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.

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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 — Date

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Approved for the College of Graduate Studies

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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

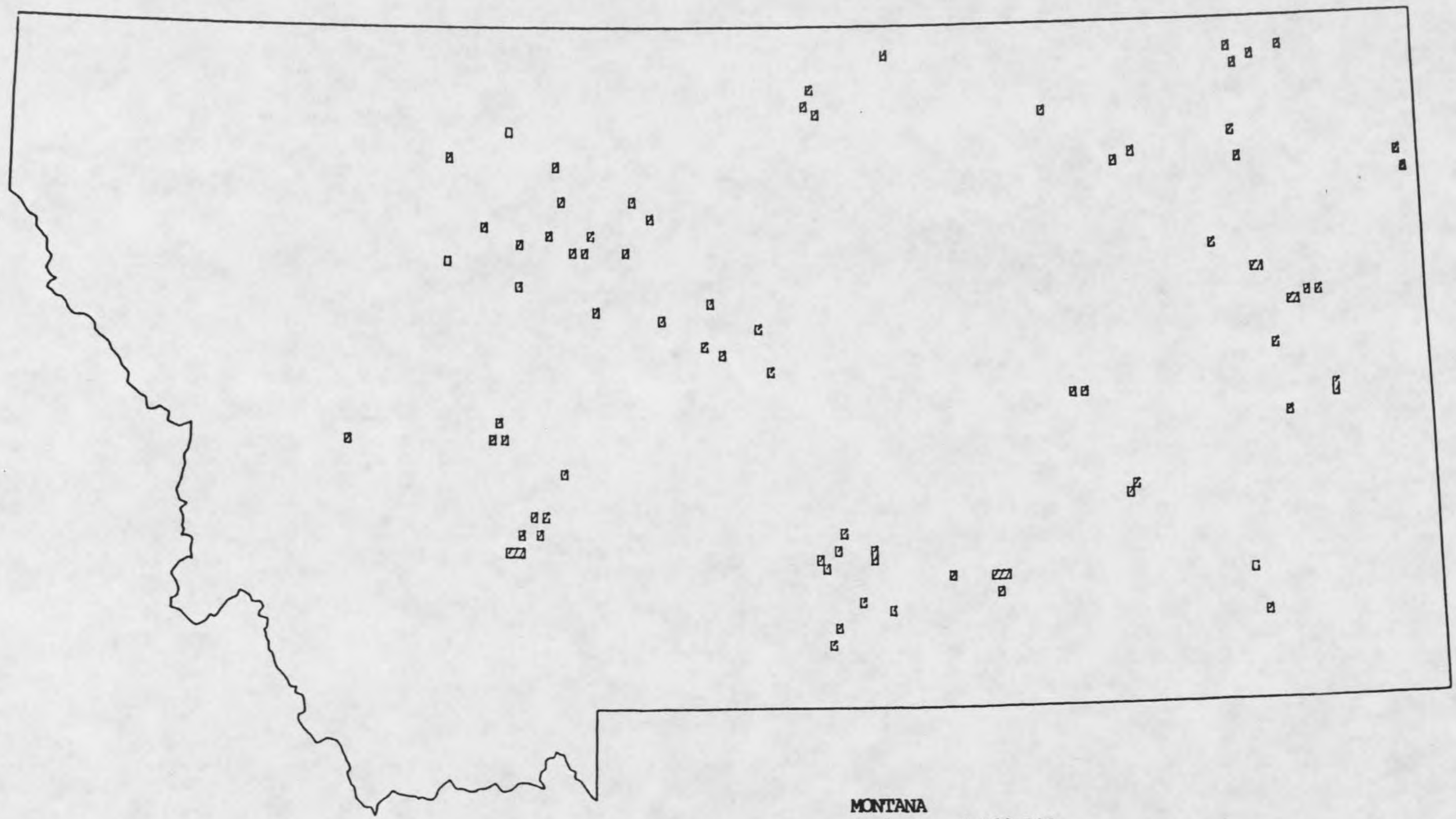
The study sites are in 24 counties distributed widely throughout Montana (Fig. 1). USDA-SCS District Conservationists worked with the Area Soil Scientists in selecting four soil series per county for inclusion in this long-term project. Most of the counties were previously mapped under the National Cooperative 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,

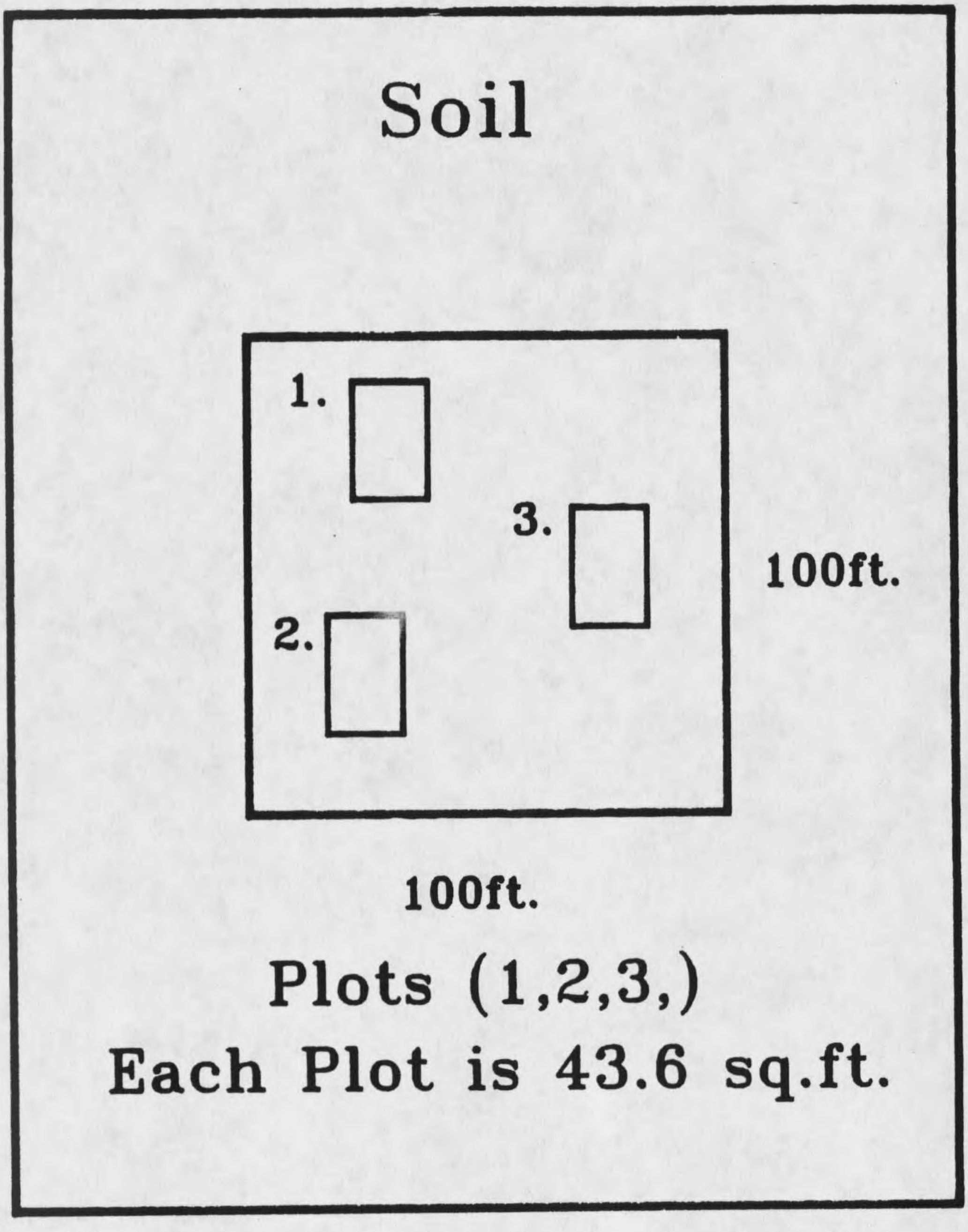


Figure 2. Plot location diagram. There may be more than one soil in a field.

