



Use of soil parameters to assess crop yield potential in Gallatin Valley, Montana : a study of soil quality
by Arsil Saleh

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

Soil survey and inventory activities involve collecting a variety of soil and environmental data and information which are subsequently available for numerous uses and applications. Some soil parameters have been identified to strongly influence quality of the soil, a term which has gained numerous definitions. Knowledge of using soil performance data in relation to crop yield may be a good learning process in approaching the study of soil quality. Understanding soil quality and its relation to dependent factors is, perhaps, helpful in making soil information more useful, especially in developing countries. The intent of the present investigation was not to develop yield estimate models based on soil parameters but rather to undertake a desktop exercise that would provide experience with the process of investigating soil quality and soil data.

The main purpose of this study was to investigate important soil parameters which influence crop yield in Gallatin Valley. Variability in environmental conditions affecting crop yield was limited by taking a relatively small geographic area, Gallatin Valley, Montana for this study. Data and information about soils were primarily obtained from Natural Resources Conservation Service's URL Websites. Twenty nine soil pedons (with 162 horizons) representing eleven soil series were involved in this study. Soil data and information were obtained only for A and B horizons ; these data were used to calculate weighted-average values, which were used in subsequent analysis. Lack of available crop yield data was addressed by applying five different approaches to obtain crop yield estimates for winter and spring wheats (*Triticum aestivum* L.), and alfalfa (*Medicago sativa* L.). Eight soil variables from the entire soil survey database were used in conjunction with estimates of crop yield to assess the role of soil properties in soil quality characterization. Statistical Analysis System (SAS) programming was used for variable selection and regression analysis.

Six 'best' regression equations were developed from this study. Two regressions predicting yield on the basis of soil properties were fit for each crop. Soil water holding capacity (WHC) proved to be the 'best' predictor of crop yield. Models involving WHC were defined as the first 'best' regressions for each crop. This independent variable was able to explain 91 percent of the variability in winter and spring wheat yields (models 1.1 and 6.1), and 87 percent of the yield variability in alfalfa (model 11). A combination of WHC and soil clay content (clay) comprised the second 'best' regression equations for each crop. This combination accounted for 64 percent variation in winter wheat yield (model 5.3), 56 percent yield variation in spring wheat (model 10.2), and 53 percent of yield variation in alfalfa (model 15.2). _ Soil survey inventory results have been shown to be very useful for assessing yield potential of winter and spring wheats, and alfalfa on a limited basis. Of the five sources of dependent variables, yield estimates from NRCS-USDA were the most significantly correlated with soil parameters. Best guess yield estimates by experienced producers were very closely correlated with the estimated yields by the NRCS-USDA. By applying further manipulations, MAPS Atlas database proved useful for characterizing soil quality.

The reader should be cautioned that the models developed here are clearly limited in their application

to yield estimation, due to the fact that the approach used was somewhat circuitous, i.e., using NRCS yield estimates based on soil water holding capacity, as the foundation for model development.

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APPROVAL

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Arsil Saleh

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

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ABSTRACT

Soil survey and inventory activities involve collecting a variety of soil and environmental data and information which are subsequently available for numerous uses and applications. Some soil parameters have been identified to strongly influence quality of the soil, a term which has gained numerous definitions. Knowledge of using soil performance data in relation to crop yield may be a good learning process in approaching the study of soil quality. Understanding soil quality and its relation to dependent factors is, perhaps, helpful in making soil information more useful, especially in developing countries. The intent of the present investigation was not to develop yield estimate models based on soil parameters but rather to undertake a desktop exercise that would provide experience with the process of investigating soil quality and soil data.

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The reader should be cautioned that the models developed here are clearly limited in their application to yield estimation, due to the fact that the approach used was somewhat circuitous, i.e., using NRCS yield estimates based on soil water holding capacity, as the foundation for model development.

1. INTRODUCTION

Soil survey and mapping is a process of inventorying information about soil and the related environmental factors. The results are soil survey reports containing information on soils, relief/topography, vegetation, geology, and climate. An integral part of soil survey is a detailed list of soil characteristics and nomenclatures.

In developed countries, soil survey inventory is an integral part of land resource management. Soil maps and taxonomic information resulting from soil surveys have been put to a number of agricultural interpretive uses (Buol et al., 1989). Besides agricultural purposes, soil survey data can also be extensively used for non-farm activities such as land use planning, environmental quality protection, highway location, real estate development, tax assessment purposes, and siting of recreation facilities and septic tank filter fields.

Following the developed countries, some developing countries have also been adopting the practice of characterizing and mapping their soils. Indonesia is one example of a country actively engaged in soil survey. Its researchers and surveyors have been reporting and documenting numerous soil inventory reports to be used publicly. However, most of the results are still "under utilized". Simultaneous to the soil survey process, many other efforts have been undertaken to improve the usefulness and to better explain soil inventory reports to users. One of these efforts is that in 1988 researchers declared the US soil classification system, Soil Taxonomy (Soil Survey Staff, 1975) to be used for classifying and reclassifying Indonesian soils.

Assessment of soil potential or quality based on soil characteristics obtained from soil survey and mapping activities in Indonesia is one way to increase the usefulness of soil survey information. The importance of relationships among soil properties, plant characteristics and populations, and environmental variables has been recently recognized (Larson, 1986).

In order to build and develop models defining soil-crop relationships, it is first necessary to collect information on soil characteristics along with crop variables. Because adequate data or crop yield records which can be used to study soil-crop relationships are not always available for most farm fields, numerous research efforts have articulated mathematical models to correlate soil characteristics with yield potential.

The current study used several approaches to gain data and information about soil and crop variables. Independent variables (in the present study those being soil parameters) were obtained from the soil survey inventory of Gallatin County, Montana conducted by the Natural Resources Conservation Service - US Dept. of Agriculture (NRCS-USDA). The soils information was made available publicly through a URL website. Dependent variables (crop yield estimates) were estimated using the Brown and Carlson (1990) equations for winter and spring wheats, and an equation by Bauder et al. (1978) for estimating alfalfa yield potentials.

This study was conducted in a relatively small geographic area with a diversity of soils. This was done to partition soil parameters from other external environmental factors which influence crop performance. Assuming "homogenous" external factors, variability in crop performance occurring in the Gallatin Valley area was expected to represent the effect of differences in soil characteristics. Winter wheat, spring wheat, and alfalfa were used for

conducting the analysis of soil-plant relationships. These crops are well suited to the environment of the Gallatin Valley.

The objectives of this study were to undertake an exercise which would investigate approaches of studying soil quality by looking at relationships between soil data and information from soil survey inventory and crop yield potentials. The ultimate goal was to gain an appreciation for methods of utilizing soil inventory data to assess soil quality. In this thesis, this was done by determining if there were identifiable soil factors which consistently or significantly influence crop performance and yield potential. Hypotheses to be tested in this study were : (1) can we use soil survey and inventory data for assessing yield potential and approaching the study of soil quality; (2) can we define soil quality using soil survey data; and (3) can a model to assess soil quality be developed using soil survey data ?

In this regard, the reader is advised to utilize and make application of the resultant models for the estimation of crop yield potential with significant apprehension. The models which have been developed here were not intended to be "stand alone" estimators and have, in fact, been developed and validated totally on the basis of similarly derived estimates. The primary focus of this investigation was to undertake an exercise which would illustrate one approach to assessing soil quality and familiarize the investigator with the potential uses of soil inventory data.

2. LITERATURE REVIEW

Soil Quality and Soil Health

Soil quality and soil health are terms of similar meaning. Soil scientists frequently refer to 'soil quality' when assessing or characterizing soil functions in the environment. On the other hand, farmers and land managers commonly consider soil health for expressing similar purposes of their soils. Rhoton and Lindbo (1997) evaluated soil quality as a means of defining the suitability of a soil for crop production purposes and environmental control.

Some soil scientists believe that soil quality is an abstract characteristic and one that can not be defined. From their perspective, soil quality is strongly dependent on external factors such as land use and soil management practices, ecosystem and environmental interactions, and socio-economic and political priorities (NRCS-USDA, 1996).

NRCS-USDA (1996) determined that the soil can and does serve many purposes, both to humans and the environment. These roles are best defined as soil function. Soil functionally provides a physical matrix, a chemical environment, and a biological setting for living organisms. Hydrologically, soil may regulate and partition water flow and storage. Moreover, it can control crop nutrient retention and cycles.

Definition of Soil Quality

A definition of soil quality may involve soil productivity, which can include an accounting of major chemical, physical, and biological characteristics of the soil. Soil

productivity may be utilized to quantify soil quality in relation to soil characteristics. One way to define soil quality is by characterization of a selection of specific soil components. For example, soil quality can be assessed by an evaluation of soil morphology, soil physical characteristics, soil chemical properties, and soil microbiological conditions (Turco et al., 1994). To define soil quality, the Soil Science Society of America (1987) takes into account attributes of soils that are inferred from soil characteristics or indirect observations (e.g. compatibility, erodibility, and fertility).

A broader definition of soil quality considers the capacity of a soil to function productively in a sustainable manner. Larson and Pierce (1991) define soil quality as the capacity of a soil to function within the ecosystem boundaries and interact positively with the environment external to that ecosystem. In addition to the 1991 definition, Pierce and Larson (1993) simply state that soil quality is fitness of soil for use, while Gregorich et al. (1994) state that soil quality is degree of fitness of a soil for a specific use. More specifically, NRCS-USDA (1996) claims soil quality as the fitness of a specific kind of soil to function within its surroundings, support plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation.

Parr et al. (1992) propose the definition of soil quality as the capability of soil to produce safe and nutritious crops in a sustained manner over the long-term, and to enhance human and animal health, without impairing the natural resource base or harming the environment. In addition, Harris et al. (1996) propose that quality of a soil is determined by the fitness of the soil body to protect water and air quality, sustain plant and animal productivity and quality and to promote human health.

Some other scientists define soil quality by looking at its function and behavior. Doran and Parkin (1994) consider soil quality as the capacity of a soil to function within ecosystem boundaries to sustain biological productivity, maintain environmental quality, and promote plant and animal health. The National Soil Survey Handbook (Soil Survey Staff, 1992) observes that soil quality is the performance of soil attributes which serve as criteria to make predictions of soil response and behavior. The attributes are inferred from observation and soil properties.

In general, researchers consider the relationship between soil and intended uses in order to evaluate soil quality. One common theme persists throughout this varied selection of definitions of soil quality. It (soil quality) is reflected in the ability of a specific soil to sustain or support a prescribed or defined use for an extended period of time.

Why is it Difficult to Define Soil Quality ?

The difficulty in defining soil quality arises from the complexity of pertinent soil properties which one attempts to assimilate into a single term or numeric value that will account for soil characteristics appropriate to a variety of uses (Rhoton and Lindbo, 1997). The complexity in the nature of soils makes this integration difficult. Doran and Parkin (1994) stated that soil quality is an abstract characteristic of the soil which is impossible to define, because it is dependent upon numerous external factors. An interpretation or perception of good soil also varies from person to person and with intended use of the soil.

Why do we Need to Define Soil Quality ?

The value of defining soil quality is that it provides a standard for whether or not a soil is managed and maintained in an acceptable states for future generations. Consequently, any definition of soil quality must be broad enough to be able to cover a number of facets of soil function (Doran and Parkin, 1994). In addition, an objective assessment or characterization of soil quality can serve as a valuable tool for soil management decision-making.

The criteria commonly used as indicators for soil quality/health are also used for assessing soil productivity. Since soil quality is still difficult to define, many people approach assessment of soil quality by trying to find some closely related factors. Rhoton and Linbo (1997) reported that effective soil depth has been highly correlated with adverse changes accompanying the modification in soil properties. Variation in effective soil depth and/or soil thicknesses due to either erosion or continual production processes may determine variability in the quality of soil. Therefore, soil depth can be used to explain differences in soil properties and accurately estimate soil productivity and erosion. At locations where soils are limited in thicknesses, effective soil depth may be a reasonable way of assigning an index of soil quality.

Soil productivity and soil erosion can be considered critical indicators in the study of soil quality because of their significant relationship to soil quality. Concepts of both soil productivity and soil erosion reflect the impacts of most soil and environmental characteristics. Soil productivity and soil erosion reflect many major soil properties and the soil's environmental condition; hence these two measurements may be adequate enough to be primary indicators of soil quality for many purposes.

Indicators for Assessment of Soil Quality

In order to assess the quality of soil, all properties that directly or indirectly determine soil function should be considered as part of the process (Visser and Parkinsons, 1992). These two scientists identified that carbon and nitrogen cycles are essential indicators of soil quality. In addition, Doran and Parkin (1994) identified pH, P_2O_5 , and K_2O as other soil factors to be considered for defining quality of a soil. They also considered soil physical properties (such as texture, rooting depth, permeability, and soil moisture), soil temperature, and microbial activity when assessing soil quality. A study by Entry et al. (1996) determined that the ratio between organic carbon and nitrogen is a poor predictor of annual crop yield but it may be an accurate indicator of soil health and a good predictor of long-term crop yield. Crop yield can be an important indicator of soil quality (Granatstein and Bezdicek, 1992), however, productivity individually is not enough to be a complete measure.

To improve Soil Quality

Quality of a soil can be improved in many different ways. Cropping diversity is a way of enhancing it. Research by Franco-Vizcaino (1996) revealed that increasing diversity of crop residues incorporated into the soil through rotations has been associated with better condition of agricultural land. This is because the soil gains improvements in soil tilth, nutritional status, and biological activity, which are indicators of soil quality. Any improvement in soil physical, chemical and biological conditions can be used to indicate changes in soil quality.

Soil Function and Soil Productivity

Soil is an integral part of the environment. It can play an important role influencing many different processes within the soil and/or in adjacent areas. NRCS-USDA (1996) identifies four roles of soil in the environment : a) to facilitate living organisms, b) to control water flows, c) to regulate changes among phases in the soil, and d) to filter, buffer, degrade, immobilize, and detoxify organic and inorganic materials.

Soil-Crop Relationships and Soil Productivity

Soil is a dynamic and living natural body that plays many important functions in terrestrial ecosystems (Doran and Parkin, 1994). Specific characteristics of the soil should be given consideration when use of the soil is intended for farm purposes (producing foods). Soil thickness, texture, and structure are among the important soil physical parameters relating to crop production through their influences on soil hydraulic properties, aeration, and nutrient holding capacity.

Soil and plant systems are very complicated. There are many variables influencing the soil properties that affect crop performance. Advances in computer technology have helped create means of considering soil variables to be combined in various interactions (Hanks and Ritchie, 1991). The combination of variables may be used to predict soil-crop relationships. A number of models with varying complexity have been proposed. The more complicated of these relationships may be less practical to farmers but may be useful to better understand the complexity of nature.

Many researchers have tried to simplify the relationships between soil and crop yield by developing models. The purpose of this model development is to organize what is known about a subject. Crop yield estimate models should be focused on growth rate, growth duration, and the extent of stresses (Ritchie, 1991). Such models should consider variables that determine root distribution in the soil (Jones et al., 1991). Hanks and Ritchie (1991) look at models as a simplification or imitation of the real thing or as a system of postulates.

Bauder (1998, personal communication) proposed evaluating soils originating from similar environments (but not necessarily the same parent material) in relation to crop yield potential to identify numerous combinations of soil variables which influence soil productivity. The significance of such an approach to the study of soil quality is the potential it lends to identifying influencing factors which frequently appear in the analysis of soil quality. He further suggested that one approach to identifying specific soil properties which can be considered synonymous with soil quality is to count the frequency with which various soil factors significantly correlate with crop yield within a reasonably confined geographic area. This would provide one approach or initial stage of evaluating soil productivity on a regional basis, based on the premise that soil quality is reflected in site yield potential.

Another method for assessing soil quality is to account for many different kinds of soil and environmental data or information (Halvorson et al., 1996). This would also allow evaluation of soil quality based on alternative uses of soil and provide a mechanism to estimate soil quality for un-sampled locations.

Brown and Carlson (1990) pointed out that water has been the most limiting factor in agricultural production in Montana. They successfully developed models for estimating

yield potentials of five different crops and the models have been expected to be applicable at a number of locations in north central Montana. Their equations consist of three main estimated values : plant available water (PAW), initial yield level (IYP), and a slope value (available water - yield relationship) for each crop. The PAW was based on stored soil water and rainfall during the growing season (May 1 through July 31). Amount of water provided by the soil was estimated by converting depth of soil wet to field capacity on the basis of soil textural classes. The other component of PAW is the amount of precipitation during the growing period. Seventy five percent of precipitation during the growing period was considered to contribute to stored soil water. Both estimation and calculation produced total amount (inches) of water available to the plant (total plant available water, PAW). IYP parameter was required to make the model more complete and rational.

Two of Brown and Carlson's equations are :

$$Y_s = 5.1 (ET - 3.8) \text{ bushels/acre} \quad [\text{Eq. 2-1}]$$

This equation is proposed to be useful for assessing yield potential of spring wheat (Y_s) and the equation prepared for winter wheat (Y_w) is as follows :

$$Y_w = 5.8 (ET - 3.9) \text{ bushels/acre} \quad [\text{Eq. 2-2}]$$

Brown and Carlson (1990) initially proposed a relationship between a variable ET (which they defined as evapotranspiration) and estimated plant yield. Inspection of the detail and approach of the Brown and Carlson models reveals that the ET term expressed in their models is, in fact, more accurately, an estimates of "plant available water" during the growing season. In as much as no attempt was actually made to either measure or estimate ET, the author has taken liberty to modify the Brown and Carlson equations in this investigation,

substituting the term PAW where ET was initially used. This has been done for the purposes of clarity and correctness of expression.

