Soil productivity (crop yield) data acquisition and analysis methods for Montana soil series

by Hassan Farah Osman

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Scdenoe in Soils

Montana State University

Abstract:

Soil productivity is the capacity of a soil for producing a specified crop or sequence of crops under a physically defined set of management practices (Soil Survey Staff, 1962). An understanding of soil productivity will permit farm planning according to soil type and eventually the development of useful crop production models.

Soil productivity data were collected for 47 major soil series in 91 fields in Montana counties. Each soil had three plots. All plots were sampled for crop yield, physical properties and chemical properties. Management and climate data were also acquired.

When data from all fields were combined and subjected to stepwise regression analysis, depth of moist soil, elevation and phosphorus were the most important factors related to yield. Depth of moist soil alone explained over half of the variability in yield of winter wheat and spring wheat. Barley yields were more responsive to available water than to depth of moist soil. Yields on typic subgroups of soils were positively related to depth of moist soil, phosphorus and available water. Yields of aridic subgroups were also related to depth of moist soil but were negatively influenced by pH and electrical conductivity.

Generally, depth of moist soil was the most influential variable affecting cereal grain yields in Montana during 1986.

The following objectives, except objective 4, have been achieved: 1. Initiation of a long-term project identifying major soil and climate factors that influence cereal grain yield in Montana.

• 2. Development of a procedure and form for collecting soil performance data on selected Montana soil series.

3. Creation of a microcomputer based soil productivity/crop yield data processing system using DBASE III+ software.

4. Determination of the minimum soil productivity data set needed in yield prediction models. Further data collection and analysis are required to identify the minimum data set necessary.

5. Contribute Montana data to the national USDA interagency soil crop yield data.

SOIL PRODUCTIVITY (CROP YIELD) DATA ACQUISITION
AND
ANALYSIS METHODS FOR MONTANA SOIL SERIES

by

Hassan Farah Osman

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

of

Master of Science

in

Soils

MONTANA STATE UNIVERSITY
Bozeman, Montana

March, 1988

APPROVAL

of thesis submitted by

Hassan Farah Osman

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.

2-23-88 | Gerald A. Nielsen
Date | Chairperson, Graduate Committee

Approved for the Major Department

2/23/88 | James W. Bauder
Date | Head, Major Department

Approved for the College of Graduate Studies

3-2-88 | [signature]
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 the 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 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: Hassan F. Osman

Date: 2/23/88

ACKNOWLEDGMENT

I would like to thank Dr. Gerald A. Nielsen, my major professor, for his encouragement, understanding and enthusiastic support during the research and development of this thesis.

Appreciation is extended to Dr. Earl Skogley, Dr. Jeff Jacobsen, who served on my graduate committee. Gratitude is also extended to Dr. Paul Brown and Don Baldridge.

Special thanks is given to Soil Conservation Service personnel for their cooperation, interest and support in this project. Those deserving recognition in the S.C.S. include Gordon Decker, Gary Tibke, Jack W. Rogers, Ronald Nadwornick and all S.C.S. District conservationists who are involved in this project across the state. These individuals are: David Doty, Scott Zimmerman, Harold Cottet, John Streich, David Heilig, Warren Kellogg, Danny Burgett, Richard Iversen, Merlin Berg, Dennis Loreth, LeRoy Hall, A. Ray McPhail, Douglas Campbell, Jeffrey Zimprich, Michael Carlson, Wendell Martinell, Wayne Nipple, Arnold Quale, El Vera Hahn, James Rose, Theodore Hawn, Charles Gephart, Frank Gariglio, Stanley French, William Zizz, Lynnel Hoffman, Michael Crowell and Robert Leinard.

Also, I would like to thank research center personnel, Jerry Bergman, Gil Stalknecht, Grant Jackson, Gregg Carlson and Greg Kushnak, for their help with processing grain samples.

Finally, I would like to thank Alma Plantenberg and Jay Wilkins for help with preparation of the manuscript, Ric Roche for assistance with adapting the data base for microcomputer processing and Paula Mousel for many hours of laboratory assistance. Thanks also to my fellow graduate students and Bernard Schaff, research associate, for their contribution to my knowledge of soils during my stay at Montana State University.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

Soil productivity is the capacity of a soil for producing a specified crop or sequence of crops under a physically defined set of management practices (Soil Survey Staff, 1962). An understanding of soil productivity will permit farm planning according to soil type and eventually the development of useful crop production models.

Soil productivity data were collected for 47 major soil series in 91 fields in Montana counties. Each soil had three plots. All plots were sampled for crop yield, physical properties and chemical properties. Management and climate data were also acquired.