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 $CaCO_3$ (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

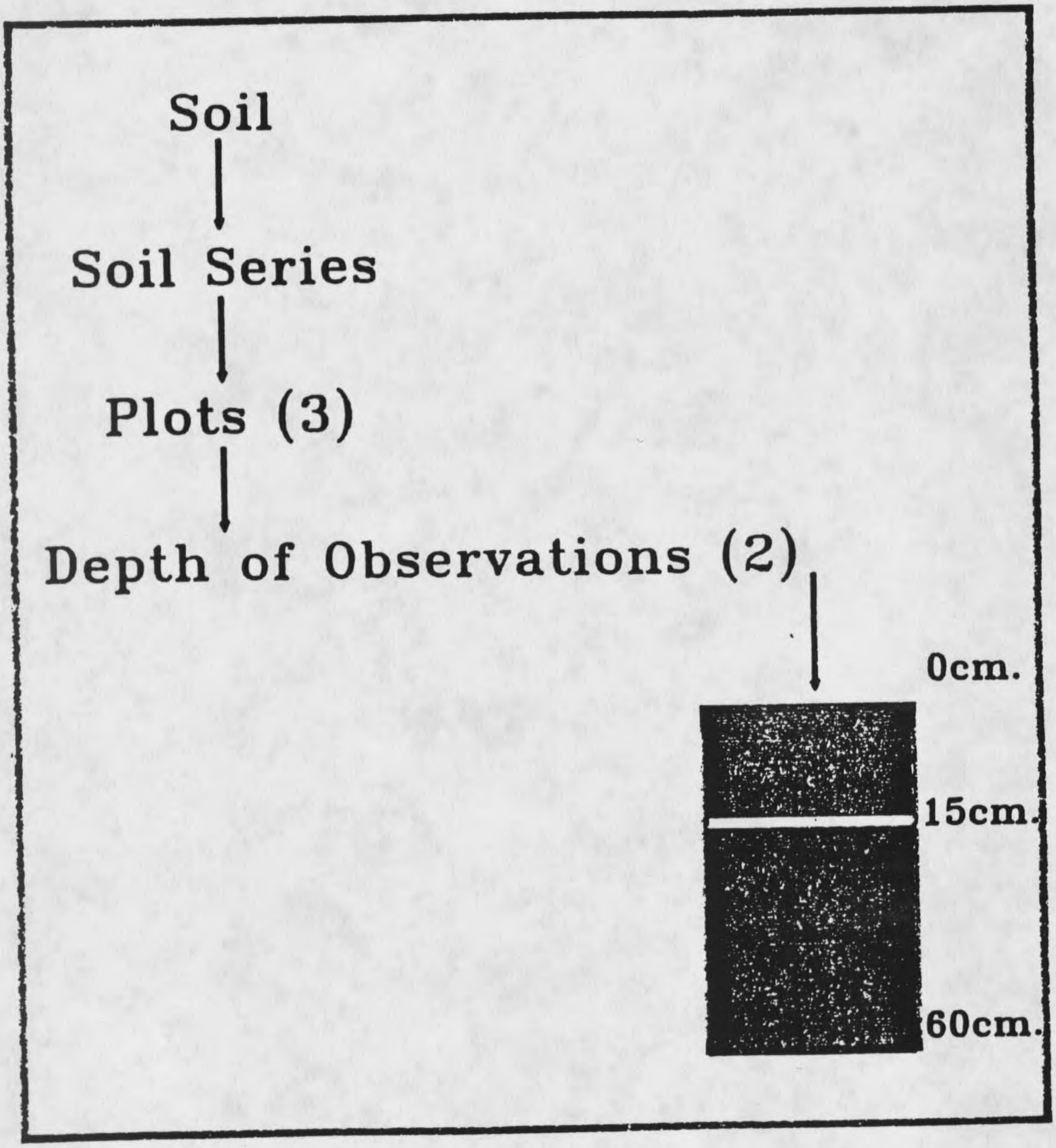


Figure 3. Soil sampling design.

and the Extension Service personnel at Montana State University in consultation with Montana USDA-ARS and SCS staff. When soil-crop yield data have been collected on key soils for several years, it will be possible to set optimum crop yield goals. Improved fertilizer recommendations and management plans would be based upon these yield goals and soil test results.

Laboratory Methods

Soil Chemical Analyses

All soil samples were air-dried. Samples were crushed and passed through a 2 mm sieve.

Standard Montana soil testing laboratory procedures were used to determine soil pH, extractable phosphorus, extractable sulfur and nitrate organic matter. Brief descriptions of each analysis follow:

Soil pH: Soil reaction was measured on 1:2 soil to water suspension, after shaking the mixture for 3 minutes. The determination was made by calomel combination electrode.

Electrical conductivity: Filtrate from the soil reaction was used to measure electrical conductivity by conductivity bridge.

Soil Phosphorus: Extractable phosphorus was determined by the Olsen (1954) method.

Soil Organic Matter: Soil organic matter was determined by modified Walkley-Black method as described by Sims and Haby (1970).

Soil Potassium: Exchangeable potassium was measured by flame emission on an atomic absorption spectrophotometer (Bower, et al. 1952).

Soil Sulfur: Extractable sulfur was determined using turbidimetric method developed by Bardsley and Lancaster, (1960), and analyzed by inductively coupled plasma Icp/5500.

Soil Nitrogen: Extracting N was developed by Sims and Jackson, (1971), and then analyzed with a Technicon Auto Analyzer 1.

Statistical Methods

Summary of data base:

The Dbase III program (Ashton-Tate, 1985, 1986) was used to calculate the mean (where applicable) and sum the number of observations for selected items and subitems.

Multiple Regression Analysis

MSUSTAT stepwise multiple regression (Lund, 1985) was used to determine which of the soil properties contribute most to crop yield, the dependent variable.

RESULTS AND DISCUSSION

Summary of Data Base

An inventory of the data base was made to illustrate the nature of the data recorded. The data base consists of four major categories: site properties, major soil characteristics, climate parameters, crop data, and crop management. Tables 2 through 7 list selected characteristics of each of the four categories of the data base. Within each category there are items and subitems. The description and coding system for recording data for all items and subitems in the different categories of the data base are given in Appendix 1.

Dbase III (Ashton Tate, 1985, 1986) computer programs were used to determine the mean (where applicable) and sum of the observations recorded. The data will provide understanding of interrelationships between soil properties, management practices, weather, and crop yields. The usefulness of the data will be extended by entering them into a nationwide data base.

Table 2. Site Characteristics and Number of Observations in the Data Base.