The Importance of Soil Organic Matter

Organic matter is a significant and controlling substance in the soil. It can influence significant properties of the soil. Doran and Parkin (1994) stated that, in general, soil organic matter can control biological, physical, and chemical characteristics of the soil. Moreover, organic matter plays a major role in determining the soil's ability to store and transmit soil water, regulate the availability of water to plants, and transport environmental pollutants up to the soil surface and into groundwater.

Calcic Horizon

Calcic horizons are subsurface horizons in which secondary carbonates have been precipitated to a significant extent (Soil Survey Staff, 1994). The high content of lime in the horizon may be derived from soil parent materials or as a result of pedogenic processes. To fulfil the criteria of calcic horizon, the accumulated carbonates should indicate an illuviation process. In more detail, Soil Survey Staff (1994) states that the layer should be at least 15 cm thick and contain not less than 15 percent CaCO_3 equivalent. High concentration of carbonates with no indications of cementation and/or induration distinguishes this horizon from a petrocalcic horizon.

Position of the lime from the soil surface has also been related to the topographic condition. The depth to the lime from the soil surface is generally shallower in soils located

on rolling to undulating areas than those of valley floor or flat areas. This phenomenon is strongly related to the erosion condition in the area. Montagne (1998, personal communication) drew a relationship between topographic condition and depth to calcareous layer in soil profile. The steeper the slopes and the more eroded the land is the shallower the depth to the calcic horizon from the soil surface.

The presence of and depth to the calcic horizon may be related to the amount of precipitation. Calcic horizons are considered to roughly indicate the average depth of water penetration into soil profile annually (Larson, 1986). Harper (1957) identified a strong relationship between the presence of calcic horizon and the amount of rainfall. Higher amounts of rainfall generally result in deeper depth to calcic horizon from the soil surface. In dry climates, the calcic horizon indicates the depth of rainfall penetration in the soil.

In terms of soil - crop relationships, the presence of calcium carbonate (CaCO_3) in rooting zones of calcareous soils can influence plant growth. Depth to calcium carbonate was found to be significantly correlated with crop production, especially cereal grain yields, in Montana (Burke, 1982). Medium level of calcium carbonate (less than 15 % CaCO_3 equivalent) in the soil column can have a positive effect on crop production, while medium to high levels of lime content can cause an imbalance of soil nutrients hence reducing the amount of crop production. Dry consistence of the calcic horizon was also positively correlated with yield.

In the field, the presence and depth of calcic horizon can be directly determined. Soil surveyors usually test this characteristic by looking at whether or not the horizon effervesces upon addition of HCl. If this characteristic is present when characterizing soil profiles, the

surveyors usually indicate it by affixing "k" or "ca" following primary horizon designations (eg. Bk, Cca, etc.).

3. MATERIAL AND METHODS

Soil and environmental variables of Gallatin Valley area were compared with respect to their relationships to crop yield estimates. The significance of the relationships was expected to show the level of importance among soil variables which influence predicted crop yields. Moreover, this project was an attempt by myself to gain a better understanding of soil quality.

Values for independent variables were obtained from the Natural Resources Conservation Service - U.S. Department of Agriculture (NRCS-USDA) soil databases by accessing URL addresses of NRCS housed in Iowa and Nebraska. Data for dependent (crop yield potential) variables were obtained from application of three algorithms and from interviewing experienced producers from the Gallatin Valley area.

Study Site and General Characteristics

The study sites were located in Gallatin Valley, Gallatin County, south western Montana (Figure 1). The study area is covered by seven sheets of topographic maps with a scale of 1:62,500 (USGS, 1947 through 1952). Geographically, the whole area is located between longitude 110°48' to 111°48' West and latitude of 45°31' to 46°04' North. Legal positions of the area were between Township T4S to T4N and Range R2W to R7E (DeYoung and Smith, 1931).

The soils of the study area were surveyed by NRCS-USDA personnel of Bozeman office and a final soil survey report is presently in the process of being completed. This

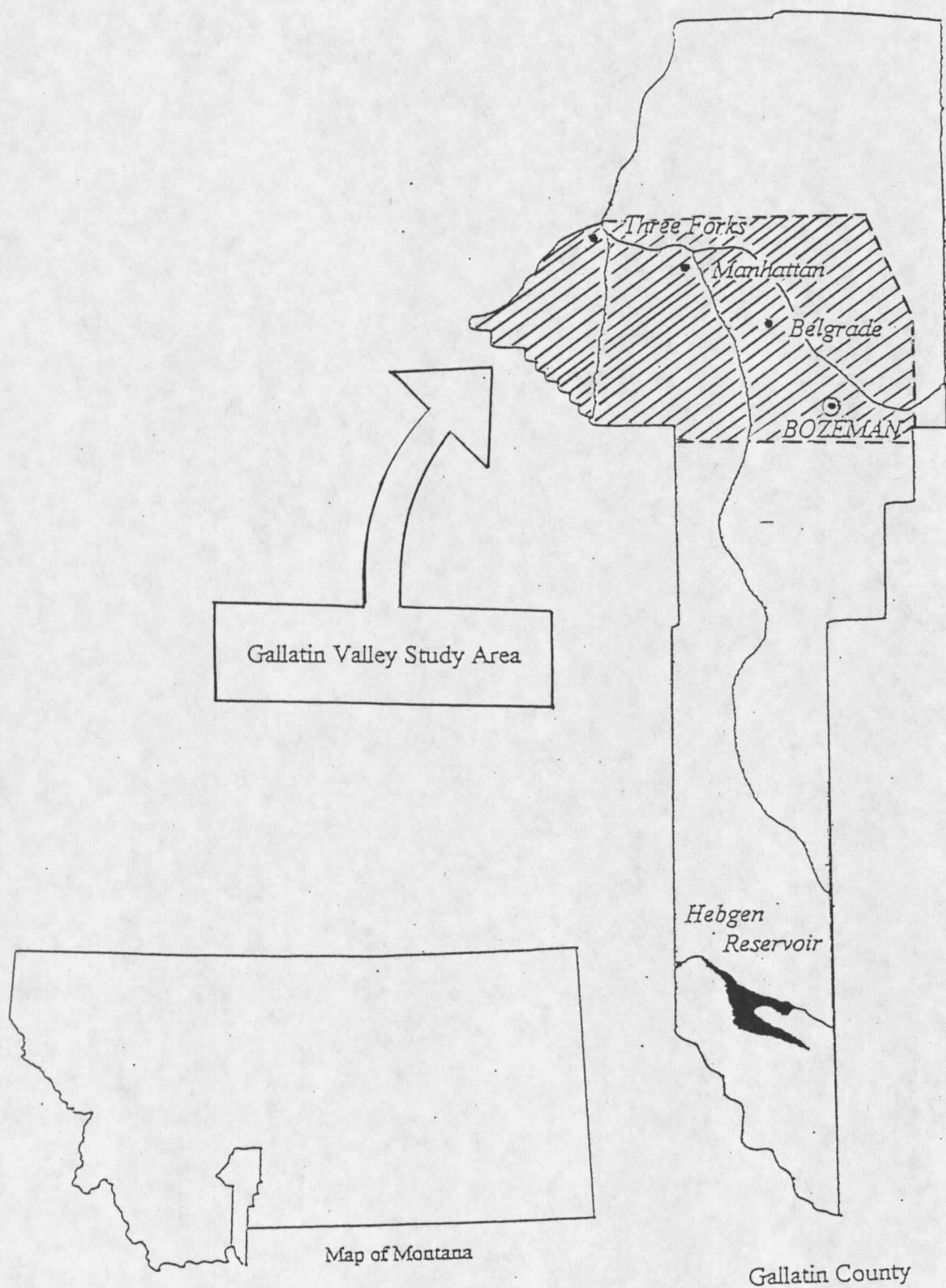


Figure 1. Study Location

location was chosen for study because it represented a relatively small geographic area with a diversity of soils having developed under a condition of "homogeneous or less variable" soil forming factors. Other reasons were that this area is well suited for cereal grains, and within the area there were many farm fields in which a number of soil series exist.

The Gallatin Valley area is characterized as receiving annual precipitation ranging from 38.1 to 55.9 cm (15 - 22 inches) and mean annual air temperature varying from 3.8 to 8.3°C (39 to 47°F) (NRCS-USDA, 1998). Physiographically, landforms of this area are commonly relict stream terraces and alluvial fans. Relief and topography of the area vary from flat to rolling plains with slope gradients up to 45 percent. Elevations vary from 1330 to 1930 m (4000 to 5800 ft) above sea level (DeYoung and Smith 1931; USGS 1947-52). Geologic parent materials of the soils in the Valley are loess, alluvial, and alluvio-colluvial (NRCS-USDA, 1998).

Soils of the Gallatin Valley area are commonly deep (greater than 100 cm thick), well drained, and moderate to moderately-slowly permeable. Top soils are somewhat thick (10 to 25 cm) and dark in color. Thicknesses of subsoils are greater than 75 cm. Some of the soils contain coarse fragments in the upper horizons and calcic horizons within the soil profiles (NRCS-USDA, 1998). Currently, land utilization of the soils included in this study is farm fields.

Selection of Soil Series

The soil series of the study, described in a semi-detailed (scale of 1:24,000) soil survey inventory in the Gallatin County (in the process of finalization), were selected based on

specific criteria. The selection process was initiated with a study of locations, geologic parent materials, climatic conditions, and slope gradients. In addition, the selection also considered capabilities of the soils for agricultural purposes, especially cereal grains. The third criterion was the availability, access to, and completeness of the data for selected soils.

Initially the data for essentially all the soils of Gallatin Valley area were listed. A check was then made of the geologic parent materials. Parent materials included loess, alluvial, and alluvio-colluvial. Soils derived from these three parent materials were selected for this study. Limited climatic information was obtained from narrative soil series descriptions. Information on slope gradients was obtained from the soil mapping units or soil morphological descriptions. Furthermore, evaluations by NRCS-USDA on the soil series capabilities for general agriculture were also taken into account. The emphasis of this project was on the mapping units having slope classes of A, B, and C. The objective of this approach (taking "similar" soil geologic parent materials, relatively small area, and certain ranges of slope gradients) was to focus as much as possible solely on 'soil' factors in further analyses.

Eleven soil series in total originating from Gallatin Valley area were selected for this study. The selected soil series were : Amsterdam, Beanlake, Beaverton, Blackdog, Bozeman, Kelstrup, Martinsdale, Meagher, Sawicki, Turner, and Windham (Table 3-1, and Appendices A and B). Each soil series was represented by the data from at least one 'representative' pedon (Appendix D). In total, twenty nine soil pedons, having 162 horizons along with soil laboratory data, were included in the analysis (Table 3-2).

Table 3-1. Soil series, parent material, and family level classification of representative pedon used as source of independent variable data.

No	Soil Name	Parent material	Classification (Family Level)
1.	Amsterdam	Loess	Typic Haploborolls, fine-silty, mixed, sup.
2.	Beanlake	Alluvium	Typic Calciustolls, fine-loamy, mixed, sup., frigid
3.	Beaverton	Alluvium	Typic Argiustolls, loamy-skeletal over sandy or sandy skeletal, mixed, sup., frigid
4.	Blackdog	Loess	Typic Argiborolls, fine-silty, mixed, sup.
5.	Bozeman	Loess	Argic-Pachic Cryoborolls, fine-silty, mixed
6.	Kelstrup	Loess	Aridic Haploborolls, coarse-silty, mixed, sup.
7.	Martinsdale	Alluvio-colluvial	Typic Argiustolls, fine-loamy, mixed, sup.
8.	Meagher	Alluvio-colluvial	Typic Argiborolls, fine-loamy, mixed, sup.
9.	Sawicki	Alluvio-colluvial	Typic Argiustolls, loamy-skeletal, mixed, sup., frigid
10.	Turner	Alluvium	Typic Argiustolls, fine-loamy over sandy or sandy skeletal, mixed, sup., frigid
11.	Windham	Alluvio-colluvial	Typic Calciustolls, loamy-skeletal, carbonatic, frigid

Note : Si = silt, L = loam, Cob = cobbly, C = clay, Gra = gravelly, sup. = superactive.

Soil names include the texture class of the Ap horizon.

The majority of the selected soil series were defined/described as loamy families of Typic Argiustolls. Others were Argiborolls, Calciborolls, Cryoborolls, and Haploborolls. All of the soils were classified as Mollisols (Soil Survey Staff, 1994). The selected soil series were assumed to have developed under "relatively homogenous" geological and climatic conditions based on inspection of the soil parent materials, and temperature and moisture

Table 3-2. Statistics of soils data and information obtained from URL Website.

No.	Soil Series	Independent Variables								
		pdn	horiz	thick	clay	BD	WRD	OC	pH	DCH
		 Number of representative data points								
2.	Amsterdam	7	42	42	42	29	18	42	42	7
3.	Beanlake	2	8	8	8	8	8	8	8	2
4.	Beaverton	2	9	9	9	-	N/A	9	9	2
5.	Blackdog	3	11	11	11	-	N/A	11	11	3
6.	Bozeman	1	9	9	9	9	5	9	9	1
7.	Kelstrup	2	10	10	10	-	N/A	10	10	2
8.	Martinsdale	4	32	32	32	17	13	32	25	4
9.	Meagher	1	4	4	4	4	4	4	4	1
10.	Sawicki	2	11	11	11	11	11	11	11	1
11.	Turner	3	13	13	6	19	19	13	19	3
12.	Windham	2	7	7	7	7	7	7	7	2
Total		29	162	162	150	104	93	157	155	28

Note : pdn = pedon; horiz = horizon; thick = thickness; BD = bulk density; WRD = water retention depth; OC = organic carbon; DCH = depth to calcic horizon; N/A = not available.

regimes. Based on evaluations by NRCS-USDA, the capabilities of the soils were classified into class 3E for general irrigated and non-irrigated farm uses. Agricultural potentials of the soils were rated as low, medium, and high.

Selection of Independent Variables

Independent variable data were obtained from profile descriptions and laboratory data of the selected soil series. Each soil horizon in the initial database was defined by 61 types of soil information. This information can be grouped into two general categories : morphological data (10 parameters or descriptors) and laboratory data (51 parameters). The laboratory data can be further divided into 3 groups : physical, chemical, and mineralogical data consisting of 28, 19, and 4 parameters, respectively.

Some of the soil morphological information was difficult to analyze quantitatively because of the data characteristics. For instance, soil consistence, rooting condition, level of effervescent, and soil structure are described qualitatively. Soil colors, coded as a combination of alpha numeric and characters, were also difficult to analyze with respect to their linear relationship with other parameters. This is because hue values of soil color charts are designed to follow cylindrical coordinates geometrically (Zelenak, 1995). In addition, although useful from interpretive perspective, soil profile descriptions were found to be ineffectual for quantitative analysis. Discussions of soil profile characteristics are included in Appendix C.

Type of soil clay mineral was disregarded in this study. Although this information was available for use, clay type was reported qualitatively in the database and the data were not available for all soil horizons. This information might be useful to help explain some properties of the soil and to make further interpretation about the soil in future studies.

Inspection of the entire database revealed that the database was incomplete with respect to some variables. Variables with incomplete data sets were eliminated from the

database. After reducing the list of above soil parameters and considering completeness of the laboratory data, 19 soil physical and 8 chemical variables were then analyzed with respect to their correlation to each other. The 27 soil variables were subjected to a correlation analysis using the Pearson coefficients with a significance level of 0.05 as the selection criteria for further inclusion in the study.

Based on Pearson coefficients, six soil variables obtained from the soils laboratory data were then selected for further study. A seventh and eighth variable, depth to calcic horizon (calcic) and soil erodibility (Kf), were subsequently added to the list. Values for depth to calcic horizon were determined from soil morphological information and horizon designations, and from soil pH laboratory data. Information on soil erodibility was provided by the NRCS field office at Bozeman. In total, eight independent soil variables were involved in the analysis (Table 3-3).

Table 3-3. Independent variable, code, and dimension of unit included in subsequent analyses.

No	Parameter	Code	Unit
1.	Soil thickness	thick	cm
2.	Soil clay content	clay	g/100 g
3.	Soil bulk density	BD	g/cm ³
4.	Soil water holding capacity	WHC	cm/cm
5.	Soil organic carbon content	OC	g/100 g
6.	Erodibility	Kf	
7.	Soil pH	pH	pH unit
8.	Depth to calcic horizon	calcic	cm

Weighted and Averaged Value of Independent Variables

Laboratory data for each soil profile were simplified to obtain single values where appropriate. The laboratory data values for clay content (clay), bulk density (BD), soil water holding capacity (WHC), organic carbon content (OC), and pH from each horizon were weighted using a method by Rhoton and Lindbo (1996) to produce single values representing soil profiles. The weighting method took into consideration thickness and variable value of the corresponding horizon. By summing the product of horizon thickness and the corresponding variable value for all horizons of the profile, and then dividing the sum by the total profile thickness, a single value for the independent variable was derived for subsequent analysis. The arithmetic weighted values for replicate soil pedons were then averaged to obtain single values for each soil series. The average weighted values of the soils data are present in Table 3-4. The formula used for weighting the variable values is as follows :

$$I = (\Sigma(t * i))/T \text{ (Rhoton and Lindbo, 1996)} \quad [\text{Eq. 3-1}]$$

where I = weighted average value, t = thickness of the horizon (cm), i = value of independent variable, and T = total thickness of the soil profile (cm).