When data from all fields were combined and subjected to stepwise regression analysis, depth of moist soil, elevation and phosphorus were the most important factors related to yield. Depth of moist soil alone explained over half of the variability in yield of winter wheat and spring wheat. Barley yields were more responsive to available water than to depth of moist soil. Yields on typic subgroups of soils were positively related to depth of moist soil, phosphorus and available water. Yields of aridic subgroups were also related to depth of moist soil but were negatively influenced by pH and electrical conductivity.

Generally, depth of moist soil was the most influential variable affecting cereal grain yields in Montana during 1986.

The following objectives, except objective 4, have been achieved:

1. Initiation of a long-term project identifying major soil and climate factors that influence cereal grain yield in Montana.
2. Development of a procedure and form for collecting soil performance data on selected Montana soil series.
3. Creation of a microcomputer based soil productivity/crop yield data processing system using DBASE III+ software.
4. Determination of the minimum soil productivity data set needed in yield prediction models. Further data collection and analysis are required to identify the minimum data set necessary.
5. Contribute Montana data to the national USDA interagency soil crop yield data.

INTRODUCTION

Along with climate, management and the genetic potential of crops, soil is a major determinant of yield. Soil provides the nutrients, water and support that a crop requires. The potential of soils to produce is dependent on basic chemical and physical properties of the soil. It is difficult to accurately estimate the effects of soil properties on crop production due to the complex interactions of soil parameters with crop, weather, and management variables. By knowing how different soil properties influence crop production, soil scientists can predict productivity of a particular soil series.

Several studies of cereal grain yield in relation to soil series have been undertaken. Soil properties such as soil moisture and fertility, soil morphological properties, temperature, topography and many other variables which influence crop yield have been recognized. These kinds of studies can help farmers make decisions about farm management based on each soil's properties and yield capabilities. Soil productivity estimates are the basis for setting optimum crop yield goals.

Objectives

The objectives of this study were:

1. To initiate a long-term project to identify major soil and climatic factors that influence small grain yields in Montana;

2. To develop a procedure and form for obtaining soil performance (yield) data for Montana soil series;
3. To set up a Montana soil performance/crop yield data processing system;
4. To determine the minimum soil performance data set needed in yield prediction models for Montana;
5. To contribute Montana data to a national soil-crop yield data base.

LITERATURE REVIEW

The review of the literature is divided into four sections. The first deals with soil productivity studies, the second section with soil-climate variables, the third considers site variables and the last discusses soil variables.

Soil Productivity Studies

Researchers have long been interested in how variation in soils and climate is related to crop yields. Soil properties and weather conditions are the dominant factors that affect yield potential. Complex interactions of soil properties with crop, weather and management variables make studying the influence of soil properties on yield difficult. In semi-arid regions of the world, such as Montana, yearly moisture differences have strong influence on year to year changes in soil productivity.

The goal of a soil scientist in making a soil map is to identify soils and record their locations on a map. Because each soil has unique use, management, and production capabilities, an important application of soil surveys is the prediction of crop yields from particular soil units. Predicted yields can help farmers set optimum yield goals and relate productivity to land evolution (Soil Survey Staff, 1962).

Currently, yield estimates are obtained by the following three methods: 1) producer surveys and visual observations, 2) examination of farm records, and 3) actual yield from sample plots of the soil unit (Odell, 1958). The third method is the most accurate method of collecting soil productivity data.

Several studies have been conducted to relate soil and crop productivity to soil type. (Allgood and Gray, 1977; Henao, 1976; Letey, et al., 1958; Leeper, et al., 1974; Rust and Odell, 1957; and Munn et al., 1982).

Allgood and Gray (1977) designed a model for predicting yield on different soils. They used two methods, the first utilized laboratory data, field observations and published yield information. The second method was based solely on diagnostic soil characteristics. Water was the most yield limiting factor in this study. Parameters that affected soil moisture such as slope, clay percent, and percent organic matter were most important in predicting yield.

Henao (1976) developed soil productivity ratings based upon over thirty physical and chemical properties. The purpose was to examine such factors as: percent carbon in the plow layer, plant available water holding capacity of the soil profile, bulk density in the subsoil horizons, pH by horizon, depth to the top of the calcium carbonate horizon. Numerical yield values were then assigned to each factor.

Karathanasis, et al. (1980) studied the relation of soil properties and other environmental factors to grain yield and quality of winter wheat grown at international sites. They reported that despite substantial variability among nursery sites in soil type, climate, and soil management, 17 to 74% of the variation in the grain yield and 20 to 94% in the grain protein content was explained by soil variation. Lowest grain yields were observed on soils with pH lower than 6.0 or on highly calcareous soils.