SITE CHARACTERISTICS	NUMBER OF OBSERVATIONS
Counties	24
Plot kind	
1. Commercial farms	90
2. Field trials of special treatments	1
3. Small research plots at experiment stations	0
4. Yield estimates	0
Plot size (1/1000 acre)	91
Soil identified by soil scientists	
Yes	87
No	4

Table 3. Soil Characteristics, Means (where applicable) and Number of Observations Stored in the Data Base. Those Characteristics Without Means were Encoded as Alphabetical Characteristics.

SOIL CHARACTERISTICS	MEAN	RANGE	NUMBER OF OBSERVATIONS
Texture			
Loam			32
Clay loam			21
Fine sandy loam			4
Sandy loam			4
Silt loam			15
Clay			2
Sandy clay loam			1
Silty clay			2
Silty clay loam			9
Gravelly clay loam			1
Slope (percent)	2.6	0.1-9.0	91
Erosion			
Slight			55
Moderate			31
Severe			3
Thickness of A horizon (cm)	16.3	7.6-33.0	91

Table 3. (Cont'd)

SOIL CHARACTERISTICS	MEAN	RANGE	NUMBER OF OBSERVATIONS
Rooting depth (cm)	136.9	63.5-152.0	91
Slope length			
Slope through site (feet)	404	10-2200	91
Slope above site (feet)	267	10-2000	91
Slope kind			
Summit			4
Shoulder			11
Back slope			25
Foot slope			46
Not reported			5
Slope shape			
Convex			4
Plane			58
Concave			12
Undulating			10
Complex			0
Not reported			7
Aspect			
North			19
South			14
East			12
West			4
Northeast			9
Northwest			8
Southeast			11
Southwest			9
Not reported			6
K factor*	0.34	0.17-0.43	91
R factor**	30	15-50	
Elevation (m)	1024	613-1486	91
Plot surface drainage			
Runon exceeds runoff			6
Neutral			65
Runoff exceeds runon			19
Not reported			1
Moist soil depth (cm)	102.9	45.7-152.0	91
Depth to free $CaCO_3$ (cm)	32.6	0-83.8	91

Table 3. (Cont'd)

SOIL CHARACTERISTICS	MEAN	RANGE	NUMBER OF OBSERVATIONS
Water holding capacity (cm)	22.7	10.4-29.7	91
Available water (cm)	16.0	6.4-28.4	91

* = Soil erodibility factor.
** = Rainfall erosion index.

Table 4. Weather Characteristics and Number of Observations Stored in the Data Base.

WEATHER CHARACTERISTICS	NUMBER OF OBSERVATIONS
Moisture reserve at planting time	
1. Above normal (<6 inches)	21
2. Normal (3-6 inches)	59
3. Below normal (<3 inches)	6
4. Not reported	5
Precipitation during growing season (qualitative)	
Above normal	25
Normal	32
Below normal	25
Not reported	9
Drought damage	
1. None	48
2. Slight	37
3. Moderate	5
4. Severe	1
Hail damage	
None	83
Slight	4
Moderate	3
Severe	1

Table 5. Crop Characteristics (where appropriate) and Number of Observations in the Data Base. Those Characteristics Without Means were Encoded as Alphabetical Characters.

CROP CHARACTERISTICS	CROP	MEAN	RANGE	# OF OBSERVATIONS
Multiple cropped				
Yes				
No				91
Current crop				
Spring wheat				30
Winter wheat				40
Barley				19
Malt barley				2
Mulch cover (percent)		21	3-99	91
Residue yield (megagram)		1.3	0.1-2.7	91
Seeding rate (kg/ha)	WW	54	27-75	40
	SW	61	50-77	30
	B	56	33-90	21
Row spacing (cm)	WW	28	15.1-35.6	40
	SW	23	15.2-30.4	30
	B	23	17.8-30.4	21
Crop yield (kg/ha)	WW	2284	882.5-5195.8	40
	SW	1892	54.6-4055.5	30
	B	2346	877.7-4174.8	21
Head density (number per 3 feet row)	WW	102	56-206	40
	SW	69	25-143	30
	B	79	50-108	21
Kernel weight (g/1000)	WW	30.8	24.2-38.2	40
	SW	32.5	24.1-39.5	30
	B	36.6	27.8-44.7	21
Test weight (lbs/bu)	WW	60.9	40.6-65.1	40
	SW	59.1	56.0-64.0	30
	B	47.8	42.8-53.6	21

WW = Winter wheat
SW = Spring wheat
B = Barley

Table 6. Crop Management Characteristics and Number of Observations in the Data Base Record.

CROP MANAGEMENT CHARACTERISTICS	NUMBER OF OBSERVATIONS
Crop residue	
Yes	79
No	7
Tillage practiced	
No till	13
Strip till	3
Other conservation tillage	57
Non-conservation tillage (Moldboard, disk plow, lister)	18
Weed control (herbicides)	
Yes	82
No	9
Crop damage by weeds	
None	64
Slight	23
Moderate	4
Severe	0
Insect and disease control (chemicals)	
Yes	38
No	53
Crop damage by insect or disease	
None	19
Slight	46
Moderate	17
Severe	9
Conservation practices other than tillage and cropping sequence	
None	32
Terraces	0
Strip cropping, contour	2
Strip cropping, field	3
Strip cropping, wind	52
Contour farming	2

Selected Variables for Statistical Analysis

There are many soil properties that affect yield directly and/or indirectly. Each variable has a particular, sometimes unknown, influence on yield. Only those variables that probably limit yield were used for statistical analysis. These variables were: thickness of the A horizon (in cm), rooting depth (cm), elevation (m), depth to free CaCO3 (cm), moist soil depth (cm), water holding capacity (cm), available water (cm), electroconductivity from 0-15 cm, organic matter from 0-15 cm, pH from 0-15 cm, nitrogen from 0-60 cm, phosphorus from 0-15 cm, potassium from 0-15 cm, and sulfur from 0-15 cm. The selection of these variables was based on common knowledge gained from the literature, personal communication, agronomic considerations and their importance as independent variables in previous multiple regression studies.

Regression Analysis for Yield Prediction

To confirm which soil properties contribute the most to the dependent variable, yield, MSUSTAT stepwise regression analysis (Lund, 1985) was used to determine the best regression model. The data were analyzed in three steps: first, all 91 fields were analyzed together, (Table 7); second, fields were sorted according to crop type [winter wheat (40), spring wheat (30) and barley (21)] (Table 9); and the third, were sorted according to soil subgroup categories, typic (31) vs aridic (22) (Table 11). Prediction equations were produced at each step. Numbers in parenthesis indicate number of fields contributing to equations.

Table 7. Statistical Values for the Selected Soil Properties and Yield for all (91) Soils (Fields) Combined.