Table 3-4. Average weighted value of the soil characteristic defined as independent variable for subsequent analyses.

No.	Soil Series	Independent Variable							
		thick	clay	BD	WHC	OC	Kf	pH	calcic
		cm	g/100g	g/cm ³	cm/cm	g/100g			cm
1.	Amsterdam	103	20.5	1.33	0.18	1.00	0.42	7.9	41.7
2.	Beanlake	152	21.5	1.48	0.14	1.23	0.37	8.2	15.2
3.	Beaverton	66	13.8	1.58	0.06	0.53	0.19	7.7	52.0
4.	Blackdog	104	22.2	1.28	0.18	1.31	0.35	7.8	61.0
5.	Bozeman	145	22.8	1.50	0.15	1.08	0.35	8.4	51.0
6.	Kelstrup	152	21.5	1.49	0.11	0.39	0.36	8.3	39.0
7.	Martinsdale	67	23.2	1.53	0.13	0.82	0.37	7.7	35.8
8.	Meagher	152	21.9	1.47	0.11	1.00	0.36	7.8	48.3
9.	Sawicki	116	18.8	1.56	0.07	1.36	0.27	6.9	> 152.4
10.	Turner	61	12.7	1.40	0.12	0.63	0.27	7.9	47.0
11.	Windham	91	22.7	1.47	0.09	0.69	0.42	8.1	53.3

Note : Soil thickness was calculated as the weighted average thickness of the A and B horizons using the method described in equation 3-1.

Obtaining Yield Estimates

Development of crop potential data (or dependent variables) was approached through calculations and estimations. Three algorithms were employed to calculate yield estimates for the study sites. Equations by Brown and Carlson (1990) for estimating winter and spring wheat yield potentials, and an equation by Bauder et al. (1978) for predicting alfalfa crop yield were used. The algorithms used were based on PAW and/or ET (inches) values as follows :

for winter wheat : $Y_w = 5.8 * (PAW - 3.9)$ bushels/acre [Eq. 3-2],

for spring wheat : $Y_s = 5.1 * (PAW - 3.8)$ bushels/acre [Eq. 3-3],

and for alfalfa hay : $Y_A = 0.2 * (ET)$ tons/acre [Eq. 3-4].

For purpose of this study and for development of these three models, PAW is defined as stored soil water and additional water (inches) during the growing season. PAW estimates were equated with ET for use in equation 3-4. The PAW values which were substituted into equations 3-2, 3-3, and 3-4 were generated from two sources of data, NRCS-USDA and MAPS Atlas.

Five different databases of yield estimates were developed for subsequent analysis with the independent soil variables. These databases were identified as 1) NRCS, 2) MAPS-1, 3) MAPS-2, 4) MAPS-3, and 5) Producers' survey.

NRCS

The lack of reliable long-term actual crop yield records for each soil series of the study necessitated use of previously documented yield estimation models to obtain dependent data. One source of yield estimates was that the NRCS-USDA. The NRCS-USDA utilizes soil survey results to predict crop-yields based on estimates of plant available water.

MAPS

Data from the MAPS Atlas database (Caprio et al., 1994) were used in conjunction with equations 3-2, 3-3, and 3-4. Information about soil water holding capacity (WHC), mean monthly precipitation (Ppt), and potential evapotranspiration (PET calculated using

Penman method) were generated from this database. The extracted information was then used to produce three different PAW or potential water use values.

- MAPS-1

MAPS-1 utilized the information on soil water holding capacity - WHC (variable number 104 of the MAPS Atlas database) and precipitation - Ppt during the growing season to calculate PAW values as follows :

$$PAW = WHC + Ppt \quad [Eq. 3-5]$$

where Ppt (precipitation) for alfalfa was taken from March through September (variables 89 through 95); for spring wheat from May through August (variables number 91 to 94), and for winter wheat from April through July (variables number 90 to 93).

- MAPS-2

The method referred to as MAPS-2 considered PAW values were similar to PET values calculated by the Penman method from April through September (variables number 37 through 42). PET (potential evapotranspiration) for winter wheat = PET values from May through July + 1/3 PET in August, for spring wheat, PET = 1/2 PET in May + PETs of June and July, and 1/3 PET in August (Schaff, personal communication); and PET for alfalfa = PET from April to August + 1/2 PET in September (Bauder, personal communication).

- MAPS-3

Considering the MAPS-2 method, Bauder (personal communication) suggested making an adjustment to derive an additional PAW estimate. The adjustments combined the MAPS-1 and MAPS-2 methods to include PET, WHC and Ppt data for calculation. The adjuster - X value was calculated as follows :

$$X = (WHC + Ppt)/PET \quad [Eq. 3-6]$$

and the PAW was approached using the following equation :

$$PAW = PET \times X \quad [Eq. 3-7].$$

Ideally, if PAWs were equal to PET, then this X values would equate to 1.0. Otherwise, the X value would be a proportionality less than 1.0, thereby reducing the Ppt contribution to PAW. The climatic data used in equations 3-6 and 3-7 were similar to those in equations 3-5. Based on PAW values obtained from application of equations 3-5 and 3-7, and the data from MAPS Atlas (Caprio et al., 1994), crop yield estimates were calculated using equations 3-2, 3-3, and 3-4 for estimating yield potentials of spring and winter wheats, and alfalfa, respectively. A summary of the PAW values calculated using the procedures defined as MAPS-1, MAPS-2, and MAPS-3 is presented in Table 3-5.

Table 3-5. Summary of the estimated PAW or potential water use value from the three MAPS methods.

No.	Soil Series	Estimated PAW value								
		MAPS-1 method			MAPS-2 method			MAPS-3 method		
		W	S	A	W	S	A	W	S	A
		 inch								
1.	Amsterdam	14.3	14.1	17.8	20.5	18.2	30.2	19.8	19.7	20.0
2.	Beanlake	17.9	17.5	20.8	20.0	17.7	29.6	19.1	19.0	19.4
3.	Beaverton	17.3	17.0	21.1	20.9	18.4	30.7	20.0	19.9	20.2
4.	Blackdog	17.6	17.2	21.4	20.9	18.4	30.7	20.2	19.9	20.2
5.	Bozeman	16.3	15.7	20.5	21.1	18.6	31.0	20.2	20.1	20.4
6.	Kelstrup	18.2	17.8	22.1	21.1	18.6	31.0	20.2	20.1	20.4
7.	Martinsdale	17.6	17.2	21.5	19.9	17.6	29.2	19.1	19.0	19.3
8.	Meagher	12.7	12.5	16.2	20.4	18.0	29.9	19.7	19.7	19.9
9.	Sawicki	18.6	17.5	24.4	19.0	16.8	27.4	18.0	17.9	18.2
10.	Turner	17.0	16.7	20.3	21.1	18.7	31.0	20.3	20.2	20.5
11.	Windham	15.6	15.5	20.2	18.2	16.1	26.7	17.3	17.2	17.5

Note : W = winter wheat, S = spring wheat, A = alfalfa.

Producers' Survey

Another method used to obtain yield potentials was by direct estimation. Seven experienced crop producers (Morgan et al., personal communication) from the Gallatin Valley were asked to provide estimated yield potentials at seven of the eleven sites. The

predictions were based on their experiences, a data set of soil and climatic conditions at each site, and an actual field site inspection where the producers discussed limitations and potentials before providing yield estimates.

Dependent Variables

Dependent variables in this study were yield prediction estimates of three indicator crops corresponding to the eleven selected soil series. The indicator crops were spring and winter wheat (*Triticum aestivum L.*), and alfalfa (*Medicago sativa L.*). Yield estimates from NRCS, application of MAPS-1, MAPS-2, and MAPS-3 data to equations 3-2, 3-3, and 3-3, and from producer estimates were the primary sources of data used in the dependent variable analysis. A summary of the various yield estimate abbreviations, by method of derivation, is presented in Table 3-6.

All of the yield data were treated as dependent variables. For purposes of statistical analysis, crop names (dependent variables) were abbreviated W (winter wheat), S (spring wheat), and A (alfalfa). Numbers following these three letters in Table 3-6 indicate sources of data or information. For example, A-1 means the yield estimation for alfalfa (A) was based on NRCS estimates (1).

Table 3-6. Dependent variable, code, and dimension of unit included in subsequent analysis.

Dependent Variable by method	Code	Unit
Alfalfa Hay NRCS	A-1	Mg/ha
Alfalfa Hay MAPS-1	A-2	Mg/ha
Alfalfa Hay MAPS-2	A-3	Mg/ha
Alfalfa Hay MAPS-3	A-4	Mg/ha
Alfalfa Hay Producers	A-5	Mg/ha
Spring Wheat NRCS	S-1	Mg/ha
Spring Wheat MAPS-1	S-2	Mg/ha
Spring Wheat MAPS-2	S-3	Mg/ha
Spring Wheat MAPS-3	S-4	Mg/ha
Spring Wheat Producers	S-5	Mg/ha
Winter Wheat NRCS	W-1	Mg/ha
Winter Wheat MAPS-1	W-2	Mg/ha
Winter Wheat MAPS-2	W-3	Mg/ha
Winter Wheat MAPS-3	W-4	Mg/ha
Winter Wheat Producers	W-5	Mg/ha

Note : 1 = NRCS, 2 = MAPS-1, 3 = MAPS-2, 4 = MAPS-3, 5 = Producers.

Statistical Methods

Independent and dependent variables used in the statistical analysis were all coded and are listed in Tables 3-2 and 3-6, respectively. Values for the independent variables used in the analysis were those listed in Table 3-4. Values for the dependent variables determined by the five estimation procedures are presented in the Results and Discussion (Tables 4-2

through 4-6). Analyses were conducted using Statistical Analysis System (SAS Inc., 1994) procedures.

Correlation Analysis

Correlation analysis was conducted using SAS Process Correlation (SAS Proc Corr) procedure, with the strength of relationships indicated by Pearson's correlation coefficient, commonly known as r (small r). The p -values (probability of significance due to treatment effect) at the 0.05 and 0.01 probability levels were determined using a t -test.

Initial analysis was completed to determine relationships among the independent variables. The eight independent variables from 11 soil series were assessed to determine correlation with each other. Any strong relationship among independent variables was inspected and subsequently assessed for possible collinearity. SAS procedures were also used to diagnose collinearity relationships among the selected independent variables. The independent variables were subsequently-correlated with the dependent variables to identify variables having strong associations with independent variables.

Regression Analysis

SAS stepwise linear regression analysis (SAS Inc., 1994) was conducted to identify soil parameters (independent variables) which were associated with estimated yields (dependent variables). This procedure worked in forward selection and assessed the significance of each independent variable sequentially. The process added variables one by one, depending on calculated F -statistic values. Variable having the highest F -statistic value

was included first. Variables with successively lower F-statistic values were sequentially considered. The NRCS soils data/information was the source of the independent variables.

This procedure helped produce regression models. Besides that, this procedure was also expected to help identify the "best" fit independent variables for regression model development. The best variables were then used to develop predictive models for estimating yields.

4. RESULTS AND DISCUSSION

The primary intent of this investigation was to design, conduct and assess a study that would provide an experience of utilizing soil survey and inventory data in an assessment of soil quality. Admittedly many approaches to soil quality have been proposed in the scientific literature and no single method has received universal acceptance. The approach used here was designed to investigate assessment of soil quality and soil potential based on a very limited set of data. Soil quality was not, in fact, defined specifically at any point in the design of this investigation. This was a concerted decision of the design, in as much as it was recognized that soil quality is dictated by the intended use of the soil resource.

Specifically for this study, the notion of soil quality was transposed with site potential for growth and agricultural production of three crops, i.e., spring and winter wheat and alfalfa. Hence, the underlying premise of this investigation was as follows : the experience of defining soil quality or potential, assessing available soil inventory data, and utilizing soil inventory data and other available resource information would expose the researcher to the diversity of approaches available for utilizing soil inventory data in the process of assessing soil quality or site capability.

Slope Impacts on Soils and Estimated crop yields

Soil mapping units (SMU) with which the soil series were associated are shown in Appendix E. The SMUs were coded with a combination of numbers and characters.

Numbers indicate the order of the soil mapping units, and characters affixed to the numbers represent slope classes of the mapping units. For instance, SMU 53B equates to mapping unit 53, slope class B. The mapping unit descriptions are part of Soil Survey Inventory Report of Gallatin County, Montana being processed by the NRCS-USDA of Bozeman. The slopes of the study sites were grouped into A, B, and C classes, which represented slope gradients of 0-4, 4-8, and 8-15 m/100 m, respectively.

NRCS yield estimates of a single soil series located on slope classes of A, B, and C were similar (Appendix E) (NRCS-USDA, 1997). In fact, yield estimates for soils of a single series with multiple slope classes did not differ significantly. The lack of significant differences in yield due to variation in slope might be the consequence of the narrow range of slope gradients of the selected soils used in this analysis. All of the selected soil series were located on slope classes of less than 15 m/100 m. One would expect some degree of significance in variation in yield among similar soils with extreme variations in slope gradient. These variations would be due to differences in solar radiation, rainfall interception, runoff, erosion, and drainage.

Crop Yield Estimates

NRCS

Table 4-1 shows crop yield estimates reported by NRCS-USDA for the eleven soil series of this study. The yield estimates for winter wheat ranged from 2.08 Mg/ha (31 bu/ac) to 4.43 Mg/ha (66 bu/ac), for spring wheat from 1.81 Mg/ha (26.9 bu/ac) to 3.94 Mg/ha (58.5 bu/ac), and for alfalfa from 1.68 Mg/ha (0.8 t/ac) to 4.49 Mg/ha (2.0 t/ac). Beaverton

series had the lowest estimated winter wheat and alfalfa yields, and essentially the same estimated spring wheat as Windham series, which had the lowest spring wheat yield. The greatest yields occurred with the Bozeman series for the three crops. Estimated alfalfa yield was relatively high in the Amsterdam and Blackdog series. Based on evaluations by NRCS-USDA, the capabilities of the soils were classified into class 3E for general irrigated and non-irrigated farm uses (NRCS-USDA, 1998). Agricultural potentials of the soils were rated as low, medium, and high (Rolfes, personal communication).

Table 4-1. Agricultural potential rating and yield estimate of winter wheat, spring wheat, and alfalfa on selected soil series, based on NRCS-USDA evaluation.

No.	Soil Series	APR	Estimated Yield					
			Winter Wheat		Spring Wheat		Alfalfa	
			Mg/ha	bu/ac	Mg/ha	bu/ac	Mg/ha	t/ac
1.	Amsterdam	high	4.30	64.0	3.82	56.8	4.49	2.0
2.	Beanlake	med	3.43	51.0	3.05	45.4	3.37	1.5
3.	Beaverton	low	2.08	31.0	1.87	27.8	1.68	0.8
4.	Blackdog	high	4.17	62.0	3.70	55.0	4.49	2.0
5.	Bozeman	high	4.43	66.0	3.94	58.5	4.49	2.0
6.	Kelstrup	med	3.63	54.0	3.22	48.0	3.37	1.5
7.	Martinsdale	med	3.43	51.0	3.05	45.4	4.04	1.8
8.	Meagher	med	3.16	47.0	2.81	41.8	3.37	1.5
9.	Sawicki	low	2.28	34.0	2.04	30.4	2.24	1.0
10.	Turner	med	2.89	43.0	2.58	38.3	3.37	1.5
11.	Windham	low	2.02	30.0	1.81	26.9	2.24	1.0

Note : Conversion from Mg/ha to ton/acre, multiply the value by 0.4457, and from Mg/ha to bushel/acre, multiply the table value by 14.881.

APR = agricultural potential rating; bu/ac = bushel/acre; t/ac = ton/acre; med = medium.

MAPS-1

The MAPS-1 procedure [Eq. 3-5 applied to Eq. 3-2, 3-3, and 3-4] estimated yield on the basis of precipitation (Ppt) during the growing season and soil water holding capacity (WHC) data, which were obtained from MAPS Atlas (Caprio et al., 1994) database. Table 4-2 provides yield estimates calculated using equations 3-2, 3-3, and 3-4 where PAW values were obtained from summing WHC and Ppt during the growing season. The yield estimates

Table 4-2. Yield estimate of winter wheat, spring wheat, and alfalfa on selected soil series based on MAPS-1 approach.

