Poorly drained soils, Vertisols, soils with vertic subgroups, and salt-affected soils were excluded from the study. In the horizons considered here, it was assumed that all water was supplied through precipitation. Therefore, poorly drained, somewhat poorly drained, and floodplain soils were not evaluated because these soils may have an additional source of moisture. Salt-affected soils and soils with vertic properties were excluded because they can have very dark colors but contain low levels of organic carbon (Soil Survey Staff, 1975).

The data were divided into 2 major subsets, (i) grassland A horizons and (ii) cropland Ap horizons, to account for potential differences in organic carbon levels due to vegetational differences. Further subdivisions for both the grassland and cropland data sets were created to determine relationships that may exist for certain groups of soils (Table 2). Stratifying and analyzing the samples in the groups listed in Table 2 should form subsets of data that are more homogeneous in soil forming factors and should improve the predictive power of regression equations. Separate models were created for each subset of data for dry and moist Munsell colors.

Table 2. Subsets selected for stepwise multiple regression analysis for grassland A horizons and cropland Ap horizons.

All horizons
Medium textured horizons
Moderately fine textured horizons
Horizons with hues of 10YR
Horizons with hues of 2.5Y
Horizons that effervesce
Horizons that do not effervesce
Second A Horizons

Particle size analysis was used to determine the textural classes of all the A horizons; these textures were grouped for analysis according to the acceptable general terms in Soil Taxonomy (Soil Survey Staff, 1975) listed in Table 3. Sufficient sample size for regression analysis existed only in the medium texture and moderately fine texture groups. The horizons were divided into these 2 texture groups to help decrease variability in organic carbon that may be due to differences in parent material.