SOIL PROPERTIES	MEAN	S.D.	RANGE
Thickness of A horizon (cm)	16.1	3.4	7.6-33.0
Rooting depth (cm)	137.0	14.2	63.5-152.0
Elevation (meters)	1024	234	613-1486
Depth to free $CaCO_3$ (cm)	32.6	21.2	6.5-83.8
Moist soil depth (cm)	102.9	32.0	45.7-152.0
Water holding capacity (cm)	22.7	4.8	10.4-29.7
Available water (cm)	16.0	5.1	6.4-28.4
Yield (kg/ha)*	2169	922	55-5196
Electrical conductivity 0-15 cm. (mmhos/cm)	0.11	0.06	0.02-0.48
Organic matter 0-15cm (percent)	2.02	0.82	0.40-4.00
pH 0-15 cm (1:2)	7.8	0.76	5.9-8.6
N 0-60 cm (mg/kg)	35.6	26.8	2.3-95.5
P 0-15 cm (mg/kg)	36.8	27.9	2.8-89.6
K 0-15 cm (mg/kg)	360.0	140.70	158.7-938.7
S 0-15 cm (mg/kg)	25.8	15.3	1.3-43.6

* Includes winter wheat, spring wheat, and barley.
SD = Standard deviation   Range = minimum and maximum values

Soil variables used in statistical analysis when all the sites (fields) were combined are presented in Table 8. The mean yield is for winter wheat, spring wheat and barley combined. Yield ranged from 55 to 5196 kg/ha, this wide range is caused mainly by two things; different crop types and different soil types. None of the soils were saline. The electrical conductivity ranged from 0.02 to 0.48 (mmhos/cm).

Table 8 shows that when all the data were combined, the three most important variables that influenced yield were moisture depth (P-value=.0000), elevation (P-value=.0493) and phosphorus (P-value=.0235).

Table 8. Yield Equations, R^2 and P-values Based on Stepwise Regression Analysis for all (91) Soil Sites.

EQUATIONS	R^2	P-VALUES		
		M	P	E
Y = -133.1+22.37(M)	.60	.00		
Y = -296.9+22.37(M)+11.02(P)	.63	.00	.00	
Y = -744.6+21.87(M)+8.90(P)+.518(E)	.65	.00	.02	.04

Y = Estimated yield (kg/ha).
M = Moist soil depth (cm).
P = Phosphorus (mg/kg).
E = Elevation (m).

The most influential factor on crop yield is moist soil depth. This variable alone has an R^2 of .60. The regression analysis indicated that elevation is positively correlated to the dependent variable (yield). As elevation increases total heat input decreases which results in less evaporation of soil water. This decrease in heat input results in fewer growing days. However, soil organic matter content and precipitation increases with elevation in most agricultural soils in Montana. This probably resulted in increased yield.

In this study, it seems that phosphorus is a more limiting factor for yield than nitrogen. However, readers are reminded that the soil samples were taken following harvest. The change in soil phosphorus at the beginning versus the end of the growing season would be very small. When phosphorus is added to the soil as fertilizer it undergoes different kinds of chemical reaction that can bind the phosphorus on to soil particles. This binding depends on the nature of the soil minerals. The change in soil phosphorus is small when compared to that of nitrogen. Because of complex interactions, phosphorus soil test values do not change much during a single year or after a single moderate addition of fertilizer. Nitrate nitrogen tests, on the other hand, change much seasonably and show the removal of nitrogen by crops during a single growing season. Phosphorus might appear to be more important than nitrogen in this study because a phosphorus test taken at harvest is a good indication of phosphorous at the beginning of the growing season, whereas a nitrate test taken at harvest will usually be low and not a good indication of nitrate that was available to the crop. In the future, soil samples will be taken at planting time.

Soil data that corresponded with yield of winter wheat, spring wheat and barley are reported in Table 10. The mean depth of soil moisture was above 100 cm and ranged from 46-152 cm. None of the soils were saline. Soil test results indicated that all the soil samples had electrical conductivity's less than 1 mmho/cm. Yields were 2284, 1982 and 2346 kg/ha for winter wheat, spring wheat and barley respectively. By correcting for mean test weights, these yields are equivalent to 34.0, 31.5 and 43.6 bu/ac. All the sites occurred at elevations between 576 m and 1486 m (1889 and 4874 feet).

Table 9. Statistical Values for the Selected Soil Characteristics and Yield as Sorted According to Crop Type: Winter Wheat (40), Spring Wheat (30), and Barley (21).

SOIL PROPERTIES	CROP	MEAN	S.D.	RANGE
Thickness of A horizon (cm)	WW	16.0	2.7	12.7-25.4
	SW	16.2	4.3	7.6-33.0
	B	16.2	3.3	10.2-25.4
Rooting depth (cm)	WW	132.0	18.9	55.9-152.0
	SW	135.5	11.5	81.3-152.0
	B	134.9	10.0	76.2-152.0
Elevation (meters)	WW	1008.0	150.6	634-1378
	SW	942.6	243.1	576-1347
	B	1173.0	216.0	719-1486
Depth to free $CaCO_3$ (cm)	WW	34.0	18.7	2.5-83.8
	Sw	34.7	23.0	2.5-91.4
	B	26.8	22.9	2.5-83.8
Moist soil depth (cm)	WW	107.7	27.6	61.0-152.0
	SW	90.4	30.6	45.7-152.0
	B	111.6	37.7	61.0-152.0
Water holding capacity (cm)	WW	22.6	4.6	13.2-28.4
	SW	23.1	4.9	10.4-29.7
	B	22.3	5.2	12.2-29.7
Available water (cm)	WW	16.8	4.1	9.9-25.7
	SW	14.7	5.7	5.8-28.4
	B	16.6	5.9	8.9-28.4
Yield (kg/ha)	WW	2284	886.0	828.5-5195.8
	SW	1892	972.9	54.6-4055.5
	B	2346	865.3	877.7-4174.8
Electrical conductivity 0-15cm (mmhos/cm)	WW	0.14	0.11	0.02-0.48
	SW	0.08	0.04	0.02-0.47
	B	0.15	0.13	0.03-0.44

Table 9. (Cont'd)

SOIL PROPERTIES	CROP	MEAN	S.D.	RANGE
Organic matter	WW	2.89	0.89	1.0-4.0
0-15 cm	SW	2.24	0.81	0.4-4.0
(percent)	B	1.99	0.87	1.0-3.3
pH	WW	7.65	0.65	5.6-8.6
0-15 cm (1:2)	SW	7.69	0.70	5.9-8.7
	B	7.46	0.63	5.8-8.6
N	WW	35.6	26.8	2.1-95.5
0-60 cm	SW	30.8	23.4	1.5-86.7
(mg/kg)	B	15.8	10.6	3.7-84.5
P	WW	12.6	7.9	2.8-37.6
0-15 cm	SW	17.6	25.1	3.8-95.5
(mg/kg)	B	15.3	6.8	4.5-24.8
K	WW	356.3	130.0	164.7-753.3
(0-15 cm)	SW	380.5	145.8	158.7-652.7
(mg/kg)	B	337.6	155.2	172.0-938.7
S	WW	11.5	9.5	1.4-50.3
0-15 cm	SW	10.2	8.6	1.3-43.2
(mg/kg)	B	8.6	5.2	2.4-24.5

SD = standard deviation
RANGE = minimum and maximum values.
WW = winter wheat
SW = spring wheat
B = barley

Table 10 shows equations for predicting yield; one each for winter wheat, spring wheat and barley. Moist soil depth alone explains 74% of the winter wheat yield variation, whereas adding nitrogen and potassium variables into the equation improves the prediction value by only 1% for each, thereby explaining 75% and 76% of the yield variation, respectively.

Table 10. Yield Equations, R^2 and P-values Based on Stepwise Regresstion Analysis for Winter Wheat (40), Spring Wheat (30) and Barley (21).