No.	Soil Series	Estimated Yield					
		Winter Wheat		Spring Wheat		Alfalfa	
		Mg/ha	bu/ac	Mg/ha	bu/ac	Mg/ha	t/ac
1.	Amsterdam	4.05	60.3	3.53	52.5	9.60	3.6
2.	Beanlake	5.46	81.2	4.70	69.9	9.78	4.4
3.	Beaverton	5.22	77.7	4.52	67.3	9.47	4.2
4.	Blackdog	5.34	79.5	4.59	68.4	9.60	4.3
5.	Bozeman	5.46	81.2	4.35	64.9	10.59	4.7
6.	Kelstrup	5.73	82.9	4.80	71.4	9.91	4.4
7.	Martinsdale	5.34	79.5	4.59	68.3	9.90	4.3
8.	Meagher	3.43	51.0	2.98	44.4	7.27	3.2
9.	Sawicki	5.73	85.3	4.69	69.9	10.95	4.9
10.	Turner	5.11	76.0	4.42	65.8	9.11	4.1
11.	Windham	4.56	67.9	4.01	59.7	9.06	4.0

Note : bu/ac = bushel/acre; t/ac = ton/acre; see note, Table 4-1, for conversion.

for winter wheat ranged from 3.43 Mg/ha (51.0 bu/ac) to 5.73 Mg/ha (85.3 bu/ac), while the estimates for spring wheat ranged from 2.98 Mg/ha (44.4 bu/ac) to 4.80 Mg/ha (71.4 bu/ac), and for alfalfa they ranged from 7.27 Mg/ha (3.2 t/ac) to 10.95 Mg/ha (4.9 t/ac). The lowest estimated values for the three crops occurred on the Meagher series. Sawicki estimated yield values appeared to be the highest for alfalfa, and Kelstrup was the highest in spring wheat yield estimates, while both series were the highest in winter wheat yield estimated values.

MAPS-2

The MAPS-2 procedure estimated crop yields based on Penman potential evapotranspiration (PET-Penman) during the growing season from MAPS Atlas database (Caprio et al., 1994). PET values for winter wheat were generated using climatic data for May to July and one-third of August. For spring wheat, the PET data were from June to July, and half of May and one third of August. PET values for alfalfa included climatic data from April through August and one half of September. Equations 3-2, 3-3, and 3-4 were utilized by inserting PET values as substitutes into PAW and ET. Soil input data included soil water holding capacity (WHC) derived from the MAPS Atlas database.

Table 4-3 presents yield estimates calculated using the MAPS-2 method. The yield estimates for winter wheat ranged from 5.57 Mg/ha (82.9 bu/ac) to 6.69 Mg/ha (99.6 bu/ac), for spring wheat from 4.20 Mg/ha (62.5 bu/ac) to 5.10 Mg/ha (75.8 bu/ac), and for alfalfa, the yield estimates ranged from 11.96 Mg/ha (5.3 t/ac) to 13.91 Mg/ha (6.2 t/ac). The lowest estimated yields for the three crops were associated with the Windham series, while the highest estimated yields for those crops were associated with the Turner series. Besides Turner, Kelstrup series was also the highest in winter wheat yield estimates.

Table 4-3. Yield estimate of winter wheat, spring wheat, and alfalfa on selected soil series based on MAPS-2 approach.

No.	Soil Series	Estimated Yield					
		Winter Wheat		Spring Wheat		Alfalfa	
		Mg/ha	bu/ac	Mg/ha	bu/ac	Mg/ha	t/ac
1.	Amsterdam	6.47	96.3	4.91	73.2	13.53	6.0
2.	Beanlake	6.42	95.6	4.78	71.1	13.26	5.9
3.	Beaverton	6.61	98.4	5.01	74.6	13.78	6.1
4.	Blackdog	6.61	98.4	5.01	74.6	13.78	6.1
5.	Bozeman	6.47	96.3	4.92	73.2	13.53	6.0
6.	Kelstrup	6.69	99.6	5.08	75.6	13.89	6.2
7.	Martinsdale	6.25	93.0	4.74	70.6	13.10	5.8
8.	Meagher	6.42	95.5	4.86	72.3	13.39	6.0
9.	Sawicki	5.87	87.4	4.46	66.4	12.32	5.5
10.	Turner	6.69	99.6	5.10	75.8	13.91	6.2
11.	Windham	5.57	82.9	4.20	62.5	11.96	5.3

Note : bu/ac = bushel/acre; t/ac = ton/acre; see note, Table 4-1, for conversions.

MAPS-3

The MAPS-3 procedure estimated crop yields based on adjustments of the PET values using the MAPS-2 method (Eq. 3-7). MAPS-3 procedure included what the investigators intended to be an adjustment or modification of the approach used to estimate PET, corrected or adjusted for the deficit between PET and PAW. The X values were calculated using equation 3-6, and the PAWs were estimated using equation 3-7. This procedure was used

to provide an accounting for both stored soil water at the beginning of the growing season and growing season rainfall. Subsequent inspection of this approach revealed that the adjustment resulted in calculating PAW to a value nearly identical to that used for MAPS-1, hence the lack of improvement in prediction.

Table 4-4 shows estimated yields calculated using the MAPS-3 method. The calculated values for winter wheat ranged from 5.49 Mg/ha (81.7 bu/ac) to 6.38 Mg/ha (94.9 bu/ac), for spring wheat from 3.87 Mg/ha (57.6 bu/ac) to 4.79 Mg/ha (71.3 bu/ac), and for

Table 4-4. Yield estimate of winter and spring wheats, and alfalfa on selected soil series based on MAPS-3 approach.

No.	Soil Series	Estimated Yield					
		Winter Wheat		Spring Wheat		Alfalfa	
		Mg/ha	bu/ac	Mg/ha	bu/ac	Mg/ha	t/ac
1.	Amsterdam	6.20	92.2	4.65	69.2	13.28	5.9
2.	Beanlake	5.94	88.4	4.44	66.0	12.97	5.8
3.	Beaverton	6.29	93.6	4.69	69.8	13.48	6.0
4.	Blackdog	6.28	93.5	4.69	69.8	13.48	6.0
5.	Bozeman	6.20	92.2	4.65	69.2	13.28	5.9
6.	Kelstrup	6.35	94.6	4.75	70.7	13.60	6.1
7.	Martinsdale	5.90	87.9	4.41	65.6	12.81	5.7
8.	Meagher	6.18	91.9	4.62	68.7	13.17	5.9
9.	Sawicki	5.49	81.7	4.10	61.1	11.96	5.3
10.	Turner	6.38	94.9	4.79	71.3	13.64	6.1
11.	Windham	5.57	78.0	3.87	57.6	11.64	5.2

Note : bu/ac = bushel/acre; t/ac = ton/acre; see note, Table 4-1, for conversions.

alfalfa the yields ranged from 11.64 Mg/ha (5.2 t/ac) to 13.64 Mg/ha (6.1 t/ac). Windham series appeared to have the lowest estimated yield for spring wheat and alfalfa, while Sawicki series had the lowest estimated winter wheat yield. Turner series yield estimates appeared to be the highest for the three crops.

Producers' Estimates

Table 4-5 is a list of "estimates" of yield potentials as reported by experienced producers from Gallatin Valley. Estimates of winter wheat yield provided by the producers ranged from 2.37 Mg/ha (35.3 bu/ac) to 4.84 Mg/ha (72.0 bu/ac), for spring wheat from 2.12 Mg/ha (31.5 bu/ac) to 4.57 Mg/ha (68.0 bu/ac), and for alfalfa yield estimates ranged from 4.94 Mg/ha (2.2 t/ac) to 8.53 Mg/ha (3.8 t/ac). As with the MAPS-3 procedure, the Windham series appeared to have the lowest predicted yields for the three crops. Yield estimates for the Turner series appeared to be the highest for the three crops. Although the relative ranking of the series were similar between the producers' estimates and those from MAPS-3, the yields estimated by the producers were quite low compared to the other estimates. This was also consistent with the MAPS-2 procedure.

Table 4-5. Yield estimate of winter wheat, spring wheat, and alfalfa on selected soil series based on Producers' input.

No.	Soil Series	Estimated Yield					
		Winter Wheat		Spring Wheat		Alfalfa	
		Mg/ha	bu/ac	Mg/ha	bu/ac	Mg/ha	t/ac
1.	Amsterdam	4.23	63.0	4.30	64.0	8.53	3.8
2.	Beanlake	3.83	57.0	3.83	57.0	6.73	3.0
3.	Beaverton	3.90	58.0	4.30	64.0	7.58	3.4
4.	Blackdog	4.66	69.3	4.61	68.6	7.54	3.4
5.	Bozeman *)	4.37	65.9	3.88	57.6	6.78	3.0
6.	Kelstrup *)	3.62	53.8	3.21	47.8	5.92	2.6
7.	Martinsdale	3.23	48.0	3.40	50.6	6.73	3.0
8.	Meagher *)	2.97	44.2	2.65	39.4	5.61	2.5
9.	Sawicki	2.69	40.0	3.02	45.0	5.90	2.6
10.	Turner	4.84	72.0	4.57	68.0	8.53	3.8
11.	Windham *)	2.37	35.3	2.12	31.5	4.94	2.2

Note : *) Estimated values for these soils were not derived from producers' field site reviews. These estimated yields were obtained through comparing the soil series characteristics reported in NRCS surveys and the visited soil series.

Correlation Analysis

A correlation analysis using SAS Process Correlation (SAS Proc Corr) procedure was conducted to determine correlation strengths between the independent and dependent variables. Tables 4-6, and 4-8 through 4-10 list the Pearson's correlation coefficients among independent variables and between independent and dependent variables, respectively.

Correlation among Independent Variables

Some independent variables were significantly correlated with each other at the 0.01 level and others were significantly correlated at the 0.05 level of probability. Soil clay content was significantly positively correlated with soil erodibility ($r = 0.91$). Bulk density was negatively correlated with soil water holding capacity ($r = -0.85$). Depth to calcic horizon was significantly negatively correlated with soil pH at 0.01 level ($r = -0.83$). All of these correlations have been previously documented.

At the 5 percent probability level, organic carbon content was significantly positively correlated with soil clay content ($r = 0.54$) and soil water holding capacity ($r = 0.59$), and negatively correlated with bulk density ($r = -0.53$). Soil erodibility was positively correlated with soil water holding capacity ($r = 0.55$) and soil pH ($r = 0.53$).

The correlation between soil pH and soil erodibility was unexpected. As pH increases, erodibility also increases. Likely pH is dependent on erosion due to a collinearity with slope effect on erosion. It may be hypothesized that erodibility is in some way affected by soil chemical properties. Helwig (1978) suggested that two variables might be highly correlated when, in fact, they are not directly associated with each other. He further suggests that the relationship of two variables could be explained by correlating them with a third variable. However, these two variables have multicollinearity values of 0.02 versus 0.98 (Table 4-7) indicating that both are potential contributors to a predictive model.

Table 4-6. Pearson's correlation coefficients among independent variables.

Var.	Independent Variable							
	thick	clay	BD	WHC	OC	Kf	pH	calcic
thick	1.00							
clay	-0.04	1.00						
BD	0.36	-0.37	1.00					
WHC	-0.42	0.52	-0.85**	1.00				
OC	-0.07	0.54*	-0.53*	0.59*	1.00			
Kf	-0.21	0.91**	-0.50	0.55*	0.37	1.00		
pH	-0.08	0.30	-0.29	0.27	-0.26	0.53*	1.00	
calcic	-0.43	-0.13	-0.02	0.04	0.47	-0.27	-0.83**	1.00

Note : ** = significant at 0.01 level (r value = 0.661);

* = significant at 0.05 level (r value = 0.532).

Multicollinearity

Multicollinearity is a means of identifying relationships among independent variables. Analysis of multicollinearity is used to select and minimize the variables that can be used in regression analysis. Precise regression models contain variables having low collinearity.

Results of multicollinearity analysis among independent variables are listed in Table 4-7. Soil water holding capacity (WHC) exhibited the least collinearity. Soil erodibility (Kf) and bulk density (BD) tended to be less collinearly related to other independent variables. Very strong collinear relationships were shown by soil thickness (thick), soil organic carbon content (OC), pH, and depth to calcic horizon (calcic). Clay exhibited a medium collinear relationship (value = 0.59) with those having strong collinearities.

Table 4-7. Multicollinearity diagnostics among independent variables.

Index	thick	clay	BD	WHC	OC	Kf	pH	calcic
9745.00	0.99d	0.59	0.10	-	0.95d	0.02	0.98d	0.99d

Note : Parameters in the same row followed by the same letter are identified as highly collinear. Collinearly related parameters should not be used conjunctively in regression analysis.

Following the rules of collinearity in association with regression analysis, the variables having high collinearity values should be avoided in association in model development. Considering the strengths of correlations among soil thickness (thick), soil organic carbon content (OC), pH, and depth to calcic horizon (calcic) in Table 4-6, combination of pH and calcic ($r = -0.83$) should firstly be disregarded in a model. Looking at Table 4-7 where OC had the weakest collinear relationship (value = 0.95) among the four variables, it may be advisable that OC was given highest preference in model development. The other collinearly related independent variables could be in the following sequence : pH, calcic, and thick. Each of the four strongly collinear variables could be combined with BD, WHC, or Kf, and any combination of each of the four with clay should be scrutinized closely.

Correlation between Independent and Dependent Variables

Statistical Analysis System (SAS) was used to complete a correlation analysis of the independent and dependent variables. Significance of correlation criteria was assessed using Pearson's coefficients. In general, there was no consistent relationship between independent

and dependent variables. Soil water holding capacity (WHC), organic carbon content (OC), and depth to calcic horizon (calcic) were positively correlated with the three dependent variables : estimated yield of winter and spring wheats, and alfalfa (Tables 4-8, 4-9, and 4-10). Soil water holding capacity (WHC) accounted for the most variability in yield estimates, this being indicated by the highest regression coefficient. The other independent variables tested were negatively correlated to crop production. In general, the independent variables correlated most significantly with the crop yields provided by the NRCS.

- Winter Wheat

Table 4-8 presents simple correlation coefficients between independent variables and winter wheat yield estimates. Soil water holding capacity (WHC) was significantly correlated

Table 4-8. Pearson's correlation coefficients between independent variables and estimated winter wheat yields.

Dependent Variable	Independent Variable							
	thick	clay	BD	WHC	OC	Kf	pH	calcic
W-1 NRCS	-0.45	0.43	-0.74**	0.95**	0.63*	0.40	0.09	0.21
W-2 MAPS-1	0.25	-0.31	0.16	-0.01	0.11	-0.44	-0.36	0.15
W-3 MAPS-2	-0.17	-0.52	-0.16	0.26	0.04	-0.55*	-0.21	0.25
W-4 MAPS-3	-0.19	-0.50	-0.18	0.27	0.03	-0.53*	-0.18	0.24
W-5 Producers	-0.28	-0.31	-0.19	0.47	0.00	-0.21	0.27	-0.08

** significance at 0.01 level ($r = 0.661$); * significance at 0.05 level ($r = 0.532$).

with W-1 ($r = 0.95$). Soil bulk density (BD) was negatively correlated with W-1 ($r = -0.74$). Soil organic carbon (OC) content was positively correlated with W-1 ($r = 0.63$). Soil erodibility (Kf) was negatively correlated with W-3 ($r = -0.55$) and W-4 ($r = -0.53$).

- Spring Wheat

Table 4-9 presents simple correlation coefficients between independent variables and spring wheat yield estimates. As in winter wheat, soil water holding capacity (WHC) was also very significantly positively correlated with S-1 ($r = 0.95$). Soil bulk density (BD) was very significantly negatively correlated with S-1 ($r = -0.76$). Soil organic carbon content (OC) was significantly positively correlated with S-1 ($r = 0.64$). In addition, S-3 correlated significantly negatively with clay ($r = -0.55$) and erodibility (Kf) ($r = -0.57$).

Table 4-9. Pearson's correlation coefficient between independent variables and estimated spring wheat yields.

Dependent Variable		Independent Variable							
		thick	clay	BD	WHC	OC	Kf	pH	calcic
S-1	NRCS	-0.46	0.42	-0.76**	0.95**	0.64*	0.40	0.10	0.22
S-2	MAPS-1	0.26	-0.33	0.14	-0.01	0.04	-0.43	-0.27	0.06
S-3	MAPS-2	-0.17	-0.55*	-0.17	0.25	0.02	-0.57*	-0.19	0.23
S-4	MAPS-3	-0.21	-0.52	-0.20	0.27	0.03	-0.52	-0.18	0.25
S-5	Producers	-0.38	-0.42	-0.41	0.31	-0.13	-0.30	0.33	-0.09

** significance at 0.01 level (r value = 0.661); * significance at 0.05 level (r value = 0.532).

- Alfalfa

Table 4-10 presents simple correlation coefficients between independent variables and alfalfa yield estimates. Soil water holding capacity was significantly positively correlated with A-1 ($r = 0.93$) but soil bulk density was negatively correlated with A-1 ($r = -0.76$). Soil organic carbon content was positively correlated with A-1 ($r = 0.56$). The other independent variables did not show significant relationships with alfalfa yield estimates.

Table 4-10. Pearson's correlation coefficient between independent variables and estimated alfalfa yields.

Dependent Variable		Independent Variable							
		thick	clay	BD	WHC	OC	Kf	pH	calcic
A-1	NRCS	-0.42	0.40	-0.76**	0.93**	0.56*	0.42	0.11	0.16
A-2	MAPS-1	0.12	-0.38	0.14	-0.12	0.15	-0.46	-0.41	0.31
A-3	MAPS-2	-0.19	-0.51	-0.13	0.12	0.04	-0.49	-0.17	0.25
A-4	MAPS-3	-0.20	-0.51	-0.14	0.12	0.04	-0.48	-0.16	0.24
A-5	Producers	-0.32	-0.29	-0.40	0.43	-0.01	-0.17	0.18	-0.01

** significance at 0.01 level (r value = 0.661); * significance at 0.05 level (r value = 0.532)

Regression Models

The independent variables for estimating yield potentials which significantly contributed to an acceptable estimate of yield, as defined by SAS Stepwise procedures, will be discussed for each crop.