Leeper, et al. (1974) studied the effect of precipitation, fertility and management variables on Illinois corn yields. They concluded that differences in corn yields due to soils, locations, and among years within locations are due to differences in climate (rainfall and temperature) and differences in the soils ability to supply water.

Rust and Odell (1957) studied yield data for many years. Soybeans, winter wheat, oats and corn yields were examined on Clinton silt loam for seven years. This study included records from several farmers under a wide range of management. They reported that more yield variation was associated with climate factors than with management and soil factors.

Munn, et al. (1982) studied the effectiveness of the paired design compared to nonpaired sampling to determine yield differences between two soils developed on glacial till in northern Montana. They concluded that percent calcium carbonate was negatively correlated with spring wheat yields on Scobey and Kevin soils.

There are three basic components affecting yield: soil, climate and management. Yield prediction accuracy suffers when any of these components are not accurately determined or held constant. To solve this problem, some researchers have compared yields of different soils where they occur together in the same field. This system holds management and macroclimate constant so yield differences are attributed to soil alone (Rennie and Clayton, 1960).

Soil Climate Variables

Soil moisture is a limiting factor for growth and development of agricultural plants used to provide food, feed, and fiber in semiarid regions of the world. The capacity of different soils to absorb, store, and provide available water to growing plants is an important factor for yield prediction. Available water storage capacity will generally increase with fineness in soil texture. However, Jamison (1956) found that an alluvial silt loam soil had a higher available storage capacity than clay soils from the southeastern United States. On the other hand, Lehane & Staple (1953) found certain Canadian Brown and Dark Brown Prairie soils have higher storage in fine-textured clays than in silt loams and silty clay loams. Army and Hanson, (1960) and Connor, (1918) studied wheat yields in the northern Great Plains, including the Canadian prairies, that were dependent on stored moisture and seasonal rainfall. The actual relationships differed from one climatic zone to another. Stored moisture and rainfall were nearly equally effective in accounting for variability in wheat yield. Effects of rainfall throughout the season were additive but yields were reduced when the moisture supply became exhausted at any time before the crop matured. They concluded that the depth of soil moisture was an important factor influencing grain yield on all soils.

Lehane and Staple, (1965) studied the influence of soil texture, depth of soil moisture storage and rainfall distribution on wheat yields in southwestern Saskatchewan. They reported that grain yields were little influenced by the amount of moisture stored in the 0-15 cm and the 15-30 cm layers at seed time, but they were increased markedly by the moisture stored below the 30 cm depth. Rainfall received during June and July and available moisture stored below the 30 cm depth were important factors influencing grain yield on all soils available for plant use. Brengle (1982) stated that for eastern Colorado, all soil types that produce wheat yields above the cost of production were found on areas that receive more than 380 mm precipitation annually.

Site Variables

Topography indirectly influences crop yield by its effect on soil properties. Lower slope positions are usually associated with increased moisture, plant growth, water infiltration and percolation, organic matter content and degree of horizon differentiation. Soils on convex positions tend to be shallower (due to erosion influences) than concave position soils which tend to accumulate more soil water (Montagne et al. 1982). Furley (1971) reported that convex slope angles were positively related to pH but negatively related to organic carbon, nitrogen, silt and clay.

Malo and Worcester, (1975) studied soil fertility and crop response at selected landscape positions in North Dakota. Soil properties measured with respect to landscape position were soluble salt content, inorganic carbon content, water table levels, and soil test levels of N, P, and K. The crop responses measured were emergence plant counts, plant height, maturity, and crop yield. They reported that minimum exchangeable K levels were found at the salt rim on the footslope, where electrical conductivity levels were high. Soil NO_2-N and extractable P levels were minimal at the shoulder position. Plant populations were lowest at the salt rim. Plant height was greatest at the backslope and least at the footslope. Lowest yields and highest grain moisture contents were found at the lowest landscape position. Highest yield occurred at the backslope, while lowest grain moisture contents were found at the shoulder position. Landscape position is helpful in determining soil types which can aid in fertilizer management decisions.

Johnson and Bartfled (1942) studied the difficulty of determining and quantifying important soil properties for dryland wheat production. They analyzed four years data and reported that effects of slope on yield were inconsistent. Production was higher on fine-textured soils than on coarse-textured soils.

