



Evaluating selected soil morphological, classification, climatic, and site variables that influence dryland small grain yield on Montana soils
by Thomas Harold Burke

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:

Rating soils based on their crop productivity capabilities is a potentially useful tool that can allow researchers to predict crop yields on a regional basis. Unfortunately, rating systems or indices have been hindered by (1) difficulties in quantifying soil properties and (2) by interference from outside variables such as management, climate, and site variables.

In order to address these problems, 184 field experiments conducted from 1968 to 1982 were selected throughout the dryland plains of Montana for evaluating selected soil morphological, classification, climatic, and site variables in relation to small grain yield. All sites chosen for study were at "optimal" management conditions in terms of fertility, weed and pest control. Data were analyzed by multiple stepwise linear regressions to identify variables related to yield.

Important soil morphological variables that were related to small grain yield included available water holding capacity ($r=+$), deep depth to Cca horizon, generally coarse, subangular blocky structure in the Cca horizon, and to a lesser extent, fine texture. Dry consistence of Cca was also positively correlated with yield in most cases, due to its positive correlation with deep depth to Cca, fine texture, and well developed structure in the Cca horizon. Other variables that were important to small grain yields in Montana included rainfall ($r=+$) and spring soil water stored from 0 to 120 cm ($r=+$). Rainfall, available water holding capacity, Cca dry consistence, and spring soil water from 0 to 122 cm accounted for 44% of yield variation, statewide.

Data were also subdivided by crop type (winter wheat, spring wheat, and barley) and by geographic location (north-central, southeastern, northeastern Montana, and Gallatin-Madison county area) for regression analysis. For crop subfiles, all yields depended on rainfall ($r=+$); spring wheat to the greatest extent and barley the least. For location subfiles, southeastern Montana was the only area without soil morphological variables appearing in its regression, suggesting that water factors were more limiting for this area.

A soil productivity index (SPI) was generated for 52 soil series considered in the study, with the "best" yielding soils in Montana (such as the Bozeman silt loam) having high available water holding capacity and relatively deep depths to Cca horizon. When SPI values were combined with water variables and crop type, 45% of yield variation was explained. Further soil productivity studies are needed to explain more yield variation.

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A thesis submitted in partial fulfillment
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Master of Science

in

Soils

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Bozeman, Montana

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ABSTRACT

Rating soils based on their crop productivity capabilities is a potentially useful tool that can allow researchers to predict crop yields on a regional basis. Unfortunately, rating systems or indices have been hindered by (1) difficulties in quantifying soil properties and (2) by interference from outside variables such as management, climate, and site variables.

In order to address these problems, 184 field experiments conducted from 1968 to 1982 were selected throughout the dryland plains of Montana for evaluating selected soil morphological, classification, climatic, and site variables in relation to small grain yield. All sites chosen for study were at "optimal" management conditions in terms of fertility, weed and pest control. Data were analyzed by multiple stepwise linear regressions to identify variables related to yield.

Important soil morphological variables that were related to small grain yield included available water holding capacity ($r=+$), deep depth to Cca horizon, generally coarse, subangular blocky structure in the Cca horizon, and to a lesser extent, fine texture. Dry consistence of Cca was also positively correlated with yield in most cases, due to its positive correlation with deep depth to Cca, fine texture, and well developed structure in the Cca horizon. Other variables that were important to small grain yields in Montana included rainfall ($r=+$) and spring soil water stored from 0 to 120 cm ($r=+$). Rainfall, available water holding capacity, Cca dry consistence, and spring soil water from 0 to 122 cm accounted for 44% of yield variation, statewide.

Data were also subdivided by crop type (winter wheat, spring wheat, and barley) and by geographic location (north-central, southeastern, northeastern Montana, and Gallatin-Madison county area) for regression analysis. For crop subfiles, all yields depended on rainfall ($r=+$); spring wheat to the greatest extent and barley the least. For location subfiles, southeastern Montana was the only area without soil morphological variables appearing in its regression, suggesting that water factors were more limiting for this area.

A soil productivity index (SPI) was generated for 52 soil series considered in the study, with the "best" yielding soils in Montana (such as the Bozeman silt loam) having high available water holding capacity and relatively deep depths to Cca horizon. When SPI values were combined with water variables and crop type, 45% of yield variation was explained. Further soil productivity studies are needed to explain more yield variation.

CHAPTER 1

INTRODUCTION

Researchers in Montana, as well as other parts of the world, have recognized a need for determining relationships between gross soil physical properties and crop production. By knowing how various soil variables influence crop production, soil scientists can determine the "soil productivity" or how much a crop can physically yield for a specific soil type. Once productivity factors are known for many soil series, researchers can then construct a soil productivity index (SPI) of soils for their particular area.

Soil productivity index values are a potentially useful tool that can allow researchers to predict crop productivity on a regional basis. This transfer of "agricultural technology" can in turn allow growers to tailor their crops to their particular soils. Other applications for using SPI values include aiding economists in determining potential values of soils and aiding in identifying productive lands for general land use planning and agricultural preservation policies.

SPI values can be determined for most dryland small grain production areas of Montana since soil properties are well documented in county soil surveys for a majority of

Montana's grain production areas. However, quantification of soil properties is essential in order to derive SPI values and consequently compare one soil type to another. Since many soil characteristics do not easily lend themselves to quantitative interpretations, researchers and SCS personnel have had difficulty in quantifying soil productivity for Montana's dryland grain production areas.

Specific problems of quantification that have faced researchers involve the qualitative nature of soil properties themselves. Many soil parameters can influence yields in subtle, indirect ways and are interrelated, making cause and effect relationships of soil properties to yield difficult to determine. Difficulties in quantifying soil productivity are also partially due to crop yields being a product of various management, genetic, and climatic factors as well as soil properties. In Montana, where the dryland production areas are semi-arid, yearly moisture differences become especially critical characteristics that can influence soil productivity values.

This study addresses these problems of quantifying soil productivity. Specific objectives of this study include:

- (1) to identify a few selected soil morphological, soil classification, field site, and soil-climatic parameters that may be important to small grain yields in Montana.

- (2) to take into account management variability of growers by using existing yield data from experiments with

"highest attainable yields" in terms of fertility, weeds, and pest management.

(3) to employ an existing information base (from county soil surveys and field experiments) to ascertain soil properties that may influence grain yield.

(4) to quantitatively examine cause and effect relationships between important variables and small grain yields, employing multiple regression techniques and correlation matrices.

(5) finally, to determine if these quantitative relationships can be useful for constructing a "soil productivity index" model for Montana's dryland grain production areas.

CHAPTER 2

LITERATURE REVIEW

Approaches of Quantifying Soil Productivity

One of the first attempts to quantify soil productivity was made by Storie in 1933. In his original index scheme, he chose a multiplicative model, examining surface texture, slope, profile morphology (depth), and other modifying factors such as pH and degree of wetness. Although Storie's model presented quantitative relationships between soil properties and crops, his ratings were based solely on soil characteristics. Huddleston (1983) called this approach an "inductive method" of indexing soil productivity; that is, soil productivity ratings are constructed based entirely on inferences about effects of soil properties on the yield (and growth) of plants. This approach was commonly taken during the 1930's and early 1940's by researchers.

After World War II however, Huddleston notes that the "deductive approach" became more popular among researchers. This method is currently used in every modern SCS soil survey in the form of yield tables. Unlike the inductive method, the deductive approach bases soil productivity entirely on comparisons of yield data from different soil types. Presently, researchers employ three methods of

collecting data for determining soil productivity: (1) using questionnaires to survey producers, (2) compiling existing data from farm records or experiment station results, and (3) actually collecting yield data on a small plot basis (Odell, 1958). By far, small plot data collection is the most precise method but perhaps the most costly.

One major limitation in using the deductive approach however is that crop yields not only reflect soil properties but climatic, management and biological variables as well. In order to account for these variables, researchers have tried sequential sampling (Olsen, 1981). When using sequential test plots, the experimenter deliberately samples plots on different (or sequential) soils within the same field (usually in a moisture catena). This method can essentially hold climatic, management, and biological variables fairly constant.

In Montana, Burke (unpublished data, 1982) sampled sequentially on three different soil series in order to show yield differences of winter wheat on no-till, minimum till and conventional summer fallow tillage in northcentral Montana. Results indicated that the Ernem series yielded much less (33 bu/ acre) than either Tanna or the Linnet-Acel complex regardless of tillage practice (see Figure One). Since the Ernem soil was much shallower than either Tanna or Linnet-Acel, lower yields were possibly influenced by Ernem having the lowest water holding capacity.

On a more quantitative basis, Munn and others (1982) randomly plotted samples sequentially between Scobey-Kevin soils in northern Montana within the same fields in order to detect yield differences in spring wheat. Using a paired t test, they observed that Scobey out-yielded Kevin in the same field at 7 different sites. In addition, more variation was detected between Scobey and Kevin than plots taken all within the same soil, indicating that soil series deliniation may be useful in detecting yield differences.

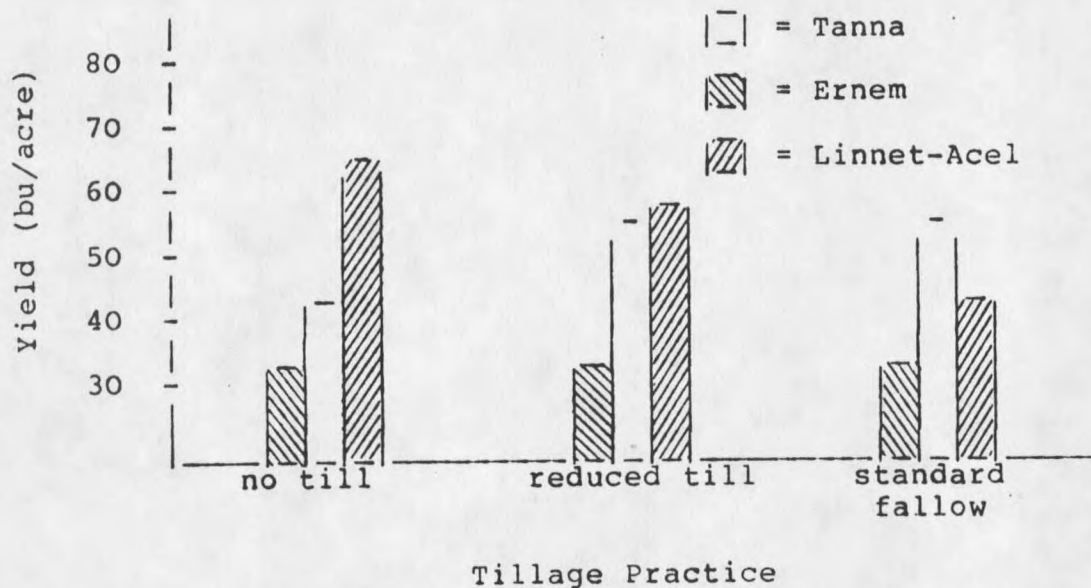


Figure 1. Yield Differences of Winter Wheat on No-Till, Minimum Till, and Standard Fallow on Three Soil Series.

For more than two soils (or populations), Duncan Range test comparisons have been successfully used by Peters

(1977) over a large area (western Alberta). For a large data base or a large area, multiple regression techniques have also been employed in determining important soil properties that influence yield and in evaluating how soil properties interact with each other (Allgood and Gray, 1978). Using a multiple regression model, Karathanasis et al. (1980) noted that 17 to 74% of the variation of grain yield was explained by soil variables on plots distributed worldwide.

Sopher and McCracken (1973) have cautioned, however, that multiple regression analysis can produce models that are unrealistic. They stressed that misuse of regression models can occur in two forms: "(1) drawing conclusions from a sample not representative of the population studied, and/or (2) literally interpreting the values of regression coefficients that are derived from highly correlated independent variables". The first misuse can be eliminated by replicating samples adequately in time and space. The second misuse is harder to alleviate since "independent" variables in soil-plant relationships are usually highly correlated, forcing coefficients to be correlated (not additive) also. This is of no consequence, Sopher and McCracken state, if the model is used solely as a predictor tool but should not be used to make cause and effect interpretations of variables unless correlations are taken into account. They suggest constructing a correlation

matrix and eliminating (or combining) those variables that are highly correlated. This technique is used in the present study. More will be said about these "multicollinearity effects" in the Materials and Methods section.

Soil Morphological, Climatic, and Site Influences on Yield

Soil Morphological Variables

The state of soil physical factors, such as texture, structure, bulk density and consistence can affect small grain yields in various ways. Soil texture indicates the relative proportions of the primary soil separates (sand, silt, and clay) in a soil. In terms of crop growth, soil texture can affect yields indirectly by affecting soil strength, pore size, air, water and soil temperature (DeJong and Rennie, 1967). Sopher and McCracken (1973) reported that an increase in clay for North Carolina soils correlated negatively with corn yield, while sand correlated positively with corn yield and silt correlated negatively (although only slightly) with yield. The negative response of increased clay to yield was attributed to higher clay amounts occurring in areas with poorer drainage. For drier areas, Allgood and Gray (1978) reported that clay in Oklahoma soils had a positive correlation with wheat yield while sand was negatively correlated (although only slightly), suggesting that finer textures may be more

beneficial to grain yield in that semi-arid area. In general, the Soil Survey Staff (1971) has rated sandy loams, loams, and silt loams as being the best textures for growing crops while coarser and finer textured soils rate lower.

Soil structure denotes the arrangement or the orientation of primary particles into secondary particles, thus indicating the distribution of micropores and macropores. In terms of crop growth, structure influences yield since roots penetrate partially by growing through existing voids and partially by moving aside soil particles (Taylor, 1974). Thus, roots tend to find structural weaknesses following voids even in rigid soil systems. With soils that are not highly structured and have high soil strength (i.e. few pores), roots must move substantial quantities of soil in their path which can reduce the plant's growing capacity.

Similar to structure, bulk density is a direct measurement of the amount of pore space that is available for water and air movement. Plant response to increased bulk density (compaction) can vary with soil type, plant species, climate and stage of development (Rosenburg, 1964). Specifically, Ferguson (1983) notes that the greatest compaction can occur in systems in which: (1) the soil particles cover a broad spectrum of sizes so that small particles can fit nicely between larger particles, (2) high surface areas and swelling clays (montmorillonite) dominate,

(3) swelling type cations (Na^+) dominate, (4) a water content that minimizes cohesion and friction exists.

In terms of soil productivity, Rosenberg (1964) noted that increasing bulk density may increase mechanical impedance, reduce aeration, and alter water availability and heat flux by decreasing pore space.

High bulk densities, however, may be beneficial to crops, particularly on sandy soils. For sandy loam soils, Rashid et al. (1976) reported that increased bulk density actually raised the water retention capacity of the soil by presumably reducing macropores (which do not strongly hold gravitational water). Excessive compaction may be harmful however. Veihmeyer and Hendrickson (1948) demonstrated that all plants tested couldn't penetrate soils with bulk density values of 1.9 g/cc or more. In Montana, bulk density problems due to compaction of cropland are not apparent up to 1.7 g/cc (Hayden Ferguson, personal communication).

Soil consistence is essentially an integrated measurement of bulk density, structure, and texture of a particular soil. It is determined by measuring soil resistance to crushing and its ability to be molded or changed in shape. Soil Survey Staff (1971) has chosen a moist consistency of "very friable" as the most suitable consistence for crop production. A firm or hard dry consistence is rated as poor and commonly implies slow permeability (Veeh, 1981).

In addition to soil physical aspects, gross morphological properties such as soil depth, available water holding capacity and depth to calcium carbonate horizon also are important factors of soil productivity. Bennet and others (1980) noted that deep soils correlated highly with high wheat yields, apparently due to increased available water holding capacity. Rapid stress to plants occurs on shallow soils with low water holding capacities which are subjected to greater climatic evapotranspiration demand than deeper soils (Richie, 1981). Soil Survey Staff (1971) recommends that a soil depth of 30 inches or greater is needed for good overall crop productivity.

In Montana, most agricultural soils have calcium carbonate accumulation, or calcic horizons, within their profiles (Montagne et al., 1982). This accumulation of free lime may negatively affect plant growth. Mortvedt (1976) postulated that high free lime levels may cause stunted growth as a result of P and micronutrient immobilization as well as serious ammonia volatilization losses in cases of improper N fertilizer management. On a worldwide scale, Karathanasis et al (1980) noted that the lowest grain yields were observed on highly calcareous soils (and on soils with a pH lower than 6.0). In northern Montana, Munn and others (1982) observed that percent CaCO_3 was highly negatively correlated with spring wheat yields on Scobey-Kevin complex, but more so on the Kevin soil than the Scobey soil. This

was explained by the fact that Kevin had its calcic horizon closer to the surface. They also postulated that the shallower calcic horizons may have induced P deficiency and thus lowered yield for Kevin soils compared with Scobey soils.

Soil-Climatic Variables

Variables that affect soil water and soil temperature can affect crop production as well. Lack of soil water, for example, can critically stress plants and result in less growth and yield. Richie (1981) states that plant stress can be caused by either (1) a deficiency of water in the root zone within the soil and/or (2) excessive atmospheric water demand from leaves.

Researchers have measured water stress of plants indirectly by estimating potential evapotranspiration (PET) which is primarily determined by weather factors such as temperature, net radiation, humidity and wind velocity (Penman, 1956). As a result, PET can essentially be used as a measure of water use where soil water is not limiting (i.e. irrigated wheat). In general, a higher PET rate occurs when weather is warm and dry which can deplete available soil water and decrease root penetration (Hsiao and Acevado, 1974).

In Montana, a semi-arid state, dryland grain production areas are often subjected to limited water situations during the growing season. Thus, PET estimates are not appropriate

for estimating water under these conditions and, instead, researchers have measured or estimated actual evapotranspiration (or AET) for semi-arid soils. For estimating AET, one needs to understand how the water-dynamics of the soil-plant-atmosphere system relates to the available water holding capacity of the soil, its depletion and replenishment (Richie, 1981). Generally, as AET decreases, soil water decreases.

To take into account both atmospheric demands and soil water supply, Denmond and Shaw (1962), using PET and AET in an equation, calculated the relative ET as follows:

$$\frac{\text{AET}}{\text{PET}} = \text{relative ET.}$$

When $\text{AET}/\text{PET} < 1$, there is a general decline in relative ET with time. If either AET decreases (soil water decreases) and/ or PET increases, relative ET slows down and the plant ceases to assimilate CO_2 . Richie (1981) has noted that when relative ET is less than one, PET becomes less important in semi-arid areas as factors affecting water transport from soil to plant become more important. He also states that variations in soil water deficiencies (AET) are the major cause in year to year variations in yield.

Precipitation during the growing season usually is beneficial to crop yield in that it increases soil water available for plant use. Runge and Odell (1958) found that water above normal precipitation was especially beneficial

on corn in Iowa approximately one month before anthesis. In contrast, Karathanasis et al. (1980) found that seasonal rainfall had a low significance or a slightly negative effect on wheat yield on a worldwide scale (apparently due to leaching of nutrient anions). For semi-arid areas, however, precipitation has positive effects on small grain yields. Brengle (1982) noted that for eastern Colorado, all land types that produce wheat yields well above the cost of production were found in areas that receive more than 380 mm precipitation annually. Thus, total amount of precipitation becomes more critical perhaps up to a point. Karathanasis did note that wheat yields increased with increased water up to 350 mm and then decreased on a worldwide basis. Apparently, Karathanasis concluded, the distribution of rainfall during the critical growth stages appeared to be more important than total amount of precipitation except at the lower end of the precipitation scale.

Soil temperature also can influence plant yield. Willis and Power (1975) reported that increasing soil temperature decreases water viscosity and surface tension while increasing hydraulic conductivity. Thus an increase in soil temperature can increase the water flow in a particular soil.

Soil temperatures can also affect crop growth and yield directly. Nielsen (1974) notes that optimal yields for barley usually occur at 18 C, while wheat yields are

optimized at 20 C. Power et al. (1970) however noted that yield potential of barley may decrease with an increase in root temperature due to higher temperatures hastening maturity.

In terms of crop yields, Black (1970) observed on eastern Montana soils that winter wheat yields were very dependent on soil temperature and soil water during May, suggesting that higher early temperatures are critical for producing good yields. Runge and Odell (1958) found that both precipitation and maximum daily temperature 50 to 74 days before and 14 to 30 days after full tassel on corn explained up to 67% of the yield variability from 1903 to 1956.

Site Variables

Site characteristics or local topography can influence crops indirectly by affecting soil properties or conditions which influence yield. Soils with south-facing aspects, for example, receive greater solar energy, resulting in higher soil temperature and a drier overall growing season than soils with north-facing aspects. The latter have more soil water during the growing season, greater organic matter, and generally thicker soil depth (Montagne et al., 1982).

Slope angles and slope positions by themselves also affect soil properties which can influence yields. Soils on convex positions tend to be shallower (due to more erosion influence) than concave-position soils which tend to

accumulate more soil water (Montagne et al., 1982). In terms of slope angle, Furley (1971) reported that high correlations exist between soil properties and slope angle on convex portions of slopes but relationships of soil angle and properties on concave areas were much poorer. On calcareous soils studied, Furley reported that convex slope angles were directly positively related to pH while negatively related to organic carbon, nitrogen, and silt and clay on convex slopes. Consequently, slope angle does affect values of certain soil properties with most of the changes occurring on convex slopes as opposed to concave slopes.

CHAPTER 3

MATERIALS AND METHODS

Plot Selection and Sampling

One hundred and eighty four field experiments were conducted between 1968 and 1982 on 123 sites throughout the state of Montana (see Figure 2). Of these 184 experiments, 182 were fertility field plots conducted by researchers from various Montana State Agriculture Experimental Field Stations (MAES) and recorded in MAES Annual Reports. In addition, these field experiments were utilized in Veeh's thesis (1981) for predicting K response based on selected soil properties. The two remaining field experiments were conducted in 1982 by the "Integrated Pest Management" team (Nissen and Juhnke, 1983). Appendix A lists the locations of each site and the number of experiments per site.