- Winter Wheat

"Best" variables and regression equations for estimating winter wheat yield are presented in Table 4-11. The equations were significant at 0.15 level of probability. The eight response equations in Table 4-11 were selected from a total of thirteen possibilities resulting from SAS stepwise procedures (Appendix G).

Five independent variables contributed to regression equations for estimating winter wheat yield potential. They were WHC, clay, Kf, BD, and calcic variables. Three independent variables, WHC, Kf, and BD, acted individually to influence yield potentials.

Surprisingly, erodibility was the only independent variable that significantly regressed against yield estimates derived from MAPS Atlas (models 2, 3.1, and 4.1). Yield estimates derived from NRCS significantly responded to WHC and calcic variables in models 1.1 and 1.2. In models 5.1, 5.2, and 5.3, three variables, BD, WHC, and clay, contributed to the regression equations. Besides influencing yield potential singly, BD was also significant when combined with clay.

Coefficients of variation (R^2) of the eight regression equations varied significantly. Model 1 which employed WHC and calcic had the highest values (R^2 0.909 and 0.940). Models 2, 3.1, and 4.1, which relied on the Kf variable singly and whose dependent data derived from MAPS Atlas, produced lower coefficients of variation, 0.194, 0.300, and 0.277, respectively. In model 5.1, BD singly produced an R^2 of 0.243. A combination of BD and clay in model 5.2 increased the R^2 value as much as 0.275, and the combination of WHC and clay in model 5.3 produced an R^2 of 0.644.

Considering the single most influencing factor to affect winter wheat yield potentials, soil water holding capacity (WHC) is proposed to be the "best" variable to build a regression

model. This "best" equation regression is represented by model 1.1. There were also some two variable Models produced. In model 1.2, the combination of WHC and calcic accounted for 94 percent of the winter wheat yield variation, and the combination of WHC and clay in model 5.3 accounted for 63.5 percent of the yield variation. A combination of BD and clay in model 5.2 produced a lower coefficient of variation, which was 51.8 percent.

Table 4-11. Regression models for estimating winter wheat yields.

Model #	Source of Dependent Variable Data (Crop Yield)	Intercept	Slope*Variable	R ²
1.1	W-1 (NRCS)	12.28	273.46 x WHC	0.909
1.2	W-1 (NRCS)	9.88	271.42xWHC + 0.14xcalcic	0.940
2.	W-2 (MAPS-1)	93.16	- 67.36 x Kf	0.194
3.1	W-3 (MAPS-2)	109.47	- 96.87 x Kf	0.300
4.1	W-4 (MAPS-3)	104.09	- 51.39 x Kf	0.277
5.1	W-5 (Producer input)	147.77	- 50.00 x BD	0.243
5.2	W-5 (Producer input)	205.90	- 71.02 x BD - 1.38 x clay	0.518
5.3	W-5 (Producer input)	88.36	199.38 x WHC - 1.85 x clay	0.635

Note : WHC input as soil water holding capacity; Kf input as erodibility; clay input as soil clay content, BD input as bulk density, and calcic input as depth to calcic horizon. See Table 3-3 for dimensions used.

Partial contribution of each independent variable to yield estimation can be used in variable selection for a model. For example, in model 1.2, WHC contributed 90.9 and calcic contributed 3.11 percent to winter wheat yield variation. The role of WHC decreased

drastically in model 5.3 (90.9 versus 36.0 percent). However, the contribution of clay in the model accounted for 27.5 percent to yield variation. Similar contribution of clay also happened in another combination equation of model 5.2.

Considering partial contribution of the independent variables and their relationship to each other, a combination of WHC and clay (model 5.3) is proposed to be second "best" regression equations of combined variables. Therefore, best regression equations for winter wheat are models 1.1, and 5.3.

- Spring Wheat

"Best" fit regression equations for spring wheat are presented in Table 4-12. The equations were significant at the 15 percent probability level. The seven response equations in Table 4-12 were selected from a total of seventeen possibilities resulting from SAS stepwise procedures (Appendix H) based on partial R^2 values.

The selected equations involved four independent variables : soil water holding capacity (WHC), erodibility (Kf), soil clay content (clay), and depth to calcic horizon (calcic). Dependent variables (yield estimates) obtained from MAPS Atlas were significantly correlated with erodibility (Kf) (models 7, 8.1, and 9.1). NRCS dependent data significantly responded to WHC and calcic (model 6.2). In model 10.2, WHC and clay contributed to another significant model.

Coefficients of variation (R^2) of the seven equations were quite variable. Model 6.1 and 6.2, which employed WHC singly and a combination of WHC and calcic, had the highest values ($R^2 = 0.912$ to 0.944). By entering the clay variable singly, model 10.1 produced a

very low coefficient of variation ($R^2 = 0.175$). Addition of WHC to the model increased the R^2 value by 219 percent from 0.175 to 0.560 (model 10.2). Models 7, 8.1, and 9.1 involved erodibility individually in the regressions. These three models produced very low R^2 values ranging from 0.186 to 0.321.

Individually, only three independent variables resulted in significant models. WHC appeared the best with a strong R^2 value of 0.912 (model 6.1). Influences of Kf in models 7, 8.1, and 9.1, and clay in model 10.1 to the spring wheat yield variation were very weak, as indicated by R^2 values.

Table 4-12. Regression Models for estimating spring wheat yields.

Model #	Source of Dependent Variable Data (Crop Yield)	Intercept	Slope*Variable	R^2
6.1	S-1 (NRCS)	11.52	237.70 x WHC	0.912
6.2	S-1 (NRCS)	9.40	235.88xWHC + 0.13xcalcic	0.944
7.	S-2 (MAPS-1)	78.52	-52.43 x Kf	0.186
8.1	S-3 (MAPS-2)	83.48	- 41.81 x Kf	0.321
9.1	S-4 (MAPS-3)	77.66	-37.98 x Kf	0.275
10.1	S-5 (Producer input)	101.45	- 1.12 x clay	0.175
10.2	S-5 (Producer input)	100.23	- 2.13xclay + 183.14xWHC	0.560

Note : WHC input as soil water holding capacity; Kf input as erodibility; clay input as soil clay content, and calcic input as depth to calcic horizon. See Table 3-3 for dimensions used.

Coefficient of variation of models solely dependent on Kf ranged from 0.186 to 0.321, while models solely dependent on clay had R^2 of 0.175. Looking at R^2 values of the three models with individual independent variables, soil water holding capacity (WHC) is proposed to be the "best" variable to build a regression model to predict spring wheat yield. This "best" equation regression is represented by the model 6.1.

Combinations of soil water holding capacity and depth to calcic horizon in model 6.2, and with soil clay content in model 10.2 appeared significantly different. In model 6.2, the combination of WHC and calcic accounted for 94.4 percent of yield variation, while in model 10.2, the combination of WHC and clay accounted for 56 percent of spring wheat yield variation.

Looking at the coefficients of variation associated with the combinations of WHC with either calcic or clay (Table 4-12), model 6.2, including a combination of WHC and calcic, seems reasonable to be another "best" equation for predicting spring wheat production. In this model, WHC was the dominant variable, while calcic contributed less to yield estimation. Compared with clay, however, the influence of depth to calcic horizon to spring wheat yield variation was just about 19 percent of the contribution of clay (partial R^2 0.033 versus 0.175).

Based on the above facts, a combination of WHC and clay was seen better than a combination of WHC and calcic. Therefore model 10.2, employing WHC and clay, is proposed to be second "best" regression equation for estimating spring wheat yield potential.

- Alfalfa

The "best fit" variables and regressions resulting from SAS stepwise procedure are presented in Table 4-13. The equations were significant at 15 percent probability level. Independent variables which contributed to yield estimation included soil water holding capacity, erodibility, and clay content. These three variables involved in the eight regressions produced by SAS. Table 4-13 includes a listing of eight simple linear models for predicting alfalfa yield. The yield estimates from NRCS and MAPS-1 (A-1 and A-2, respectively) significantly responded to single soil variables, while the other three yield estimates included two "best" dependent variables regressions.

The range in the coefficient of variation (R^2) of the eight regressions for alfalfa shown in Table 4-13 was quite wide. Soil water holding capacity (WHC) in model 11, which was based on NRCS yield estimates, singly accounted for 86.6 percent of yield variation. In model 13.1 and 14.1, soil clay content (clay) contributed approximately 26 percent of the yield variability, and in model 12, erodibility (Kf) accounted for 21.2 percent of the variation of alfalfa yield. Soil water holding capacity (WHC) appeared to be the most influential independent variable to affect alfalfa crop yields. This is consistent with the fact that yield estimates identified as MAPS-1, MAPS-2, and MAPS-3 all relied on inputs of available water to calculate the yield values for the dependent variables. Model 11, which accounted for nearly 87 percent of the yield variability based on only soil water holding capacity (WHC), could be proposed to be the "best" for estimating yield potential for alfalfa.

Table 4-13. Regression models for estimating alfalfa yields.

Model #	Source of Dependent Variable Data (Crop Yield)	Intercept	Slope*Variable	R ²
11.	A-1 (NRCS)	0.30	9.08 x WHC	0.866
12.	A-2 (MAPS-1)	5.08	-3.76 x Kf	0.212
13.1	A-3 (MAPS-2)	7.30	-0.09 x clay	0.261
13.2	A-3 (MAPS-2)	7.24	-0.13 x clay + 8.55 x WHC	0.461
14.1	A-4 (MAPS-3)	7.15	-0.09 x clay	0.260
14.2	A-4 (MAPS-3)	7.09	-0.13 x clay + 8.55 x WHC	0.467
15.1	A-5 (Producer input)	3.64	7.44 x WHC	0.182
15.2	A-5 (Producer input)	5.46	13.76 x WHC - 0.13 x clay	0.534

Note : WHC input as soil water holding capacity; Kf input as erodibility; and clay input as soil clay content. See Table 3-3 for dimensions used.

Combinations of soil water holding capacity and soil clay content in models 13.2, 14.2, and 15.2 appeared to affect alfalfa yield similarly. In model 15.2, these two variables accounted for 53.4 % of the yield variation. The other 'two-combination' effects in models 13.2 and 14.2 contributed 46.1 and 46.7 percent to the yield variation, respectively. Inclusion of soil clay content in the models tended to reduce the individual effect of soil water holding capacity on the variation in estimated alfalfa yield as much as 33.2 to 40.5 percent.

Disregarding the correlation between WHC and clay, soil water holding capacity and clay content were combined into a single regression model. Considering the coefficients of variation of the three possible combinations of WHC and clay in models 13.2, 14.2, and 15.2 of Table 4-13, model 15.2 seems reasonable to be second "best" equation.

Water was the Most Important Independent Variable

Results of the correlation analysis between independent and dependent variables (Tables 4-8, 4-9, and 4-10) suggest that three soil parameters consistently appeared to be significantly correlated with the dependent variables. They were soil water holding capacity (WHC), soil bulk density (BD), and soil organic carbon content (OC). In addition, soil erodibility (Kf) and soil clay content (clay) were frequently significantly correlated with some dependent variables. A list of the "best" regression equations proposed for predicting crop yields is presented in Table 4-14. In all models, WHC appeared either singly or in association with the other soil parameters.

Table 4-14. Summary of 'best' regression equations for predicting yields of alfalfa, spring wheat, and winter wheat in Gallatin Valley.

Crop	Best 1 (R ²)	Best 2 (R ²)
1. Winter Wheat	$\bar{Y}_w = 12.28 + 273.46xWHC$ (0.909)	$\bar{Y}_w = 8.36 + 199.30xWHC - 1.85xclay$ (0.635)
2. Spring Wheat	$\bar{Y}_s = 11.52 + 237.70xWHC$ (0.912)	$\bar{Y}_s = 100.23 + 183.14xWHC - 2.13xclay$ (0.560)
3. Alfalfa	$\bar{Y}_A = 0.30 + 9.08xWHC$ (0.866)	$\bar{Y}_A = 5.46 + 13.76xWHC - 0.13xclay$ (0.534)

Note : Dimension units are tons/ha.

The above results and facts suggested that, in the Gallatin Valley environment, water is the most important factor to be considered for managing the lands for farm uses. This

output strongly supports Brown and Carlson's (1990) statement, attesting to the value of checking soil moisture conditions prior to managing farm fields.

5. SUMMARY AND CONCLUSION

Soil survey and inventory is an attempt to gather soil and environmental data from the field and organize these data such that they are usable for interpretative uses. The information gained from the field can be documented many different ways. In developed countries, soil survey data are routinely stored electronically, allowing access by many parties. On the other hand, in many developing countries (for instance Indonesia), the data may remain underutilized for decades.

Some soil parameters have long been known to strongly influence plant growth and production. The strength of influence of each soil parameter is very much dependent on type and variety of plant. Different plants and crops may respond to soil characteristics differently.

The major focus of this research was to investigate important soil parameters in conjunction with crop production on soils of the Gallatin Valley, Montana. Limitations due to environmental heterogeneity, resolution of soil data and lack of availability of crop production records were addressed by the application of several modeling approaches. To limit environmental variability, a relatively small geographic area was considered for this study. Soil data resolution was controlled by taking weighted-average values of significant soil parameters of the A and B horizons. Lack of crop yield data was overcome by utilization of five different approaches to estimate yield. By employing these approaches, the data available for analysis were quite sufficient to provide general knowledge of soil-crop relationships as an integral part of the study of soil quality.

Six 'best' regression equations were developed from this study for estimating crop yields of alfalfa, spring wheat, and winter wheat. Two regressions were fit for each crop. The first 'best' of the two regressions for each crop consists of a single independent variable which was WHC. The second 'best' regression equation was composed of two independent variables, which were a combination of WHC and clay content.

Simple regression analysis showed that soil water holding capacity (WHC) better predicted crop yield than any other single independent variable. The regression equations developed were able to explain as much as 87 percent of the variability in predicted alfalfa yield, and 91 percent of the variability in spring and winter wheat yields. Percent clay singly contributed little predictive power to yield estimation. The combination of clay content and soil water holding capacity accounted for 53 percent of the variation in alfalfa yield, 56 percent of the variation in spring wheat yield, and 64 percent of the variation in winter wheat yield, respectively.

Tests of the five sources of dependent (estimated yield) variables with an independent data set (soil properties) revealed that yield estimates from NRCS-USDA were the most significantly correlated with the independent variables for the three crops examined. Producers with long time experience farming Gallatin Valley soils were able to make reasonably reliable estimates. Their estimates were surprisingly close to the estimated yields proposed by NRCS-USDA.

Admittedly, it is possible that the approaches used in working with the data generated from MAPS Atlas database for estimating yield were inappropriate. With additional manipulation, it may be possible to develop other approaches to utilize MAPS Atlas database for intended uses in assessing soil quality.

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APPENDICES

Appendix A. Official soil series descriptions and their URL addresses

Data pertaining to soil series used in this study were obtained from the following internet website :

No.	Soil Series	Internet Website
1.	Amsterdam	http://www.statlab.iastate.edu/soils/ods/dat/A/AMSTERDAM.html
2.	Beanlake	http://www.statlab.iastate.edu/soils/ods/dat/B/BEANLAKE.html
3.	Beaverton	http://www.statlab.iastate.edu/soils/ods/dat/B/BEAVERTON.html
4.	Blackdog	http://www.statlab.iastate.edu/soils/ods/dat/B/BLACKDOG.html
5.	Bozeman	http://www.statlab.iastate.edu/soils/ods/dat/B/BOZEMAN.html
6.	Kelstrup	http://www.statlab.iastate.edu/soils/ods/dat/K/KELSTRUP.html
7.	Martinsdale	http://www.statlab.iastate.edu/soils/ods/dat/M/MARTINSDALE.html
8.	Meagher	http://www.statlab.iastate.edu/soils/ods/dat/M/MEAGHER.html
9.	Sawicki	http://www.statlab.iastate.edu/soils/ods/dat/S/SAWICKI.html
10.	Turner	http://www.statlab.iastate.edu/soils/ods/dat/T/TURNER.html
11.	Windham	http://www.statlab.iastate.edu/soils/ods/dat/W/WINDHAM.html

Below is a brief description of each soil series, as described at this website.

1. AMSTERDAM SERIES (Rev. JB-JAL 10/97)

The Amsterdam series consists of very deep, well drained soils that formed in alluvium, lacustrine, or loess deposited materials mixed with volcanic ash. These soils are on alluvial fans, stream terraces and lake terraces. Slopes are 0 to 25 %. Mean annual precipitation is about 15 in., and mean annual temperature is about 42 °F.

Taxonomic Class : Fine-silty, mixed, superactive Typic Haploborolls

Type Location : Gallatin County, Montana; 500 ft north and 2,440 ft east of the SW corner of sec. 7, T. 2 S., R. 5 E.

Range in Characteristics : Soil temperature - 40 to 45 °F. Moisture control section - between 4 and 12 in. Mollic epipedon thickness - 7 to 15 in. Depth to Bk horizon - 10 to 22 in.

Geographic Setting : Landform - alluvial fans, stream terraces and lake terraces. Elevation - 4,000 to 6,000 ft. Slope - 0 to 25 %. Parent material - alluvium, lacustrine, or loess deposited materials mixed with volcanic ash. Climate - long, cold winters; moist springs; warm summers. Mean annual precipitation - 15 to 19 in. Mean annual temperature - 38 to 43 °F. Frost-free period - 90 to 110 days.