Ferguson and Gorby (1967) reported that 15 kg of P fertilizer was required for optimum yield on well drained soils. But twice as much was required for poorly drained soils. They suggested this was due to the changes in micro-climatic factors as affected by the slope shape, size and aspect. Burke (1984) analyzed soil morphological classification, climatic, and site variables that influence dryland small grain yield. He found that rainfall was the major variable affecting crop yields, with spring wheat affected the most and barley the least. Schroeder and Doll (1984) studied the productivity of prime, nonprime and reclaimed soils in western North Dakota. They indicated that productivity differences between pachic and typic Haploborolls were mainly due to differences in available water at seeding caused by landscape position. In an associated study, Carter and Doll (1983) eliminated the effects of landscape position on productivity by comparing yield of wheat growth under optimum conditions in greenhouses, they found that wheat yields on pachic soils were significantly higher than on typic soils.

Soil Variables

Soil factors such as texture, structure and depth to calcium carbonate are important factors that affect soil productivity. Soil texture indicates the relative proportions of the primary soil separates (sand, silt and clay) in a soil. In terms of crop growth, soil texture can influence yield indirectly by affecting pore size, air and water. Gray (1966) reported that clay in Oklahoma soils had a slightly positive correlation with wheat yield while sand was negatively correlated suggesting that finer textured soil may be more beneficial to grain yield in that semi-arid area.

Soil structure denotes the arrangement of primary particles into secondary particles. In terms of crop growth, structure influences yield since roots penetrate partially by growing through existing voids and partially by moving aside soil particles (Taylor, 1974).

Available water holding capacity and depth to calcium carbonate horizon influence yield. Bennet, et al. (1980) noted that deep soils correlated highly with high wheat yields, apparently due to increased available water holding capacity. Soil Survey Staff (1971) recommends that a soil depth of 30 inches or greater is needed for good overall crop productivity.

In Montana most agricultural soils have a calcium carbonate accumulation or calcic horizon, within their profiles (Montagne et al., 1982).

In evaluating selected soil and climatic variables in Montana, Burke (1984) reported that available water holding capacity, depth to calcium carbonate, dry consistence, and spring soil water from 0-122 cm accounted for 44% of yield variation statewide. Depth to calcium carbonate was positively correlated with cereal grain yield. Dry consistence of CK horizon was also positively correlated with yield, due to its positive correlation with the greater depth to CK and fine texture.

Mortvedt (1976) postulated that shallow depth to $CaCO_3$ may cause stunted plant growth as a result of P and micronutrient immobilization.

Larson (1986) studied the influence of soil series on cereal grain yield in Montana. He reported that depth to calcium carbonate, organic matter content at 0-15 cm, and soil pH 0-15 cm were the most yield-limiting soil properties according to stepwise regression analysis (R^2=.83). Yield differences between soil series in the same field ranged from 0.07 to 1.88 Mg/ha (1 to 28 bu/ac).