Plot selection for this thesis was based on the criteria that (1) weeds and disease problems were adequately controlled so as not to influence grain yields and, (2) that fertility levels of N, P and K were adequate so as to not limit yields. Thus the highest yields recorded by researchers that corresponded to a particular plot were considered "highest attainable yields" in terms of

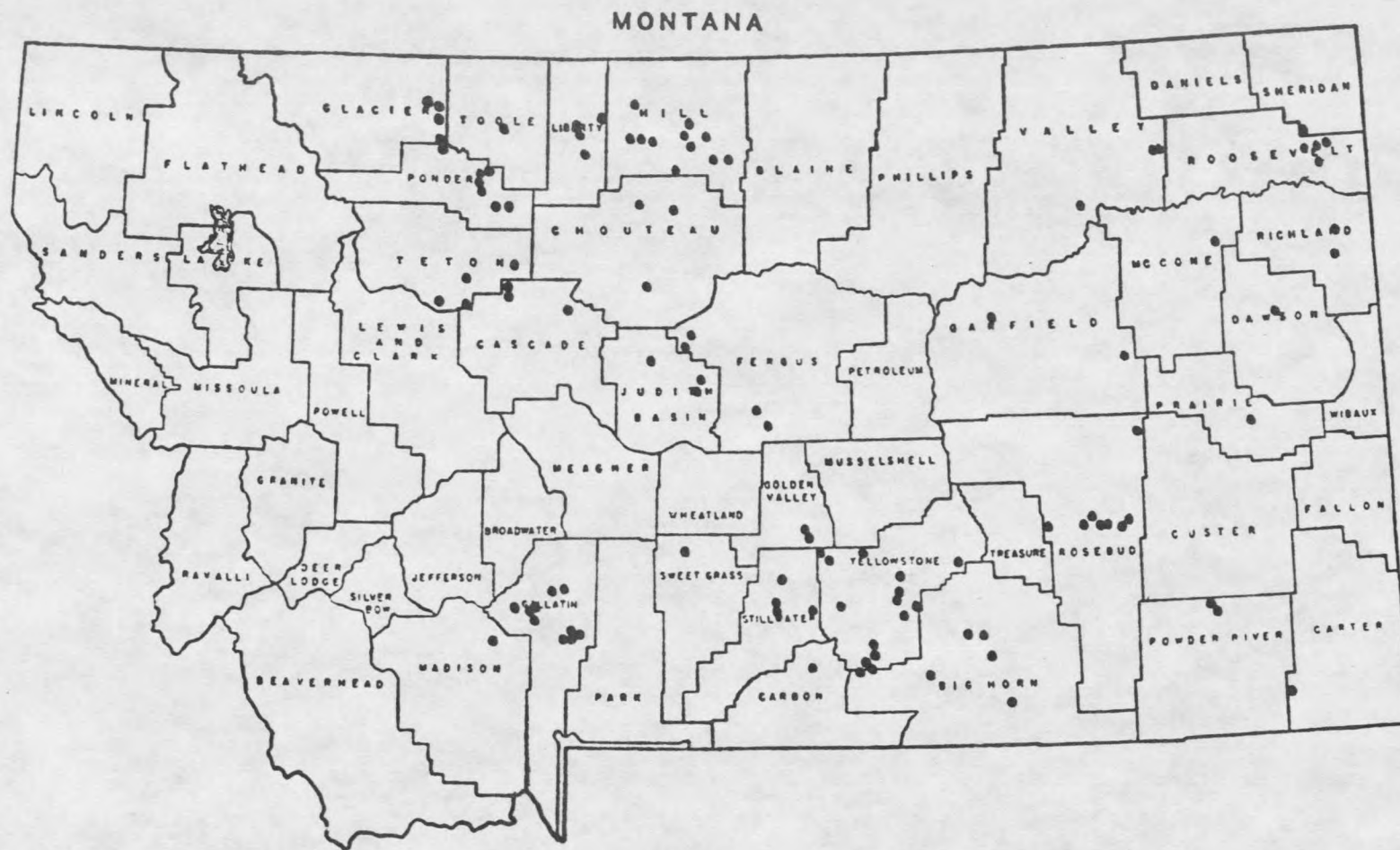


Figure 2. Location of Study Sites.

fertility, weed, and disease control. Field experiments where severe drought was apparent were also included in this study if water data were recorded for that particular site. In this way, management and climatic variables were at least partially accounted for.

For collecting physical soil data, soils were sampled as near the center of the old experiment sites as possible, as explained by Veeh (1981). Core samples, from a Giddings probe, were divided into plow layer (Ap) horizon, B horizon (based on structural and textural differences induced by clay accumulation) and a "Cca" horizon where strong reaction occurred with dilute hydrochloric acid. For the IPM sites, one pit was dug on the convex slope and one for the concave slope for each site, and analyzed separately. Since yield data for the IPM sites were averaged on both convex and concave slopes, soil sample data were likewise averaged for each site.

Variable Selection and Measurement

Listed in Table 1 are the variables considered in this study and used in multiple regression and correlation analyses. This section will explain in detail how variables were measured and, where appropriate, how variables were coded.

Table 1. Variables Considered in the Study.

Var. Number	Variable Name	Units	Format	Cases with Missing Data
AGRONOMIC-EXPERIMENT VARIABLES				
V01	SITE	A NUMBER	F3.0	0
V02	SITE EXP. #	A NUMBER(1-3)	F1.0	0
V03	CROP	coded value	F1.0	0
V04	YEAR	(68-82)	F2.0	0
V05	CARD #	1-3	F1.0	0
V06	YIELD	Kg/ha	F4.0	0
SOIL MORPHOLOGICAL VARIABLES				
V08	DRY CONSISTENCE Ap	Ks/cm ²	F2.1	0
V09	DRY CONSISTENCE B	Ks/cm ²	F2.1	16
V10	DRY CONSISTENCE Cca	Ks/cm ²	F2.1	2
V11	BULK DENSITY Ap	g/cm ³	F3.2	0
V12	BULK DENSITY B	g/cm ³	F3.2	16
V13	BULK DENSITY Cca	g/cm ³	F3.2	2
V14	STRUCTURE GRADE Ap	coded value	F1.0	8
V15	STRUCTURE SIZE Ap	coded value	F1.0	8
V16	STRUCTURE TYPE Ap	coded value	F1.0	8
V17	STRUCTURE GRADE B	coded value	F1.0	32
V18	STRUCTURE SIZE B	coded value	F1.0	32
V19	STRUCTURE TYPE B	coded value	F1.0	32
V20	STRUCTURE GRADE Cca	coded value	F1.0	8
V21	STRUCTURE SIZE Cca	coded value	F1.0	8
V22	STRUCTURE TYPE Cca	coded value	F1.0	8
V23	TEXTURAL CLASS	coded value	F2.0	3
V24	TEXTURAL FAMILY	coded value	F2.0	3
V26	THICKNESS OF B	cm	F2.0	15
V27	DEPTH TO Cca	cm	F2.0	2
V53	AVAL. WATER HOLD. CAPACITY	coded value	F1.0	26
V54	SOIL THICKNESS	coded value	F1.0	26
SITE VARIABLES				
V25	GEOGRAPHIC LOCATION	coded value	F1.0	0
V28	ELEVATION	m	F4.0	0
V29	SLOPE	percent	F2.1	0
V30	ASPECT	coded value	F2.0	4
V31	LATITUDE	degrees; minutes	F4.2	0
SOIL CLASSIFICATION VARIABLES				
V32	MEAN ANN. SOIL TEMP.	'C	F3.1	32
V33	TEMP. REGIME	coded value	F1.0	1
V39	MOISTURE REGIME	coded value	F2.0	24
SOIL-CLIMATIC VARIABLES				
V34	TEMP.(APRIL)	'C	F2.0	158
V35	TEMP.(MAY)	'C	F2.0	144
V36	TEMP.(JUNE)	'C	F2.0	141
V37	TEMP.(JULY)	'C	F2.0	142
V38	RAINFALL (GROWING SEASON)	cm	F3.1	60
V40	TOTAL SPRING SOIL WATER	cm	F4.1	52
V41	SPRING SOIL WATER (0-30 CM)	cm	F3.1	71
V42	SPRING SOIL WATER (30-60 CM)	cm	F3.1	71
V43	SPRING SOIL WATER (60-90 CM)	cm	F3.1	72
V44	SPRING SOIL WATER (90-122 CM)	cm	F3.1	80
V45	SPRING SOIL WATER (122-152 CM)	cm	F3.1	116
V46	SPRING SOIL WATER (152-183 CM)	cm	F3.1	142
V47	SPRING SOIL WATER (0-30 CM)	cm	F3.1	71
V48	SPRING SOIL WATER (0-60 CM)	cm	F4.1	71
V49	SPRING SOIL WATER (0-90 CM)	cm	F4.1	72
V50	SPRING SOIL WATER (0-122 CM)	cm	F4.1	72
V51	SPRING SOIL WATER (0-152 CM)	cm	F4.1	72
V52	SPRING SOIL WATER (0-183 CM)	cm	F4.1	72
V55	POTENTIAL EVAPOTRANS.	cm	F2.0	0
V56	FROST-FREE SEASON LENGTH	days	F3.0	0
V57	TOTAL AVAIL. WATER (V38 + V40)	cm	F3.1	101
V58	TOTAL AVAIL. WATER TO 122 CM (V38 + V50)	cm	F3.1	101
V59	TOTAL AVAIL. WATER TO 90 CM (V38 + V49)	cm	F3.1	101

Agronomic Data

Agronomic data considered for analysis were type of crop (V03) and the grain yield (V06). Year of the experiment (V04) was also included in the regression analysis in order to detect yearly trends of other variables (climatic variables, for example).

Coded values for crop type are shown in Table 2 and are ordered from winter wheat (highest test weight) to barley (lowest test weight).

Table 2. Coding Scheme for Crop Type

Crop type	Coded value
winter wheat	1
spring wheat	2
barley	3

Yield data (in kg/ha) were recorded from annual reports listing the highest yield (average of 3 or 4 reps) for that particular field plot at a particular fertility level. For the IPM plots, fertility rates were considered adequate so one average value was recorded for each plot.

Soil Morphological Variables

Dry consistence measurements were recorded for A, B, and Cca horizons, if present (V08 TO V10). Actual measurements of dry consistence were obtained using a penetrometer (CL-700: Soiltest, Inc.) which measures the force needed to crush an unconfined ped (in kg/cm²). This method was

avored by Veeh (1981) because of its more quantitative (less subjective) approach as opposed to assigning values (i.e. "hard" to "loose"). Using the penetrometer, Veeh recorded values (which are employed in this study) from five peds of uniform size and thickness from each horizon and averaged these values for each horizon.

Bulk density measurements by the clod method (Black, 1965) were recorded for each site. The average value from three large peds for each horizon was used in the analysis (V11 to V13).

Soil structure values (V14 to V22) were obtained from either field observation or (in most cases) from the soil series description that corresponded to a particular site (see Appendix A). In an attempt to quantify soil structure descriptions, coded one-digit numbers were used for grade, size, and type for each horizon to reflect the trend from weak to strong, fine to coarse, and wide or angular peds to small round peds (see Table 3).

Table 3. Coding Scheme for Structure.

Grade	Coded value	Size	Coded value	Type	coded value
weak	1	fine	1	platy	1
moderate	2	medium	2	prismatic	2
strong	3	coarse	3	columnar	3
				angular	
				blocky	4
				subangular	
				blocky	5
				granular	6
				massive	7
				single grain	8

Each horizon has three values for structure; one each for grade, size, and type. For structure type, some values were not applicable for particular horizons. For example, Ap structure type values were recorded as either 1,4,5, or 6; for the B horizon, 2,3,4, or 5; and for the Cca horizon 2,4,5, or 7. Thus a "high" structure type value for the Cca horizon would indicate a massive structure (7) while a high structure type rating for the Ap horizon would indicate a granular structure (6) and a subangular blocky structure (5) in the B horizon. It is important to distinguish structure type values in this way when examining correlation relationships with yield.

Textural class (V23) refers to the texture dominant at the surface of a given soil and is usually associated with the soil series name. The values were taken from either soil series descriptions or hand textured in the field for sites not classified. The coding scheme used for textural class in the analysis appears in Table 4, where the lowest value corresponds to coarse texture and the highest value to fine texture.

Table 4. Coding Scheme for Textural Class.

Textural class	Coded value
fine-sandy loam	1
loam	2
silt loam	3
silty clay loam	4
clay loam	5
clay	6

Soil surveyors use textural family to denote the dominant texture in the control section in the profile (usually the B horizon if argillic). The name itself is derived from the classification name at the family level. Table 5 shows the coding scheme of the textural family with values increasing from coarse to fine.

Table 5. Coding Scheme for Textural Family.

Textural family	coded value
Coarse-loamy	1
Fine-loamy	2
Fine-silty	3
Fine (montmorillonitic)	4

Other soil morphological variables that were considered in this study were depth to Cca or carbonate layer (V27), thickness of B horizon (V26), available water holding capacity (V53), and soil depth to paralithic or lithic contact (V54). Depth to Cca and thickness of B horizon were field measured, and available water holding capacity (AWC) and soil depth were estimated from soil series descriptions. Table 6 and 7 show the coding scheme for AWC and soil depth.

Table 6. Coding Scheme for Available Water Holding Capacity.

	Cm	Coded value
low	0-13	1
medium	13-18	2
high	18-25	3
very high	>25	4

Soil Classification Variables

Soil classification variables refer to those parameters that can be derived from either the soil series name or the particular classification given for a series. In most cases, the soil series (and hence its classification) was determined by researchers from MAES Annual Reports. If not found in the reports, however, the legal description of the fertility plot was compared with the appropriate SCS county soil survey to determine the soil series of a particular site. Some counties, particularly Hill and Liberty County, have not been surveyed so series (and classifications) for these sites were not known (see Appendix A).

Table 7. Coding Scheme for Soil Depth to Lithic or Paralithic Contact.

	Cm	Coded value
shallow	<50	0
deep	50-150+	1

Classification variables included in the study were mean annual soil temperature (V32), temperature regime (V33), and moisture regime (V39). Appendix B shows the category of moisture regime and temperature regime for each series considered in the analysis. In addition, textural class and textural family are also displayed in Appendix B for each series.

Soil temperature and moisture regimes were coded as shown in Tables 8 and 9, respectively, with temperature

regimes coded from cold to warm and moisture regimes from wet to dry. These regimes were obtained from the classification names as explained by Veeh (1981).

Table 8. Coding Scheme for Temperature Regime.

Temperature regime	Coded value
Cryic	1
Frigid	2
Mesic	3

Table 9. Coding Scheme for Moisture Regime.

Moisture regime	Coded value
Udic	1
Ustic	2
Ustic-Aridic	3
Aridic-Ustic	4

Site Variables

Site variables considered in the study include aspect (V30), slope percent (V29), latitude (V31), elevation (V26), and geographical location (V25). Aspect and slope percent variables were recorded in the field while taking core samples. Latitude, elevation, and geographical location were obtained from topographic maps and legal description for each site.

Two of the variables, aspect and geographical location, were entered as coded values. Figure 3 shows the coding scheme for aspect in which a number from one to eight was assigned to correspond with azimuth degrees (Veeh, 1981;

Schaff, 1979). Although somewhat limited in determining north-south relationships, this scheme does allow east-west interpretations with east generally being a low value and west being a high value.

Geographical location, the second coded variable, was used in the analysis in order to separate plots into areas of more uniformity. Although somewhat arbitrary, these areas were separated on the basis of how close sites were to one another, growing season differences, and differences in general climatic conditions. Figure 4 shows the four areas delineated for the state of Montana. A number (1-4) was assigned as the coded value for this variable. Note that most of the spring wheat was in location 2 and 3, most of the barley was in location 1, and most of the winter wheat was in location 4.

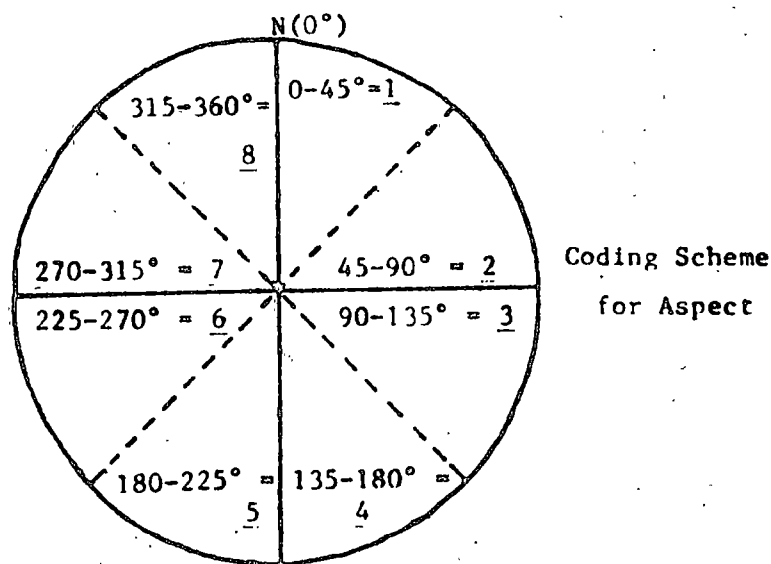


Figure 3. Coding Scheme for Aspect.

Soil-Climatic Variables

Soil-climatic variables are considered here to be those parameters that are influenced by year to year "growing condition" variability. The variables considered for analysis are rainfall (V38), available spring soil water (V40-V52), soil temperature (V34-V36), potential evapotranspiration (V55), and length of frost-free season (V56).

Rainfall (in cm) was recorded from MAES Annual Reports for plots that had rainfall data. The value used in the analysis was that of total rainfall during the growing season (spring planting to harvest) without regard for distribution throughout the growing season. For winter wheat experiments, researchers began recording "growing season" rainfall as early as possible in the spring when they seeded nearby spring wheat and barley sites.

MAES researchers also recorded soil temperature readings during the growing season, mostly in Locations 4 and 1. Average monthly temperatures were recorded and put into the analysis.

Spring soil water was also observed by many MAES researchers and recorded for most of the sites used in this study. However, some water values were recorded as available water (cm) while others were calculated and recorded as total water (cm); that is, available water plus water held at greater tensions than at wilting point. In

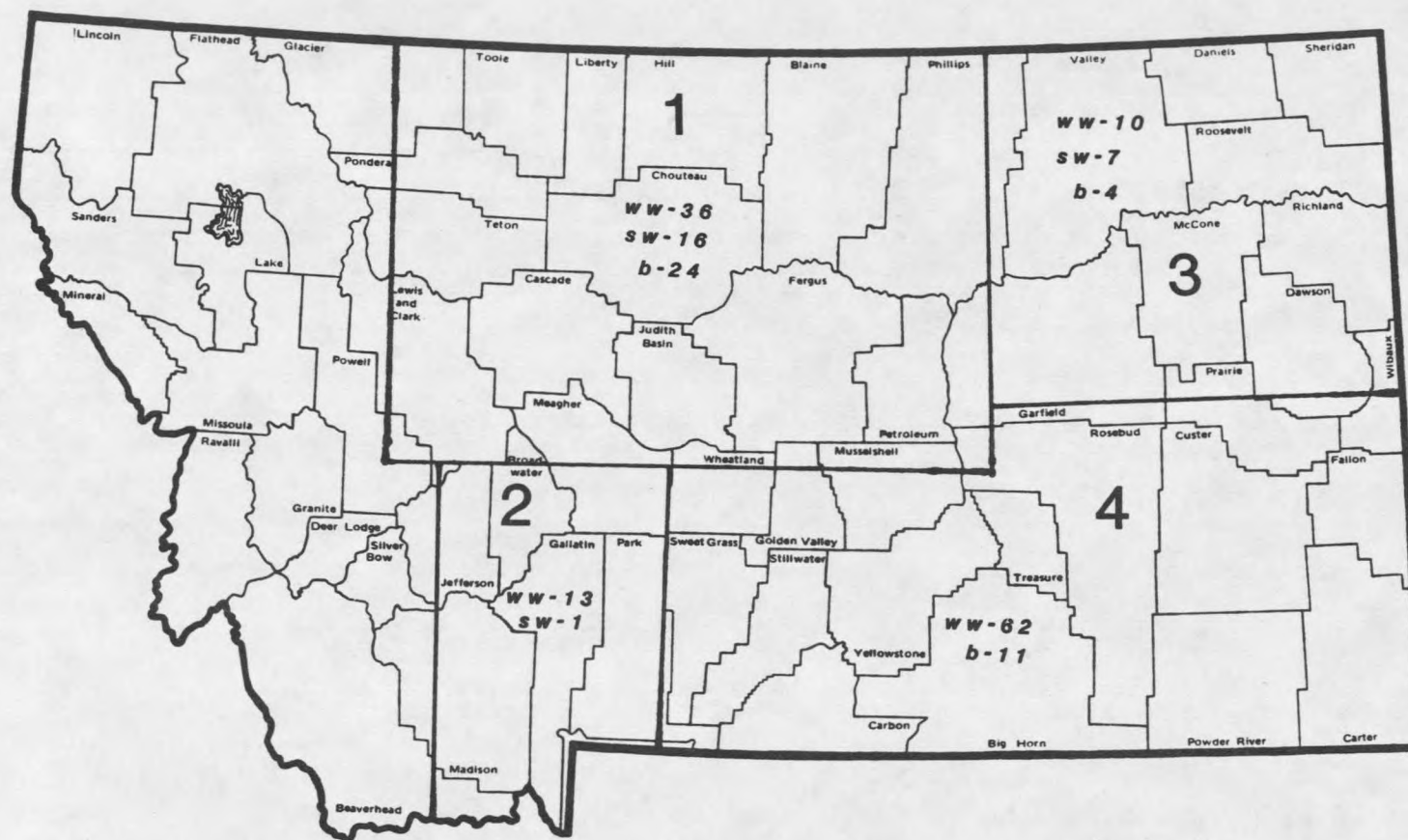


Figure 4. Delineation of geographic location (V25) and the number of experiments according to crop in each.
 WW = winter wheat, SW = spring wheat,
 B = barley

order to introduce only one value per plot into the analysis, I estimated available water by converting total water values into available water values by using the "doubling rule" where:

$$\begin{aligned}\text{Total water} &= \text{Field Capacity Water (FC)} \\ \text{Water held at wilting point (WP)} &= \text{FC} / 2 \\ \text{Plant Available Water} &= \text{FC} - \text{WP}\end{aligned}$$

For the IPM sites, available soil water in the spring was estimated using the Brown Moisture Probe (Brown, 1960).

Once all water values were converted to spring available water, I subdivided these values; (1) total spring available soil water (V40), (2) spring available soil water in increments of 30 cm of the soil profile down to 183 cm (V41-V46), and spring available soil water on a cumulative soil profile bases to 183 cm (V47-V52). In addition, on plots where both rainfall and soil water values were recorded, I included total available water for the growing season (that is, rainfall plus soil available water). Variables 57 through 59 in Table 1 indicate total available water for the growing season (rainfall plus available spring soil water) at varying profile depths.

Soil water values were divided into these variables in order to detect relationships between rainfall and various depths of soil water and also to see which water relationships relate the best to grain yields.

Potential evapotranspiration (PET) is a climatic variable that was considered for analysis which can indicate

radiant energy demand on small grains. PET values were recorded by overlaying a plot location map on an average annual PET map of Montana (Caprio, 1973) and then recording the corresponding average annual PET. In order to more accurately estimate PET for a particular year for a plot in question, I adjusted above or below the average annual PET based on nearby experimental weather station evaporative pan records. In this way, PET more nearly reflected that specific year's weather pattern than did the average PET. PET measured in this fashion is very approximate and is not as precise as relative ET measurements (which were not available).

The length of the frost-free season was estimated in a similar manner as PET. Using the Average Frost-Free Season Map of Montana (Caprio, 1965), I recorded the average frost-free season days for a plot in question and then adjusted above or below this average depending on the number of frost-free days recorded for that particular year (based on nearby experiment weather station records). Thus, frost-free season length is also a very approximate measurement since planting dates may not have exactly coincided with frost-free season length.

Statistical Methods

All the variables considered for analysis (in Table 1) were put in an SPSS stepwise multiple linear regression

program (Nie et al., 1975) which also computed useful Pearson correlations for the variables considered. Appendix C presents all raw data that were entered into the program.