Drainage and Permeability : Well drained; moderately slow permeability.

Use and Vegetation : Amsterdam soils are used mainly for irrigated cropland and non irrigated cropland; some in grass. Potential native vegetation is mainly

Distribution and Extent : Amsterdam soils are of moderate extent in intermountain valleys of southwestern Montana.

MLRA Office Responsible : Bozeman, Montana

Series Established : Gallatin Valley Area, Montana, 1931.

2. BEANLAKE SERIES (Rev. JAL 5/97)

The Beanlake series consists of very deep, well drained soils that formed in till or alluvium. These soils are on moraines, till plains, alluvial fans, stream terraces and escarpments. Slopes are 0 to 45 %. Mean annual precipitation is about 16 in., and mean annual temperature is about 43 °F.

Taxonomic Class : Fine-loamy, mixed, superactive, frigid Typic Calciustolls

Type Location : Lewis and Clark County, Montana; 2,500 ft north and 2,200 ft east of the SW corner of sec. 19, T. 20 N., R. 7 W.

Range in Characteristics : Soil temperature - 42 to 47 °F. Moisture control section is between 4 and 12 in. Mollic epipedon thickness is 7 to 8 in. The surface layer is calcareous when mixed to 7 in.

Geographic Setting : Landforms - moraines, till plains, alluvial fans, stream terraces and escarpments. Elevation - 3,800 to 6,000 ft. Slope - 0 to 45 %. Parent material - till or alluvium. Climate - long, cold winters; moist springs; warm summers. Mean annual precipitation - 12 to 19 in., most of which falls as snow in winter or as snow or rain early in

spring and in summer. Mean annual air temperature - 40 to 45 °F. Frost-free period - 70 to 120 days.

Drainage and Permeability : Well drained; moderate permeability.

Use and Vegetation : Beanlake soils are used mainly for rangeland. Potential native vegetation is mainly rough fescue, bluebunch wheatgrass, Idaho fescue, Columbia needlegrass, prairie june grass, forbs, and shrubs; some areas support thin stands of limber pine, Rocky Mountain juniper, and Douglas fir.

Distribution and Extent : Beanlake soils are inextensive in west-central Montana along the eastern front of the Rocky Mountains.

MLRA Office Responsible : Bozeman, Montana

Series Established : Choteau-Conrad Area, parts of Teton and Pondera Counties, Montana, 1991.

3. BEAVERTON SERIES (Rev. NRS-CNG-CJH 10/98)

The Beaverton series consists of very deep, well drained soils that formed in gravelly alluvium or glacial outwash materials. These soils have extremely gravelly sand at a depth of 10 to 20 in. These soils are on alluvial fans, stream terraces, hills, and outwash plains. Slopes are 0 to 25 %. Mean annual precipitation is about 16 in., and mean annual air temperature is about 42 °F.

Taxonomic Class : Loamy-skeletal over sandy or sandy-skeletal, mixed, superactive, frigid Typic Argiustolls

Type Location : Glacier County, Montana; 1,000 ft north and 200 ft east of the SW corner of sec. 31, T. 33 N., R. 10 W.

Range in Characteristics : Soil temperature - 41 to 47 . Mollic epipedon thickness - 7 to 14 in. (may include all or only part of the Bt horizons). Control section - 25 to 35 % clay. Depth to k horizon - 10 to 20 in. Bk and 2C horizon - horizons are allowed.

Geographic Setting : Landform - alluvial fans; stream terraces; hills; outwash plains. Elevation - 2,400 to 5,800 ft. Slope - 0 to 25 %. Parent material - gravelly alluvium or glacial outwash materials derived from a mixture of rock sources. Climate - cool, with long, cold winters; moist springs; and warm summers. Mean annual precipitation - 13 to 19 in. Mean annual air temperature - 39 to 45 °F. Frost-free season - 90 to 130 days.

Drainage and Permeability : Well drained; moderate permeability in the solum and rapid permeability in the 2C horizon.

Use and Vegetation : Used mainly as rangeland, grain, and hay crops. The potential native vegetation is mainly bluebunch wheatgrass, western wheatgrass, prairie sandreed, needleandthread, little bluestem, plains muhly, sand dropseed, shrubs, and forbs.

Distribution and Extent : Throughout the northern Great Plains and Rock Mountain regions. The series is of moderate extent.

MLRA Office Responsible : Bismarck, North Dakota

Series Established : Milk River Area, Montana, 1928. (Benchmark soil).

4. BLACKDOG SERIES (Rev. EWC-GAR-JAL 6/97)

The Blackdog series consists of very deep, well drained soils that formed in loess. These soils are on relict stream terraces. Slopes are 0 to 15 %. Mean annual precipitation is about 17 in., and the mean annual temperature is about 41 °F.

Taxonomic Class : Fine-silty, mixed, superactive Typic Argiborolls

Type Location : Gallatin County, Montana; 850 ft south and 1500 ft east of the northwest corner of sec. 26, T.1N., R.5E.

Range in Characteristics : Mean annual soil temperature - 41 to 45 °F. Moisture control section - between 4 and 12 in. Mollic epipedon thickness - 7 to 15 in. and may include part of the Bt horizon. Depth to the Bk horizon - 18 to 30 in.

Geographic Setting : Landform - relict stream terraces. Elevation - 4,700 to 5,700 ft. Slope - 0 to 15 %. Parent material - loess. Climate - long, cold winters; moist springs; warm summers. Mean annual precipitation - 15 to 19 in. Mean annual air temperature - 39 to 43 °F. Frost-free period - 90 to 110 days.

Drainage and Permeability : Well drained; moderately slow permeability.

Use and Vegetation : Blackdog soils are used mainly for cropland, hayland and pasture. Potential native vegetation may include bluebunch wheatgrass, Idaho fescue, Richardson needle grass, mountain brome, sedges, lupine, western yarrow, sticky geranium, common snowberry and wild rose as well as other grasses, forbs and other woody shrubs.

Distribution and Extent : Blackdog soils are of small extent in southwestern Montana.

MLRA Office Responsible : Bozeman, Montana

Series Established : Gallatin County, Montana, 1997.

5. BOZEMAN SERIES (Rev. TJH/JEB 9/73)

Typically, Bozeman soils have very dark gray, silt loam A1 horizons, dark grayish brown and brown prismatic blocky, silty clay loam B2t horizons, and pale brown silt loam C1ca horizons.

Taxonomic Class : Fine-silty, mixed Argic Pachic Cryoborolls

Type Location : Gallatin County, Montana; on Ft. Ellis Livestock Experiment Station; 1,670 ft east, 960 ft south of NW corner sec. 15, T.2S., R.6E.

Range in Characteristics : The noncalcareous part is 15 to 40 in. thick. The mollic epipedon is 15 to 30 in. thick and includes part or all of the B2t horizon in some pedons. The solum is neutral or mildly alkaline. Mean annual soil temperature ranges from 41 to 47 °F.

Geographic Setting : Bozeman soils are on nearly level to moderately sloping plains and dissected sideslopes of mountain valleys. Slope gradients range from 0 to 20 %. Elevation ranges from 4,000 to 6,000 ft. The soils formed in loess derived from mixed alluvial sources. The climate is cool sub humid. Annual precipitation ranges from 16 to 24 in. Mean annual temperature ranges from about 38 to 45 °F. The average frost-free period is less than 110 days.

Principal Associated Soils : These are the competing Amsterdam, Bridger, Huffine, and Robana soils.

Drainage and Permeability : Well-drained; slow or medium runoff; moderate permeability.

Use and Vegetation : Used as dryland and irrigated cropland, and as rangeland. Principal native vegetation is rough fescue, Idaho fescue, mountain brome grass, bluegrass, rosebush, snowberry, and sagebrush.

Distribution and Extent : Mountain valleys in Montana, Wyoming, and Idaho. The series is of moderate extent.

MLRA Office Responsible : Bozeman, Montana

Series Established : Gallatin County, Montana, 1905.

6. KELSTRUP SERIES (Rev. ZRS-JB-JAL 7/97)

The Kelstrup series consists of very deep, well drained soils that formed in loess. These soils are on relict stream terraces. Slopes are 0 to 15 %. The mean annual precipitation is about 14 in. and the mean annual temperature is about 43 °F.

Taxonomic Class : Coarse-silty, mixed, superactive Aridic Haploborolls

Range in Characteristics : Mean annual soil temperature - 43 to 47 °F. Moisture control section - between 4 and 12 in.; dry in some part for six tenths or more of the cumulative days per year when the soil temperature at a depth of 20 in. is higher than 41 °F. Mollic epipedon thickness - 7 to 10 in. Depth to calcic horizon - 11 to 20 in.

Geographic Setting : Landform - relict stream terraces. Elevation - 4,200 to 5,000 ft. Slope - 0 to 15 %. Parent material - loess. Climate - long, cold winters; moist springs; warm summers. Mean annual precipitation - 12 to 16 in. Mean annual air temperature - 41 to 45 °F. Frost-free period - 95 to 115 days.

Drainage and Permeability : Well drained; moderate permeability.

Use and Vegetation : Kelstrup soils are used as nonirrigated cropland, rangeland and wildlife habitat. The principal crops are barley and winter wheat. Potential native vegetation includes bluebunch wheatgrass, green needlegrass, needleandthread, western wheatgrass, and Idaho fescue.

Distribution and Extent : Kelstrup soils are of small extent in the intermountain valleys of southwestern Montana.

MLRA Office Responsible : Bozeman, Montana

Series Established : Gallatin County, Montana, 1997.

7. MARTINSDALE SERIES (Rev. DES-JAL 7/98)

The Martinsdale series consists of very deep, well drained soils that formed in alluvium or colluvium. These soils are on alluvial fans, stream terraces, escarpments and hills. Slopes are 0 to 35 %. Mean annual precipitation is about 16 in., and mean annual temperature is about 41 °F.

Taxonomic Class : Fine-loamy, mixed, superactive, frigid Typic Argiustolls

Type Location : Wheatland County, Montana; 225 ft south of the NE corner of sec. 2, T. 6 N., R. 14 E.

Range in Characteristics : Soil temperature - 38 to 47 ° F. Moisture control section - between 4 and 12 in. and moist in all or some parts from April through mid July, and September through mid November. Mollic epipedon thickness - 7 to 16 in. and includes all or part of the Bt1 horizon. Depth to Bk horizon - 11 to 30 in. Soil phases - gravelly, cobbly substratum, cool, stony

Geographic Setting : Landform - alluvial fans; stream terraces; escarpments; foot slopes of hills and mountains; uplands mantled with old alluvium. Elevation - 3,000 to 6,200 ft. (In Colorado the elevation is 6,800 to 8,200 ft). Slope - 0 to 35 %. Parent material - alluvium; colluvium. Climate - long, cold winters; moist springs; and warm, dry summers. Mean annual precipitation - 14 to 19 in. Mean annual air temperature - 36 to 45 ° F. Frost-free period - 70 to 130 days.

Drainage and Permeability : Well drained; moderately slow permeability.

Use and Vegetation : Used mainly for production of irrigated and nonirrigated small grain and alfalfa crops. Potential native vegetation is mainly needle and thread, western wheatgrass, bluebunch wheatgrass, prairie junegrass, blue grama, forbs, and some shrubs.

Distribution and Extent : Widely distributed over state of Montana and in Colorado. Series is of moderate extent.

MLRA Office Responsible : Bozeman, Montana

Series Established : Upper Musselshell Valley Area, Montana, 1941.

8. MEAGHER SERIES (Rev. JB-JAL 2/98)

The Meagher series consists of very deep, well drained soils that formed in alluvium or colluvium. These soils are on stream terraces, alluvial fans and escarpments. Slopes are 0 to 35 %. Mean annual precipitation is about 16 in. and mean annual temperature is about 41 ° F.

Taxonomic Class : Fine-loamy, mixed, superactive Typic Argiborolls

Type Location : Meagher County, Montana; 1,900 ft north and 50 ft west of the SE corner of sec. 35, T. 8 N., R. 6 E.

Range in Characteristics : Soil temperature - 40 to 45 ° F. Moisture control section - between 4 and 12 in. Mollic epipedon thickness - 7 to 10 in. Depth to Bk horizons - 11 to 20 in. Depth to loamy-skeletal material - 20 to 35 in.

Geographic Setting : Landform - alluvial fans; stream terraces; escarpments. Elevation - 4,000 to 6,000 ft. Parent material - alluvium or colluvium. Slope - 0 to 35 %. Climate - long, cold winters; moist springs; short summers. Mean annual precipitation - 14 to 19 in., most of which falls during spring and early summer. Mean annual air temperature - 38 to 43 ° F. Frost-free period - 70 to 120 days.

Drainage and Permeability : Well drained; moderate permeability.

Use and Vegetation : Meagher soils are used for rangeland and irrigated and nonirrigated cropland. The potential native vegetation is mainly rough fescue, bluebunch wheatgrass, Idaho fescue, green needle grass, western wheatgrass, Sandberg bluegrass, prairie junegrass, forbs, and shrubs.

Distribution and Extent : Meagher soils are of small extent mainly in west-central Montana.

MLRA Office Responsible : Bozeman, Montana

Series Established : Gallatin County, Montana 1997; proposed Meagher County, Montana, 1991.

9. SAWICKI SERIES (Rev. DES-JB-JAL 7/98)

The Sawicki series consists of very deep, well drained soils that formed in alluvium and colluvium from hard fine grained igneous rock, gneiss, schist and sandstone. These soils are on alluvial fans, stream terraces, drainageways, escarpments and sideslopes of hills and mountains. Slopes are 0 to 70 %. Mean annual precipitation is about 17 in., and mean annual air temperature is about 40 ° F.

Taxonomic Class : Loamy-skeletal, mixed, superactive, frigid Typic Argiustolls

Type Location : Jefferson County, Montana; 200 ft south and 2,650 ft west of the NE corner of sec. 9, T. 3 N., R. 3 W.

Range in Characteristics : Mean annual soil Temperature - 38 to 45 ° F. Moisture control section - between 4 and 12 in. Mollic epipedon thickness - 7 to 16 in. Surface stones or boulders - 0 to 3 percent.

Geographic Setting : Landform - alluvial fans, stream terraces, drainage ways, escarpments and sideslopes of hills and mountains. Elevation - 4,400 to 7,000 ft. Slope - 0 to 70 %. Parent material - alluvium and colluvium from hard fine grained igneous rock, gneiss, schist and sandstone. Climate - long, cold winters; moist springs; warm summers. Mean annual precipitation - 15 to 19 in. Mean annual air temperature - 38 to 43 °F. Frost-free period - 70 to 110 days.

Drainage and Permeability : Well drained, moderate permeability.

Use and Vegetation : Sawicki soils are primarily used for rangeland, wildlife habitat and watershed. The potential native vegetation is mainly Rocky Mountain juniper, big sagebrush, Idaho fescue, rough fescue, bluebunch wheatgrass, prairie junegrass, western yarrow, lupine, and arrowleaf baslomroot. Areas with a forest canopy have an overstory of Douglas-fir and limber pine or ponderosa pine and an understory of rough fescue, Idaho fescue, Rocky Mountain juniper and big sagebrush.

Distribution and Extent : Sawicki soils are of moderate extent in southwestern Montana.

MLRA Office Responsible : Bozeman, Montana

Series Established : Gallatin County, Montana, 1997; proposed in Jefferson County, Montana, 1994.

10. TURNER SERIES (NRS-CJH 10/98)

The Turner series consists of very deep, well drained soils that formed in alluvium and have very gravelly loamy coarse sand at a depth of 20 to 40 in. These soils are on alluvial fans, stream terraces, and relict stream terraces. Slopes are 0 to 15 %. Mean annual precipitation is about 16 in., and mean annual air temperature is about 44 °F.

Taxonomic Class : Fine-loamy over sandy or sandy-skeletal, mixed, superactive, frigid Typic Argiustolls

Type Location : Blaine County, Montana; 1,540 ft west and 2,470 ft north of the SE corner of sec. 21, T. 27 N., R. 19 E.

Range in Characteristics : Soil temperature - 41 to 47 °F. Mollic epipedon thickness - 7 to 15 in. and includes part of the Bt horizon. Moisture control section is between 4 and 12 in. Depth to Bk horizon - 11 to 20 in. Depth to 2Bk horizon - 20 to 40 in. Phases - flooded, gravelly, stony, wet.

Geographic Setting : Landform - alluvial fans, stream terraces, relict stream terraces. Elevation - 1,900 to 5,200 ft. Slope - 0 to 15 %. Parent material - alluvium that is 20 to 40 in. thick over very gravelly coarse sand. Climate - cool, with long, cold winters; moist springs; warm summers. Mean annual precipitation - 13 to 19 in. Mean annual air temperature - 39 to 45 °F. Frost-free season - 90 to 135 days.

Drainage and Permeability : Well drained. Permeability is moderate in the A and B horizons and rapid in the sandy-skeletal horizons.

Use and Vegetation : Turner soils are used for dryland and irrigated crops and as rangeland. Major crops are small grain and hay. Potential native vegetation is mainly bluebunch wheatgrass, little bluestem, western wheatgrass, green needlegrass, needleandthread, prairie sandreed, forbs, and shrubs.