METHODS AND MATERIALS

Locations

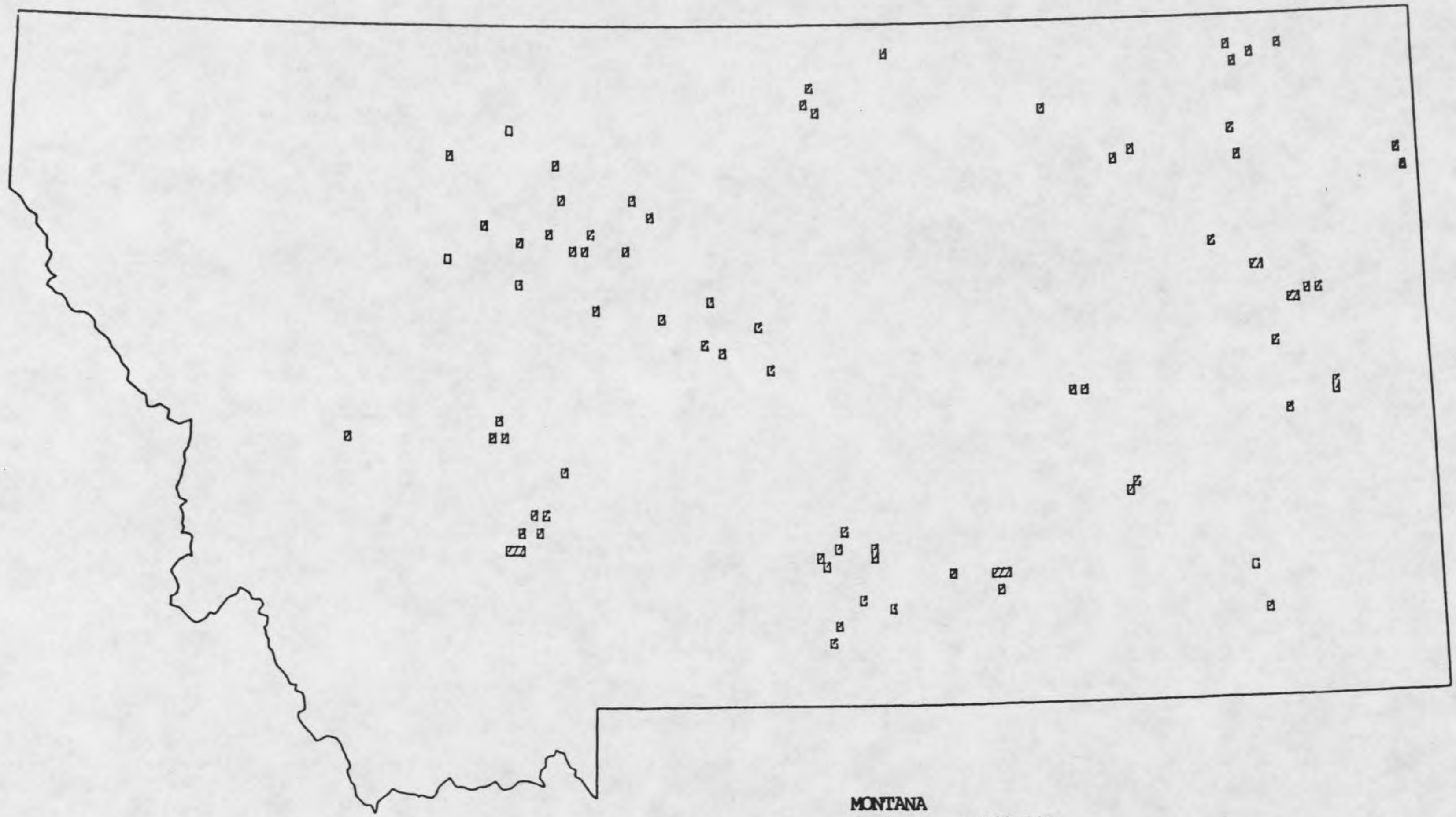
The study sites are in 24 counties distributed widely throughout Montana (Fig. 1). USDA-SCS District Conservationists worked with the Area Soil Scientists in selecting four soil series per county for inclusion in this long-term project. Most of the counties were previously mapped under the National Cooperative Soil Survey (NCSS) program. A few do not have completed soil surveys. In both situations, an Area Soil Scientist went to the study sites and identified the soil series.

Criteria used to select soils for this study are as follows:

1. The soils have potential for wheat and barley production
2. The soils are extensive in the state or in a county

Soil Series Studied

The soil series is the lowest category of the national soil classification system. The purpose of the series category is closely related to interpretive uses of the system. Soil series are the most homogeneous class in the soil taxonomy system (Soil Survey Staff, 1975). Since all soils are different, ranges specified for the series must not cross the limits of the family to which the series belongs. Quantitive limits are given for the ranges in the properties that are definitive of the series. These properties affect land use and management (NCSS Handbook, 1983). Table 1 shows the soil series



MONTANA
Scale 1: 4,500,000
Albers Equal Area Projection
R. Irwin R. Snyder C. Ford
Plant & Soil Science Department
Montana State University, Bozeman, MT.
Montana Agricultural Experiment Station

Figure 1. Location of Study Sites for SCS/MSU Soil Performance (crop yield) Data Base, 1986.

studied and their classification according to Soil Taxonomy (1975).

Table 1. Classification of Soil Series Studied, 1986/1987.