As indicated in Table 1, many plots had missing soil temperature, spring soil water, and rainfall data. Since the analysis of R^2 values and the interpretation of significant F-values should be based on the number of sites with complete data, most regressions were run by excluding or restricting soil temperature, spring soil water, or rainfall variables at various times. Six broad categories of regressions with restrictions were run as follows:

- (1) Regressions including all cases restricting temperature, rainfall, and water variables (total possible cases = 184).
- (2) Regressions including cases with rainfall only (excluding temperature and soil water variables). (total possible cases = 123).
- (3) Regressions including cases with soil water only (excluding temperature and rainfall variables). (total possible cases = 114).
- (4) Regressions including cases with both rainfall and soil water variables (temperature variable excluded). (total possible cases = 83).
- (5) Regressions including cases with both rainfall and soil water variables except V57 to V59 (temperature variables excluded). (total possible cases = 83).
- (6) Regressions including cases with all variables (n = 42; considered for statewide cases only).

Within each of the above categories, regression runs were divided into subfiles; one for the statewide case, one for

each location (1-4), and one for each crop type for a total of 8 subfiles.

For all regression runs, I allowed a maximum of 5 variables to enter each regression equation. With more than 5 variables the contribution of additional variables to predict yield was low and multicollinearity problems began to develop (that is, later variables that entered the equation were dependent on earlier variables). The level of statistical significance ($p = .05$) for each regression equation was determined from standard F-tables (Ott, 1977). Appendix D presents the regressions computed by SPSS, totaling 190 possible regressions to analyze.

To make inferences on variable relationships with yield and correlations with other variables, it was desirable to reduce the 190 regression equations into one or two "best" equations for statewide cases and each subfile. "Best" equations were developed by subjecting all stepwise equations to the following criteria:

- (1) Variables in the equation could not be significantly correlated ($p = .05$) to each other (i.e. no multicollinearity problems). Thus, later variables that entered the equation (5 or less) that were correlated to earlier variables were eliminated. Multicollinearity reductions were desirable to make cause and effect interpretations more reliable.

(2) Variables left in the equation had to either be directly related to yield or make a contribution to variables in the correlation matrices that were directly related to yield. This was done to assure that variables in the equation had some physical function to yield rather than just being an extra statistical variate to complete the equation.

(3) For some equations, variables that were directly correlated to yield ($p = .05$) in the correlation matrices were not entered during the stepwise process. In these cases, regressions were rerun including variables that weren't considered the first time and then tested for significance at $p = .05$. These equations also appear in Appendix D with the SPSS runs under the heading "Extra Runs".

(4) For small sample sizes ($n < 20$), variables allowed to enter the equation were restricted to $1/5$ the sample size as suggested by Tabachnick and Fidell (1983). This was done because more cases need to be present than variables or the regression solution becomes perfect, and therefore meaningless. For cases where $n < 5$, a few regressions for location 2 and 3 were thrown out (see Appendix E).

After subjecting all equations to criteria 1 through 4, five to six "best" regression equations were chosen for each subfile (one "best" equation for each category). Appendix V

shows these equations for each category and for each subfile.

(5) Next, in order to pick one "best" equation for each subfile, equations in Appendix E for each subfile were compared using "adjusted R^2 values". Adjusted R^2 values were needed for comparisons because the number of cases (n) and variable number varied from regression to regression. I calculated an adjusted R^2 as suggested by Seber (1977) in which:

$$R^2 \text{ adjusted} = 1 - [1 - R^2] [n/(n-p)]$$

where n is the number of cases and p is the number of parameters (number of variables plus one for the coefficient). The regressions with the highest adjusted R^2 per subfile were picked for detailed study in the Results and Discussion section.

As a final check to see if, indeed, the variables in the "best" equations were representative of the population in question, Pearson correlation matrices were employed to identify variables that were significantly correlated directly with yield (significance at $p = .05$). For each subfile, matrices that were considered included:

- (1) correlation matrix without temperature, rainfall and water variables.
- (2) correlation matrix with rainfall and without temperature and water variables.
- (3) correlation matrix with soil water and without temperature and rainfall variables.

- (4) correlation matrix with both rainfall and soil water and without temperature variables.
- (5) correlation matrix with all variables included (statewide subfile only).

Matrices were categorized for each subfile in this manner because many plots had missing soil temperature, spring soil water, and rainfall data (see Table 1). Appendix F shows the correlation matrices associated with the "best" equation variables that were chosen based on criteria one through five.

Once all the correlations were determined, variable occurrence frequencies for all categories were calculated as follows:

$$\% \text{ frequency} = \frac{\# \text{ of times variable was correlated with yield}}{\# \text{ of times variable was allowed in matrices}}$$

The variable occurrence frequencies are shown Appendix G.

Variable occurrence frequency values were compared with corresponding "best" regression variables for statewide cases and each subfile in the Results and Discussion section. This was done in order to determine if variables in the best equation were important only for that particular sample size or (if the variable's frequency was high), if the variable was more representative of the population in question. If, for example, a variable entered the "best" equation for the winter wheat subfile but its frequency of occurrence (in relation to winter wheat yield) was only 25%, the particular variable may not be very important for

winter wheat. Thus, interpreting important variables that were related to grain yield was facilitated by employing both regression techniques and correlation matrices.

CHAPTER 4

RESULTS AND DISCUSSION

Identifying Important VariablesAll Locations and Crops (Statewide)

The "best" regression equation for all locations and crops includes rainfall, available water holding capacity, dry consistence of Cca horizon, and spring soil water to 122 cm as variables (Table 10). All variables were positively correlated to yield. Rainfall (V38) contributed the most toward grain yield, accounting for 16.3% of yield variation. Available water holding capacity (V53) contributed almost as much as rainfall, accounting for 15.7% of yield variation

Table 10. "Best" Regression for Statewide Cases (n = 83).

Var#.	Var. Name	B	R ²	R ² change
V38	Rainfall	+55*	.163	.163
V53	Available water holding capacity	+236*	.320	.157
V10	Dry consistence Cca	+303*	.400	.080
V50	Spring soil water (0 to 122 cm)	+37*	.471	.071
	(constant)	+186		
Adjusted R ² = .437				

* significant at p = .05

and dry consistence of Cca (V10) and spring soil water to 122 cm (V50) accounted for 8.0% and 7.1% of yield variation, respectively.

Rainfall was not only directly correlated with yield but also correlated with total seasonal available water variables (see Table 11). This is expected since rainfall is a major component of these variables. In addition, rainfall was also positively correlated with year, indicating that later years in the study (particularly 1982) were wetter than earlier years of the study.

Available water holding capacity or AWC, the second variable in the "best" equation, was not only correlated directly with yield but also with morphological, site, and classification parameters as well. Soil depth was highly correlated with AWC ($r = .92$; Appendix F1). Other morphological variables that were correlated with high AWC included coarse, strong structure in the B horizon which may facilitate greater AWC compared with massive or weak structure (which also may have less macropore space). Also correlated with AWC was fine texture in the subsoil, suggesting that more water could be held in the subsoil of soils with high clay content.

In terms of site variables, available water holding capacity was correlated with location (see Table 11), indicating that southeastern soils of Montana (location 4) had higher water holding capacities than northcentral

Montana (location 1) for the sites considered. In addition, higher MAST and drier moisture regimes ($r=+$) also correlated with higher AWC values, but this was probably due to higher AWC, MAST, and dry moisture regime values all corresponding to southeastern Montana sites.

Table 11. Variables Related to "Best" Variables; Statewide.

"Best" Variable	Other Variables	Cor. (r) with "best"*	% Freq.**
Rainfall		1.00	100%
	total avail. water		
	variables	+	100%
	year	+	100%
Avail. Water			
Hold. Cap.		1.00	80%
	soil thickness	+	80%
	structure grade B	+	20%
	structure size B	+	40%
	textural family	+	20%
	location	+	100%
	MAST	+	20%
	moisture regime	+	60%
	temp.(April)	+	100%
Dry Const. Cca		1.00	80%
	dry const. Ap	+	100%
	dry const. B	+	20%
	textural class	+	20%
	textural family	+	20%
	frost-free season length	+	60%
Spring Soil Water (0-122)		1.00	40%
	other spr. soil water		
	variables	+	~60%
	total available water		
	for growing sea.	+	100%
	elevation	+	40%
	latitude	-	100%

* see Appendix F1 for correlation values.

** % values refer to frequency occurrence of variables directly related to yield. See Appendix G1 for % freq. occurrence from matrices.

In terms of soil-climatic variables, AWC was correlated positively with soil temperature during April (see Table 11) which in itself is important to plant growth, since higher temperatures in April should speed up seed germination and/or seedling growth.

Dry consistence of Cca, the third variable in the "best" equation, was directly correlated with yield and with dry consistence of Ap and dry consistence of B. At first, a positive correlation between yield and dry consistence Cca seems puzzling since one usually assumes that high dry consistence values imply a harder soil which is generally less favorable for plant growth. However, from Table 11, dry consistence Cca appears to be also correlated with fine texture ($r = +$), which suggests that more water (and cations) are retained for plant consumption. Thus for these particular sites, a high value for dry consistence may imply fine texture rather than a "hard" soil.

From Appendix F1, dry consistence Cca was also correlated with coarse, strong subangular blocky structure in the Cca horizon (+V20, +V21, -V22) which, together with fine texture, may indicate greater water availability and infiltration. Finally, dry consistence Cca was positively correlated with a longer frost-free season (Table 11), although this correlation was lower than texture and Cca blocky structure correlations with Cca dry consistence. This indicates that dry consistence may be more influenced

by texture and structure in the Cca than length of growing season.

The final variable in the "best" equation, spring soil water to 122 cm, was correlated with most of the other spring soil water variables in Table 11 as well as yield. In addition, high levels of spring soil water were related to higher elevations and lower latitudes, suggesting that most of the soils with more adequate water in the spring occurred in the southern part of the state but at higher elevations (where perhaps more winter precipitation had occurred).

Other variables that were not related to the "best" equation variables but were directly correlated with yield included (see Appendix G1) crop type (-V03) and soil structure type of the B horizon (+V19). Since these variables weren't related to any of the "best" equation variables, one can assume that they are less important in accounting for the variation of grain yields.

Overall, it appears that both rainfall and available water holding capacity were equally the most important variables to grain yield ($R^2 = .163$ and $.157$, respectively), followed by dry consistence of Cca ($R^2 = .08$) and spring soil water to 122 cm ($R^2 = .071$). I would consider fine texture and coarse, subangular blocky structure also important for overall grain yields since these variables influenced both available water holding capacity and dry

consistence of Cca as well as being directly correlated with yield.

Subfile: Winter Wheat (Statewide)

The "best" regression equation for winter wheat experiments includes total available water to 122 cm, depth to Cca, structure size of the Ap, and available water holding capacity as "best" variables (Table 12). All variables were positively correlated with yield. Of the four variables in the equation, total available water for the growing season to 122 cm (V58) contributed the most toward winter wheat yield accounting for 26.5% of yield variation. Depth to Cca accounted for about 11% of yield variation, and structure size of Ap (V15) and available water holding capacity (V53) both accounted for approximately 4% of yield variation.

Table 12. "Best" regression for winter wheat cases (n=62).

Var.#	Var. Name	B	R ²	R ² change
V58	Total available water (122 cm)	+45*	.265	.265
V27	Depth to Cca	+20*	.373	.108
V15	Structure size Ap	+218*	.411	.038
V53	Available water holding capacity	+126	.450	.039
	(constant)	+610		

Adjusted R² = .402

* significant at p = .05

Total available water to 122 cm (TAW) was correlated with rainfall and various spring soil water variables (Table 13). In addition, TAW was positively correlated with year indicating again that later years were probably wetter than the earlier years studied. TAW was also correlated with dry consistence of Ap. Similar to dry consistence Cca, dry consistence Ap was also positively related to yield, perhaps due to dry consistence measurements being related again to fine texture (which can contribute to higher water holding capacities).

The second variable in the "best" equation, depth to Cca, correlated positively with dry consistence of Cca (see Table 13). This implies that dry consistence Cca may be positively associated with yield due to deeper calcic horizons for winter wheat cases rather than being associated with finer texture (as was postulated for statewide cases).

The third variable in the equation, structure size of the Ap horizon, correlated positively with yield, indicating that coarse structure increased yields. However, Ap structure size had a frequency occurrence less than 50% and was not related to any other variable (see Table 13). This suggests that structure size Ap may be an important variable for this particular sample but perhaps not very important for winter wheat in general.

Table 13. Variables Related to "Best" Variables;
Winter Wheat.

"Best" Variable	Other Variables	Cor. (r) with "best"	% Freq.**

Total Avail. Water for Growing Seas. (to 122 cm)		1.00	100%
	rainfall	+	100%
	spring soil water variables	+	100%
	year	+	100%
	dry const. Ap	+	100%

Depth to Cca		1.00	50%
	dry const. Cca	+	75%

Structure Size Ap	-----	1.00	25%

Avail. Water Holding Cap		1.00	75%
	soil thickness	+	75%
	spring soil water (0-122cm)	+	100%

* see Appendix F2 for correlation values.

** % values refer to frequency of variables directly related to yield. See Appendix G2 for % freq. occurrence from matrices.

Available water holding capacity, the fourth variable, correlated positively with soil depth (see Table 13). AWC was also correlated again with greater spring soil water to 122 cm. As shown in Appendix F2, AWC was also correlated with finer texture (+V24) in the subsoil, granular structure in the Ap horizon (+V16) and massive structure in the Cca horizon (+V22), indicating that in addition to soil depth, texture and structure play an important role in the water holding capacity of the soil.

Overall, total available water for the growing season appeared to be the most important variable for winter wheat yields followed by the depth to the Cca horizon. Unlike statewide cases, total available water for the growing season and depth to Cca appeared to be more important to winter wheat cases than available water holding capacity.

Subfile: Spring Wheat (Location 1 and 3)

The "best" regression equation for spring wheat experiments included rainfall (V38) as the only "best" variable, accounting for 77.3% of spring wheat yield variation (Table 14). The influence of other variables may not have been detected, since the number of cases was only 14.

Table 14. "Best" Regression for Spring Wheat Cases (n=14).

Var.#	Var. Name	B	R ²	R ² Change
V38	Rainfall	+86*	.773	.773
	(constant)	+892		
Adjusted R ² = .689				

* significant at p = .05

Rainfall appeared to be a fairly independent variable, being correlated only to total available water variables and total spring soil water (Table 15).

Other variables that were correlated with spring wheat yields directly but not in "best" regression (see Appendix

G3) include some morphological variables (V10,V21,V54), site variables (V25,V18,V31), and classification variables (V32,V33). However, their frequencies were only 25%, indicating their correlations weren't as important as rainfall. Water variables (V41,V47 to V49) and length of frost-free season (V56) were more important (with frequencies of 50%) but were also not related to rainfall.

Table 15. Variables Related to "Best" Variable; Spring Wheat.

"Best" Variable	Other Variables	Cor. (r) with "best"*	% Freq.**
Rainfall		1.00	100%
	total spring soil water	+	50%
	total avail. water variables	+	100%

* see Appendix F3 for correlation values.

** % values refer to frequency of variables directly related to yield. See Appendix G3 for % freq. occurrence from matrices.

For the spring wheat "best" equation, the adjusted R^2 value (.677) was much higher than for all crops or winter wheat R^2 values (.437 and .402, respectively). Perhaps spring wheat yields were more sensitive to rainfall than winter wheat (or when compared with all three crops combined). Another consideration is that although the R^2 value for spring wheat was adjusted, the value may still be slightly inflated because the number of spring wheat cases was relatively small ($n = 14$).

Subfile: Barley (Location 1, 3, and, 4)

Two "best" equations were chosen from barley experiments since their adjusted R^2 's were almost identical (Table 16). In both equations, structure type of the Cca (V22) contributed the most toward yield, accounting for approximately 46% of yield variation. Its relationship with barley yield was negative, indicating that subangular blocky structure positively influenced yield while massive structure did not. The second variable in both equations, structure size of the B (V18) accounted for approximately 21% of yield variation and was positively correlated with yield suggesting that coarse structure in the B horizon related to high yields.

The third variable in equation 1, structure size of the Cca (V21), also contributed to yield (8.7%) although its coefficient wasn't significant at $p = .05$, meaning that V21 didn't add much to the equation. Structure size Cca was also negatively correlated with yield indicating that small structure size in Cca contributed to higher yields.

For equation 2, its third variable, available total water for the growing season to 90 cm (V59), accounted for 9.5% of yield variation. However, its coefficient wasn't significant ($p = .05$), indicating available total water for the growing season didn't add much to the equation. It was positively correlated to yield.

Structure type Cca was positively correlated with structure size Ap indicating that soils with massive Cca

Table 16. "Best" Regressions for Barley Cases.

Var. #	Var. Name	B	R ²	R ² change
EQUATION 1 - cases with soil water only (n=19)				
V22	Structure type Cca	-475*	.455	.455
V18	Structure size B	+441*	.655	.200
V21	Structure size Cca	-372	.742	.087
	(constant)	+4674		
Adjusted R ² = .673				
EQUATION 2 - cases with soil water and rainfall (n = 13)				
V22	Structure type Cca	-438*	.467	.467
V18	Structure size B	+310*	.682	.215
V59	Available water for growing season (to 90 cm)	+63	.777	.095
	(constant)	+2552		
Adjusted R ² = .666				

* significant at p = .05

structure tended to have coarse structure in the overlying Ap horizon (Table 17). Implications of this for yield are uncertain. From the correlation matrix (Appendix F4), structure type Cca was also negatively correlated with various spring soil water variables (-V40 to -V42, -V48, -V49), indicating that subangular blocky structure in Cca

(versus massive structure) had higher spring soil water levels. This may influence high barley yields although it was not directly correlated.

Table 17. Variables Related to "Best" Variables; Barley.

"Best" Variable	Other Variables	Cor. (r) with "best"*	% Freq.**
Structure Type Cca		1.00	50%
	structure size Ap	+	50%
Structure Size B		1.00	50%
	structure grade B	+	25%
	structure type B	+	25%
	avail water hold cap	+	50%
Structure Size Cca		1.00	50%
	structure size Ap	+	50%
Total Avail. Water for Growing Seas. (90 cm)		1.00	100%
	rainfall	+	100%

* see Appendix F4 for correlation values.

** % values refer to frequency of variables directly related to yield. See Appendix G4 for % freq. occurrence from matrices.

Structure size of B, the second variable in both "best" equations, was highly correlated with structure grade B ($r = +$) and structure type B ($r = +$), indicating that coarse, strong subangular blocky structure relates to high yields of barley (Table 17). In addition, structure size B was correlated positively with available water holding capacity.

Structure size Cca, the third variable in equation 1, was not directly correlated with yield (Appendix G4) nor was it correlated with any other variable directly related to

yield except structure size Ap. Thus structure size Cca is probably not as important as structure type of Cca or structure size B in terms of barley yield.

Available water for the growing season to 90 cm, the third variable in the second equation, was directly correlated to yield for 100% frequency, indicating that it was an important variable but accounted for a smaller variation of yield compared with structure type Cca and structure size B. As expected, it was also related to rainfall.

Another variable that was directly related to yield (with frequencies at least 50%), but not included in the regression equation was length of growing season (see Appendix G4). Although length of growing season was probably an important variable, it accounts for a very small amount of yield variation since it was not introduced into the equation.

Overall, structure type of Cca was probably important to yield (for both equations) not only because of its direct relationship with yield but also because of its relationship to spring water variables as well (see Appendix F4). Although not as important as Cca structure type, structure size B is probably important in that coarser, blocky structure in the B horizon influenced high yields. Also structure size B was correlated with available water holding capacity, which may also play an important role in

producing barley yields. Equation 2 is perhaps better than equation 1 for explaining barley yield since total available water in equation 2 was frequently more directly related to yield (100%) than structure size Cca in equation 1 (50%).

For barley cases, the adjusted R^2 value (.666) was only slightly lower than for spring wheat (.689) and much higher than either of the R^2 values for winter wheat (.402) or statewide cases (.437). Compared with winter wheat and spring wheat cases, water variables were less important to barley sites while structure variables (in Cca and B) and water holding capacity were more important to barley cases. This may be due to barley generally being more drought resistant than the wheats, and hence less dependent on rainfall and spring soil water.

To summarize crop subfiles, all yields depended on rainfall; spring wheat to the greatest extent and barley perhaps the least. Available water holding capacity and various structure variables were important for winter wheat and barley but not for spring wheat, perhaps because spring wheat yields were so dependent on rainfall. Depth to Cca appeared more important for winter wheat than for spring wheat or for barley.

Subfile: Northcentral Montana (Location 1);
winter wheat, spring wheat, barley

The "best" regression equation for northcentral Montana includes available total water for the growing season to 122

cm, crop type, dry consistence of Cca, and soil depth (Table 18). Out of the four variables, available total water for the growing season to 122 cm (V58) contributed the most toward yield, accounting for 34.4% of yield variation. Crop type (V03) and dry consistence of Cca(V10) both accounted for approximately 13% of yield variation. Finally, soil depth (V54) accounted for 9.2% of yield variation. All variables were positively correlated with yield except crop type (implying that winter wheat generally yielded more than barley).

Table 18. "Best" Regression for Location 1 cases (n = 27)

Var.#	Var. Name	B	R ²	R ² change
V58	Available total water for growing sea.(0-122cm)	+38*	.344	.344
V03	Crop type	-376*	.480	.136
V10	Dry consistence Cca	+471*	.613	.133
V54	Soil depth	+274*	.705	.092
	(constant)	+389		
Adjusted R ² = .651				

* significant at p = .05

Available total water to 122 cm was correlated directly with yield and as expected, with rainfall and other spring water variables that were associated with yield (Table 19). In addition it was also positively correlated with year.

Crop type, the second variable in the "best" equation, was negatively correlated with structure grade B and structure size B, suggesting that winter wheat sites were associated with strong, coarse structure in the B horizon while barley sites had weak, fine structure. This may account for winter wheat out-yielding barley, although there are also inherent differences between winter wheat and barley.

Table 19. Variables Related to "Best" Variables; Location 1.

"Best" Variable	Other Variables	Cor.(r) with "best"	% Freq.**

Avail. Total Water for Growing Sea. (0-122cm)		1.00	100%
	rainfall	+	100%
	spr. soil water variables	+	~80%
	year	+	50%

Crop Type		1.00	25%
	structure grade B	-	75%
	structure size B	-	75%

Dry Const. Cca		1.00	25%

Soil Thickness		1.00	25%
	avail. water. hold. cap.	+	75%
	structure grade Ap	+	25%
	structure type Ap	+	25%
	structure grade B	+	75%
	structure size B	+	75%
	moisture regime	+	25%

* see Appendix F5 for correlation values.

** % values refer to frequency of variables directly related to yield. See Appendix G5 for % freq. occurrence from matrices.

Dry consistence of Cca, the third variable to enter the "best" equation, was directly correlated to yield but not

correlated significantly with any other variables (see Table 18 and Appendix F5). In addition, dry consistence Cca had a low frequency (25%) indicating that it is probably an important variable for this particular sample only and not for northcentral Montana in general.