Distribution and Extent : Turner soils are mainly on the plains of central and eastern Montana. They are of moderate extent.

MLRA Office Responsible : Bismarck, North Dakota

Series Established : Reconnaissance of northern plains of Montana, 1929.

11. WINDHAM SERIES (Rev. DES-JAL 7/98)

The Windham series consists of very deep, well drained soils that formed in very gravelly alluvium and colluvium derived mainly from limestone. These soils are on alluvial fans, stream terraces, escarpments, ridges, divides, hills and mountains. Slopes are 0 - 85 %. Mean annual precipitation is about 16 in., and mean annual temperature is about 41 °F.

Taxonomic Class : Loamy-skeletal, carbonatic, frigid Typic Calcicustolls

Type Location : Fergus County, Montana; 33 ft north and 595 ft west of the SE corner of sec. 12, T. 15 N., R. 17 E.

Range in Characteristics : Soil temperature - 38 to 46 °F. Moisture control section - between 4 and 12 in. Mollic epipedon thickness - 7 to 16 in. Depth to calcic horizon - 5 to 10 in. Surface stones or boulders - 0 to 3 %.

Geographic Setting : Landform - alluvial fans, stream terraces, escarpments, ridges, divides, hills, mountains. Elevation - 3,000 to 6,800 ft. Slope - 0 to 85 %. Parent material - alluvium and colluvium derived mainly from limestone but also from marly siltstone and other limy sedimentary rock. Climate - long, cold winters; moist springs; warm summers. Mean annual precipitation - 14 to 22 in. Mean annual temperature - 36 to 45 °F. Frost-free season - 70 to 130 days.

Drainage and Permeability : Well drained; moderate permeability.

Use and Vegetation : Windham soils are used mainly as rangeland. A few small areas are used as cropland when in complex with other soils. Potential native vegetation is bluebunch wheat grass, western wheatgrass, needle and thread, blue grama, prairie junegrass, shrubs, and forbs.

Distribution and Extent : Mainly in central Montana and near the mountain front. It is of moderate extent.

MLRA Office Responsible : Bozeman, Montana

Series Established : Big Horn County Area, Montana, 1970.

Appendix B. URL addresses of narrative description of representative pedons

Information pertaining to the representative pedons of each soil series was obtained from the following internet website :

No.	Soil Series	Internet Website (http://vmhost.)
1.	Amsterdam	cdp.state.ne.us/~nslsoil/HTBIN/DBFND3?series=amsterdam
2.	Beaverton	cdp.state.ne.us/~nslsoil/HTBIN/DBFND3?series=beaverton
3. *)	Blackdog	cdp.state.ne.us/~nslsoil/HTBIN/DBFND3?series=farland
4.	Bozeman	cdp.state.ne.us/~nslsoil/HTBIN/DBFND3?series=bozeman
5.	Kelstrup	cdp.state.ne.us/~nslsoil/HTBIN/DBFND3?series=kelstrup
6.	Martinsdale	cdp.state.ne.us/~nslsoil/HTBIN/DBFND3?series=martinsdale
7.	Turner	cdp.state.ne.us/~nslsoil/HTBIN/DBFND3?series=turner

Note : *) described as Farland Series in the above URL address.

Narrative descriptions for Beanlake, Meagher, Sawicki, and Windham series were obtained from NRCS field office of Bozeman in April 1998. This info can be found in Soil Survey and Inventory report of the Gallatin County Montana.

Below is the narrative descriptions of typical pedons of the four soil series.

- Beanlake Series

Depth class : very deep
Drainage class : well drained
Permeability : moderate
Landform : alluvial fans, relict stream terraces, stream terraces, escarpments
Parent material : alluvium
Slope range : 0 - 45 percent
Elevation range : 4400 - 6000 feet
Annual precipitation : 12 - 19 inches
Ann. air temperature : 41 - 47 ° F
Frost free period : 90 - 110 days

Taxonomic Class : Fine-loamy, mixed Typic Calciborolls

Typical Pedon

Beanlake gravelly loam, 8 to 15 percent slopes, in rangeland, Gallatin Valley, Montana; 1400 feet east and 1500 feet south of the northwest corner of section 10, R.3E, T.2S.

A = 0 to 6 inches; grayish brown (10 YR 5/2), gravelly loam; very dark grayish brown (10YR 3/2) moist; weak fine granular structure; slightly hard, very friable, slightly sticky and slightly plastic; 5 percent pebbles; many very fine and fine roots; strongly effervescent, moderately alkaline (pH 8.0); clear smooth boundary.

Bk1 = 6 to 13 inches; light gray (10 YR 7/2), loam; pale brown (10 YR 6/3) moist; weak, medium, subangular blocky structure; slightly hard, very friable, sticky and slightly plastic; 5 percent pebbles; common very fine and fine roots; violently effervescent, moderately alkaline (pH 8.2); clear wavy boundary.

Bk2 = 13 to 26 inches; light gray (10 YR 7/2), loam; pale brown (10 YR 6/3) moist; weak, medium, subangular blocky structure; slightly hard, very friable, slightly sticky and slightly plastic; 10 percent pebbles; few very fine and fine roots; violently effervescent, moderately alkaline (pH 8.2); clear wavy boundary.

Bk3 = 26 to 60 inches; light gray (10 YR 7/2), gravelly loam; light brownish gray (10 YR 6/2) moist; massive structure; slightly hard, very friable, slightly sticky and slightly plastic; 20 percent pebbles, 5 percent cobbles; few very fine and fine roots; violently effervescent, moderately alkaline (pH 8.4).

- Meagher Series

Depth class : very deep
Drainage class : well drained
Permeability : moderate
Landform : alluvial fans, escarpments, stream terraces
Parent material : alluvium or colluvium
Slope range : 4 - 35 percent
Elevation range : 4500 - 5700 feet
Annual precipitation : 12 - 19 inches
Ann. air temperature : 39 - 43 ° F
Frost free period : 90 - 110 days

Taxonomic Class : Fine-loamy, mixed Typic Argiborolls

Typical Pedon

Meagher loam, in an area of Anceney-Trimad-Meagher complex, 15 to 60 percent slopes, in rangeland, Gallatin County, Montana; 2200 feet south and 1900 feet west of the northeast corner of section 11, T.2S, R.1E.

A = 0 to 6 inches; dark grayish brown (10 YR 4/2) loam, very dark grayish brown (10YR 3/2) moist; moderate, fine subangular blocky structure parting to moderate fine granular structure; slightly hard, soft, slightly sticky and slightly plastic; few medium, common fine, and many very fine roots; 5 percent cobbles; 10 percent pebbles; neutral (pH 7.2); clear wavy boundary.

Bt = 6 to 19 inches; brown (10 YR 5/3) clay loam, dark brown (10 YR 4/3) moist; moderate medium subangular blocky structure; slightly hard, friable, sticky and plastic; few medium, fine and very fine roots; common thin clay films coating ped faces and pores; 5 percent cobbles, 5 percent pebbles; neutral (pH 7.2); clear wavy boundary.

Bk = 19 to 31 inches; very pale brown (10 YR 7/3) loam, light yellowish brown (10 YR 6/4) moist; weak medium subangular blocky structure; soft, friable, slightly sticky and slightly plastic; few medium, fine and very fine roots; 5 percent cobbles, 5 percent pebbles; violently effervescent, moderately alkaline (pH 8.4); clear smooth boundary.

2Bk = 31 to 60 inches; light gray (10 YR 7/2) very cobbly loam, brown (10 YR 5/3); massive structure; soft, friable, sticky and plastic; few fine and very fine roots; 30 percent cobbles, 30 percent pebbles; violently effervescent, moderately alkaline (pH 8.2).

- Sawicki Series

Depth class : very deep
Drainage/Permeability : well drained/moderately slow
Landform : alluvial fans, stream terraces, hills, drainageways
Parent material : alluvium and colluvium derived from gneiss, schist, and arkosic sandstone
Slope range : 0 - 60 percent
Elevation range : 4700 - 7000 feet
Annual precipitation : 15 - 19 inches
Ann. air temperature : 39 - 43 ° F
Frost free period : 90 - 110 days
Taxonomic Class : loamy-skeletal, mixed Typic Argiborolls

Typical Pedon

Sawicki very stony loam, 2 to 8 percent slopes, in rangeland, Gallatin County, Montana; 700 feet south and 2800 feet west of the northeast corner of section 12, T.1NS, R.5E.

A = 0 to 5 inches; dark grayish brown (10 YR 4/2) very stony loam, very dark grayish brown (10YR 3/2) moist; moderate medium granular structure; soft, friable, slightly sticky and slightly plastic; many very fine, common fine and few medium pores; many very fine roots, few medium roots; 10 percent pebbles; 25 percent cobbles, 5 percent stones; neutral (pH 7.2); gradual wavy boundary.

Bt1 = 5 to 12 inches; dark grayish brown (10 YR 4/2) cobbly sandy clay loam, dark brown (10 YR 3/3) moist; moderate medium subangular blocky structure; slightly hard, very friable, slightly sticky and slightly plastic; few faint clay films on ped faces and pebbles surfaces; common very fine and fine, and few medium and coarse roots; many very fine, common fine and few medium pores; few faint clay films on faces of peds and on pebbles; 10 percent pebbles, 10 percent cobbles, 5 percent stones; neutral (pH 7.2); gradual wavy boundary.

Bt2 = 12 to 23 inches; dark yellowish brown (10 YR 4/4) very cobbly sandy clay loam, brown (10 YR 4/3) moist; moderate medium subangular blocky structure; slightly hard, friable, sticky and slightly plastic; common fine and very fine roots; common very fine, fine and few medium pores; common distinct clay films on faces of peds and on pebbles; 25 percent pebbles, 25 percent cobbles, 5 percent stones; slightly alkaline (pH 7.8); gradual wavy boundary.

BC = 23 to 31 inches; dark yellowish brown (10 YR 4/4) very cobbly sandy clay loam, brown (10 YR 4/3) moist; weak fine subangular blocky structure; slightly hard, friable, slightly sticky and slightly plastic; few fine and very fine roots; common very fine and fine, and few medium pores; 25 percent pebbles, 25 percent cobbles, 5 percent stones; slightly alkaline (pH 7.8); gradual wavy boundary.

C = 31 to 60 inches; dark yellowish brown (10 YR 4/4) very cobbly coarse sandy loam, brown (10 YR 4/3) moist; massive; loose, nonsticky and nonplastic; few very fine and fine roots; 30 percent pebbles, 25 percent cobbles, 5 percent stones; neutral (pH 7.2).

- Windham Series

Depth class : very deep
Drainage class : well drained
Permeability : moderate
Landform : alluvial fans, stream terraces, hills
Parent material : limestone alluvium or limestone colluvium
Slope range : 0 - 60 percent
Elevation range : 4600 - 6800 feet
Annual precipitation : 15 - 22 inches
Ann. air temperature : 39 - 43 ° F
Frost free period : 90 - 110 days

Taxonomic Class : Loamy-skeletal, carbonatic Typic Calciborolls

Typical Pedon

Windham gravelly loam, 8 to 15 percent slopes, in rangeland, Gallatin County, Montana; 100 feet south and 300 feet west of the northeast corner of section 17, T.3N, R.5E.

A = 0 to 6 inches; dark grayish brown (10 YR 4/2) gravelly loam, very dark grayish brown (10YR 3/2) moist; moderate medium granular structure; slightly hard, friable, slightly sticky and slightly plastic; common fine and fine roots; 15 percent pebbles and 10 percent cobbles; strongly effervescent; slightly alkaline (pH 7.6); clear wavy boundary.

Bk1 = 6 to 14 inches; light brownish gray (10 YR 6/2) gravelly loam, brown (10 YR 5/3) moist; weak medium subangular blocky structure; slightly hard, friable, slightly sticky and slightly plastic; few very fine and fine roots; 15 percent pebbles and 5 percent cobbles; lime disseminated and as crusts and pendants on rock fragments; violently effervescent; moderately alkaline (pH 8.0); gradual wavy boundary.

Bk2 = 14 to 60 inches; white (10 YR 8/2) extremely cobbly loam, very pale brown (10 YR 7/3) moist; massive; slightly hard, friable, sticky and slightly plastic; few very fine roots; 30 percent cobbles, 40 percent pebbles; lime disseminated and as crusts and pendants on rock fragments; violently effervescent; moderately alkaline (pH 8.2).

Appendix C. General characteristics of the soils in the Gallatin Valley.

Top soils

The upper horizons of soils (usually called as top soils) are pedologically designated as A horizons (Buol et al., 1989). NRCS-USDA reported that the upper-most horizons of the selected soil series were composed of Ap (p = plowed) horizons for agricultural lands and A horizons for other land uses. Thicknesses of the Ap horizons were generally 15 cm or more while the thicknesses of the A horizons were 10 to 15 cm thick.

Soil matrix colors in the upper layers of the selected soils series were relatively less variable. Measured in moist conditions using Munsell Soil Chart (Soil Survey Staff, 1975), soil matrix colors of the Ap and A horizons ranged from 10 YR 3/2 (very dark grayish brown) to 10 YR 5/2 (grayish brown). Closely related to soil colors, soil organic carbon contents in the upper layer were generally high, greater than 1.0 g/100g soil. Soil textures were commonly loam with some variations in coarse fragment contents. Some soils are also composed of stones and cobbles in the upper layers. Soil reaction (pH) ranged from slightly acid to alkaline (pH 6.5 to 8.9).

Most of the soil structures in the upper layers were weak to moderate in grades, fine to medium in sizes, and granular in shapes. These structural performances indicated that soil aggregates in the upper layers of the whole soil series were generally still in the process towards stability. This process has been delayed by frequent obstructions from farming activities. Lynch and Bragg (1985) suggest that soil structure is important to many soil physical properties, because it can control the distribution of soil pores which in turn indirectly affects some soil physical characteristics. A natural agent which primarily breaks soil aggregates down is water through either rainfall or run-off, while soil organic matter supports the soil aggregation process.

Sub Soils

The sub surface horizons of the soil series were grouped into three different horizons. They were designated as Bw (cambic), Bt (argilic), and Bk (calcic) horizons. Beanlake and Windham series were determined having only Bk as sub surface horizons. The combination of Bw and Bk in the sub surface horizons occurred in Amsterdam, Bridger, and Kelstrup series, while the Bt and Bk combination was found in Beaverton, Blackdog, Bozeman, Martinsdale, Meagher, and Turner series. Thicknesses of sub-surface horizons of the selected soils ranged from 51 to 139 cm. Turner series has the thinnest B horizon while Martinsdale is characterized by having the thickest one among the selected soil series.

Soil matrix colors of the three types of B horizons were slightly different. In Bt (argilic) horizons, soil matrix colors were very dark grayish brown to brown (10 YR 3/2 through 5/3), and were dark brown (10YR 3/3 to 4/3) in Bw (cambic) horizons. The Bk (calcic) horizons were characterized by having a wide range of soil matrix colors. The colors varied from dark brown through very pale brown (10 YR 4/3 through 10YR 7/3) and dark grayish brown to grayish brown (2.5 Y 4/2 to 2.5 Y 5/2).

The sizes of soil particles composing the B horizons were very variable. In the Bt horizons, soils were silty loam, clay loam, loam, and clay textured. Slight variations were due to the content of coarse fragments. The Bw horizons had only silt loam textural classes, while Bk layers were the most variable among the B horizons because of the presence of gravel and very coarse sand particles widened the textural variations of the Bk horizon and determined soil texture modifiers.

Appendix D. URL addresses of primary characterization data of the soil series

Data pertaining to soil series used in this study were obtained from the following internet website :

No.	Soil Series	Internet Website
1.	Amsterdam	http://vmhost.cdp.state.ne.us/nslsoil/HTBIN/DBFND3?series=Amsterdam
2.	Beanlake	http://vmhost.cdp.state.ne.us/nslsoil/HTBIN/DBFND3?series=Beanlake
3.	Beaverton	http://vmhost.cdp.state.ne.us/nslsoil/HTBIN/DBFND3?series=Beaverton
4.	Blackdog	http://vmhost.cdp.state.ne.us/nslsoil/HTBIN/DBFND3?series=Farland
5.	Bozeman	http://vmhost.cdp.state.ne.us/nslsoil/HTBIN/DBFND3?series=Bozeman
6.	Kelstrup	http://vmhost.cdp.state.ne.us/nslsoil/HTBIN/DBFND3?series=Kelstrup
7.	Martinsdale	http://vmhost.cdp.state.ne.us/nslsoil/HTBIN/DBFND3?series=Martinsdale
8.	Meagher	http://vmhost.cdp.state.ne.us/nslsoil/HTBIN/DBFND3?series=Meaghre
9.	Sawicki	<u>http://vmhost.cdp.state.ne.us/nslsoil/HTBIN/DBFND3?series=Sawicki</u>
10.	Turner	http://vmhost.cdp.state.ne.us/nslsoil/HTBIN/DBFND3?series=Turner
11.	Windham	http://vmhost.cdp.state.ne.us/nslsoil/HTBIN/DBFND3?series=Windham

Appendix E. Soil mapping unit (SMU), slope classes, and yield estimates for alfalfa and winter wheat provided by NRCS-USDA for the selected soil series.