SOIL SERIES	SUBGROUP	FAMILY
Absorokee	Typic Argiborolls	Fine, Montmorillonitic
Amesha	Borollic, Calciorthids	Coarse-Loamy, Mixed
Bearpaw	Typic Argiborolls	Fine, Montmorillonitic
Bonfri	Borollic Haplargids	Fine-Loamy, Mixed
Brocko	Borollic Calciorthids	Coarse-Silty, Mixed
Cambert	Typic Ustochrepts	Fine-Silty, Mixed, Frigid
Cherry	Typic Ustochrepts	Fine-Silty, Mixed, Frigid
Chinook	Aridic Haploborolls	Coarse-Loamy, Mixed
Cushman	Ustollic Haplargids	Fine-Loamy, Mixed, Mesic
Danvers	Typic Argiborolls	Fine, Montmorillonitic
Ehtridge	Aridic Argiborolls	Fine, Montmorillonitic
Fairfield	Typic Argiborolls	Fine-Loamy, Mixed
Farland	Typic Argiborolls	Fine-Silty, Mixed
Fort Collins	Ustollic Haplargids	Fine-Loamy, Mixed, Mesic
Gilt Edge	Haplustollic Natrargids	Fine, Montmorillonitic, Mesic
Havre	Ustic Torrifluvents	Fine-Loamy, Mixed(Calc), Frig.
Havrelon	Typic Ustifluvents	Fine-Loamy, Mixed(Calc), Mesic
Hesper	Ustollic Haplargids	Fine, Montmorillonitic, Mesic
Judith	Typic Calciborolls	Fine-Loamy, Carbonate
Keiser	Ustollic Haplargids	Fine-Silty, Mixed, Mesic
Kobar	Borollic Camborthids	Fine, Montmorillonitic
Kremlin	Aridic Haploborolls	Fine-Loamy, Mixed
Lambeth	Ustic Torriorthents	Fine-Silty, Mixed(Cal), Frigid
Lonna	Borollic Camborthids	Fine, Montmorillonitic
Marias	Udorthentic Chromusterts	Fine, Montmorillonitic
Martinsdale	Typic Argiborolls	Fine-Loamy, Mixed
McRae	Ustollic Camborthids	Fine-Loamy, Mixed, Mesic
Musselshell	Borollic Calciorthids	Coarse-Loamy, Carbonate
Olney	Ustollic Haplargids	Fine-Loamy, Mixed, Mesic
Pendroy	Udorthentic Chromusterts	Very-Fine, Montmor., Frigid
Phillips	Borollic Paleargids	Fine, Montmorillonitic
Rothiemay	Aridic Calciborolls	Fine-Loamy, Mixed
Sappington	Aridic Argiborolls	Coarse-Loamy, Mixed
Savage	Typic Argiborolls	Fine, Montmorillonitic
Scobey	Aridic Argiborolls	Fine, Montmorillonitic
Shaak	Abruptic Argiborolls	Fine, Montmorillonitic
Shambo	Typic Haploborolls	Fine-Loamy, Mixed
Shane	Abruptic Argiborolls	Very-Fine, Montmorillonitic
Tally	Typic Haploborolls	Coarse-Loamy, Mixed
Tanna	Aridic Argiborolls	Fine, Montmorillonitic
Telstad	Aridic Argiborolls	Fine-Loamy, Mixed
Turner	Typic Argiborolls	Fine-Loamy, Mixed
Vanstel	Borollic Haplargids	Fine-Silty, Mixed
Varney	Aridic Argiborolls	Fine-Loamy, Mixed

Table 1. (Cont'd)

SOIL SERIES	SUBGROUP	FAMILY
Williams	Typic Argiborolls	Fine-Loamy, Mixed
Winifred	Typic Haploborolls	Fine, Montmorillonitic
Yamac	Aridic Haploborolls	Fine-Loamy, Mixed

Classification according to Soil Taxonomy (Soil Survey Staff, 1975).

Selection of Variables

The majority of the variables studied in this research were chosen by a national interagency Soil-Crop Yield Committee (USDA-SCS, 1983) for inclusion in a nationwide database. Eleven additional variables were added in Montana following review by Department of Plant and Soil Science and Extension Service personnel at Montana State University in consultation with Montana USDA-ARS & SCS staff. These variables were added to help explain differences in crop yields under agricultural conditions of Montana. The eleven additional variables added to the national form are: depth to free $CaCO_3$, electrical conductivity, elevation, hail damage, head density, kernel weight, moist soil depth, mulch cover, plot fertility, plot surface drainage and test weight. The description of each variable in the Soil-Crop Yield Data form modified for Montana is included in Appendix 1.

Field Methods

Soil Selection

During April 1986, the SCS State Soil Scientist, District Conservationists, and Area Soil Scientists selected four soil series in each of the twenty-four counties participating in this research project. Paired sites (one in crop and one in fallow) having the same soil series were selected where the crop-fallow farming system is practiced. The cropped site of the pair is sampled each year. Crop rotation was generally winter wheat or spring wheat followed by fallow, followed by winter wheat, spring wheat or barley.

Plot Selection

Following field verification of the soil series, 3 small plots (replications) were chosen by selecting an area of the designated soil series that was within the range of characteristics given in the official series description. For each soil series, the three plots (replications) were located within an area of 10,000 square feet. Plot size was 43.6 square feet. Each District Conservationist kept the plot location record so as to be able to sample the exact same plots from year to year. All sites were in commercial cereal grain production fields. Figure 2 is an example plot location diagram.

Crop Sampling

Wheat, and barley samples were harvested between late July and early September 1986. Soil Conservation Service (SCS), Department of Plant & Soil Science (MSU-P&SS), and Extension Service (CES) personnel at Montana State University provided harvest instructions. The instructions are given in Appendix 2.