Finally, soil depth or thickness was correlated with yield as well as being highly correlated with available water holding capacity ($r = .99$). Other variables that soil thickness correlated with included coarse, granular structure of Ap ($r = +$); strong, coarse structure in the B horizon ($r = +$); and drier moisture regimes ($r = + .97$).

From Appendix G5, other variables that had at least 50% occurrence but were not generated in the equation included structure type B (+V19) and various spring water variables (+V48, +V49). Their absence in the "best" equation, however, in one form or another indicates that these variables probably aren't as important as the variables included within the equation.

Subfile: Gallatin-Madison County Areas (Location 2);
winter wheat

Two "best" equations were chosen since their adjusted R^2 values were identical (Table 20). From equation 1, dry consistence of B (V09) contributed the most toward yield, accounting for 69.7% of yield variation. Following V09, depth to Cca (V27) accounted for 14.9% of yield's variation and PET (V55) accounted for 4.2% of yield variation. Both

V09 and V27 were positively correlated with yield while V55 (PET) was negatively correlated with yield.

For the second equation, bulk density of the Ap horizon (V11) was the only variable generated, accounting for 89.2% of yield variation. V11 was also negatively correlated with yield, indicating that lower surface bulk density for location 2 sites was beneficial for yields.

Table 20. "Best" Regression for Location 2 cases.

Var.#	Var. Name	B	R ²	R ² change
EQUATION 1 - cases excluding rainfall, soil water and soil temperature variables (n = 13).				
V09	Dry consistence B	+619*	.697	.697
V27	Depth to Cca	+19*	.846	.149
V55	PET	-29	.888	.042
	(constant)	+3004		
Adjusted R ² = .854				
EQUATION 2 - cases including soil water and excluding rainfall, soil temperature variables (n = 8).				
V11	Bulk density Ap	-7587*	.892	.892
	(constant)	+15109		
Adjusted R ² = .856				

* significant at p = .05

Dry consistence of B was correlated directly with yield for 50% of the correlation matrices considered (Table 21). Dry consistence of B was also correlated with dry consistence of Ap indicating that, in general, soil profiles

had either high or low consistency throughout the profile. Possible reasons for dry consistence B being correlated to yield may be due to its correlation with strong, granular structure in the Ap horizon (+V14,+V16) (see Appendix VI5). In addition, dry consistence B was positively correlated with higher elevation and year from Table 21, which were both correlated with high precipitation. Thus, the contribution of dry consistence to yield may be due to its relationship with structure in the Ap or to its association with increased elevation and later years.

Depth to Cca, the second variable in equation 1, was directly correlated with yield, all correlations considered. It was negatively correlated with bulk density of A and B (from Table 20) but positively correlated with bulk density Cca, indicating that deeper calcic horizons had less pore space than the overlying Ap and B. Also, deeper calcic horizons tended to have strong, coarse structure with high consistence but no set correlation with type of Cca structure. Perhaps, high dry consistence values were again correlated with strong, coarse structure. In addition, deeper calcic horizons were associated with wetter (udic-ustic) moisture regimes ($r = -$) suggesting greater rainfall (and consequently more leaching of calcium carbonate to deeper depths over a long period of time). All of these correlations help explain why a deeper calcic horizon may be related to high yield.

The third variable in equation 1, PET, was negatively correlated directly to yield, indicating that the hot or dry growing seasons yielded less than cool, moist growing seasons. PET, itself, had a frequency of only 25%, suggesting that it wasn't very important compared to other variables in equation 1.

Table 21. Variables Related to "Best" Variables; Location 2.

"Best" Variable	Other Variables	Cor. (r) with "best"	% Freq.**
Dry Const. B		1.00	50%
	year	+	50%
	dry const. Ap	+	50%
	elevation	+	50%
Depth to Cca		1.00	100%
	dry const.Cca	+	100%
	bulk density Ap	-	50%
	bulk density B	-	25%
	bulk density Cca	+	25%
	structure grade Cca	+	50%
	structure size Cca	+	50%
	moisture regime	-	25%
Pot. Evapo.	-----	1.00	25%
Bulk Den. Ap		1.00	50%
	dry const.B	-	25%
	dry const. Cca	-	100%
	bulk density Cca	-	25%
	depth to Cca	-	100%
	avail. water hold.cap.	-	25%
	moisture regime	+	25%

* see Appendix F6 for correlation values.

** % values refer to frequency of variables directly related to yield. See Appendix G6 for % freq. occurrence from matrices.

From equation 2 in Table 20, bulk density of Ap was negatively correlated with yield as well as with dry

consistence of B and depth to Cca; two variables that were generated in equation 1. In addition, bulk density A_p was also associated with dry consistence Cca ($r = -$), bulk density Cca ($r = -$), moisture regime ($r = +$), and available water holding capacity ($r = -$). Thus, it appears that an increase in surface bulk density decreases available water holding capacity, is associated with shallow depth to carbonates, is in a drier moisture regime and yet associated with lower dry consistence in the underlying B and Cca horizons.

Note that water variables did not appear in any of these correlations and were not correlated with any of the "best" equation variables. Perhaps water variables are correlated with elevation and year but not very strongly. Apparently, rainfall and spring soil water were not as important for sites in this area of the state where soil physical properties dominated. Since the sites for these particular years had adequate rainfall and spring soil water (i.e. no drought years), water levels weren't limiting to yield.

Overall, both equations in Table 20 have variables that were highly correlated with each other as well as with yield. Consequently, both equations were equally adequate in explaining yield variation in the Gallatin-Madison County areas. Soil morphological variables (bulk density, depth to Cca, dry consistence B) appeared to be more

important to yields in this area than rainfall or spring soil water since water was not limiting.

Subfile: Northeastern Montana (Location 3);
winter wheat, spring wheat, barley

The "best" regression equation for northeastern Montana includes only one variable, structure type of Cca (V22), which accounts for 72.2% of yield variation (Table 22). V22 was negatively correlated with yield, indicating that subangular blocky structure rather than massive structure helped increase yields in location 3.

Table 22. "Best" Regression for Location 3 (n = 7).

Var.#	Var. Name	B	R ²	R ² change
V22	Structure type Cca	-501*	.772	.722
	(constant)	+5483		
Adjusted R ² = .611				

* significant at p = .05

Depth to Cca was highly correlated to structure type Cca ($r = -.89$, Appendix G7) indicating that subangular blocky structure in the Cca horizon was associated with deeper calcic horizons (Table 23). This also suggests that soil matrix (or CaCO_3) translocation to the calcic horizon has taken place. It appears that only depth of Cca had an occurrence frequency of 50% while the other variables (including structure type Cca) had frequencies of 25%. This indicates that perhaps none of the variables were really

very reliable in explaining the variation of yield in north-eastern Montana except for depth to Cca.

Year of plot was also directly correlated to yield (as implied in Table 23). Since year was also correlated negatively with structure type Cca, perhaps plots that were sampled in the earlier years might have had more massive structure.

Table 23. Variables Related to "Best" Variable; Location 3.

"Best" Variable	Other Variables	Cor. (r) with "best"*	% Freq.**
Structure Type Cca		1.00	25%
	year	-	25%
	depth to Cca	-	50%

* see Appendix F7 for correlation values.

** % values refer to frequency of variables directly correlated to yield. See Appendix G7 of % freq. occurrence from matrices.

Overall, it appears that perhaps both depth to carbonates and structure type Cca were important to yield although only structure type Cca appears in the "best" equation. Similar to location 2, location 3 yields were not well correlated to either rainfall or spring soil water, indicating that water was either not limiting or soil characteristics in these areas were more important.

Subfile: Southeastern Montana (location 4);
winter wheat, barley

The "best" equation for southeastern Montana includes available total water for the growing season (122 cm) and

slope (Table 24). Available water for the growing season to 122 cm (V58) contributed the most to yield, accounting for 26.7% of yield variation. V58 was positively correlated with yield. The second variable, slope (V29), was negatively correlated with yield and accounted for 9.1% of yield variation.

Table 24. "Best" Regression for Location 4 cases (n = 46).

Var. #	Var. Name	B	R ²	R ² change
V58	Available water for growing season (122 cm)	+47*	.267	.267
V29	Slope	-257*	.358	.091
	(constant)	+2482		
Adjusted R ² = .313				

* significant at p = .05

Total available water for the growing season (V58) was correlated directly to yield with a frequency of 100%, indicating that it is a reliable variable for southeastern Montana (Table 25). V58 was also correlated with rainfall and various spring soil water variables (which were also correlated with yield). In addition, V58 was slightly correlated with dry consistence Ap ($r = .29$), suggesting a higher clay content associated with high consistence in Ap might aid in holding spring soil water.

Slope, the second variable in the equation, was directly (negatively) correlated with yield, suggesting that lower

yields occur on steeper slopes. Slope was also negatively correlated with length of frost-free season, indicating that sites with greater slopes had shorter periods of frost-free days. Other factors that correlated with increased slope but were not correlated with yield themselves (see Appendix G8) included a decrease in dry consistence in B (-V09), a decreased bulk density in B (-V12), shallower depth to Cca (-V26,-V27), eastern aspects (-V30) and decreased PET (-V55). All of these factors may have contributed to yield indirectly by being related to slope.

Table 25. Variables Related to "Best" Variables; Location 4.

"Best" Variable	Other Variables	Cor.(r) with "best"	% Freq.**

Total Avail. Water for Growing Sea. (122cm)		1.00	100%
	dry consist. Ap	+	50%
	rainfall	+	100%
	spring soil water variables	+	~60%

Slope		1.00	50%
	frost-free season length	-	75%

* see Appendix F8 for correlation values.

** % values refer to frequency of variables directly related to yield. See Appendix G8 for % freq. occurrence from matrices.

Overall, total available water for the growing season seemed to be the most important variable in terms of grain yield in southeastern Montana while slope appears to be less important. In contrast to location 2 and 3, water variables appeared to be more important for southeastern

Montana than soil morphological variables, indicating water's limitation to the area. Also, adjusted R^2 for area 4 was considerably lower than for other locations (as well as statewide cases), suggesting that perhaps unmeasured climatic variability and management practices may be more important factors in this location than in other locations. This seems plausible since experimental sites were more widely separated in location 4 than in other locations.

Relating Soil Series to Soil Productivity

In the previous section, I evaluated important variables that can contribute to "good" growing conditions of small grains in Montana. In this section, I will evaluate the usefulness of these variables for constructing a soil productivity index (SPI) for soil series used for field experiments (see Appendix B). Unlike the first section, I will be concentrating only on morphological, soil classification variables which can be differentiated based on soil series descriptions by themselves.

Process

To determine SPI values for each soil series studied on a statewide basis, I employed available water holding capacity and dry consistence of Cca, since these variables were generated in the "best" equation in Table 10. Available water holding capacity by itself, was put into a

equation to generate initial SPI values using the following equation:

$$Y = 2474.8 + 173.2(\text{Avail. Water Hold. Cap.})$$

for 154 experiments. Y values were converted to relative SPI values by assigning 100 to soils with the highest Y value (and thus the highest available water holding capacity). These values are shown in Table 26 to Table 29. Available water holding capacity by itself, accounted for approximately 3% ($R^2 = .027$) of yield variation.

To include dry consistence of Cca into an SPI equation, dry consistence values had to be converted into morphological variables that could be distinguished from soil series descriptions. This was done because, although dry consistence descriptions are given in many soil descriptions, the readings in this study were measured in Kg/cm^2 while also representing other morphological characteristics. Morphological variables that were directly correlated with yield and directly correlated with dry consistence Cca but not correlated with AWC (see Appendix F1) were depth to Cca, textural class, structure size Cca, and a classification variable, temperature regime. Thus, these variables represented dry consistence Cca's relationship with yield without correlating with AWC.

SPI values using AWC and dry consistence Cca variables were generated using the following equation:

$$\begin{aligned}
 Y = & 2095.6 + 160.1(\text{AWC}) \\
 & + 12.5 (\text{depth to Cca}) \\
 & + 36.4 (\text{structure size Cca}) \\
 & + 12.8 (\text{textural class}) \\
 & - 43.0 (\text{temp. regime})
 \end{aligned}$$

Y values were converted to relative SPI values by assigning 100 to soils with the highest Y value. If a particular soil series had more than one Y value due to field variation of depth to Cca and structure size Cca, values were averaged. Within this equation, available water holding capacity accounted for 2% of yield variation while dry consistence of Cca accounted for 4.6% of the variation (depth to Cca = 3.8%; structure size Cca = .4%; textural class = .3%; and temperature regime = .06%) for a total of 6.6% of yield accounted for.

Results

SPI values are shown in Tables 26 through 29; initial SPI values derived from AWC only and final SPI values derived from AWC and dry consistence Cca variables.

If one were to "grade" soil productivity potentials in northcentral Montana, "good" soils (80-89 range) would include Joplin, Danvers, Coffee Creek, Scobey, Gerber, Kevin, Marias, and Evanston for final SPI values (see Table 26). If considering just AWC SPI values, all soils would be rated "excellent" (90 to 100). However, because of varying depths to Cca, all soils were rated lower for SPI values based on AWC + dry consistence Cca than SPI values based solely on AWC.

Table 26. Northcentral Montana SPI Values (Location 1).

based on....	AWC	AWC + Dry Consis. Cca
Soil Series		
Joplin	95	88
Danvers	95	84
Coffee Creek	95	82
Scobey	95	82
Gerber	95	81
Kevin	95	81
Marias	95	80
Evanston	95	80
Pendroy	95	78
Williams	95	76
Rothiemay	95	76
Brockway	95	75
Telstad	95	75
Judith	89	75
Cargill	89	73
Winifred	89	71

For the Gallatin and Madison County area (see Table 27), Bozeman soil rated "excellent" due to its high water holding capacity and relative deep depth to Cca horizon, while Amsterdam rated "good", Manhattan "fair" (70-79), and Evanston, in this case, "poor" (60-79), although all have excellent water-holding capacities.

Table 27. Gallatin-Madison Area SPI Values (Location 2).

based on....	AWC	AWC + Dry Const. Cca
Soil Series		
Bozeman	100	100
Amsterdam	100	82
Manhattan	95	78
Evanston	95	66

Martinsdale, Dooley, Williams, Evanston, and Vida rated "good", while Parshall and Cherry rated "fair" for northeastern Montana (Table 28). Cherry rated fair because of a shallow Cca horizon while Parshall's rating was due to a combination of limiting water holding capacity and shallow Cca (which is part of the dry consistence Cca variable in this case).

Table 28. Northeastern Montana SPI Values (Location 3).

based on...	AWC	AWC + Dry Const. Cca
Soil Series		
Martinsdale	95	88
Dooley	95	88
Williams	95	86
Evanston	95	85
Vida	95	84
Cherry	100	78
Parshall	89	75

From Table 29, Lonna, Farland, Savage, Kremlim, and Williams soils rated excellent (90-100) while Wormser rated as "poor" (<70).

Overall, Bozeman rated the best soil for growing small grains while Evanston (in Madison County) and Wormser rated the least conducive to small grain production. However, Evanston rated 80 in northcentral Montana and 85 in northeastern Montana suggesting that perhaps depth to Cca varied since depth to calcareous material for Evanston may range from 8 to 20 inches (from established series description).

This brings up the problem of accounting for morphological variability within the soil series. Perhaps Evanston SPI values should be averaged if large discrepancies exist and may also point up a need for narrower range in this characteristic for soil classification purposes.

Table 29. Southeastern Montana SPI values (Location 4).

based on...	AWC	AWC + Dry Const. Cca
Soil Series		
Savage	95	96
Kremlin	95	94
Lonna	100	92
Williams	95	92
Farland	100	90
Fort Collins	100	87
Marias	95	87
Chanta	89	86
Kobar	95	85
Danvers	95	84
Floweree	100	83
Vanstel	100	81
Gilt Edge	95	83
Havre	95	83
Shaak	95	80
Thurlow	95	79
Yamac	95	79
Tanna	84	79
Edgar	95	78
Richfield	95	77
Wages	95	76
Vona	89	75
Chama	89	74
Marvin	89	74
Absarokee	84	72
Bainville	84	71
Degrad	89	70
Wormser	84	68

Despite variability problems within a particular soil series, SPI values can be a useful tool for predicting small grain yields in Montana. For land use planners, SPI values (such as the ones generated in Tables 26 to 29) indicate average expectations of crop productivity for a particular soil.

In conjunction with climatic and crop factors, SPI values can potentially aid growers in predicting crop yields for a particular year as well as a particular soil. A "first approximate" SPI-climatic-crop type model is expressed in the following equation:

$$Y = 4038.5 + 18.6(X_1) + 59.0(X_2) - 106.7(X_3) + 1.8(X_1 * X_3) - 5043.5(X_4) + 1267.2(X_4^2)$$

where:

- Y = small grain yield (kg/ha).
- X₁ = SPI value based on AWC and dry consistence Cca.
- X₂ = rainfall (cm).
- X₃ = spring soil water to 122 cm (cm).
- X₄ = crop type (1 = winter wheat; 2 = spring wheat; 3 = barley).
- X₁*X₃ = interaction of SPI and spring soil water to 122 cm.
- X₄² = curvilinear function of crop type.

This equation accounted for 45.7% of yield variation, similar to the "best" equation for all crops and locations in Table 10. Based on individual "R² change" values, rainfall accounted for 14% of yield variation, SPI/spring soil water interaction 16.8%, crop type (both linear and curvilinear functions) 7.7%, spring soil water by itself 6.6%, and SPI by itself 0.5%. Thus, an interaction between SPI and spring soil water to 122 cm is an important

relationship to small grain yields perhaps due to spring soil water being related to available water holding capacity (particularly for shallow soils).

As an example of using this equation for a management tool, one cooperator had both Marias (87 rating) and Wormser (68 rating) soils on his property in Golden Valley County. Table 30 shows a hypothetical situation where one growing season is wet (25 cm of rainfall during the growing season) and one is dry (5 cm of rainfall during the growing season) for varied spring soil water values.

Table 30. Hypothetical Example - Yield Predictions.

Soil Series	spr. soil water (0-122 cm)	Expected Yields (kg/ha)	
		wet year (25 cm)	dry year (5 cm)
Marias	12 *	3964	2774
Wormser	12 *	3190	2010
Marias	20 **	4353	3173
Wormser	13 **	3206	2026

* spr. water somewhat limiting.

** spr. water not limiting; Wormser water holding capacity limiting.

In this simple representation, soil productivity is noticeably influenced by water values; either spring soil water, rainfall or both. It would be difficult to project a yield goal without accounting for water variables. Marias in a dry year (2774 kg/ha or 3173 kg/ha) and Wormser in a

wet year (3190 kg/ha or 3206 kg/ha) would appear to yield very similarly given different spring soil water conditions.

Although SPI values have been generated for specific soil series in this study, their usefulness to growers may be limited since, by themselves, they accounted for only 5% of yield variation. Combining SPI values with selected water variables and crop types (that were considered in this study) accounted for 45% of yield variation; better than 5% but not high enough for prediction purposes. Thus, these SPI values are presently not very useful to individual growers although with increased information, they may become useful.

CHAPTER 5

SUMMARY AND CONCLUSIONS

One hundred and eighty four field experiments conducted from 1968 to 1982 throughout the dryland plains of Montana were selected for evaluating soil morphological, soil classification, soil-climatic and site variables in relation to small grain yield. Data were obtained from Montana State University Agriculture Experiment Station records and corresponding county soil survey reports. All sites chosen for study were at optimal fertility and controlled for weeds and diseases, thus minimizing variation from general management inputs. Data were analyzed by multiple stepwise linear regressions.

Within the regression process itself, the data were subdivided from total statewide cases into subfiles by crop type (winter wheat, spring wheat, and barley) and by four geographical locations (northcentral, southeastern, northeastern Montana, and Gallatin-Madison area). "Best" regression equations were chosen for each subfile (as well as statewide cases) from a possible 190 equations using criteria to eliminate multicollinearity associations. For each regression, a corresponding correlation matrix and frequency table were employed to assist in determining if

"best" equation variables were important variables to yield. "Best" variables with high frequencies of occurrence from matrices were usually regarded as important variables in terms of yield.

In examining soil-climatic variables; rainfall, spring soil water, soil temperature, potential evapotranspiration, and length of frost-free season variables were considered. In equations where it appeared, rainfall was positively correlated with yield, indicating that increased rain during the growing season caused higher yields. Rainfall was usually also correlated with year, suggesting that later years of the study were wetter than earlier years.

Similar to rainfall, spring soil water variables were all positively correlated with yield. The most frequent spring soil water variable to appear in the equations was spring soil water from 0 to 122 cm, rather than any particular smaller depth increment.

Soil temperature was only considered for statewide cases since temperature data were missing for a majority of the plots considered. Although not in the "best" equation, soil temperature in April correlated with yield positively, suggesting that warm temperatures in the early spring were beneficial to seed germination and seedling growth activity.

Potential evapotranspiration (PET) was negatively correlated with yield in Gallatin-Madison County areas only, suggesting that this area had high evaporative demands

on small grains for those particular years studied. Overall, PET wasn't an important variable compared with other variables in the analysis.

Length of frost-free season, the final soil-climatic variable considered for analysis, was correlated positively to yield; specifically to barley and spring wheat. Hence, barley and spring wheat may be more sensitive to length of growing season than winter wheat.

In examining soil morphological variables, dry consistence, bulk density, structure, texture, depth to Cca, thickness of B, available water holding capacity, and soil depth or thickness variables were all considered in the analysis.

Available water holding capacity (AWC) was positively correlated with yield for all crops. In addition, AWC was consistently highly correlated with soil thickness, suggesting that deeper soils have a greater water holding capacity. Other reasons for correlations between high AWC and high yields may be due to greater AWC being related to coarse, strong structure in the B horizon; strong, granular structure in the Ap horizon (allowing water entrance into the profile) and finer texture in the subsoil (which would allow for greater water storage). Available water holding capacity was also correlated positively with spring soil water for winter wheat cases.

Favorable structure in terms of its relation to yield

was usually strong, coarse granular structure in the Ap horizon; strong, coarse subangular blocky structure in the B horizon; and coarse, strong angular structure in the Cca horizon. These types of structures facilitate greater water infiltration and water uptake by plants, and may relate to greater crop root penetration.

Depth to Cca (or calcic) horizon was positively correlated with yield. In addition, depth to Cca was always highly correlated with thickness of B since the Ap horizon thickness was fairly constant for all sites (8 to 10 cm). Deeper calcic horizons are probably beneficial to yields because excessive CaCO_3 at the surface can tie up P and various micronutrient anions. Shallow Cca layers also may indicate a particular site gets or retains less rainfall (in the long term) and, therefore, may indicate a dry site. Shallower Cca horizons may also be related to eroded sites which would have less organic matter.

Fine texture at the surface and in the subsoil were both positively correlated with small grain yield, suggesting that finer texture in Montana is beneficial to yield; perhaps in holding more water and cations. However, texture was not as important to yield by itself, compared with available water holding capacity, structure, depth to Cca, and dry consistence values.

Dry consistence variables of Ap, B, and Cca horizons were all generally positively correlated with yield. This

seems puzzling at first since one tends to think that high dry consistence readings from a penetrometer would imply hard soils with "less than optimum" conditions for plant growth. However, a majority of high readings were correlated to either coarse, strong structure and/or fine textures and deeper Cca horizons. This suggests that strong, dry consistence readings may indicate structural and textural trends more than indicating "hard" soils.