CROP	EQUATIONS	R^2	P-VALUES AW	E	K	M	N	P	RD
Winter wheat									
	Y=-706.2+27.77(M)	.74				.00			
	Y=-577.9+27.06(M)-2.03(N)	.75				.00	.27		
	Y=-715.3+26.06(M)-2.03(N)+.72(K)	.76			.22	.00	.18		
Spring wheat									
	Y=-241.1+23.58(M)	.55				.00			
	Y=-597.5+24.85(M)+13.74(P)	.67				.00		.00	
	Y=-1472+24.26(M)+10.42(P)+.950(E)	.72		.04		.00		.02	
Barley									
	Y=612.9+1042.2(Aw)	.51	.00						
	Y=-690.6+112.9(Aw)+.989(E)	.57	.00	.13					

WW = Winter wheat
SW = Spring wheat
B = Barley
Y = Estimated yield (kg/ha).
M = Moist soil depth (cm).
N = Nitrogen (mg/kg).
K = Potassium (mg/kg).
P = Phosphorus (mg/kg).
E = Elevation (m).
AW = Available water (cm).

In the second equation for winter wheat, nitrogen has a negative influence on estimated yield. This negative influence may be caused by the time of soil sampling. Soils were sampled following harvest, therefore, in most productive fields nitrogen had been depleted by plant uptake. Where soil water or other factors limited yield, and nitrogen was not used, the nitrogen soil test was high. In spring wheat, moist soil depth (cm), phosphorus (mg/kg) and elevation (m) again appeared to be the most limiting factors of yield. However, moist soil depth explains less variation in spring wheat yields than it does for winter wheat yields.

In barley, available water (cm) and elevation (m) were related to yield. This was the first time that available water appeared in the regression analysis. The low P-values for available water indicates that this variable was highly correlated with yield. Adding one more variable in the equations, elevation, did not contribute much to the estimated yield.

Soil data that correspond with the yield of typic and aridic soil subgroups category are presented in Table 11. Compared with the aridic subgroup, the typic subgroup had higher organic matter, nitrogen and phosphorus contents, lower pH, lower electrical conductivity and greater depth to calcium carbonate. There was no difference in moist soil depth, available water, water holding capacity, rooting depth and thickness of A horizon between the two subgroups. The typic subgroup had a slightly higher yield.

Table 11. Statistical Values for the Selected Soil Variables and Yield as Sorted According to the Soil Classification Subgroup Category of Typic (31) vs. Aridic (22) Argiborolls and Haploborolls.

SOIL PROPERTIES	SUBGROUP	MEAN	S.D.	RANGE
Thickness of A horizon (cm)	Typic	16.2	3.2	12.7-25.6
	Aridic	16.5	3.0	10.2-25.4
Rooting depth (cm)	Typic	122.9	27.7	83.8-152.0
	Aridic	112.9	24.3	63.5-140.3
Elevation (m)	Typic	1037	252	613-1486
	Aridic	1089	203	728-1379
Depth to free $CaCO_3$ (cm)	Typic	39.6	17.8	12.7-91.4
	Aridic	31.4	14.2	6.2-61.0
Moist soil depth (cm)	Typic	102.4	33.4	61.0-152
	Aridic	101.8	28.7	45.7-152
Water holding capacity (cm)	Typic	21.6	4.7	13.9-27.2
	Aridic	21.4	4.4	10.1-26.4
Available water (cm)	Typic	15.1	4.9	6.4-26.9
	Aridic	15.3	4.7	5.0-24.6
Yield (kg/ha)*	Typic	2159	1078.0	480.9-4174.7
	Aridic	2082	625.7	367.3-3404.5
Electrical conductivity 0-15 cm (mmhos/cm)	Typic	0.07	0.03	0.02-0.18
	Aridic	0.23	0.15	0.02-0.26
Organic matter 0-15 cm (percent)	Typic	2.28	0.75	1.00-4.00
	Aridic	1.87	0.40	1.00-3.43
pH 0-15 cm (1:2)	Typic	7.2	0.73	5.9-8.1
	Aridic	7.4	0.78	6.0-8.6

Table 11. (Cont'd)

SOIL PROPERTIES	SUBGROUP	MEAN	S.D.	RANGE
N, 0-60 cm (mg/kg)	Typic	26.9	20.3	4.5-86.7
	Aridic	20.2	18.2	1.2-95.5
P, 0-15 cm (mg/kg)	Typic	27.7	21.5	3.8-99.8
	Aridic	14.1	5.3	3.3-25.2
K, 0-15 cm (mg/kg)	Typic	350.2	128.0	158.7-652.7
	Aridic	329.6	104.9	164.7-564.0
S, 0-15 cm (mg/kg)	Typic	6.7	4.5	1.3-23.3
	Aridic	8.9	5.6	2.6-25.0

* = Includes winter wheat, spring wheat, and barley.
SD = Standard deviation.
Range = Minimum and maximum values.
Typic = Typic Argiborolls and Typic Haploborolls.
Aridic = Aridic Argiborolls and Aridic Haploborolls.

Typic soils are usually deeper and darker than aridic subgroup soils. Moist soil depth was the variable of greatest influence on crop yield with an R^2 of 0.66 for typic subgroup soils (Table 12). Also, available water was related positively to crop yield. The soil chemical property that appeared in the equation for typic subgroup soils was phosphorus. It increased the R^2 value to 0.77 and had a highly significant P-value of 0.00.

Table 12. Yield Equations, R^2 and P-values Based on Stepwise Regression Analysis for Typic (31) and Aridic (22) Soils.

SUBGROUP	EQUATIONS	R^2	M	P	P-VALUES Aw	pH	Ec
Typic							
	Y=-532.6+26.29(M)	.66	.00				
	Y=-876.2+26.54(M)+14.60(P)	.77	.00	.00			
	Y=-1150+18.45(M)+15.141(P)+72.22(Aw)	.81	.00	.00	.01		
Aridic							
	Y=514.9+15.40 (M)	.50	.00				
	Y=2566+15.36(M)-261.5(pH)	.56	.00			.11	
	Y=2856+14.69(M)-295.8(pH)-208.8(Ec)	.60	.00			.07	.17

Y = Estimated yield.
M = Moist soil depth (cm).
P = Phosphorus (mg/kg).
Aw = Available water (cm).
Ec = Electrical conductivity (mmhos/cm).

Moist soil depth was positively related to yield in aridic subgroup soils, while pH and electrical conductivity were negatively related to yields. As pH increased yield decreased. At higher pH, phosphorus and trace elements become less available to the plant. The pH of the aridic soils ranged from 6.00 to 8.60. However, the effect of pH values on the equation was not highly significant (P-value of 0.11).

All the soils in this study were considered to be good agricultural soils with no salt problems, thus, electrical conductivity was not expected to have large influences on yield. The electrical conductivity of aridic soils ranged from 0.02 to 0.26 which is a low E.C. The appearance of electrical conductivity in the equation for aridic soils did not contribute much to R^2. However, it influenced the P-value of the pH which decreased from 0.11 to 0.07.

SUMMARY AND CONCLUSIONS

Soil productivity data collection was conducted during the 1986 growing season in 91 fields (each one having 3 plots) in 24 counties across the state. All fields chosen for the study were in commercial farms growing cereal grains. The data collected included site, soil, crop, climate and management properties.