Soil Sampling

After the completion of grain harvest, soil samples were taken,

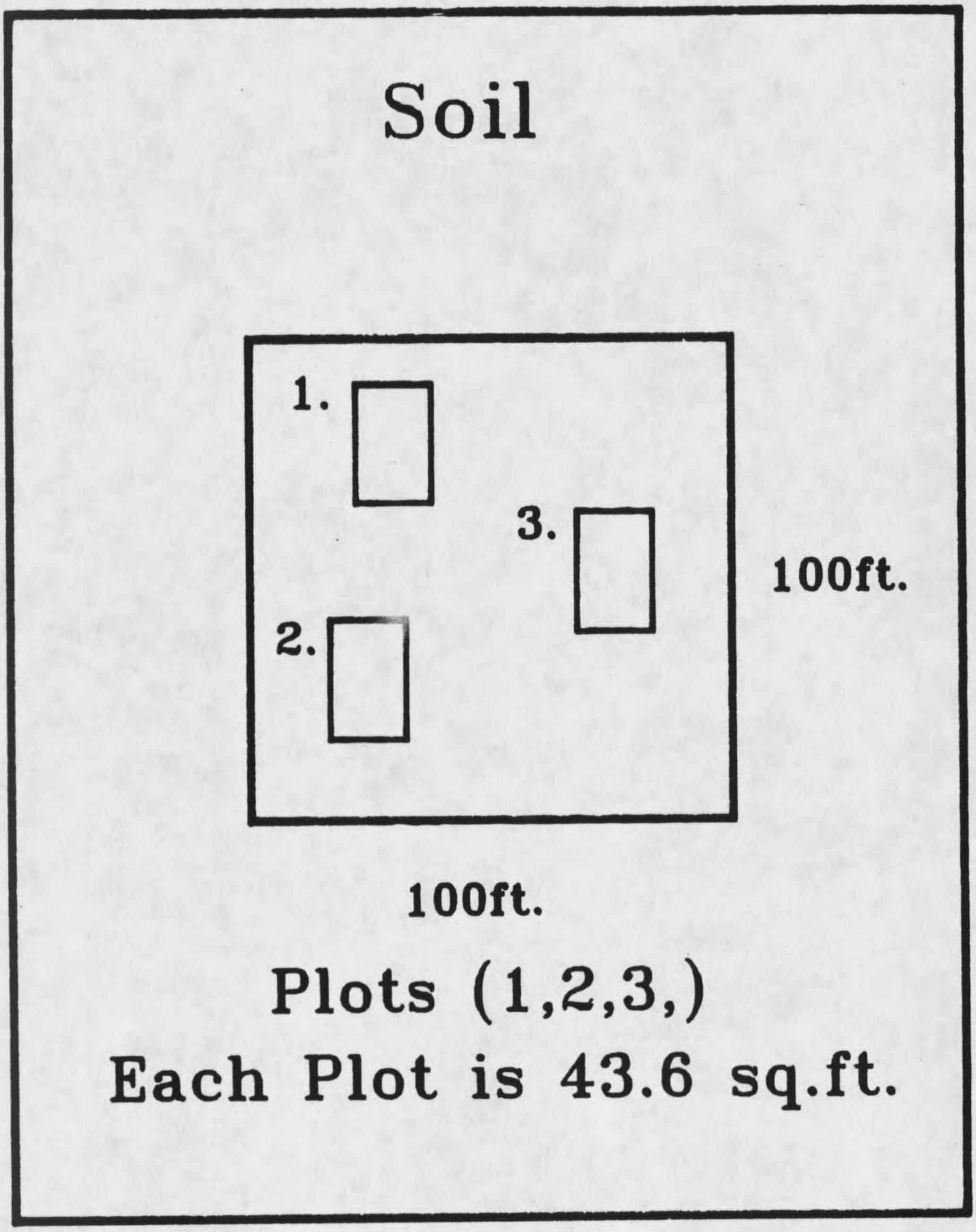


Figure 2. Plot location diagram. There may be more than one soil in a field.

labeled and sent to Montana State University Soil Testing Laboratory for chemical analysis. Soil tests included surface pH (1:2), organic matter (at a depth of 0-15 cm), electrical conductivity (at a depth of 0-15 cm), Olsen phosphorus (at a depth of 0-15 cm), extractable potassium (at a depth of 0-15 cm), extractable sulfur (at a depth 0-15 cm) and nitrate-nitrogen (at depths of 0-15 and 15-45 cm). Figure 3 shows soil sampling design.

Soil morphological properties were measured for each plot at the time of soil sampling. The depth to free CaCO3 (cm) was determined using 10% HCl to indicate effervescence. SCS, MSU, and CES personnel wrote soil sampling instructions. The instructions are given in Appendix 3.