Bulk density appeared in the "best" equation in Gallatin-Madison County area where lower bulk densities of Ap facilitated higher yields. However, higher bulk densities of B and Cca of these same soils related to higher yields (although only slightly), but most of these bulk densities were in the 1.20 to 1.40 g/cm³ range indicating that increased bulk density in this case wasn't detrimental.

In examining site variables, geographical area, latitude, elevation, slope, and aspect variables were included in the analysis. In terms of geographic area, yields from southeastern Montana were greater than those from the northcentral portion of the state. Similarly, higher yields occurred at southern latitudes, suggesting that climatic factors were more severe in the northern part of the state.

Slope was negatively correlated with yield in southeastern Montana only, indicating that steeper slopes yielded less. This may be due to steeper slopes being associated

with shallower Cca, shorter growing seasons, and eastern aspects since all of these variables were also negatively correlated with slope. Water runoff may also be a factor in reduced yields on steeper slopes. Overall however, slope was not correlated strongly with yield, perhaps since slopes ranged from only 0% to 9%.

Similar to slope, elevation wasn't very critical to yield in most cases although it was slightly correlated positively with winter wheat and barley yield in north-central Montana and the Gallatin-Madison county area. The relationship between elevation and yield might be due to higher winter precipitation for higher elevations, since elevation was also positively correlated with spring soil water for some cases.

In examining soil classification variables, temperature regime, moisture regime, and mean annual soil temperature (MAST) variables were considered in this study. Overall, none of these variables contributed very much to yield variation relative to soil-climatic and morphological variables. However, in cases when these variables were correlated with yield (although slightly), they all correlated positively. Thus, higher MAST, mesic temperature, and drier moisture regimes appeared to be related to higher yields, usually however by being associated with other beneficial variables.

Besides soil related variables, crop type as a variable was also considered in this study. Winter wheat produced higher yields than spring wheat and barley. Rainfall appeared to be more important to spring wheat than winter wheat or barley suggesting that barley and winter wheat may have been more drought tolerant or drought escaping.

For dryland small grain production in Montana, the statewide "best" equation ($Y = 186 + 55(\text{rainfall}) + 236(\text{available water holding capacity}) + 303(\text{dry consistence of Cca}) + 37(\text{spring soil water from 0 to 122 cm})$) sums up the contribution of the most important variables that were related to yield in this study. High dry consistence Cca readings were correlated with coarse, strong structure, fine textured soil, and deeper depths to Cca for most cases. Thus, for this particular study, dry consistence readings integrate positive variables into one value rather than indicating simply that soils are "hard".

From the "best" statewide regression equation, a soil productivity index was generated for all soil series considered in the study. Generally, the "best" soils in the state (such as the Bozeman silt loam) were ones with high available water holding capacities and deep depths to Cca horizons. About 45% of yield variation was accounted for when soil productivity index values were combined with water variables and crop type. This percent is reasonable since many management, genetic, and climatic variables were left

out of the study. Future soil productivity studies might consider such variables as varieties, seeding rate, seeding date, yield components and other pertinent agronomic data. Rather than recording total growing season rainfall only, monthly records of rainfall would be helpful to account for distribution of rainfall, adding information for yield relationships with rainfall.

This study has demonstrated that quantitative relationships between soil morphological, classification, climatic, and site factors can be roughly determined from existing research data. Employing soil fertility research plots with "good" management practices can narrow management variability. Unfortunately, some field-related variables such as temperature had many missing values, demonstrating the need for a coordinated effort by soil researchers and agronomists to collect information for soil potentials work. In addition, although this study concentrated on linear relationships between yield and soil properties, curvilinear relationships would need to be explored for better modeling "fits".

In short, more research is needed to evaluate soil productivity for Montana's agricultural lands. A systematic method for collecting long term performance data is desirable for Montana to counteract yearly climatic variability and management variability over a long period of time. It is hoped that this study has helped in the process

of determining soil productivity indices for Montana's dryland grain production areas by (1) pointing out a few important variables for future soil productivity data analyses, and by (2) beginning the process of assigning productivity values to soil series in Montana.

LITERATURE CITED

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- Allgood, F.P. and F. Gray. 1978. Utilization of soil characteristics in computing productivity ratings of Oklahoma soils. *Soil Sci.* 125:359-366.
- Bennett, C.M., T.H. Webb, and A.R. Wallace. 1980. Influence of soil type on barley yield. *New Zealand J of Expt. Agric.* 8:111-115.
- Black, A.L. 1970. Soil water and soil temperature influences on dryland winter wheat. *Agron. J.* 62:797-801.
- Black, C.A. (ed). 1965. *Methods of Soil Analysis - Part I*, pgs. 381-383. American Society of Agronomy, Inc.; Madison, Wis.
- Brengle, K.G. 1982. *Principles and Practices of Dryland Farming*. Colorado Associated University Press, Boulder CO
- Brown, P.L. 1960. Soil Moisture Probe. *Montana Farmer Stockman* 47:9.
- Caprio, J.M. 1965. Average Length of Freeze-Free Season map. Coop. Extension Service, Montana State Univ., Bozeman MT, Folder No. 83.
- Caprio, J.M. 1973. Average Annual Potential Evapotranspiration Map. Coop Extension Service, Montana State Univ., Bozeman, MT, Bull. 607.
- DeJong, E. and D.E. Rennie. 1967. Physical soil factors influencing the growth of wheat. pgs.61-132. In *Canadian Centennial Wheat Symposium*, Modern Press, Sask.
- Denmond, O.T and R.H. Shaw. 1962. Availability of soil water to plants as affected by soil moisture content and meteorological conditions. *Agron. J.* 54:385-390.
- Ferguson, H. 1983. Soil compaction and tillage. In *Soil Erosion and Tillage; Proceedings of a Conference*. Montana Chapter, Soil Conservation Society of America, Bozeman MT

- Furley, P.A. 1971. Relationships between slope form and soil properties developed over chalk parent materials. In Slopes, form and processes (D. Brunsten, editor). Instr. Br. Geographers Special Publ.: no.3, pgs. 141-164.
- Hsiao, T.C. and E. Acevedo. 1974. Plant response to water deficits, water use efficiency, and drought resistance. Agric. Meteorol. 14:59-84.
- Huddleston, J.H. 1983. Development and use of soil productivity ratings in the United States. Geoderma (in press).
- Karathanasis, A.D., V.A. Johnson, G.A. Peterson, D.H. Sander, and R.A. Olsen. 1980. Relation of soil properties and other environmental factors to grain yield and quality of winter wheat grown at international sites. Agron. J. 72:329-336.
- Montagne, C., L.C. Munn, G.A. Nielsen, J.W. Rogers, and H.E. Hunter. 1982. Soils of Montana. USDA- SCS, Montana Ag. Ex. Sta. Bull. 744.
- Mortvedt, J.J. 1976. Soil chemical constraints in tailoring plants to fit problem soils. 2. Alkaline soils pgs. 141-149. In: Plant Adaptation to Mineral Stress in Problem Soils (M.J. Wright ed). Cornell Agric. Exp. Sta., Ithaca, N.Y.
- Munn, L.C., B.D. Schweitzer, R.E. Lund, and G.A. Nielsen. 1982. Use of paired sampling to quantify soil productivity. Agron. J. 74:148-151.
- Nielsen, K.F. 1974. Roots and root temperatures. In The Plant Root and Its Environment. University Press of Virginia, Charlottesville, VA.
- Nie, N.H., C.H. Hull, J.G. Jenkins, K. Steinbrenner, and D.H. Bent. 1975. Statistical Package for the Social Sciences. McGraw-Hill Book Company; New York, N.Y.
- Nissen, S., and M. Juhnke. 1983. Small grains integrated pest management in northcentral Montana. Coop. Ext. Service, Montana State University, Bozeman, MT. Bull. 1289.
- Odell, R.T. 1958. Soil Survey interpretation; yield prediction. SSSAJ 22:157-160.

- Olsen, G.W. 1981. Soils and the Environment: a guide to soil surveys and their applications. Chapman and Hall, New York, N.Y.
- Ott, L. 1977. An Introduction to Statistical Methods and Data Analysis. Wadsworth Publishing Company Inc. Belmont, Calif.
- Penman, H.L. 1956 . Evaporation: an introductory survey. Netherlands J. Agr. Sci. 4:9-29.
- Peters, T.W. 1977. Relationships of yield data to agroclimates, soil capability classification and soils of Alberta. Can. J. Soil Sci. 57:341-347.
- Power, J.F., D.L. Grunes, W.O. Willis, and G.A. Reichman. 1963. Soil temperature and phosphorus effects upon barley growth. Agron. J. 55:389-392.
- Rashid, S. and K.H. Sheikh. 1976. Response of wheat to different levels of soil compaction. Phytion 18:43-56.
- Richie, J.T. 1981. Water dynamics in the soil-plant-atmosphere system. Plant and Soil 58:81-96.
- Rosenberg, N.J. 1964. Plant response to soil compaction. Adv. Agron. 16:181-195.
- Runge, E.C. and R.T. Odell. 1958. The relation between precipitation temperature, and the yield of corn on the Agronomy South Farm, Urbana, Illinois. Agron.J. 52:245-247.
- Schaff, B.E. 1979. Influence of soil profile and site characteristics on the response of winter wheat to K on Montana soils. M.S. Thesis. Montana State Univ., Bozeman, MT.
- Seber, G.A.F. 1977. Linear Regression Analysis. John Wiley and Sons, New York, N.Y.
- Soil Survey Staff. 1971. Guide for interpreting engineering uses of soils: Soil Conservation Service, USDA: Washington, D.C., U.S. Government Printing Office. 87 pgs.
- Sopher, C.D. and R.J. McCracken. 1973. Relationships between soil properties, management practices, and corn yields on south Atlantic Coastal Plains Soils. Agron. J. 65:595-599.

- Storie, R.E. 1933. An index for rating the agricultural value of soils. Cal. Agr. Exp. Sta. Bull. 556.
- Tabachnick, B.G. and L.S. Fidell. 1983. Using Multivariate Statistics. Harper and Row, New York, N.Y.
- Taylor, H.M. 1974. Root behavior as affected by soil structure and strength. In: The Plant Root and Its Environment. University Press of Virginia, Charlottesville, VA.
- Veeh, R.H. 1981. The influence of selected soil properties, soil type and site characteristics, soil temperature, and soil moisture on the response of small grains to potassium on Montana Soils. M.S. Thesis, Montana State Univ., Bozeman, MT.
- Veihmeyer, F.J. and Hendrickson A.H. 1948. Soil density and root penetration. Soil Sci. 65:487-493.
- Willis, W.O. and J.F. Power. 1975. Soil temperature and plant growth in the Northern Great Plains. In: Prairie: A multiple view (M.K. Wali, editor). Northern Plains Research Center, Univ. of North Dakota Press, Mandan, N.D.

APPENDICES

APPENDIX A

SITE NUMBERS, COOPERATORS, COUNTY,
LEGAL DESCRIPTIONS AND SOIL SERIES

SITE NUMBERS, COOPERATORS, COUNTY, LEGAL DESCRIPTIONS AND SOIL SERIES

Site	Cooperator	County	No. Fertility Experiments	Legal Description	Soil Series
1	Destaffney	Pondera	1	S1/2, Sec. 19, T28N, R1W	Scobey
2	Berkrum	Glacier	1	SE1/4 of SW1/4, Sec. 20, T34, R5W	Kevin
3	Bende	Powder River	1	NW1/4, Sec. 7, T1S, R50E	Vona
4	Kelly	Bighorn	2	SW1/4 of SW1/4 Sec. 26, T3S, R34E	Keiser
5	Rowland	Carbon	2	NW1/4, Sec. 10, T4S, R26E	Absarokee
6	Wieler	Stillwater	1	NE1/4 of SW1/4, Sec. 11, T4N, R20E	Tanna
7	Bates	Gallatin	1	SE1/4, Sec. 32, T1N, R3E	Amsterdam
8	Daua	Yellowstone	1	NW1/4 of NE1/4, Sec. 7, T4S, R26E	Shask
9	Torske, W.	Bighorn	1	SE1/4, Sec. 7, T2S, R33E	Gilt Edge
10	Erickson, L.	Bighorn	2	SE1/4 of NW1/4, Sec. 11, T4N, R23E	
11	Cooper	Gallatin	1	SW1/4, Sec. 27, T1N, R1E	Unnamed loam
12	Fransen Bros.	Toole	1	NW1/4 of NE1/4, Sec. 24, T32N, R1W	Telstad
13	Lakev	Liberty	1	SE1/4 of NE1/4, Sec. 10, T33N, R5E	
14	Ellins	Hill	5	SW1/4 of NW1/4, Sec. 5, T32N, R9E	
15	Reinowski	Hill	2	NE1/4 of NW1/4, Sec. 4, T31N, R13E	
16	Warnick	Hill	1	SE1/4 of SE1/4, Sec. 19, T31N, R15E	
17	Gredoire	Hill	1	NW1/4, Sec. 18, T31N, R16E	Williams
18	Rolston	Hill	4	NW1/4, Sec. 21, T32N, R13E	Telstad
19	Redekopp	Valley	2	SW1/4, Sec. 30, T31N, R45E	Dooley
20	Coulter	Garfield	3	SW1/4, Sec. 4, T19N, R34E	Cherry
21	Erickson, K.	McCone	2	NW1/4 of NW1/4, Sec. 3, T24N, R49E	Vida
22	Missley	Dawson	1	SE1/4 of SE1/4, Sec. 12, T19N, R53E	Farnuf
23	Fadhl	Rosebud	2	NW1/4 of NW1/4, Sec. 28, T12N, R44E	Chama
24	Halside	Roosevelt	2	SE1/4 of SE1/4, Sec. 19, T31N, R55E	Williams
25	Oberdfell	Richland	2	NE1/4 of SW1/4, Sec. 13, T23N, R57E	Chama
26	Mocassin Station	Judith Basin	7	SW1/4 of SE1/4, Sec. 16, T15N, R14E	Judith
27	Metcalf	Judith Basin	3	SE1/4 of SW1/4, Sec. 14, T16N, R14E	Judith
28	Nemec	Fergus	1	NW1/4, Sec. 6, T18N, R13E	Danvers
29	Lee	Judith Basin	1	SE1/4 of SW1/4, Sec. 7, T17N, R11E	Winifred
30	Bates	Gallatin	1	SE1/4, Sec. 32, T1N, R3E	Amsterdam
31	Torske	Bighorn	1	SW1/4, Sec. 7, T2S, R33E	Gilt Edge
32	Wieler	Stillwater	1	SW1/4, Sec. 18, T1N, R20E	Tanna
33	Daua	Yellowstone	1	SW1/4, Sec. 18, T4S, R26E	Absarokee
34	Bende	Powder River	1	SW1/4, Sec. 6, T1S, R50E	Farland
35	Erpelding	Rosebud	1	SE1/4, Sec. 16, T6N, R41E	Fort Collins
36	Dyk	Gallatin	2	NW1/4, Sec. 6, T1S, R3E	Manhattan
37	Patterson	Stillwater	1	SW1/4 of SW1/4, Sec. 23, T4S, R30E	Absarokee
38	Holland	Rosebud	2	NE1/4, Sec. 20, T6N, R42E	Edsar
39	Holland	Rosebud	1	NE1/4, Sec. 20, T6N, R32E	Edsar
40	Miklovich	Bighorn	1	NE1/4, Sec. 33, T5S, R35E	Richfield
41	Torske, L.	Bighorn	1	SW1/4, Sec. 7, T2S, R33E	Gilt Edge
42	Dyk	Gallatin	1	SW1/4, Sec. 7, T1N, R3S	Manhattan
43	Herzos	Stillwater	1	NW1/4, Sec. 21, T3N, R20E	Tanna
44	Erpelding	Rosebud	1	SE1/4, Sec. 15, T6N, R41E	Fort Collins
45	Brinkman	Fergus	1	NW1/4, Sec. 31, T19N, R13E	Danvers
46	Bolins	Fergus	2	SW1/4, Sec. 33, T18N, R14E	Coffee Creek
47	Cash	Musselshell	2	NW1/4, Sec. 30, T5N, R25E	Bainville
48	Daua	Yellowstone	1	SW1/4, Sec. 18, T4S, R26E	Absarokee
49	Pidwerbecki	Valley	1	SW1/4, Sec. 14, T27N, R40E	Evanston
50	Redekopp	Valley	1	N1/2 of NW1/4, Sec. 32, T31N, R45E	Martinsdale
51	Erpelding	Rosebud	1	SE1/4, Sec. 15, T6N, R41E	Fort Collins
52	Erpelding	Rosebud	1	NE1/4, Sec. 15, T6N, R41E	Fort Collins
53	Hela	Garfield	1	NE1/4, Sec. 32, T17N, R43E	Cherry
54	Hauks	Gallatin	1	SE1/4 of SW1/4, Sec. 32, T2S, R5E	Amsterdam
55	Perry	Choteau	1	SE1/4 of SE1/4, Sec. 31, T23N, R10E	Gerber
56	Works	Choteau	2	SW1/4 of SE1/4, Sec. 24, T28N, R9E	Evanston
57	Miklovich	Bighorn	1	NW1/4 of SW1/4, Sec. 27, T6S, R36E	Savage
58	Pehl	Prairie	3	SE1/4 of SW1/4, Sec. 20, T12N, R52E	Chauta
59	Schaff	Golden Valley	1	E1/2 of NE1/4, Sec. 6, T5N, R22E	Woraser
60	Simer, Inc.	Gallatin	1	SW1/4, Sec. 31, T2S, R5E	Bozeman

61	Lassila	Cascade	1	SW1/4, Sec. 33, T21N, R5E	Gerber
62	Visser	Madison	2	NE1/4, Sec. 9, T3S, R1W	Evanston
63	Works	Choteau	1	SE1/4, Sec. 24, T28N, R9E	Evanston
64	Draine	Carter	1	NE1/4, Sec. 8, T7S, R55E	Kreamlin
65	Holland	Rosebud	1	SW1/4 of NW1/4, Sec. 21, T6N, R43E	Flowerree
66	Dahlman	Rosebud	1	NW1/4, Sec. 13, T6N, R41E	Havre
67	Koch-Fox	Gallatin	1	SE1/4 of NE1/4, Sec. 22, T2S, R6E	Bozeman
68	Todd	Gallatin	1	NW1/4, Sec. 21, T2S, R4E	Amerstam
69	Kronebusch	Pondera	1	NW1/4, Sec. 8, T29N, R2W	Kevin
70	Kronebusch	Pondera	1	SE1/4 of SE1/4, Sec. 36, T30N, R3W	Kevin
71	DeStaffany	Pondera	1	SW1/4, Sec. 29, T28N, R1W	Scobey
72	DeStaffany	Pondera	1	E1/2 of SE1/4, Sec. 30, T28N, R1W	Scobey
73	Huffine	Gallatin	1	NE1/4, Sec. 7, T2N, R5E	Amsterdam
74	Keil	Pondera	1	SW1/4, Sec. 23, T30N, R2W	Joplin
75	Gettel	Cascade	2	SE1/4, Sec. 8, T22N, R1E	Carsill
76	Sommerfeldt	Cascade	1	NE1/4, Sec. 17, T22N, R1E	Carsill
77	Dahlaan	Teton	1	NW1/4, Sec. 33, T24N, R11E	Scobey
78	Michael	Yellowstone	1	NE1/4 of NE1/4, Sec. 30, T2N, R28E	Thurlow
79	Goldenstein	Gallatin	1	SW1/4 of SE1/4, Sec. T2S, R5E	Bozeman
80	Huntley Sta.	Yellowstone	1	SW1/4 of NW1/4, Sec. 15, T2N, R28E	Thurlow
81	Teymoes	Teton	1	NE1/4, Sec. 25, T23, R3W	Rothiemay
82	McOmber	Teton	1	SW1/4, Sec. 14, T21N, R5W	Rothiemay
83	Pearson Bros.	Teton	1	NW1/4, Sec. 32, T21N, R3W	Rothiemay
84	Barber, L.	Fergus	1	NE1/4, Sec. 18, T19N, R14E	Coffee Creek
85	Martens	Choteau	3	NW1/4 of SW1/4, Sec. 33, T28N, R12E	Marias
86	Schaff	Golden Valley	1	NW1/4 of SW1/4, Sec. 24, T6N, R21E	Marias
87	Bitz	Hill	3	SW1/4 of SW1/4, Sec. 10, T30N, R12E	
88	Spicher	Hill	1	NW1/4 of NE1/4, Sec. 12, T32N, R10E	
89	Res. Site Hinsham	Hill	2	SE1/4 of SE1/4, Sec. 6, T32N, R10E	
90	Res. Site Rudyard	Hill	3	NW1/4 of NW1/4, Sec. 27, T32N, R9E	
91	Veraulus	Glacier	1	NE1/4 of SE1/4, Sec. 1, T34N, R6W	Pendroy
92	Vermulus	Glacier	4	SW1/4 of NW1/4, Sec. 6, T34N, R5W	Pendroy
93	Johnson	Glacier	1	SW1/4 of NW1/4, Sec. 26, T32N, R5W	Brockway
94	Lahey	Liberty	1	SE1/4, Sec. 35, T33N, R5E	
95	Kammerzell	Liberty	1	SE1/4 of NE1/4, Sec. 5, T31N, R6E	
96	Cady	Liberty	1	NW1/4 of SW1/4, Sec. 26, T34N, R7E	
97	Kaercher	Hill	4	SW1/4 of SW1/4, Sec. 2, T32N, R14E	
98	Donovan	Hill	1	NW1/4 of SE1/4, Sec. 33, T34N, R13E	
99	Tviet	Richland	2	SW1/4 of SE1/4, Sec. 25, T25N, R43E	Vida
100	Christofferson	Roosevelt	1	NW1/4 of SW1/4, Sec. 17, T29N, R56E	Williams
101	Hoye	Roosevelt	1	SE1/4 of SW1/4, Sec. 12, T30N, R56E	Williams
102	Benson	Roosevelt	3	NE1/4 of SE1/4, Sec. 22, T30N, R55E	Parshall
103	Waters	Roosevelt	1	SE1/4 of SW1/4, Sec. 16, T30N, R56E	Williams
104	Holland	Rosebud	1	NE1/4 of NE1/4, Sec. 19, T6N, R43E	Flowerree
105	Hansen	Sweetgrass	3	SW1/4 of SE1/4, Sec. 36, T5N, R14E	Flowerree
106	Mosdal	Stillwater	2	NE1/4 of SW1/4, Sec. 12, T3N, R20E	Tanna
107	Larsen	Rosebud	1	SE1/4 of SE1/4, Sec. T6N, R41E	Evanston
108	Warren	Bishorn	1	NW1/4 of SW1/4, Sec. 7, T2S, R34E	Wases
109	Herzos	Stillwater	1	SW1/4 of SW1/4, Sec. 21, T3N, R20E	Yamac
110	McFarland	Yellowstone	1	SW1/4 of SE1/4, Sec. 10, T1N, R24E	Bainville
111	Becker	Yellowstone	1	NE1/4 of SW1/4, Sec. 26, T2S, R26E	Absarokee
112	Warren	Bishorn	1	SE1/4, Sec. 18, T2S, R34E	Richfield
113	Sire	Yellowstone	2	SW1/4, Sec. 22, T1N, R29E	Danvers
114	Larsen	Rosebud	1	SE1/4 of NW1/4, Sec. 24, T6N, R41E	Desrand
115	Eastlick	Stillwater	3	NW1/4 of NW1/4, Sec. 11, T1N, R22E	Marvin
116	Lee	Yellowstone	1	NW1/4 of NW1/4, Sec. 3, T3S, R26E	Absarokee
117	Larsen	Rosebud	2	SW1/4 of SE1/4, Sec. 24, T6N, R41E	Desrand
118	Keller	Yellowstone	1	NW1/4, Sec. 29, T4N, R32E	Kobar
119	Losan	Yellowstone	2	SW1/4, Sec. 36, T1N, R28E	Shaak
120	Warren	Bishorn	2	SW1/4, Sec. 18, T2S, R34E	Richfield
121	Haines	Rosebud	2	SW1/4 of NW1/4, Sec. 16, T6N, R38E	Vanstel
122	Keller	Yellowstone	1	SW1/4, Sec. 21, T4N, R32E	Lonna
123	Losan	Yellowstone	1	NE1/4 of NW1/4, Sec. 36, T1N, R38E	Danvers