No	Soil Series	SMU	Slope Class	----- Estimated Yield -----	
				Alfalfa ^{1/}	WinterWheat ^{2/}
				Mg/ha	Mg/ha
1.	Amsterdam	53B, 453B	B	4.49	4.30
		53C, 453C, 558C	C	4.49	4.30
2.	Beanlake	63B, 452B	B	3.37	3.43
		163C, 452C	C	3.37	3.36
3.	Beaverton	149B	B	1.68	2.08
4.	Blackdog	50B	B	4.49	4.17
		50C	C	4.49	4.17
5.	Bozeman	50B	B	4.49	4.17
6.	Kelstrup	431B	B	3.37	3.63
		31C	C	3.37	3.63
7.	Martinsdale	52B	B	4.04	3.43
		52C	C	4.04	3.43
8.	Meagher	257B	B	3.37	3.16
		57C, 257C	C	3.37	3.16
9.	Sawicki	261B	B	2.24	2.28
		261C	C	2.24	2.28
10.	Turner	457A	A	3.37	3.16
		57B	B	3.37	2.89
11.	Windham	266B,	B	2.24	2.02
		166C,	C	2.24	2.02

Source : NRCS-USDA office at Bozeman. ^{1/} To convert estimated yield to tons/acre, multiply the table value by 0.4457. ^{2/} To convert estimated yield to bushels/acre, multiply the table value by 14.881.

Appendix F. SAS program

OPTION NOCENTER LS = 80; DATA TEMP;

INPUT depth clay BD WHC OC Kf pH calcic W-1 S-1 A-1 W-2 S-2 A-2 W-3 S-3 A-3 W-4 S-4 A-4 W-5 S-5 A-5;

CARDS;

```
104 22.23 1.28 0.18 1.31 0.35 7.81 19 62 55.03 2 79.5 68.3 4.28 98.4 75 6.14 93.5 69.8 6.01 86.1 90.7 5.14
104 22.23 1.28 0.18 1.31 0.35 7.81 19 59 52.34 1.8 75.6 65 3.85 93.6 71 5.53 89 66.4 5.41 82 86.3 4.63
67 23.18 1.53 0.13 0.82 0.37 7.75 13 51 44.35 1.8 79.5 68.3 4.28 93 71 5.84 87.9 65.6 5.71 70 70 4.86
145 23.18 1.53 0.13 0.82 0.37 7.75 13 48 41 1.3 74.8 63.2 3.09 87.5 65 4.22 82.7 60.6 4.12 65.9 64.7 3.51
103 20.49 1.33 0.18 1.0 0.39 7.87 42 64 56.79 2 60.3 52.5 3.56 96.3 73 6.03 92.2 69.2 5.92 85 94 5.38
61 12.7 1.4 0.12 0.625 0.269 7.76 12 43 38.32 1.5 76 65.8 4.06 99.6 76 6.2 94.9 71.3 6.08 85 84 5.48
152 21.93 1.47 0.11 1.0 0.36 7.8 19 47 41.84 1.5 51 44.4 3.24 95.5 72 5.97 91.9 68.7 5.87 82.3 81 5.29
96 21.93 1.47 0.11 1.0 0.36 7.8 19 43 39 1.2 46.7 41.4 2.59 87.4 67 4.78 84.1 64 4.7 75.3 75.5 4.24
152 21.5 1.48 0.14 1.23 0.37 8.15 6 51 45.35 1.5 81.2 69.9 4.36 93.6 71 5.91 88.4 66 5.78 77 82 4.7
66 13.81 1.58 0.06 0.53 0.195 7.66 21 31 27.77 0.8 77.7 67.3 4.22 98.4 75 6.14 93.6 69.8 6.01 80 91 4.7
86 22.7 1.47 0.09 0.69 0.42 8.13 0 30 26.89 1 67.9 59.7 4.04 82.9 62 5.33 78 57.6 5.19 66.6 75 4.06
91 22.7 1.47 0.09 0.69 0.42 8.13 0 26 24 0.8 58.8 53.3 3.03 71.9 56 4 67.6 51.4 3.9 57.8 66.9 3.04
120 10.73 1.6 0.05 0.45 0.16 7.74 14 27 24.25 0.8 77.7 67.3 4.22 98.4 75 6.14 93.6 69.8 6.01 80 91 4.7
116 18.75 1.56 0.07 1.36 0.27 6.94 60 34 30.41 1 85.3 69.9 4.88 87.4 66 5.49 81.7 61.1 5.33 53.8 57.5 3.25
```

PROC REG DATA = TEMP;

Model W-1 = depth clay BD WHC OC Kf pH calcic/VIF TOL COLLIN;

Model W-1 = depth clay BD WHC OC Kf pH calcic/SELECTION = RSQUARE BEST =1;

Model W-1 = depth clay BD WHC OC Kf pH calcic/SELECTION = STEPWISE;

Model S-1 = depth clay BD WHC OC Kf pH calcic/VIF TOL COLLIN;

Model S-1 = depth clay BD WHC OC Kf pH calcic/SELECTION = RSQUARE BEST =1;

Model S-1 = depth clay BD WHC OC Kf pH calcic/SELECTION = STEPWISE;

Model A-1 = depth clay BD WHC OC Kf pH calcic/VIF TOL COLLIN;

Model A-1 = depth clay BD WHC OC Kf pH calcic/SELECTION = RSQUARE BEST =1;

Model A-1 = depth clay BD WHC OC Kf pH calcic/SELECTION = STEPWISE;

Model W-2 = depth clay BD WHC OC Kf pH calcic/VIF TOL COLLIN;

Model W-2 = depth clay BD WHC OC Kf pH calcic/SELECTION = RSQUARE BEST =1;

Model W-2 = depth clay BD WHC OC Kf pH calcic/SELECTION = STEPWISE;

Model S-2 = depth clay BD WHC OC Kf pH calcic/VIF TOL COLLIN;

Model S-2 = depth clay BD WHC OC Kf pH calcic/SELECTION = RSQUARE BEST =1;

Model S-2 = depth clay BD WHC OC Kf pH calcic/SELECTION = STEPWISE;

Model A-2 = depth clay BD WHC OC Kf pH calcic/VIF TOL COLLIN;

Model A-2 = depth clay BD WHC OC Kf pH calcic/SELECTION = RSQUARE BEST =1;

Model A-2 = depth clay BD WHC OC Kf pH calcic/SELECTION = STEPWISE;

Model W-3 = depth clay BD WHC OC Kf pH calcic/VIF TOL COLLIN;

Model W-3 = depth clay BD WHC OC Kf pH calcic/SELECTION = RSQUARE BEST =1;

Model W-3 = depth clay BD WHC OC Kf pH calcic/SELECTION = STEPWISE;

Model S-3 = depth clay BD WHC OC Kf pH calcic/VIF TOL COLLIN;

Model S-3 = depth clay BD WHC OC Kf pH calcic/SELECTION = RSQUARE BEST =1;

Model S-3 = depth clay BD WHC OC Kf pH calcic/SELECTION = STEPWISE;

Model A-3 = depth clay BD WHC OC Kf pH calcic/VIF TOL COLLIN;

Model A-3 = depth clay BD WHC OC Kf pH calcic/SELECTION = RSQUARE BEST =1;

Model A-3 = depth clay BD WHC OC Kf pH calcic/SELECTION = STEPWISE;

Appendix F (continued)

Model W-4 = depth clay BD WHC OC Kf pH calcic/VIF TOL COLLIN;
Model W-4 = depth clay BD WHC OC Kf pH calcic/SELECTION = RSQUARE BEST =1;
Model W-4 = depth clay BD WHC OC Kf pH calcic/SELECTION = STEPWISE;
Model S-4 = depth clay BD WHC OC Kf pH calcic/VIF TOL COLLIN;
Model S-4 = depth clay BD WHC OC Kf pH calcic/SELECTION = RSQUARE BEST =1;
Model S-4 = depth clay BD WHC OC Kf pH calcic/SELECTION = STEPWISE;
Model A-4 = depth clay BD WHC OC Kf pH calcic/VIF TOL COLLIN;
Model A-4 = depth clay BD WHC OC Kf pH calcic/SELECTION = RSQUARE BEST =1;
Model A-4 = depth clay BD WHC OC Kf pH calcic/SELECTION = STEPWISE;
Model W-5 = depth clay BD WHC OC Kf pH calcic/VIF TOL COLLIN;
Model W-5 = depth clay BD WHC OC Kf pH calcic/SELECTION = RSQUARE BEST =1;
Model W-5 = depth clay BD WHC OC Kf pH calcic/SELECTION = STEPWISE;
Model S-5 = depth clay BD WHC OC Kf pH calcic/VIF TOL COLLIN;
Model S-5 = depth clay BD WHC OC Kf pH calcic/SELECTION = RSQUARE BEST =1;
Model S-5 = depth clay BD WHC OC Kf pH calcic/SELECTION = STEPWISE;
Model A-5 = depth clay BD WHC OC Kf pH calcic/VIF TOL COLLIN;
Model A-5 = depth clay BD WHC OC Kf pH calcic/SELECTION = RSQUARE BEST =1;
Model A-5 = depth clay BD WHC OC Kf pH calcic/SELECTION = STEPWISE;
RUN;

Note : W = winter wheat; S = spring wheat; A = alfalfa

1 = NRCS; 2 = MAPS-1; 3 = MAPS-2; 4 = MAPS-3; 5 = Producers' input

Appendix G. SAS results of complete regression models for estimating winter wheat yields.

Model #	Source of Dependent Variable Data (Crop Yield)	Intercept	Slope*Variable	R ²
1.1	W-1 (NRCS)	12.28	273.46 x WHC	0.909
1.2	W-1 (NRCS)	9.88	271.42xWHC + 0.14xcalcic	0.940
1.3	W-1 (NRCS)	-41.98	331.04xWHC + 30.81xBD + 0.14xcalcic	0.957
2.	W-2 (MAPS-1)	93.16	- 67.36 x Kf	0.194
3.1	W-3 (MAPS-2)	109.47	- 96.87 x Kf	0.300
3.2	W-3 (MAPS-2)	107.87	137 x WHC - 96.87xKf	0.748
4.1	W-4 (MAPS-3)	104.09	- 51.39 x Kf	0.277
4.2	W-4 (MAPS-3)	102.50	137.56xWHC - 94.44xKf	0.723
5.1	W-5 (Producer input)	147.77	- 50.00 x BD	0.243
5.2	W-5 (Producer input)	205.90	- 71.02 x BD - 1.38 x clay	0.518
5.3	W-5 (Producer input)	88.36	199.38 x WHC - 1.85 x clay	0.635
5.4	W-5 (Producer input)	113.22	168.45xWHC - 15.07xBD - 1.81xclay	0.641
5.5	W-5 (Producer input)	12.11	188.45xWHC + 10.34xpH - 2.0xclay	0.710

Note : WHC input as soil water holding capacity; Kf input as erodibility; clay input as soil clay content, BD input as bulk density, and calcic input as depth to calcic horizon. See Table 3-3 for dimensions used.

Appendix H. SAS results of complete regression models for estimating spring wheat yields.

Model #	Source of Dependent Variable Data (Crop Yield)	Intercept	Slope*Variable	R ²
6.1	S-1 (NRCS)	11.52	237.70 x WHC	0.912
6.2	S-1 (NRCS)	9.40	235.88xWHC + 0.13xcalcic	0.944
7.	S-2 (MAPS-1)	78.52	-52.43 x Kf	0.186
8.1	S-3 (MAPS-2)	83.48	- 41.81 x Kf	0.321
8.2	S-3 (MAPS-2)	82.28	103.28xWHC - 74.33xKf	0.766
9.1	S-4 (MAPS-3)	77.66	-37.98 x Kf	0.275
9.2	S-4 (MAPS-3)	76.49	100.61xWHC - 69.70xKf	0.716
10.1	S-5 (Producer input)	101.45	- 1.12 x clay	0.175
10.2	S-5 (Producer input)	100.23	- 2.13xclay + 183.14xWHC	0.560
10.3	S-5 (Producer input)	-16.99	166.34xWHC + 15.90xpH - 2.36xclay	0.711
10.4	S-5 (Producer input)	-134.90	311.36xWHC + 16.99xpH + 1.24xclay	0.787
10.5	S-5 (Producer input)	-96.84	267.27xWHC + 16.8xpH	0.779
10.6	S-5 (Producer input)	-229.44	230.77xWHC + 33.57xpH + 0.34xcalcic	0.832
10.7	S-5 (Producer input)	-282.86	173.17xWHC - 105.03xKf + 46.58xpH + 0.46xcalcic	0.856

Appendix H. (continued)

Model #	Source of Dependent Variable Data (Crop Yield)	Intercept	Slope*Variable	R ²
10.8	S-5 (Producer input)	-304.23	128.96xWHC - 158.24xKf + 52.28xpH + 0.52xcalcic	0.869
10.9	S-5 (Producer input)	-206.19	-158.32xKf + 50.81xWHC + 49.66xpH - 43.68xBD + 0.48xcalcic	0.911
10.10	S-5 (Producer input)	-185.48	-153.11xKf - 59.48xBD + 50.5xpH + 0.5xcalcic	0.901

Note : WHC input as soil water holding capacity; Kf input as erodibility; clay input as soil clay content, and calcic input as depth to calcic horizon. See Table 3-3 for dimensions used.

Appendix I. Estimated yield potentials at the visited sites by experienced producers
of Gallatin Valley

Site #	Respondent	Non-Irr W		Irrig. WW		Non-Irr SW		Irrig SW		Non-Irr Alf		Irrig Alf	
		LTA	BGYP	LTA	BGYP	LTA	BGY	LTA	BGYP	LTA	BGYP	LTA	BGYP
..... bushel/Acre ton/Acre													
1	Matt Flikkema	55	65	70	78	48	55	80	95	3.5	4.5	5.5	6.0
	Rob Brownell	55	85	80	110	45	85	90	125	2.5	4.0	3.5	5.0
	Dick Morgan	40	60	70	80	40	70	70	90	1.5	2.0	3.5	4.0
	Le Roy	60	70	80	90	55	65	75	80	3.0	2.5	5.0	5.0
	George	60	75	75	90	70	75	80	90	4.0	4.0	5.0	5.5
	Ron Carlstrom	70	70	80	80	80	80	90	90	3.0	3.0	5.0	5.0
	Jim Bauder	55	60	60	75	50	50	60	65	3.0	3.5	4.5	5.5
2	Matt Flikkema	48	55	69	75	42	50	75	100	3.5	5.4	4.0	6.0
	Rob Brownell	40	70	70	100	35	80	85	110	2.0	3.5	3.0	4.5
	Dick Morgan	40	50	65	75	40	60	50	80	1.4	2.0	2.0	4.0
	Le Roy	55	60	75	80	45	65	65	85	2.0	3.0	5.0	5.0
	George	50	55	65	70	60	65	75	80	3.0	3.0	4.0	4.0
3	Matt Flikkema	20	25	25	30	15	25	20	35	1.5	3.0	2.0	3.0
	Rob Brownell	35	50	60	80	30	70	70	90	2.0	3.5	2.5	4.0
	Dick Morgan									2.0	2.0	2.0	2.0
	Le Roy	40	50	60	65	40	50	65	65	2.0	2.0	4.0	4.0
	George	25	35	30	40	30	35	35	40	2.5		3.0	
4	Matt Flikkema	50	60	60	70	50	65	65	80	5.0	5.0	6.0	6.4
	Rob Brownell	55	85	80	110	45	85	90	125	2.5	4.0	3.5	5.0
	Dick Morgan	50	65	70	80	45	60	60	70	2.0	2.5	3.0	4.0
	Le Roy	75	85	75	90	70	80	70	85	3.0	3.0	5.0	6.0
	George	50	65	65	75	45	50	50	60	4.0	4.5	5.0	6.0
5	Matt Flikkema	50	75	75	85	40	70	85	100	2.5	3.5	3.8	4.5
	Rob Brownell	35	70	65	100	30	60	75	100	1.5	3.0	2.5	4.5
	Dick Morgan	40	45	55	65	50	55	60	70	1.5	2.0	3.0	4.0
	Le Roy	30	45	45	60	30	45	50	65	2.0	2.0	5.0	5.0
	George	45	50	60	75	40	55	60	75	4.0	4.5	5.0	5.5
6	Matt Flikkema	40	50	48	65	35	50	40	60	3.0	4.5	4.5	6.0
	Rob Brownell	40	70	70	90	35	60	70	90	1.2	2.5	2.8	3.8
	Dick Morgan	40	45	55	65	50	55	60	70	2.0	2.5	3.5	4.5
	Le Roy	35	40	50	70	40	45	55	75	2.0	3.0	5.0	5.0
	George	30	35	45	60	30	43	45	55	2.0	2.5	4.0	5.0
7	Matt Flikkema	60	65	80	85	60	70	100	110	3.5	5.5	6.0	6.4
	Rob Brownell	45	60	85	100	40	60	95	120	2.0	3.0	3.5	4.5
	Dick Morgan	50	60	70	80	45	60	70	75	2.0	3.0	3.0	4.5
	Le Roy	50	70	70	85	60	70	80	85	3.0	3.0	6.0	6.0
	George	50	60	65	75	50	60	65	80	4.0	4.5	5.5	5.5

LTA = Long Term Average
WW = Winter Wheat

BGYP = Best Guess Yield Potential
SW = Spring Wheat

Date : July 2, 1998
Alf = Alfalfa

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