Following harvest, soil samples were taken within the plots at two depths (0-15 cm and 15-60 cm). The soil samples were analyzed for pH, electrical conductivity, organic matter, nitrogen, phosphorus, potassium and sulfur. The soil morphological properties measured included thickness of A-horizon (cm), moist soil depth and depth to calcium carbonate (cm). Some of the variables were selected for multiple regression analysis on the basis of their agronomic importance in crop yield in order to determine the most yield limiting factors of dryland production in Montana. Analysis of soil productivity data indicated that depth of moist soil was the most important (P-value-.00) factor for explaining crop yield in Montana during 1986. Phosphorus (0-15 cm) and elevation (m) were the second and third most important factors respectively.

All but one of the original objectives set up for the project have been achieved. Objective four was not completely achieved as it will require several years of data analysis to reach a definite conclusion. The original objectives were:

1. Initiate a long-term project to identify major soil and climatic factors that influence small grain yield in Montana. This objective has been reached. Data collected in 1986 has been used in this research, part of the data for 1987 has been collected and stored. The work of 1988 is planned and on schedule.
2. Develop a procedure and form for obtaining soil performance data for Montana soil series. Procedures and forms developed have been used successfully for two years. A description of this objective is included as part of the methods and material section. Details are given in Appendices 1, 2 and 3.
3. Set up a Montana soil performance/crop yield data processing system. A data processing system has been created using Dbase III on a microcomputer.
4. Determine the minimum soil performance data set needed in yield prediction models for Montana. One year's data has been analyzed to determine the important yield affecting factors. This objective requires further data collection and analysis for several years to identify the most important properties of soil, climate and management that limit cereal grain yield.
5. Contribute Montana data to a national soil-crop yield data base. Work is going on to submit the data to the USDA interagency soil-crop yield committee.

RECOMMENDATIONS

All the soils included in this project were in commercial fields. After the first year, some of the sites were lost to the Conservation Reserve Program (CRP). These sites should be discounted and replacement sites established where two or more contrasting soils occur within the same field. Effects of soil properties will be identified more rapidly and at lower cost if data are acquired from contrasting soils in the same field. This approach not only reduces travel cost, but more importantly, it holds macroclimate variables and management variables constant so that the effect of soil properties on yield can be readily recognized. Once relationships between soil properties and yield are understood, yield prediction models can be developed for purposes of assigning expected yield values to all phases of all Montana soil series used for dryland agriculture.

Most of Montana agricultural land is semi-arid and non-irrigated. Since stored soil water and growing season precipitation are major factors that determine soil productivity (crop yield), precipitation data is needed to help explain the role of other factors. Therefore, the installation of rain gauges at all the sites is recommended so that the amount of precipitation that occurs during the growing season can be recorded.

Recent research at Montana State University by Veeh, (1981) has shown that soil temperature has a strong influence on the diffusion of nutrients as potassium through the soil solution to plant root. Soil temperature is also important for the mineralization of nitrogen. Because these factors affect crop yield, soil temperature should be measured. Unfortunately, we have not yet identified a method that is both inexpensive and reliable.

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APPENDICES

APPENDIX 1

Description of Variables in the Montana Soil Productivity Data Form

This appendix includes the variables along with their descriptions and forms for recording data.

This research is part of a cooperative project which include participation by the following agencies: 1) U.S.D.A. Soil Conservation Service; 2) Montana Agricultural Experiment Station and Extension Service Montana State University; and, 3) U.S.D.A. Agricultural Research Service. A national interagency soil-crop yield committee (U.S.D.A.-S.C.S. 1983) in Washington, D.C. selected most of the variables to be included in a nation-wide data base. They provided descriptions of each variable and procedure for recording values in the data base. Eleven additional variables were added to the national system in order to better explain yield differences in Montana.

Instructions for completing form SCS-SOI-1, Soil-Crop Yield Data. Modified for Montana, 4/86

(a) Line 1

(1) Sample number.

(i) State code. Use the two-character alphabetic Federal Information Processing Standards (FIPS) code, e.g., VA.

(ii) County code. Use the three-character numerical FIPS code.

(iii) Set up a sequence of two-digit numbers for each field and another sequence of one-digit numbers for each soil within the field and another sequence of numbers from 1-3 indicating plot numbers. Keep a log of these numbers as a record for testing at the same sites in subsequent years.

(2) Kind of plot.

Enter one of the following codes:

1 - Yield measurements in commercial farm fields.
2 - Yield measurements in field trials of special treatment practices (fertilizer field trials, variety trials, conservation tillage trials).
3 - Yield measurements of small research plots at experiment stations (variety tests, fertilizer tests).
4 - Yield estimates.

(3) Size of plot.

1/1000 acre

(4) Location.

Use a map such as a 7 1/2 degree quad, aerial photograph or soil survey to record the location.

(i) X coordinate. Enter latitude north. Separate degrees, minutes and seconds by a hyphen, e.g., 25-05-03.

(ii) Y coordinate. Enter longitude west, e.g., 108-25-49.

(iii) Other location description, e.g., NE 1/4 sec. 12, T. 31 N., R. 11 W. Other coordinates that locate plot from permanent landmarks.

(5) Agency.

Enter the abbreviation of the agency entering the data.

(6) Date.

Enter the date the form is filled out, e.g., 8/14/81

(b) Line 2

(1) Soil Symbol.

Enter the soil symbol of the area at the sample site (if known).

(2) Soil name.

Enter the name of the soil identified at the sample site or through reference to the soil survey, e.g., NORFOLK FINE SANDY LOAM, 3-5 PERCENT SLOPE.

(3) Soil ident at plot?

Indicate whether soil is identified at the plot by soil scientists. Enter Y for yes or N for no.

(c) Line 3

(1) Soil interpretations record number.

Enter the number of the soil interpretations record (if known) e.g., VA0026.

(2) USDA texture.

Enter the textural symbols including modifier of the surface layer, e.g., GR-L. Use only the approved symbols in the National Soils Handbook.

(3) Slope.

Enter the slope to the nearest percent on slopeas greater than 1 percent: enter to the nearest 0.1 percent for slopes less than 1 percent.

(4) Flooding.

Enter the flooding frequency that most nearly represents sample site. Use NONE, RARE, OCCAS, OR FREQ. Do not use COMMON.

(5) Other phase criteria.

Enter the critical phase terms on the interpretations record, other than surface texture, slope, or flooding, that are needed to select the correct capability and yield interpretations for the component, e.g., ERODED, MOD ALKALI, SEV ER. Use the same terms to define the critical phase criteria as those used in the interpretations record. Use appropriate abbreviations listed in the National Soils Handbook.

(d) Line 4

(1) Erosion.

Enter the code that most nearly represents the estimate of erosion:

1 - Slight
2 - Moderate
3 - Severe

(2) Color of A horizon.

Enter the color (Munsell notation) of the A horizon.

(3) Thickness of A Horizon.

Enter the thickness of the A horizon (inches).

(4) Organic matter.

Enter an estimate or measurement of the percent of organic matter (organic carbon x 1.75) in the A horizon.

(5) pH.

Enter the pH of the surface "6" inches at time of harvest, e.g., 6.7.

(6) Rooting depth (inches).

Measure the depth to fragipan, bedrock, gravel, or other root-impeding layer. If greater than 60 inches, enter >60.