Total Experiments with Yield Data = 184

APPENDIX B

SOIL SERIES INFORMATION

Series Name	Classification[1]	Textural Class	Textural Family[1]	Moist. Resime[1]	Temp. Resime[1]	Avail. Water Cap[2]	Soil Depth[3]
Absarokee	Typic Argiboroll	clay loam	fine-montmorill.	ustic	frigid	low	shallow
Amsterdam	Typic Cryoboroll	silt loam	fine-silty	udic	cryic	v. high	deep
Bainville	Ustic Torrefluent	clay loam	fine-silty	aridic-ustic	mesic	low	shallow
Bozeman	Pachic Argiboroll[4]	silt loam	fine-silty	udic	cryic	v. high	deep
Bridger	Arctic Cryoboroll	loam	fine-loamy	udic	cryic	high	deep
Brockway	Borollic Calciorthid	silt loam	fine-silty	aridic-ustic	frigid	high	deep
Carsill	Borollic Calciorthid	silty-clay loam	fine-silty	aridic-ustic	frigid	medium	shallow
Chama	Typic Haploboroll	silt loam	fine-silty	ustic	frigid	medium	shallow
Chanta	Aridic Haploboroll	loam	fine-loamy	ustic-aridic	frigid	medium	shallow
Cherry	Typic Ustochrept	silty-clay loam	fine-silty	ustic	frigid	v. high	deep
Coffee Creek	Typic Haploboroll	clay loam	fine-montmorill.	ustic	frigid	high	deep
Danvers	Typic Argiboroll	clay loam	fine-montmorill.	ustic	frigid	high	deep
Desrand	Aridic Argiboroll	loam	fine-loamy	ustic-aridic	frigid	medium	deep
Dooley	Typic Argiboroll	fine-sandy loam	fine-loamy	ustic	frigid	high	deep
Edgar	Ustollic Camborhith	loam	fine-loamy	aridic-ustic	mesic	high	deep
Evanston	Aridic Argiboroll	loam	fine-loamy	ustic-aridic	frigid	high	deep
Farland	Typic Argiboroll	silt loam	fine-silty	ustic	frigid	v. high	deep
Farnuf	Typic Argiboroll	loam	fine-loamy	ustic	frigid	high	deep
Flowerree	Aridic Haploboroll	silt loam	fine-silty	ustic-aridic	frigid	v. high	deep
Fort Collins	Ustollic Haplarid	loam	fine-loamy	aridic-ustic	mesic	v. high	deep
Gerber	Udorthentic Chromustert	silty-clay loam	fine-montmorill.	ustic	frigid	high	deep
Gilt Edge	Haplustollic Natrasid	silty-clay loam	fine-montmorill.	aridic-ustic	mesic	high	deep
Havre	Ustic Torrefluent	loam	fine-loamy	aridic-ustic	frigid	high	deep
Joplin	Aridic Argiboroll	loam	fine-loamy	ustic-aridic	frigid	high	deep
Judith	Typic Calciboroll	gravelly-clay-loam	fine-loamy	ustic	frigid	medium	deep
Keiser	Ustollic Haplarid	silty-clay loam	fine-silty	aridic-ustic	mesic	v. high	deep
Kevin	Aridic Argiboroll	clay loam	fine-loamy	ustic-aridic	frigid	high	deep
Kobar	Borollic Camborhith	silty-clay loam	fine-montmorill.	aridic-ustic	frigid	high	deep
Kremlin	Aridic Haploboroll	loam	fine-loamy	ustic-aridic	frigid	high	deep
Lonna	Borollic Camborhith	silt loam	fine-silty	aridic-ustic	frigid	v. high	deep
Manhattan	Typic Calciboroll	fine-sandy loam	coarse-loamy	ustic	frigid	high	deep
Marias	Udorthentic Chromustert	clay	fine-montmorill.	aridic-ustic	frigid	high	deep

Martinsdale	Typic Arsiaboroll	loam	fine-loamy	ustic	frigid	high	deep
Marvan	Udorthentic	clay loam	fine-montmorill.	aridic-ustic	frigid	medium	deep
	Chromustert						
Parshall	Pachic Haploboroll	fine-sandy loam	coarse-loamy	ustic	frigid	medium	deep
Pendroy	Udorthentic	clay	fine-montmorill.	aridic-ustic	frigid	high	deep
	Chromustert						
Richfield	Aridic Arsiustoll	silty-clay loam	fine-montmorill.	ustic-aridic	mesic	high	deep
Rothiemay	Aridic Caliboroll	loam	fine-loamy	ustic-aridic	frigid	high	deep
Savage	Typic Arsiaboroll	silty-clay loam	fine-montmorill.	ustic-aridic	frigid	high	deep
Scobey	Aridic Arsiaboroll	clay loam	fine-montmorill.	ustic-aridic	frigid	high	deep
Shaak	Abruptic Arsiaboroll	silty-clay loam	fine-montmorill.	ustic	frigid	high	deep
Tanna	Aridic Arsiaboroll	clay loam	fine-montmorill.	ustic-aridic	frigid	low	shallow
Telstad	Aridic Arsiaboroll	loam	fine-loamy	ustic-aridic	frigid	high	deep
Thurlow	Ustollic Haplargid	clay loam	fine-montmorill.	aridic-ustic	mesic	high	deep
Unnamed	Typic Cryoboroll	loam	fine-loamy	udic	cryic		
Vanstel	Ustollic Haplargid	clay loam	fine-montmorill.	aridic-ustic	frigid	v. high	deep
Vida	Typic Arsiaboroll	loam	fine-loamy	ustic	frigid	high	deep
Vona	Ustollic Haplargid	fine-sandy loam	coarse-loamy	aridic-ustic	mesic	medium	deep
Wases	Aridic Arsiaboroll	loam	fine-loamy	ustic-aridic	mesic	high	deep
Williams	Typic Arsiaboroll	loam	fine-loamy	ustic	frigid	high	deep
Winifred	Typic Haploboroll	clay loam	fine-montmorill.	ustic	frigid	medium	shallow
Wormser	Aridic Arsiustoll	clay loam	fine-montmorill.	ustic-aridic	mesic	low	shallow
Yamac	Borollic Camborthid	loam	fine-loamy	aridic-ustic	frigid	high	deep

[1] Classification, Textural Family, Water Resimer and Temp. Resime derived from Soil Taxonomy (1975).

[2] Avail. Water Holding Cap. levels derived from "Soils of Montana" (1982)

where:

v. high	> 25 cm
high	18-25 cm
medium	13-18 cm
low	0-13 cm

[3] Soil Depth levels derived from "Soils of Montana" (1982)

where:

shallow	<50 cm
deep	50-150 cm

[4] Alternate classification for Bozeman is Arsic Pachic Cryoboroll.

APPENDIX C
COMPLETE DATA SET

COMPLETE DATA SET

FORMAT STATEMENT (CP6-SPSS)

INPUT FORMAT FOR V01 TO V56

```

FIXED (F3.0,F1.0,F1.0,F2.0,X,F1.0,X,F4.0,29X,
3F2.1,X,3F3.2,X,9F1.0,F2.0,F1.0,X,F2.0,X,F2.0/
10X,F4.0,X,F2.1,F2.0,X,F4.2,F3.1,X,F1.0,X,F2.0,
X,F2.0,X,F2.0,F2.0,X,F3.1,F2.0,4X,F4.1,X,F3.1,
F3.1,X,F3.1,X,F3.1,X,F3.1,X,F3.1/ 17X,6F4.1,X,
F1.0,X,F2.0,X,F3.0)

```

("/" indicates end of line)

NOTE: Refer to the next page. Input format begins in column 1. It ends for each card 2 columns before the last column (with all number ones). The column with all number ones represents geographical location (V25), which is not part of the input format above but is located elsewhere in the data file. Refer to Table 1 as a cross reference; it includes variable names, numbers, and format for each variable.

EXAMPLE: 1st Line Format

V01 =	084	F3.0
V02 =	1	F1.0
V03 =	1	F1.0
V04 =	68	F2.0
V05 =	1	F1.0
V06 =	3756	F4.0
V08 =	4.4	F2.1
V09 =	3.9	F2.1
V10 =	3.3	F2.1
etc.		

INPUT FORMAT FOR V57 TO V59

```

COMPUTE V57 = V38 + V40
COMPUTE V58 = V38 + V50
COMPUTE V59 = V38 + V49

```

[illegible]

[illegible]

[illegible]

1041176	2	823	20	7	4616	69	2	8	12	17	23	117	3	97	27	31	21	18	4		
1041176	3				27	58	79	97				41	80	131					4		
41171	1	3039										3039	36	149176170	116322	7	5	34	25	41	4
41171	2	990	15	3	4532106	3						85	4	147					4		
41171	3											41	66	120					4		
1181178	1	4551										382241	149161171	326222325	4	44	25	46	4		
1181178	2	899	10	7	4605	69	2	7	10	16	20	193	4	84	36	19	11	18	4		
1181178	3				36	55	66	84				31	82	149					4		
1211180	1	1199										173624	138149157	316224	7	5	44	15	28	4	
1211180	2	838	20	7	4617	67	2	9	19	21	25	86	4	132	31	43	37	21	4		
1211180	3				31	74	111	132				41	74	143					4		
581175	1	3510										433428	170138138	126224225	2	24	25	46	4		
581175	2	777	10	7	4647	58	2					3	153	40	45	50	18		4		
581175	3				40	85	135	153				41	63	128					4		
781180	1	3536										323630	138150149	111222132	5	44	8	23	4		
781180	2	929	20	4	4555	92	3	6	15	16	21	131	4	131	34	38	36	24	4		
781180	3				34	72	110	131				31	84	138					4		
381171	1	3092										322338	162155148	211224	7	2	24	15	25	4	
381171	2	792	20	6	4616	94	3					91	4	109					4		
381171	3											41	74	132					4		
581173	1	3029										433428	170138138	126224225	2	24	25	46	4		
581173	2	777	10	7	4647	58	2					149	3	79	9	42	28		4		
581173	3				9	51	79					20	75	124					4		
651175	1	3422										373340	152145151	216322234	3	34	18	36	4		
651175	2	820	10	8	4616	69	2					3	248	35	45	36	45	50	37	4	
651175	3				35	80	116	161	211	248		41	69	121					4		
251171	1	3409										192426	128134121	125222225	3	34	10	23	4		
251171	2	701	10	7	4745	61	2					2	107	43	38	25	00	00	00	4	
251171	3				43	81	107					20	71	109					4		
1051178	1	2742										39	30	157	158	216322234	3	34	10	4	
1051178	2	1409	45	2	4608	69	2	2	8	13	17	207	3	155	38	46	45	26		4	
1051178	3				38	84	129	155				41	48	139					4		
1101176	1	2715										443534	165160165	131224135	5	34	13	25	4		
1101176	2	1158	20	7	4551106	3	0	8	9	13		249	4	90	39	27	38		4		
1101176	3				39	66	90					10	71	109					4		
101171	1	2570										203833	158160166	131224135	5	34	20	30	4		
101171	2	1158	10	3	4607106	3						44	4	013					4		
101171	3											10	61	115					4		
1091176	1	3814										342527	163148158	216222132	2	24	13	25	4		
1091176	2	1249	40	1	4600	61	2	5	9	14	17	137	4	160	39	41	37	42	4		
1091176	3				39	80	117	160				31	66	113					4		
1131177	1	3497										334134	155157160	216212232	5	44	23	41	4		
1131177	2	1181	10	7	4549	64	2	1	8	14	18	112	2	172	47	47	45	33	4		
1131177	3				47	94	139	172				31	76	129					4		
101170	1	2979										203833	158160166	131224135	5	34	20	30	4		
101170	2	1158	10	3	4607106	3						172	4						4		
101170	3											10	61	113					4		
661175	1	3656										303733	144149155	126	7	4	24	33	48	4	
661175	2	801	10	2	4617	67	2					4	218	38	39	42	40	28	31	4	
661175	3				38	77	119	159	187	218		31	72	115					4		
1171180	1	1691										292421	168154159	116222125	2	24	28	41	4		
1171180	2	829	20	8	4616	60	2	11	17	21	27	156	3	99	25	33	26	15	4		
1171180	3				25	58	84	99				21	90	143					4		
251170	1	2777										192426	128134121	125222225	3	34	10	23	4		
251170	2	701	10	7	4745	61	2					2	241	41	48	43	41	33	36	4	
251170	3				41	89	132	173	206	241		20	67	109					4		
1141177	1	2468										434526	169156156	116222125	2	24	25	46	4		
1141177	2	826	10	7	4616	60	2	15	22	23		66	3	112	42	43	16	11	4		
1141177	3				3	42	85	101	112			21	85	137					4		
31170	1	2959										171824	149134149	216132135	1	14	15	30	4		
31170	2	1036	80	6	4545108	3						181	4						4		
31170	3											21	66	112					4		

41170 1 2403	303936 149176170 116322 7 5 34 25 41 4
41170 2 990 15 3 4532106 3	150 4
41170 3	41 66 118
1191178 1 5123	474641 166168159 221322122 4 44 15 30 4
1191178 2 1194 5 7 4548 67 2 4 7 17 19	350 2 174 47 38 42 47
1191178 3	31 74 146
1201179 1 2574	253642 163159164 4 44 13 33 4
1201179 2 996 30 2 4539106 3 11 16 23	97 3 172 87 37 23 25
1201179 3	31 79 128
81170 1 2537	344742 145161166 221322122 4 44 15 30 4
81170 2 1302 25 3 4530 67 2	220 2
81170 3 109	31 60 108
311171 1 3984	414242 164159148 216313224 4 44 30 51 4
311171 2 935 15 3 4540106 3	73 4 218
311171 3	31 75 125
321171 1 3831	423923 164151149 216222232 5 44 15 25 4
321171 2 1508 50 7 4550 67 2	136 3 180
321171 3	20 61 117
351171 1 3158	283725 162148141 216222125 2 24 18 33 4
351171 2 827 20 2 4616114 3	111 4 94
351171 3	41 73 117
1161178 1 4222	364444 163177185 121314214 5 44 20 30 4
1161178 2 1274 10 2 4537 58 2 6 10 14 18	398 2 176 46 46 44 400
1161178 3	46 92 136 176
1211179 1 2546	10 68 139
1211179 2 838 20 7 4617 67 2 7 12 17 22	173624 138149157 316224 7 5 44 15 28 4
1211179 3	63 4 207 73 50 36 48
801177 1 4654	41 65 133
801177 2 920 10 1 4556 92 3 6 7 11 17	322335 155141140 111222132 5 44 8 23 4
801177 3	110 4 171 53 42 45 31
231171 1 1822	31 81 131
231171 2 884 45 8 4647 61 2	142327 141137145 125222225 3 34 18 30 4
231171 3	2 165 46 36 33 28 15 08 4
1171178 1 3994	20 74 107
1171178 2 829 20 8 4616 60 2 6 10 15 19	292421 168154159 116222125 2 24 28 41 4
1171178 3	201 3 108 37 28 31 12
861179 1 2349	21 80 155
861179 2 1127 30 2 4616 64 2 8 14 19	154744 118178167 316334334 6 44 33 46 4
861179 3	72 4 141 59 29 33 20
51170 1 2993	31 66 123
51170 2 1249 10 7 4530 58 2	404626 166157155 121314214 5 44 5 15 4
51170 3	117
91170 1 2561	10 64 123
91170 2 935 15 1 4540106 3	354141 157171171 216313224 4 44 20 30 4
91170 3	132 4
231170 1 4109	31 76 123
231170 2 884 45 8 4647 61 2	142327 141137145 125222225 3 34 18 30 4
231170 3	2 245 48 53 48 41 33 17 4
1111179 1 2675	20 69 107
1111179 2 1211 20 2 4538 58 2 6 9 16	264224 136167149 121314214 5 44 23 38 4
1111179 3	70 2 161 67 33 34 27
341171 1 1723	10 67 139
341171 2 1036 30 2 4545 67 2	383525 150166162 115222235 3 34 28 46 4
341171 3	154 2 183
1231179 1 2850	41 68 113
1231179 2 1188 10 5 4548 64 2 6 7 16 20	294141 138156163 216212232 5 44 15 33 4
1231179 3	85 2 145 50 13 53 29
471173 1 2898	31 72 125
471173 2 1203 20 7 4609106 3	212837 139150163 131224135 5 34 13 28 4
471173 3	43 4 154 50 55 49
1121177 1 3369	10 66 105
1121177 2 996 20 2 4539106 3 6 13 20 22	474542 163150161 4 44 13 33 4
	118 3 137 42 37 30 28 4

1121177 3	42 79 109 137	31 85 131	4
61170 1 2995		223718 14 5168163 216222232 5 44 20 30	4
61170 2 1508 40 7 4550 67 2		99 3	4
61170 3		20 61 115	4
381173 1 3756		322338 162155148 211224 7 2 24 15 25	4
381173 2 792 20 6 4616 94 3		126 4 94 15 26 23 31	4
381173 3	15 41 64 95	41 80 120	4
1071176 1 3046		132918 159163172 216222 7 2 24 20 30	4
1071176 2 829 10 7 4616 72 2 8 13 20 27		97 3 110 32 30 32 12	4
1071176 3	32 62 94 106	31 81 127	4
1151177 1 2293		424039 157163173 216 215 5 44 15 25	4
1151177 2 1211 20 2 4551 75 2 7 10 16 18		107 4 151 44 19 43 45	4
1151177 3	44 63 106 151	21 71 120	4
1051179 1 3316		39 30 157 158 216322234 3 34 10	4
1051179 2 1409 45 2 4608 69 2 8 14 20		92 3 147 77 25 24 21	4
1051179 3	77 102 126 147	41 48 119	4
1081176 1 2685		403233 159158168 216122 7 2 24 13 33	4
1081176 2 967 25 1 4540100 3 6 11 15 21		237 3 132 35 32 31 35	4
1081176 3	35 67 98 133	31 81 123	4
581174 1 2765		433428 170138138 126224225 2 24 25 46	4
581174 2 777 10 7 4647 58 2		3 200 51 67 44 17 21	4
581174 3	51 118 162 179	20 71 97	4
1151179 1 3598		424039 157163173 216 215 5 44 15 25	4
1151179 2 1211 20 2 4551 75 2 5 9 14 20		58 4 210 80 41 47 42	4
1151179 3	80 121 168 210	21 66 117	4
571173 1 3106		344543 154155169 131222132 4 44 23 43	4
571173 2 1060 30 6 4517 69 2		47 2 233 28 46 50 45 64	4
571173 3	28 74 124 169 233	31 66 100	4
1221179 1 3510		274138 151161159 215215 7 3 34 41 61	4
1221179 2 896 10 7 4605 64 2 7 14 18 22		93 4 175 67 34 40 34	4
1221179 3	67 101 141 175	41 80 128	4
481173 1 2075		373939 156158160 121314214 5 44 28 43	4
481173 2 1264 25 1 4529 58 2		47 2 123 23 71 29	4
481173 3	23 94 123	10 65 108	4
331171 1 1664		364630 153157159 121314214 5 44 13 25	4
331171 2 1264 30 3 4529 58 2		68 2 61	4
331171 3		10 59 110	4
1051177 1 2470		39 30 157 158 216322234 3 34 10	4
1051177 2 1409 45 2 4608 69 2 6 10 16 18		110 3 141 34 34 35 38	4
1051177 3	34 68 103 141	41 53 123	4
1151178 1 3598		424039 157163173 216 215 5 44 15 25	4
1151178 2 1211 20 2 4551 75 2 5 7 15 16		274 4 189 50 54 47 38	4
1151178 3	50 104 151 189	21 69 137	4
51171 1 3052		404626 166157155 121314214 5 44 5 15	4
51171 2 1249 10 7 4530 58 2		132 2 114	4
51171 3		10 64 125	4
511173 1 3923		143037 170159160 216212232 2 24 23 38	4
511173 2 827 10 5 4616114 3		126 4 90 22 38 21 9	4
511173 3	22 60 81 90	41 81 119	4
391174 1 3858		293324 158148150 211224 7 2 24 13 25	4
391174 2 792 20 6 4616 94 3		146 4 286 48 52 56 56 74	4
391174 3	48 100 156 212	41 77 108	4
1061176 1 2323		354346 148165163 216222232 5 44 33 53	4
1061176 2 1280 10 8 4601 67 2 0 5 10 15		138 3 107 38 36 33	4
1061176 3	38 74 107	20 69 113	4
901275 1 2439		33 34 167 151 225 224 1 11 15	1
901275 2 899 10 3 4846 2		199 198 33 45 34 29 29 28	1
901275 3	33 78 112 141 170 198	50 105	1
921272 1 3010		404521 167160147 214 134 6 41 10 20	1
921272 2 1161 5 2 4844 69 2		4	1
921272 3		31 62 107	1
701275 1 3152		273530 135134162 216222132 5 21 25 41	1

[illegible]

[illegible]

APPENDIX D

SPSS PRODUCED REGRESSIONS

APPENDIX D1 - SPSS produced regressions; statewide cases restricting temperature, rainfall, and soil water (n=184).

Regression step	F	R ²	SE
(1) Y = 2332 + 221(V53)*	27.65*	.131	883.9
(2) Y = 1682 + 233(V53)* + 217(V10)*	20.69*	.186	858.2
(3) Y = -1991 + 220(V53)* + 176(V10)* + 52(V04)*	15.97*	.210	847.7
(4) Y = -1476 + 236(V53)* + 199(V10)* + 59(V04)* - 17(V55)*	13.68*	.217	837.2
(5) Y = -1828 + 194(V53)* + 214(V10)* + 61(V04)* - 16(V55)* + 128(V18)*	12.25*	.256	827.4

EXTRA RUN			
(6) Y = -1650 + 213(V53)* + 182(V10)* + 50(V04)* - 127(V03)	12.78*	.222	843.7

* significance at p=.05.