Soil - Crop Yield Data

An optimum yield goal can be derived from the collection and analysis of soil productivity (crop yield) data. In order to estimate the optimum yield goal for a soil, it is essential to characterize soil and crop yield relationships. Difficulties arise in explaining these relationships because crop yield is a product of various management, genetic, and climatic factors as well as soil properties. In Montana dryland farming areas, variable soil moisture has the greatest influence on year to year differences in crop yield. (Burke, 1984)

Uniform procedures for collecting the data are required. A proposed nationwide system for collecting data was provided by the USDA Soil Conservation Service (1983) in Washington, DC. Some modification of the procedures were made by the Plant and Soil Science Department

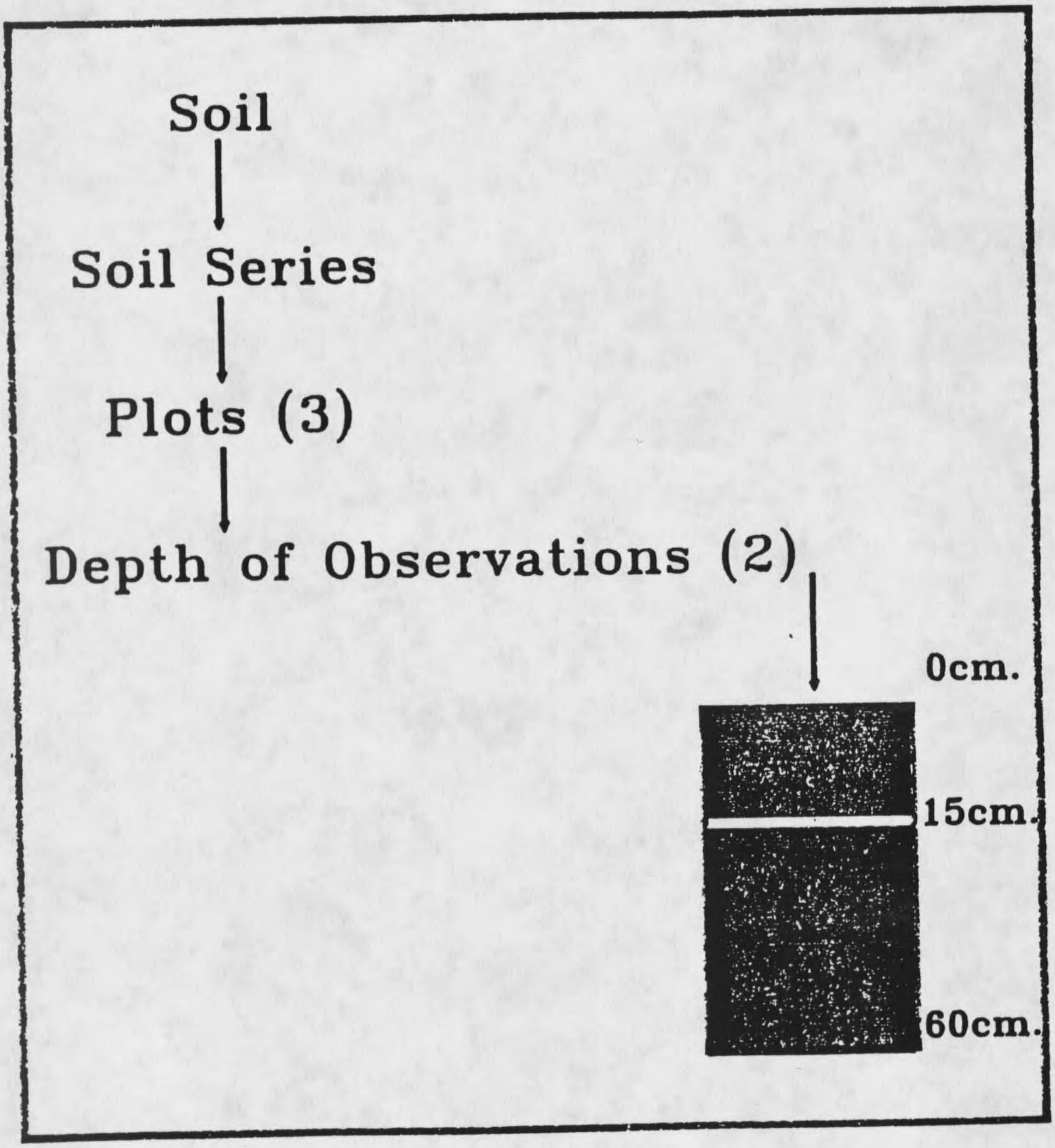


Figure 3. Soil sampling design.