(7) Slope length.

(i) Through site (ft). Enter the length of slope through the sample site, in feet. On terraced land enter the distance between terraces. <u>Slope length</u> is the distance from the point of origin of overland flow to either (a) the point where the slope decreases to the extent that deposition begins or (b) the point where runoff enters an area of concentrated flow or channel.

(ii) Above site (ft). Enter the length of slope from point of origin of overland flow to <u>the sample point in feet</u>.

(8) Slope.

(i) Kind.

Enter the code that most nearly represents kind of slope at sample site:

1 - Summit
2 - Shoulder
3 - Back slope
4 - Foot slope

(ii) Shape.

Enter the code that most nearly represents the slope shape:

1 - Convex
2 - Plane
3 - Concave
4 - Undulating
5 - Complex

(9) Aspect.

On slopes where aspect is important enter one of the 8 points of the compass that the slope faces, e.g., NE.

(10) K factor.

Enter the soil erodibility (K) factor.

(11) Elevation.

In feet from USGS maps or other suitable sources.

(12) Plot surface drainage.

1 - runon exceeds runoff
2 - neutral
3 - runoff exceeds runon

(13) Moist soil depth (inches).

Using brown soil moisture probe, one probe per plot.

(e) Line 5

(1) Moisture reserve at planting time. (Local opinion).

Enter one of the following codes:

1 - Above normal (+6 inches)
2 - Normal (3-6 inches)
3 - Below normal (<3 inches)

(2) Moisture reserve at beginning of spring growing season following fall planting (winter wheat, rye, etc.).

Enter one of the following codes:

1 - Above normal (+6 inches)
2 - Normal (3-6 inches)
3 - Below normal (<3 inches)

(3) Precipitation during the growing season.

(i) Qualitative. Enter the code that represents qualitative judgment: Consult "Soil Water Guidelines and Precipitation Probabilities" of MT and ND.

1 - Above normal
2 - Normal
3 - Below normal

(ii) By month. If monthly records are available enter to the nearest inch the precipitation for each month. If rain gauges are installed and monitored near plots, keep records of precipitation to nearest 0.1 inch.

(4) Drought damage.

Enter the code that represents the judgment of the amount of crop damage caused by drought:

0 - None
1 - Slight
2 - Moderate
3 - Severe

(5) Water damage.

Enter the code that represents the judgment of the amount of crop damage caused by excessive wetness:

0 - None
1 - Slight
2 - Moderate
3 - Severe

(6) R factor.

Enter the R (Rainfall) factord.

(7) Hail damage.

0 - None
1 - Slight
2 - Moderate
3 - Severe

(f) Line 6

(1) Multiple-cropped.

Is the site doubled or triple cropped? Enter Y for yes or No for no.

(2) Current crop.

Enter the crop name from the crop list exhibit in the National Soils Handbook.

(3) Cultivar (variety).

Enter the name or identification of the crop variety.

(4) Previous crops.

Enter the names of the crops grown in first, second, and third previous crop seasons. (Enter chemical or mechanical fallow if applicable.) 1985, 1984, 1983.

(5) Mulch cover, in percent, at seeding time.

(g) Line 7

(1) Planting information.

(i) Date.

Enter the date of planting (month/day/year) if known, e.g., 5/15/80.

(ii) Timing.

Enter the code that represents the estimate of timeliness of planting:

1 - Early
2 - Normal
3 - Late

(iii) Seeding rate.

Enter the pounds per acre that were planted.

(iv) Row spacing.

Enter the row spacing in inches.

(2) Harvest information.

(i) Date.

Enter the date of harvest (month/day/year), e.g., 9/10/80.

(ii) Timing.

Enter the code that represents the estimate of timeliness of harvesting:

1 - Early
2 - Normal
3 - Late

(iii) Crop Yield.

Enter the amount of harvested crop per acre, e.g., 110. Use standard procedures for measuring yield.

(iv) Unit of measure.

Enter the unit of measure for the crop, e.g., bu/acre.

(v) Residue yield (t/acre).

Enter the air-dry tons per acre of crop residue (estimate if necessary).

(3) Yield components

(i) Head density--Number of heads counted in 3 ft. of row.

(ii) Kernel weight in grams per 1000 kernels

(iii) Test weight in lbs. per bushel.

(h) Line 8

(1) Commercial fertilizer.

(i) NPK

Enter the pounds of elemental nitrogen, phosphorus, and potassium applied per acre.

(ii) Other fertilizer materials (excluding lime)

(1) Specify kind, e.g., ZINC

(2) Enter the pounds per acre applied.

(2) Organic materials.

(i) Enter tons of manure applied per acre.

(ii) Enter the code representing the kind of manure:

1 - Cattle
2 - Poultry
3 - Hog
4 - Horse
5 - Sludge (human)
6 - Other

(3) Crop residues returned.

Enter Y for yes and N for no.

(4) Tillage.

Enter the code that represents the kind of tillage practice at the sample site:

1 - No till (slot tillage)
2 - Strip till
3 - Other conservation tillage
4 - Nonconservation tillage (moleboard, disk plow, lister)

(5) Weed control.

(i) Were herbicides used for this crop?

Enter Y for yes or N for no.

(ii) Enter the number of cultivations used primarily or partly for weed control (include fallow period) only for year in question.

(iii) Enter the code that represents the extent of weed damage on the crop:

0 - None
1 - Slight
2 - Moderate
3 - Severe

(6) Insect and disease control.

(i) Were chemicals used to control insects or disease? Enter Y for yes, N for no.

(ii) If chemical control was used, enter the code that represents the kind of treatment:

1 - Foliage
2 - Seed
3 - Soil
4 - Two or more of the above treatments

(iii) If foliage treatment, enter the number of chemical applications.

(iv) Enter the code that represents the extent of insect or disease damage on this crop:

0 - None
1 - Slight
2 - Moderate
3 - Severe

(i) Line 9

(1) Other damage.

Enter the code that represents the extent of damage from other causes such as hail, wind, lodging, freezing, etc.:

0 - None
1 - Slight
2 - Moderate
3 - Severe

(2) Conservation practices, other than tillage and cropping sequence.

Enter one of the following conservation practices codes. If more than one used, enter the code listed first:

0 - None
1 - Terraces
2 - Stripcropping, contour
3 - Stripcropping, field
4 - Stripcropping, wind
5 - Contour farming

(3) Irrigation.

(i) Was irrigation water applied to this crop?

Enter Y for yes or N for no.

(ii) Type:

1 - Furrow
2 - Sprinkler
3 - Drip
4 - Flood

(iii) Enter the code that represents the adequacy of irrigation in meeting crop moisture requirements:

1 - Good
2 - Fair
3 - Poor

(4) Drainage.

(i) Is this soil artificially drained?

Enter Y for yes or N for No.

(ii) Enter the code that represents the damage to the crop caused by inadequate drainage system.

0 - None
1 - Slight
2 - Moderate
3 - Severe

(5) C factor.

Enter the C factor (cover and management factor used in the Universal Soil Loss Equation) applicable to the site.

(6) Plot Fertility by Soil Test

(i) NPKS

Enter the code that represents the level of fertility.

1 - Low
2 - Medium low
3 - Medium
4 - Medium high
5 - High

(7) Measure depth to free $CACO_3$ (inches) using 10 percent HCL at time of soil sampling or when soil scientists select plots.