APPENDIX D2 - SPSS produced regressions; statewide cases including rainfall data only excluding temperature and soil water variables (n=123).

Regression step	F	R ²	SE
(1) Y = 2073 + 59(V38)*	34.28*	.221	851.8
(2) Y = 1564 + 59(V38)* + 213(V53)*	29.33*	.328	794.1
(3) Y = 848 + 57(V38)* + 233(V53)* + 235(V10)*	25.49*	.391	759.2
(4) Y = -36 + 55(V38)* + 227(V53)* + 204(V10)* + 9(V56)*	22.42*	.430	736.5
(5) Y = 225 + 53(V38)* + 211(V53)* + 205(V10)* + 9(V56)* - 184(V03)*	19.39*	.450	725.7

* significant at p=.05

APPENDIX D3 - SPSS produced regressions; statewide cases including soil water data only and excluding rainfall and temperature variables (n=114).

Regression step	F	R ²	SE
(1) Y = 2262 + 241(V53)*	20.84*	.157	894.1
(2) Y = 1380 + 249(V53)* + 289(V10)*	17.91*	.243	850.5
(3) Y = 1246 + 247(V53)* + 275(V10)* + 56(V44)*	15.49*	.297	823.9
(4) Y = 835 + 229(V53)* + 288(V10)* + 43(V44)* + 113(V42)*	13.13*	.325	810.9
(5) Y = 264 + 219(V53)* + 278(V10)* + 37(V44)* + 106(V42)* + 1(V28)	11.47*	.347	801.4

* significant at p=.05

APPENDIX D4 - SPSS produced regressions; statewide cases including soil water and rainfall without temperature or V57 to V58 (n=83).

Regression step	F	R ²	SE
(1) Y = 2122 + 57(V38)*	15.77*	.163	927.9
(2) Y = 1534 + 59(V38)* + 245(V53)*	18.79*	.320	841.8
(3) Y = 684 + 55(V38)* + 263(V53)* + 277(V10)*	17.26*	.396	798.1
(4) Y = 186 + 55(V38)* + 236(V53)* + 303(V10)* + 37(V50)*	17.37*	.471	751.6
(5) Y = 469 + 57(V38)* + 284(V53)* + 294(V10)* + 39(V50)* - 251(V14)*	16.11*	.511	727.2

* significant at p=.05

APPENDIX D5 - SPSS produced regressions; statewide cases including soil water and rainfall variables (with V57 to V59) without temperature variables.

Regression step	F	R ²	SE
(1) $Y = 1551 + 50(V58)^*$	27.61*	.254	875.9
(2) $Y = 806 + 52(V58)^* + 248(V25)^*$	23.53*	.370	809.8
(3) $Y = 716 + 49(V58)^* + 184(V25)^* + 149(V53)^*$	19.04*	.420	782.3
(4) $Y = -21 + 48(V58)^* + 123(V25) + 186(V53)^* + 272(V10)^*$	18.61*	.489	739.3
(5) $Y = 269 + 49(V58)^* + 85(V25) + 240(V53)^* + 278(V10)^* - 216(V14)^*$	16.41*	.516	723.8

EXTRA RUN			
(6) $Y = 331 + 48(V58)^* + 233(V25)^* + 194(V08)^*$	17.62*	.401	

* significant at p=.05

APPENDIX D6 - SPSS produced regressions; statewide cases including rainfall, soil water, and soil temperature variables (n=42).

Regression step	F	R ²	SE
(1) $Y = 1656 + 50(V59)^*$	12.70*	.241	745.6
(2) $Y = 1995 + 42(V59)^* - 36(V51)^*$	10.96*	.350	693.5
(3) $Y = 10058 + 47(V59)^* - 69(V51)^* - 106(V04)$	8.46*	.400	679.9
(4) $Y = 12988 - 15(V59) - 88(V51)^* - 145(V04)^* + 63(V58)^*$	7.85*	.459	654.4
(5) $Y = 12150 - 54(V59) - 85(V51)^* + 116(V04) + 92(V58)^* - 80(V36)$	7.42*	.508	632.9

EXTRA RUN			
(6) $Y = 1454 + 37(V59)^* - 34(V51)^* + 203(V08)$	8.44	.400	680.2

APPENDIX D7 - SPSS produced regressions; winter wheat cases restricting rainfall, soil water, and soil temperature (n=121).

Regression step	F	R ²	SE
(1) $Y = 2579 + 159(V53)^*$	9.79*	.076	793.6
(2) $Y = 1923 + 157(V53)^* + 227(V08)^*$	9.85*	.143	767.4
(3) $Y = 1617 + 173(V53)^* + 218(V08)^* + 224(V12)^*$	8.59*	.181	753.7
(4) $Y = -1563 + 164(V53)^* + 200(V08)^* + 223(V12)^* + 44(V04)^*$	7.64*	.209	743.8
(5) $Y = -1130 + 180(V53)^* + 190(V08)^* + 285(V12)^* + 54(V04)^* - 185(V55)^*$	7.38*	.243	730.7

* significant at p=.05

APPENDIX D8 - SPSS produced regressions; winter wheat cases including rainfall and excluding soil water and soil temperature (n=86).

Regression step	F	R ²	SE
(1) $Y = 2471 + 41(V38)^*$	11.51*	.121	778.1
(2) $Y = 1731 + 45(V38)^* + 22(V27)^*$	11.57*	.218	738.1
(3) $Y = 1057 + 39(V38)^* + 22(V27)^* + 242(V08)^*$	10.77*	.283	711.2
(4) $Y = 663 + 42(V38)^* + 20(V27)^* + 249(V08)^* + 151(V53)^*$	10.52*	.342	685.4
(5) $Y = 619 + 40(V38)^* + 20(V27)^* + 225(V08)^* + 164(V53)^* + 83(V21)$	9.25*	.366	676.7

EXTRA RUN

(6) $Y = -1465 + 40(V38)^* + 20(V27)^* + 239(V08)^* + 142(V53)^* + 30(V04)$	8.80*	.355	682.8
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* significant at p=.05

APPENDIX D9 - SPSS produced regressions; winter wheat cases including soil water and excluding rainfall and soil temperature (n=82).

Regression step	F	R ²	SE
(1) $Y = 2431 + 145(V43)^*$	7.93*	.090	810.4
(2) $Y = 1649 + 151(V43)^* + 258(V10)^*$	8.91*	.184	772.2
(3) $Y = 1246 + 120(V43)^* + 285(V10)^* + 171(V53)^*$	9.12*	.260	740.3
(4) $Y = 1288 + 85(V43) + 270(V10)^* + 178(V53)^* + 34(V44)$	7.86*	.289	729.7
(5) $Y = 1084 + 76(V43) + 270(V10)^* + 181(V53)^* + 34(V44) + 192(V15)$	7.11*	.319	719.4

EXTRA RUN			
(6) $Y = 599 + 104(V43)^* + 263(V10)^* + 165(V53)^* + 112(V08) + 1(V28)$	6.59*	.303	727.9

* significant at p=.05

APPENDIX D10 - SPSS produced equations; winter wheat cases including rainfall and soil water (without V57 to V59) and excluding soil temperature (n=62).

Regression step	F	R ²	SE
(1) $Y = 2445 + 42(V50)^*$	11.02*	.155	825.5
(2) $Y = 1889 + 43(V50)^* + 43(V38)^*$	10.65*	.265	776.3
(3) $Y = 1019 + 46(V50)^* + 50(V38)^* + 24(V27)^*$	11.58*	.375	722.3
(4) $Y = 840 + 50(V50)^* + 45(V38)^* + 21(V27)^* + 229(V15)$	10.12*	.415	704.5
(5) $Y = 511 + 51(V50)^* + 40(V38)^* + 16(V27)^* + 246(V15)^* + 175(V10)$	9.26*	.453	687.8

* significance at p=.05

APPENDIX D11 - SPSS produced regressions; winter wheat cases including rainfall, soil water variables (with V57 to V59) and excluding soil temperature variables (n=62).

Regression step	F	R ²	SE
(1) $Y = 1859 + 44(V58)^*$	21.61*	.264	770.1
(2) $Y = 999 + 48(V58)^* + 23(V27)^*$	17.58*	.373	716.9
(3) $Y = 815 + 48(V58)^* + 21(V27)^* + 214(V15)$	13.49*	.411	701.1
(4) $Y = 610 + 45(V58)^* + 20(V27)^* + 218(V15)^* + 126(V53)$	11.62*	.450	683.9
(5) $Y = 831 + 46(V58)^* + 20(V27)^* + 367(V15)^* + 192(V53)^* - 136(V22)^*$	12.26*	.522	642.3

APPENDIX D12 - SPSS produced regressions; spring wheat cases excluding rainfall, soil water and soil temperature variables (n=23).

Regression step	F	R ²	SE
(1) $Y = 1460 + 414(V21)^*$	5.19*	.198	924.4
(2) $Y = 856 + 463(V21)^* + 130(V32)^*$	7.34*	.423	803.3
(3) $Y = -1638 + 281(V21) + 221(V32)^* + 954(V10)^*$	12.00*	.650	637.9
(4) $Y = -3749 + 323(V21)^* + 234(V32)^* + 889(V10)^* + 19(V56)^*$	12.36*	.730	576.1
(5) $Y = -816 + 299(V21)^* + 241(V32)^* + 707(V10)^* + 23(V56)^* - 46(V55)^*$	13.32*	.797	517.3

* significant at p=.05

APPENDIX D13 - SPSS produced regressions; spring wheat cases including rainfall and excluding soil water, soil temperature (n=14).

Regression step	F	R ²	SE
(1) $Y = 892 + 86(V38)^*$	32.90*	.733	602.7
(2) $Y = 192 + 82(V38)^* + 395(V25)^*$	45.85*	.893	398.6
(3) $Y = 803 + 72(V38)^* + 508(V25)^* - 355(V24)$	41.72*	.926	347.4
(4) $Y = -78 + 67(V38)^* + 521(V25)^* - 395(V24)^* + 9(V56)$	35.92*	.941	326.8
(5) $Y = -1179 + 61(V38)^* + 521(V25)^* - 732(V24)^* + 13(V56) + 1(V28)$	36.00*	.957	294.6

* significant at p=.05

APPENDIX D14 - SPSS produced regressions; spring wheat cases including soil water and excluding rainfall and soil temperature variables (n=13).

Regression step	F	R ²	SE
(1) $Y = -1649 + 480(V48)^*$	21.34*	.660	664.7
(2) $Y = -1981 + 570(V48)^* - 234(V19)^*$	24.94*	.833	488.4
(3) $Y = -2314 + 400(V48)^* - 210(V19)^* + 433(V41)$	24.19*	.890	418.5
(4) $Y = -7 + 332(V48)^* - 190(V19)^* + 447(V41)^* - 31(V55)$	24.50*	.924	367.1
(5) $Y = 4158 + 148(V48) - 144(V19)^* + 404(V41)^* - 82(V55)^* + 111(V32)$	32.47*	.959	290.5

EXTRA RUN

(6) $Y = 1334 + 407(V48)^* - 40(V55)$	12.95*	.721	630.9
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* significance at p=.05

APPENDIX D15 - SPSS produced regressions; spring wheat cases including rainfall, soil water variables (without V57 to V59) and excluding soil temperature variables (n=9).

Regression step	F	R ²	SE
(1) $Y = 1151 + 52(V38)^*$	6.22*	.471	545.1
(2) $Y = 247 + 67(V38)^* + 450(V25)^*$	16.00*	.842	321.6
(3) $Y = 1931 + 40(V38)^* + 514(V25)^* - 854(V24)^*$	67.10*	.976	138.0
(4) $Y = 1464 + 41(V38)^* + 587(V25)^* - 798(V24)^* + 105(V45)^*$	146.39*	.993	81.7
(5) $Y = 1327 + 43(V38)^* + 584(V25)^* - 673(V24)^* + 83(V45) - 44(V18)$	172.17*	.997	67.5

* significant at p=.05

APPENDIX D16 - SPSS produced regressions; spring wheat cases including rainfall, soil water variables (with V57 to V59) and excluding soil temperature variables (n=9).

Regression step	F	R ²	SE
(1) $Y = 631 + 50(V59)^*$	7.00*	.500	530.0
(2) $Y = -159 + 58(V59)^* + 375(V25)$	10.24*	.773	385.3

* significant at p=.05

APPENDIX D17 - SPSS produced regressions; barley cases excluding rainfall, soil water, and soil temperature variables (n=39).

Regression step	F	R ²	SE
(1) $Y = 2364 + 291(V18)^*$	6.75*	.155	1021.3
(2) $Y = 29950 + 379(V18)^* - 199(V22)^*$	6.75*	.273	960.3
(3) $Y = -4537 + 357(V18)^* - 184(V22)^* + 102(V04)$	6.20*	.347	922.9
(4) $Y = -6373 + 302(V18)^* - 230(V22)^* + 123(V04)^* + 1113(V16)$	5.05*	.373	917.8
(5) $Y = -7575 + 319(V18)^* - 227(V22)^* + 139(V04)^* + 279(V16)^* - 462(V14)$	4.97*	.429	888.5

EXTRA RUN			
(6) $Y = -5949 + 273(V18)^* + 113(V04)^*$	5.91*	.247	977.1

* significant at p=.05

APPENDIX D18 - SPSS produced regressions; barley cases including rainfall variables and excluding soil water and temperature variables (n=23).

Regression step	F	R ²	SE
(1) $Y = 1555 + 95(V38)^*$	13.43*	.390	909.6
(2) $Y = -111 + 93(V38)^* + 13(V56)^*$	18.04*	.643	712.7
(3) $Y = -441 + 58(V38)^* + 16(V56)^* + 336(V18)^*$	22.67*	.781	572.2
(4) $Y = -5690 + 49(V38)^* + 17(V56)^* + 361(V18)^* + 3217(V11)^*$	26.50*	.855	479.4
(5) $Y = -6986 + 53(V38)^* + 19(V56)^* + 390(V18)^* + 4052(V11)^* - 24(V26)^*$	29.28*	.896	417.6

* significant at p=.05

APPENDIX D19 - SPSS produced regressions; barley cases including soil water and excluding rainfall, soil temperature variables (n=19).

Regression step	F	R ²	SE
(1) $Y = 4351 - 476(V22)^*$	14.21*	.455	880.9
(2) $Y = 4055 - 515(V22)^* + 354(V18)^*$	15.19*	.650	722.5
(3) $Y = 4674 - 475(V22)^* + 441(V18)^*$ - 372(V21)*	14.35*	.742	645.8
(4) $Y = 4306 - 511(V22)^* + 389(V18)^*$ - 549(V21)* + 191(V16)	13.76*	.797	592.2
(5) $Y = 4148 - 470(V22)^* + 427(V18)^*$ - 474(V21) + 271(V16)* - 383(V20)	13.10*	.834	555.3
* significant at p=.05			

APPENDIX D20 - SPSS produced regressions; barley cases including rainfall and soil water variables (without V57 to V59) and excluding soil temperature (n=12).

Regression step	F	R ²	SE
(1) $Y = 4119 - 455(V22)^*$	8.76*	.467	933.7
(2) $Y = 2952 - 403(V22)^* + 104(V38)^*$	12.64*	.730	690.6
(3) $Y = 30639 - 413(V22)^* + 129(V38)^*$ - 383(V04)*	28.80*	.915	416.25
* significant at p=.05			

APPENDIX D21 - SPSS produced regressions; barley cases including rainfall, soil water variables (with V57 to V59) and excluding soil temperature variables (n=12).

Regression step	F	R ²	SE
(1) Y = 4119 - 455(V22)*	8.76*	.467	933.7
(2) Y = 4030 - 533(V22)* + 388(V18)*	9.65*	.682	760.0
(3) Y = 5248 - 553(V22)* + 353(V18)* - 304(V23)*	14.12*	.840	569.9
(4) Y = 6520 - 432(V22)* + 474(V18)* - 299(V23)* - 29(V55)	17.96*	.910	455.4
(5) Y = 7860 - 516(V22)* + 547(V18)* - 287(V23) - 31(V55) - 279(V41)	44.92*	.974	266.3

EXTRA RUN			
(6) Y = 2552 - 438(V22)* + 310(V18) + 63(V59)	9.28*	.777	675.5

* significant at p=.05

APPENDIX D22 - SPSS produced regressions; Location 1 cases excluding rainfall, soil water and temperature variables (n=76).

Regression step	F	R ²	SE
(1) Y = 2173 + 270(V17)*	15.07*	.169	889.7
(2) Y = -5574 + 252(V17)* + 104(V04)*	11.89*	.246	853.5
(3) Y = -6410 + 302(V17)* + 107(V04)* + 264(V08)*	10.03*	.294	831.1
(4) Y = -7532 + 531(V17)* + 123(V04)* + 261(V08)* - 206(V19)	8.48*	.324	819.6
(5) Y = -7861 + 526(V08)* + 132(V04)* + 225(V08) - 195(V19) - 58(V22)	6.99*	.333	819.6

EXTRA RUN			
(6) Y = -5962 + 232(V17)* + 100(V04)* + 1(V28)	8.68	.266	848.1

* significant at p=.05

APPENDIX D23 - SPSS produced regressions; Location 1 cases including rainfall variables and excluding soil water, temperature variables (n=39).

Regression step	F	R ²	SE
(1) $Y = 1473 + 70(V38)^*$	22.08*	.373	725.9
(2) $Y = -2059 + 103(V38)^* + 51(V55)^*$	23.19*	.563	614.7
(3) $Y = -4904 + 103(V38)^* + 43(V55)^* + 2173(V13)^*$	20.58*	.638	567.2
(4) $Y = -5202 + 99(V38)^* + 37(V55)^* + 2542(V13)^* + 99(V29)$	17.37*	.671	548.5
(5) $Y = -5382 + 104(V38)^* + 39(V55)^* + 2598(V13)^* + 124(V29)^* - 47(V30)$	15.16*	.697	534.8

EXTRA RUN			
(6) $Y = -2925 + 78(V38)^* + 2832(V13)^*$	18.65*	.509	651.7

* significant at p=.05

APPENDIX D24 - SPSS produced regressions; Location 1 cases including soil water variables and excluding rainfall, soil temperature variables (n=38).

Regression step	F	R ²	SE
(1) $Y = 1190 + 301(V42)^*$	10.91*	.233	777.3
(2) $Y = 1184 + 244(V42)^* + 185(V17)^*$	8.77*	.334	734.4
(3) $Y = 1842 + 243(V42)^* + 238(V17)^* - 172(V22)^*$	9.02*	.443	681.3
(4) $Y = 1909 + 244(V42)^* + 557(V17)^* - 156(V22)^* - 277(V19)^*$	9.31*	.530	635.0
(5) $Y = 1888 + 528(V42)^* + 577(V17)^* - 160(V22)^* - 277(V19)^* - 318(V43)^*$	9.23*	.591	602.1

* significant at p=.05

APPENDIX D25 - SPSS produced regressions; Location 1 cases including rainfall, soil water variables (without V57 to V59) and excluding soil temperature variables (n=27).

Regression step	F	R ²	SE
(1) $Y = 1078 + 288(V42)^*$	9.57*	.277	747.9
(2) $Y = 824 + 225(V42)^* + 46(V38)^*$	8.07*	.402	693.9
(3) $Y = -372 + 188(V42)^* + 52(V38)^* + 424(V10)^*$	9.20*	.545	618.1
(4) $Y = -728 + 102(V42) + 66(V38)^* + 525(V10)^* + 188(V53)^*$	13.71*	.714	501.6
(5) $Y = -33 + 66(V42) + 62(V38)^* + 546(V10)^* + 158(V53)^* - 346(V03)^*$	15.86*	.790	439.0

* significant at p=.05

APPENDIX D26 - SPSS produced regressions; Location 1 cases including rainfall, soil water variables (with V57 to V59) and excluding soil temperature (n=27).

Regression step	F	R ²	SE
(1) $Y = 1002 + 50(V58)^*$	13.12*	.344	712.1
(2) $Y = 1832 + 43(V58)^* - 432(V03)^*$	11.07*	.480	647.3
(3) $Y = 798 + 37(V58)^* - 479(V03)^* + 410(V10)^*$	12.15*	.613	570.3
(4) $Y = 389 + 38(V58)^* - 376(V03)^* + 471(V10)^* + 274(V54)^*$	13.15*	.705	509.0
(5) $Y = 233 + 56(V58)^* - 397(V03)^* + 548(V10)^* + 286(V54)^* - 150(V44)^*$	14.50*	.775	454.6

* significant at p=.05

APPENDIX D26 - SPSS produced regressions; Location 2 cases excluding rainfall, soil water and soil temperature variables (n=13).

Regression step	F	R ²	SE
(1) $Y = 1404 + 789(V09)^*$	25.34*	.697	600.3
(2) $Y = 913 + 700(V09)^* + 23(V27)^*$	27.42*	.846	449.4
(3) $Y = 3004 + 619(V09)^* + 19(V27)^* - 29(V55)$	23.77*	.888	403.8
(4) $Y = -3523 + 482(V09)^* + 21(V27)^* - 26(V55) + 91(V04)$	19.39*	.906	391.2
(5) $Y = -1275 + 571(V09)^* + 18(V27)^* - 32(V55) + 127(V04) - 3(V28)$	16.48*	.922	382.8
* significant at p=.05			

APPENDIX D27 - SPSS produced regressions; Location 2 cases including rainfall and excluding soil water, temperature variables (n=10).

Regression step	F	R ²	SE
(1) $Y = 1409 + 860(V09)^*$	47.30*	.855	425.1
(2) $Y = 695 + 769(V09)^* + 41(V26)^*$	40.01*	.920	338.8
(3) $Y = -16264 + 886(V09)^* + 46(V26)^* + 3607(V31)$	33.20*	.943	307.6
(4) $Y = -175262 + 1038(V09)^* + 55.3(V26)^* + 3856(V31) - 192(V10)$	28.69*	.958	288.8
* significant at p=.05			

APPENDIX D28 - SPSS produced regressions; Location 2 cases including soil water and excluding rainfall, soil temperature variables (n=8).

Regression step	F	R ²	SE
(1) Y = 15109 - 7587(V11)*	49.85*	.893	376.4
(2) Y = 14213 - 7401(V11)* + 554(V03)	31.27*	.926	342.3
(3) Y = 14278 - 8408(V11)* + 656(V03) + 23(V55)	23.46*	.946	326.2
(4) Y = 11155 - 7097(V11)* + 567(V03) + 23(V55) + 400(V13)	25.80*	.972	272.9

EXTRA RUN

(5) Y = 12758 - 6244(V11)* + 9(V27)	31.20*	.926	342.7
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* significant at p=.05

APPENDIX D29 - SPSS produced regressions; Location 2 cases including rainfall, soil water variables (with and without V57 to V59) and excluding soil temperature (n=6).

Regression step	F	R ²	SE
(1) Y = 1820 + 53(V27)*	141.90*	.973	218.0

* significant at p=.05

APPENDIX D30 - SPSS produced regressions; Location 3 cases excluding rainfall, soil water and soil temperature variables (n=14).