(8) Name(s) of recorder(s)

U.S. DEPARTMENT OF AGRICULTURE
Soil Conservation Service

SCS-SOI-1
4-81
MT 4-86

SOIL-CROP YIELD DATA
MONTANA

KEYING INSTRUCTIONS: DUPLICATE SAMPLE NUMBER ON ALL LINES

Line 1

Sample Number ST	CO	ID	Kind of Plot	Size of Plot	Location: X Coord.	Y Coord.	Other Description	Agency	Date MO	DY	YR
MT	021	03211	1	1/1000	47-22-09	105-02-53	NE4 NE4 Sec. 35, T19N, R52E	SCS	10		86

Line 2 — Soil Ident

Soil Symbol	Soil Name	Soil Ident. at Site Y-N
Cd	Cherry Silty Clay Loam, 2-4 % Slope	Y

Line 3 — Soil Info

Interp Record Number	USDA Texture	Slope (PCT)	Flooding	Other Phase Criteria
ND0082	SICL	4	None	None

Line 4 — Other Soil Info

Erosion	A Horizon: Color	Thickness (IN)	Organic Matter (PCT)	pH	Rooting Depth (IN)	Slope Length: Thru Site (FT)	Above Site (FT)	Slope: Kind	Shape	Aspect	K Factor	Elevation (FT)	Plot Surface Drainage	Moist Soil Depth (IN)
2	10YR 5/2	6"			76"	1700	750	3	3	5	.37	2680	2	76"

Line 5 — Weather

Moisture Reserve: At Planting	At Start of Grow Seas	Precipitation During Growing Season: Qual	1	2	3	4	5	6	7	8	9	10	11	12	Drought Damage	Water Damage	R Factor	Hail Damage
1	1	1	0	0	0	0	2.4	3.8	2.1	0	4	1	1	1	0	0	37	0

Line 6 — Crop Data

Multi Cropped Y-N	Current Crop	Current Cultivar (Variety)	First Previous Crop	Second Previous Crop	Third Previous Crop	Mulch Cover (PCT)
N	Barley	Hector	Summerfallow	Winter wheat	Barley	60

Line 7 — Crop Data (Cont)

Planting Date MO	DY	YR	Timing	Rate LB/AC	Row Spac	Harvest Date MO	DY	YR	Timing	Crop Yield	Unit Meas	Residue T/AC	Head Density (# per 3 ft row)	Kernel Wt (G/1000)	Test Wt (LB/BU)
3	30	86	1	52	10	8	5	86	1	58	bu/Ac.	1	91		

Line 8 — Crop MGT.

Commercial Fertilizer LB/AC N	P	K	Other: Kind	LB/AC	Organic Materials: Manure T/AC	Kind	Crop Y-N	Tillage	Weed Control: Chem Y-N	Num Cult	Crop Damage	Insect/Disease Control: Chem Y-N	Kind Treat	Num Applic	Crop Damage
0	0	0						3	Y	0	0	Y	4	1	1

Line 9 — Crop MGT. (Cont)

Other Damage	Cons Pract	Irrigation: Y-N	Type	Adequacy	Drainage: Y-N	Crop Damage	C Factor	Plot Fertility: N	P	K	S	Depth to Free $CaCO_3$ (IN)	Name of the Recorder(s)
0	4	N			N	0	.136					0	M. Carlson, D. Winchell, Setima

Figure 4. Soil-Productivity (crop yield) data form.

APPENDIX 2

Crop Sampling Instructions

During April 1986, the S.C.S. State Soil Scientist, District Conservationists and Area Soil Scientists selected four soil series on commercial farms in each of the twenty-four counties participating in this project. Since commercial farms were used, row spacing was different from one farm to another. This appendix includes the grain harvest procedure for uniform sampling according to their row spacing written by Plant and Soil Science Department, Extension Service personnel at Montana State University and Soil Conservation Service staff.

GRAIN HARVEST PROCEDURE FOR MONTANA SOIL PERFORMANCE COOPERATIVE PROJECT

I) Harvest 1/1000th acre plots each consisting of 4 rows of the length specified in the following table. For example, if rows are 10 inches apart, sample 13 feet, 1 inches.

Row spacing (inches)	Length of 4 row plot (feet and inches)	Length of 4 row plot (feet and tenths)
6	21' 9"	21.8
7	18' 8"	18.7
8	16' 4"	16.3
9	14' 6"	14.5
10	13' 1"	13.1
12	10' 11"	10.9
14	9' 4"	9.3
16	8' 2"	8.2

II) A. Examine all 4 rows to determine whether or not they are uniform and representative. Select the row that is most representative for head count.

B. Clip heads from the other 3 rows and place heads in a paper bag (a number 46 grocery bag, for example).

C. Count number of heads from 3 feet to the representative row, record.

D. Clip all heads from the representative row and place heads in sample bag with the other heads.

III) Label with the sampler's name, sample number and date. The sample number is established as follows:

A. County code, use the three-character numerical FIPS code.

B. Set up a sequence of two-digit numbers to identify fields within the county.

C. Set up a sequence of one-digit numbers for each soil within the field.

D. Set up another sequence of numbers from 1 to 3 indicating plot numbers.
Example: 0090621 - 9th county (Carbon), 6th field, 2nd soil, 1st plot.

IV) Close bag with a stapler, such as an arrow p-22, or plier-type stapler.

V) Store in dry area for future threshing.

APPENDIX 3

Soil Sampling Instructions

A standard soil sampling procedure is described in this appendix. This procedure was developed by Plant and Soil Science Department, Extension Service personnel at Montana State University and Soil Conservation Service personnel to ensure uniform soil sampling by many individuals across the twenty-four counties included in this cooperative project.

SOIL SAMPLING PROCEDURE FOR SOIL PERFORMANCE COOPERATIVE PROJECT

All samples should be taken between rows, not within rows. Remove surface crop residues from each location. All samples should be air-dried immediately after collection to prevent microbial action. Take two representative soil samples from each plot. The procedure is as follows:

Composited Sample Number 1

In a clean plastic pail, place 3 randomly selected soil samples from 0 to 6 inches. Use a bucket auger to collect the samples. Mix the soil thoroughly, take a composite sample, air-dry, and then place in the plastic lined paper bag provided.

Composited Sample Number 2

From the same 3 cores, from which composited sample Number 1 was obtained, sample from 6 to 24 inches with the bucket auger. Please each subsoil sample into a clean plastic pail. Mix the soil thoroughly, take a composite sample, air-dry, and then place in the plastic lined paper bag provided.

A 1 to 1.5 pound (3/4 bag) sample is needed. Samples should be loosely packed in the plastic lined paper bag that is provided. Don't seal moist samples in plastic bags or jars.

Label with the sampler's name, sample number, and date. The sample number is established as follows:

1. County code: Use the three character numberical FIPS code.

2. Set up a sequence of two-digit numbers to identify fields within the county.

3. Set up a sequence of one-digit numbers for each soil within a field.

4. Set up another sequence of numbers from 1 to 3 indicating plot numbers (replications).

5. Set up a one-digit number for sampling depth, 1 signifying 0 to 6 inches and 2 signifying 6 to 24 inches.

Example: 00906232 - 9th county (Carbon), 6th field, 2nd soil, 3rd plot, 6 to 24 inch depth.

1687-2548