Regression step	F	R ²	SE
(1) $Y = -3976 + 63(V56)^*$	9.50*	.442	529.1
(2) $Y = 2096 + 40(V56) - 54(V55)$	6.21*	.530	506.9
(3) $Y = 9867 + 9(V56) - 110(V55) - 303(V19)$	5.09*	.605	487.8
(4) $Y = 10059 + 16(V56) - 119(V55) - 327(V19) - 187(V03)$	4.38*	.656	479.8
(5) $Y = 9998 + 14(V56) - 118(V55) - 394(V19) - 261(V03) + 100(V30)$	4.04*	.717	461.8

* significant at p=.05

APPENDIX D31 - SPSS produced regressions; Location 3 cases including rainfall and excluding soil water, temperature (n=7)

Regression step	F	R ²	SE
(1) $Y = 5483 - 501(V22)^*$	13.01*	.722	497.8
(2) $Y = 6824 - 511(V22)^* - 475(V53)$	17.15*	.896	341.4
(3) $Y = 6222 - 452(V22)^* - 589(V53)^* + 278(V08)$	19.33*	.951	270.5

* significant at p=.05

APPENDIX D32 - SPSS produced regressions; Location 3 cases including soil water variables and excluding rainfall, soil temperature variables (n=12).

Regression step	F	R ²	SE
(1) Y = 5968 - 2467(V13)*	8.23*	.452	356.7
(2) Y = 6352 - 2977(V13)* + 234(V03)	5.50*	.550	340.4
(3) Y = 7360 - 3095(V13)* + 287(V03) - 441(V14)	4.39*	.622	331.0
(4) Y = 6945 - 3004(V13)* + 334(V03) - 456(V14) + 14(V51)	3.73	.680	325.0
(5) Y = 6916 - 2689(V13)* + 215(V03) - 339(V14) + 29(V51) - 155(V42)	4.04	.771	297.6

* significant at p=.05

APPENDIX D33 - SPSS produced regressions; Location 3 cases including soil water, rainfall variables (with and without V57 to V59) and excluding soil temperature variables (n=4).**

Regression step	F	R ²	SE
(1) Y = 1558 + 273(V29)*		.994	

* significant at p=.05

** since n=4, R² value (and regression) is essentially meaningless.

APPENDIX D34 - SPSS produced regressions; Location 4 cases excluding rainfall, soil water, and soil temperature variables (n=73).

Regression step	F	R ²	SE
(1) $Y = 1082 + 16(V56)^*$	5.14*	.067	778.8
(2) $Y = 1651 + 14(V56) - 119(V19)$	4.53*	.115	764.3
(3) $Y = 2264 + 11(V56) - 131(V19)^*$ - 113(V29)	3.94*	.148	775.1
(4) $Y = 2373 + 11(V56) - 100(V19)$ - 112(V29) - 53(V22)	3.30*	.163	754.1
(5) $Y = 2625 + 12(V56) - 102(V19)$ - 127(V29) - 74(V22) - 169(V03)	2.98*	.182	750.9

* significant at p=.05

APPENDIX D35 - SPSS produced regressions; Location 4 cases including rainfall and excluding soil water, temperature variables (n=61).

Regression step	F	R ²	SE
(1) $Y = 2471 + 44(V38)^*$	9.75*	.141	773.3
(2) $Y = 1148 + 41(V38)^* + 11(V56)^*$	9.42*	.262	723.3
(3) $Y = -938 + 35(V38)^* + 11(V56)^*$ + 1409(V11)	7.83*	.292	714.7
(4) $Y = -378 + 36(V38)^* + 9(V56)^*$ + 1336(V11) - 69(V22)	6.50*	.317	708.0
(5) $Y = -1335 + 32(V38)^* + 11(V56)^*$ + 1728(V11) - 113(V22)* + 261(V14)*	6.34*	.366	788.6

* significant at p=.05

APPENDIX D36 - SPSS produced regressions; Location 4 cases including soil water variables and excluding rainfall, soil temperature variables (n=56).

Regression step	F	R ₂	SE
(1) $Y = 3544 - 236(V29)^*$	5.71*	.096	835.0
(2) $Y = 3385 - 220(V29)^* + 45(V44)^*$	5.52*	.173	806.2
(3) $Y = 3734 - 219(V29)^* + 46(V44)^* - 159(V19)^*$	5.82*	.251	774.1
(4) $Y = 3662 - 246(V29)^* + 54(V44)^* - 275(V19)^* + 250(V18)$	5.27*	.293	759.9
(5) $Y = 3931 - 250(V29)^* + 51(V44)^* - 317(V19)^* + 323(V18)^* - 64(V16)$	4.72*	.321	752.1

* significant at p=.05

APPENDIX D37 - SPSS produced regressions; Location 4 cases including rainfall, soil water variables (without V57 to V59) and excluding soil temperature variables (n=46).

Regression step	F	R ₂	SE
(1) $Y = 2401 + 49(V38)^*$	9.15*	.172	834.0
(2) $Y = 1100 + 46(V38)^* + 10(V56)^*$	8.92*	.293	779.5
(3) $Y = 1046 + 46(V38)^* + 8(V56)^* + 28(V50)$	7.23*	.340	761.8
(4) $Y = 1748 + 43(V38)^* + 6(V56) + 34(V50)^* - 204(V29)$	6.58*	.391	741.0
(5) $Y = 2378 + 44(V38)^* + 4(V56) + 35(V50)^* - 223(V29)^* - 92(V22)$	6.11*	.433	723.9

EXTRA RUN

(6) $Y = 2515 + 44(V38)^* + 42(V50)^* - 258(V29)^*$	7.86*	.360	750.8
---	-------	------	-------

* significant at p=.05

APPENDIX D38 - SPSS produced regressions; Location 4 cases including rainfall, soil water variables (with V57. to V59) and excluding soil temperature (n=46).

Regression step		F	R ₂	SE
(1)	Y = 1944 + 45(V58)*	16.03*	.267	784.7
(2)	Y = 2484 + 44(V58)* - 257(V29)*	12.01*	.358	742.6
(3)	Y = 2902 + 44(V58)* - 259(V29)* 03* .267 784.7			
(2)	Y = 2484 + 44(V58)* - 257(V29)*	12.01*	.358	742.6
(3)	Y = 2902 + 44(V58)* - 259(V29)* - 105(V22)*	10.11*	.419	714.9
(4)	Y = 3550 + 42(V58)* - 266(V29)* - 126(V22)* - 136(V23)	8.57*	.455	700.8
(5)	Y = 4674 + 42(V58)* - 318(V29)* - 113(V22)* - 167(V23) - 13(V55)	7.38*	.480	693.3

* significant at p=.05

APPENDIX E
"BEST" REGRESSIONS FOR ALL DATA FILES BY
RESTRICTIVE CATEGORY

APPENDIX E1 - "Best" regressions for statewide cases for each restriction category.

- (1) for cases excluding rainfall, soil temperature and soil water (n=184).

$$Y = -1649 + 213(V53)^* + 182(V10)^* + 50(V10)^* - 127(V03)$$

$$R^2 = .222$$

$$\text{Adjusted } R^2 = .200$$

- (2) for cases including rainfall and excluding soil temperature and soil water (n=123).

$$Y = 225 + 53(V38)^* + 211(V53)^* + 205(V10)^* + 9(V56)^* - 184(V03)$$

$$R^2 = .450$$

$$\text{Adjusted } R^2 = .422$$

- (3) for cases including soil water and excluding soil temperature and rainfall variables (n=114).

$$Y = 1246 + 247(V53)^* + 276(V10)^* + 56(V44)^*$$

$$R^2 = .297$$

$$\text{Adjusted } R^2 = .271$$

- (4) for cases including soil water and rainfall variables (without V57 to V59) excluding soil temperature variables (n=83).

$$Y = 186 + 55(V38)^* + 236(V53)^* + 303(V10)^* + 37(V50)^*$$

$$R^2 = .471$$

$$\text{Adjusted } R^2 = .437$$

- (5) for cases including soil water and rainfall variables (with V57 to V59) excluding soil temperature variables (n=83).

$$Y = 331 + 48(V58)^* + 233(V25)^* + 194(V08)^*$$

$$R^2 = .401$$

$$\text{Adjusted } R^2 = .371$$

- (6) for cases including rainfall, soil water, and soil temperature variables (n=42).

$$Y = 1454 + 37(V59)^* - 34(V51)^* + 203(V08)$$

$$R^2 = .400$$

$$\text{Adjusted } R^2 = .337$$

* significant at p=.05

APPENDIX E2 - "Best" regressions for winter wheat cases for each restriction category.

-
- (1) for cases excluding rainfall, soil water, soil temperature (n=121).

$$Y = -1563 + 164(V53)^* + 200(V08)^* + 231(V12)^* + 44(V04)^*$$

$$R^2 = .209$$

$$\text{Adjusted } R^2 = .175$$

- (2) for cases including rainfall and excluding soil water, soil temperature (n=86).

$$Y = -1465 + 40(V38)^* + 20(V27)^* + 239(V08)^* + 142(V53)^* + 30(V04)$$

$$R^2 = .355$$

$$\text{Adjusted } R^2 = .307$$

- (3) for cases including soil water and excluding rainfall, soil temperature variables (n=82).

$$Y = 599 + 104(V43)^* + 263(V10)^* + 165(V53)^* + 112(V08) + 1(V28)$$

$$R^2 = .303$$

$$\text{Adjusted } R^2 = .248$$

- (4) for cases including rainfall and soil water (without V57 to V59) and excluding soil temperature (n=62).

$$Y = 1019 + 46(V50)^* + 50(V38)^* + 24(V27)^*$$

$$R^2 = .375$$

$$\text{Adjusted } R^2 = .332$$

- (5) for cases including rainfall and soil water variables (with V57 to V59) and excluding soil temperature (n=62).

$$Y = 610 + 45(V58)^* + 20(V27)^* + 218(V15)^* + 126(V53)$$

$$R^2 = .450$$

$$\text{Adjusted } R^2 = .402$$

* significant at p=.05

APPENDIX E3 - "Best" regressions for spring wheat cases for each restrictive category.

- (1) for cases excluding rainfall, soil water and soil temperature variables (n=23).

$$Y = 856 + 463(V21)^* + 130(V32)^*$$

$$R^2 = .423 \quad \text{Adjusted } R^2 = .336$$

- (2) for cases including rainfall and excluding soil water, soil temperature variables (n=14).

$$Y = 892 + 86(V38)^*$$

$$R^2 = .773 \quad \text{Adjusted } R^2 = .689$$

- (3) for cases including soil water and excluding rainfall and soil temperature variables (n=13).

$$Y = -1649 + 480(V48)^*$$

$$R^2 = .660 \quad \text{Adjusted } R^2 = .558$$

- (4) for cases including rainfall, soil water variables (without V57 to V59) and excluding soil temperature variables (n=9).

$$Y = 1151 + 52(V38)^*$$

$$R^2 = .471 \quad \text{Adjusted } R^2 = .320$$

- (5) for cases including rainfall, soil water variables (with V57 to V59) and excluding soil temperature variables (n=9).

$$Y = 631 + 50(V59)^*$$

$$R^2 = .500 \quad \text{Adjusted } R^2 = .357$$

* significant at p=.05

APPENDIX E4 - "Best" regressions for barley cases for each restrictive category.

(1) for cases excluding rainfall, soil water, and soil temperature variables (n=39).

$$Y = -5949 + 273(V18)^* + 113(V04)^*$$

$$R^2 = .247$$

$$\text{Adjusted } R^2 = .184$$

(2) for cases including rainfall variables and excluding soil water and temperature variables (n=23).

$$Y = -111 + 93(V38)^* + 13(V56)^*$$

$$R^2 = .643$$

$$\text{Adjusted } R^2 = .589$$

(3) for cases including soil water variables and excluding rainfall, soil temperature variables (n=19).

$$Y = 4674 - 475(V22)^* + 441(V18)^* - 372(V21)^*$$

$$R^2 = .742$$

$$\text{Adjusted } R^2 = .673$$

(4) for cases including rainfall and soil water variables (without V57 to V59) and excluding soil temperature variables (n=12).

$$Y = 2952 - 403(V22)^* + 104(V38)^*$$

$$R^2 = .730$$

$$\text{Adjusted } R^2 = .640$$

(5) for cases including rainfall, soil water variables (with V57 to V59) and excluding soil temperature variables (n=12).

$$Y = 2552 - 438(V22)^* + 310(V18) + 63(V59)$$

$$R^2 = .777$$

$$\text{Adjusted } R^2 = .666$$

* significant at p=.05

APPENDIX E5 - "Best" regressions for location 1 cases for each restrictive category.

(1) for cases excluding rainfall, soil water and temperature variables (n=76).

$$Y = -5962 + 232(V17)^* + 100(V04)^* + 1(V28)$$

$$R^2 = .266$$

$$\text{Adjusted } R^2 = .225$$

(2) for cases including rainfall variables and excluding soil water, temperature variables (n=39).

$$Y = -2925 + 78(V38)^* + 2832(V13)^*$$

$$R^2 = .509$$

$$\text{Adjusted } R^2 = .469$$

(3) for cases including soil water variables and excluding rainfall, soil temperature (n=38).

$$Y = 1842 + 243(V42)^* + 238(V17)^* - 277(V19)^*$$

$$R^2 = .443$$

$$\text{Adjusted } R^2 = .377$$

(4) for cases including rainfall, soil water variables (without V57 to V59) and excluding soil temperature variables (n=27).

$$Y = -372 + 188(V42)^* + 52(V38)^* + 424(V10)^*$$

$$R^2 = .545$$

$$\text{Adjusted } R^2 = .466$$

(5) for cases including rainfall, soil water variables (with V57 to V59) and excluding soil temperature (n=27).

$$Y = 389 + 38(V58)^* - 376(V03)^* + 471(V10)^* + 274(V54)^*$$

$$R^2 = .705$$

$$\text{Adjusted } R^2 = .651$$

* significant at p=.05

APPENDIX E6 - "Best" regressions for location 2 cases for each restrictive category.

(1) for cases excluding rainfall, soil water and soil temperature variables (n=13).

$$Y = 3004 + 619(V09)^* + 19(V27)^* - 29(V55)$$

$$R^2 = .888$$

$$\text{Adjusted } R^2 = .854$$

(2) for cases including rainfall and excluding soil water, temperature variables (n=10).

$$Y = 1409 + 860(V09)^*$$

$$R^2 = .855$$

$$\text{Adjusted } R^2 = .819$$

(3) for cases including soil water and excluding rainfall, soil temperature variables (n=8).

$$Y = 15109 - 7587(V11)^*$$

$$R^2 = .892$$

$$\text{Adjusted } R^2 = .856$$

(4) for cases including rainfall, soil water variables (with and without V57 to V59) and excluding soil temperature (n=6).**

$$Y = 1820 + 53(V27)^*$$

$$R^2 = .973$$

$$\text{Adjusted } R^2 = .960$$

* significant at p=.05

** cases may be too few for adequate representation for regression.

APPENDIX E7 - "Best" regressions for location 3 cases for each restrictive category.

 (1) for cases excluding rainfall, soil water and soil temperature variables (n=14).

$$Y = -3976 + 63(V56)^*$$

$$R^2 = .442$$

$$\text{Adjusted } R^2 = .350$$

(2) for cases including rainfall variables and excluding soil water, temperature variables (n=7).

$$Y = 5483 - 501(V22)^*$$

$$R^2 = .772$$

$$\text{Adjusted } R^2 = .611$$

(3) for cases including soil water variables and excluding rainfall, soil temperature variables (n=12).

$$Y = 5968 - 2467(V13)^*$$

$$R^2 = .452$$

$$\text{Adjusted } R^2 = .340$$

(4) for cases including soil water and rainfall variables (with and without V57 to V59) and excluding soil temperature variables (n=4).**

$$Y = 1558 + 273(V29)^*$$

$$R^2 = .994$$

$$\text{Adjusted } R^2 = .988$$

 * significant at $p=.05$

** since $n=4$, R^2 values (and regression) are essentially meaningless.

APPENDIX E8 - "Best" regressions for location 4 cases for each restrictive category.

 (1) for cases excluding rainfall, soil water, soil temperature variables (n=73).

$$Y = 2264 + 11(V56) - 14(V19)^* - 113(V29)^*$$

$$R^2 = .148$$

$$\text{Adjusted } R^2 = .099$$

(2) for cases including rainfall and excluding soil water, temperature variables (n=61).

$$Y = 1148 + 41(V38)^* = 11(V56)^*$$

$$R^2 = .262$$

$$\text{Adjusted } R^2 = .220$$

(3) for cases including soil water variables and excluding rainfall, soil temperature variables (n=56).

$$Y = 3734 - 219(V29)^* + 46(V44)^* - 159(V19)^*$$

$$R^2 = .251$$

$$\text{Adjusted } R^2 = .193$$

(4) for cases including rainfall and soil water variables (without V57 to V59) and excluding soil temperature variables (n=46).

$$Y = 2515 + 44(V38)^* + 42(V50)^* - 258(V29)^*$$

$$R^2 = .360$$

$$\text{Adjusted } R^2 = .299$$

(5) for cases including rainfall and soil water variables (with V57 to V59) and excluding soil temperature variables (n=46).

$$Y = 2482 + 44(V58)^* - 257(V29)^*$$

$$R^2 = .358$$

$$\text{Adjusted } R^2 = .313$$

 * significant at p=.05

APPENDIX F
CORRELATION MATRICES FOR "BEST"
VARIABLES FOR ALL DATA FILES

Appendix F1. Correlation matrix for "best" variables for statewide cases.

	V06	V38	V53	V10	V50
V04	.26	.33			.24
V08	.29			.35	
V09				.33	
V10	.25			1.00	
V11		.28			
V13				.59	-.29
V14			.37		
V16			.32	-.28	
V17			.44		
V18			.48	-.27	
V20			-.26	.32	
V21				.27	
V22			.27	-.39	
V23				.32	
V24			.23	.36	
V25	.27		.31	.23	
V26			.25		
V27				.24	
V28					.22
V30					-.35
V31	-.23				-.21
V32			.32		-.22
V34	.31 [1]		.40 [1]		
V33				.29	
V38	.40	1.00			
V39	.25		.68		
V40				-.25	.80
V41					.63
V42					.61
V43					.74
V44		.35			.50
V45					.54
V46					.40
V50					1.00
V51					.53
V52			-.22		.40
V53	.38		1.00		
V54	.31		.92		
V55			.34		
V56	.30			.24	
V57	.43 [2]	.60 [2]			.62 [2]
V58	.50 [2]	.68 [2]			.71 [2]
V59	.28 [2]	.59 [2]			

* Significant at $p=.05$ ($r > .209$)[1] Significant at $p=.05$ ($r > .303$)[2] Significant at $p=.05$ ($r > .210$)

Appendix F2. Correlation matrix for "best" variables for winter wheat cases.

	V06	V58	V27	V15	V53
V04	.27	.34			
V08	.32	.28			
V09			.53		
V10	.29		.35		
V11			-.28		
V12			.47		
V13			.31		
V14				.35	.47
V15	.28			1.00	
V16					.39
V17				.46	.35
V18				.45	.42
V19				.52	
V20				.34	
V21				.43	
V22				.42	.33
V23				.34	
V24				.28	.33
V26			.82		
V29			-.25		
V38	.31	.63			
V39					.54
V40	.26	.58			
V41	.41	.87			
V42	.30	.46			
V43	.33	.59			
V44	.30	.66			
V45		.30			
V46		.34			
V50	.39	.75			.28
V51		.30			
V52		.33			
V53	.30				1.00
V54	.26				.90
V55			.23		
V57	.41	.87			
V58	.51	1.00			
V59		.40			

Appendix F3. Correlation matrix for "best" variables for spring wheat cases.

	V06	V38
V11		.61
V38	.86	1.00
V40		.68 [2]
V58		.98 [2]
V59		.98 [2]

* significant at $p=.05$ ($r>.532$)

[2] significant at $p=.05$ ($r>.666$)

Appendix F4. Correlation matrix for "best" variables for barley cases. (significant at $p=.05$; $r>.456$)

	V06	V22	V18	V21	V59
V09		-.51			
V10		-.48			
V14			.49	.73	
V15	-.53	.61		.47	
V16				.60	
V17			.90		
V18			1.00		
V19			.89		
V20				.59	
V21				1.00	
V22	-.67	1.00			
V23					-.63 [2]
V31		.56			
V38	.61 [2]				.88 [2]
V39			.48		
V40		-.47			
V41		-.49			
V42		-.48			
V46			-.68	-.46	
V48		-.54			
V49		-.51			
V53	.47		.48		
V56	.68				
V57					.74 [2]
V58					.81 [2]
V59	.64 [2]				1.00 [2]

[2] significant at $p=.05$ ($r>.576$)

Appendix F5. Correlation matrix for "best" variables for location 1 cases.

	V06	V58	V03	V10	V54
V03	-.48		1.00		
V04		.49			
V09					.49
V10	.41			1.00	
V11		.43			
V12					.40
V14					.50
V15			.42		
V16					.51
V17			-.47		.63
V18			-.43		.59
V23					.52
V24					.42
V32					.47
V38	.50	.72			
V39					.97
V40		.67			
V41	.51	.58			
V42	.53	.74			
V43	.41	.68			
V44		.63			
V46		.71			
V50		.72			
V51		.39			
V52		.47			
V53					.99
V54					1.00
V55					.65
V57	.51	.91			
V58	.58	1.00			

significant at $p=.05$ ($r>.381$)

Appendix F6. Correlation matrix for "best" variables for location 2.

	V06	V09	V27	V55	V11 [2]
V04	.69	.73			
V08	.55	.84		-.65	
V09	.84	1.00			-.73
V10	.70	.58	.79		-.85
V11	-.94 [2]	-.73			1.00
V12			-.58		
V13	.82		.80		-.80
V14		.72			
V16		.58			
V17		.72			
V18		.58			
V20	.69	.58	.64		
V21	.69	.58	.64		
V27	.57		1.00		-.68
V28	.56	.74			
V31		-.61			
V39	-.80		-.70		.79
V53	.69 [2]				-.67
V55	-.63			-1.00	

significant at $p=.05$ ($r>.553$)

[2] significant at $p=.05$ ($r>.666$)

Appendix F7. Correlation matrices for "best" variables for location 3.

	V06	V22
V04	-.82 [2]	.80
V22	-.85 [2]	1.00
V27	.79 [2]	-.89

* significant at $p=.05$ ($r>.754$)

Appendix F8. Correlation matrix for "best" variables for location 4.

	V06	V58	V29
V04		.46	
V08	.30	.29	
V09			-.64
V12			-.67
V26			-.55
V27			-.53
V29	-.32		1.00
V30			-.53
V31		-.30	
V38	.41	.75	
V40		.43	
V41		.33	
V43		.46	
V44	.31	.66	
V47		.33	
V48		.34	
V49		.42	
V50	.32	.68	
V55			-.33
V56	.38		-.30
V57	.47	.88	
V58	.52	1.00	

significant at $p=.05$ ($r>.29$)

APPENDIX G
FREQUENCY OCCURENCE OF VARIABLES
DIRECTLY CORRELATED WITH YIELD FROM
ALL CORRELATION MATRICES

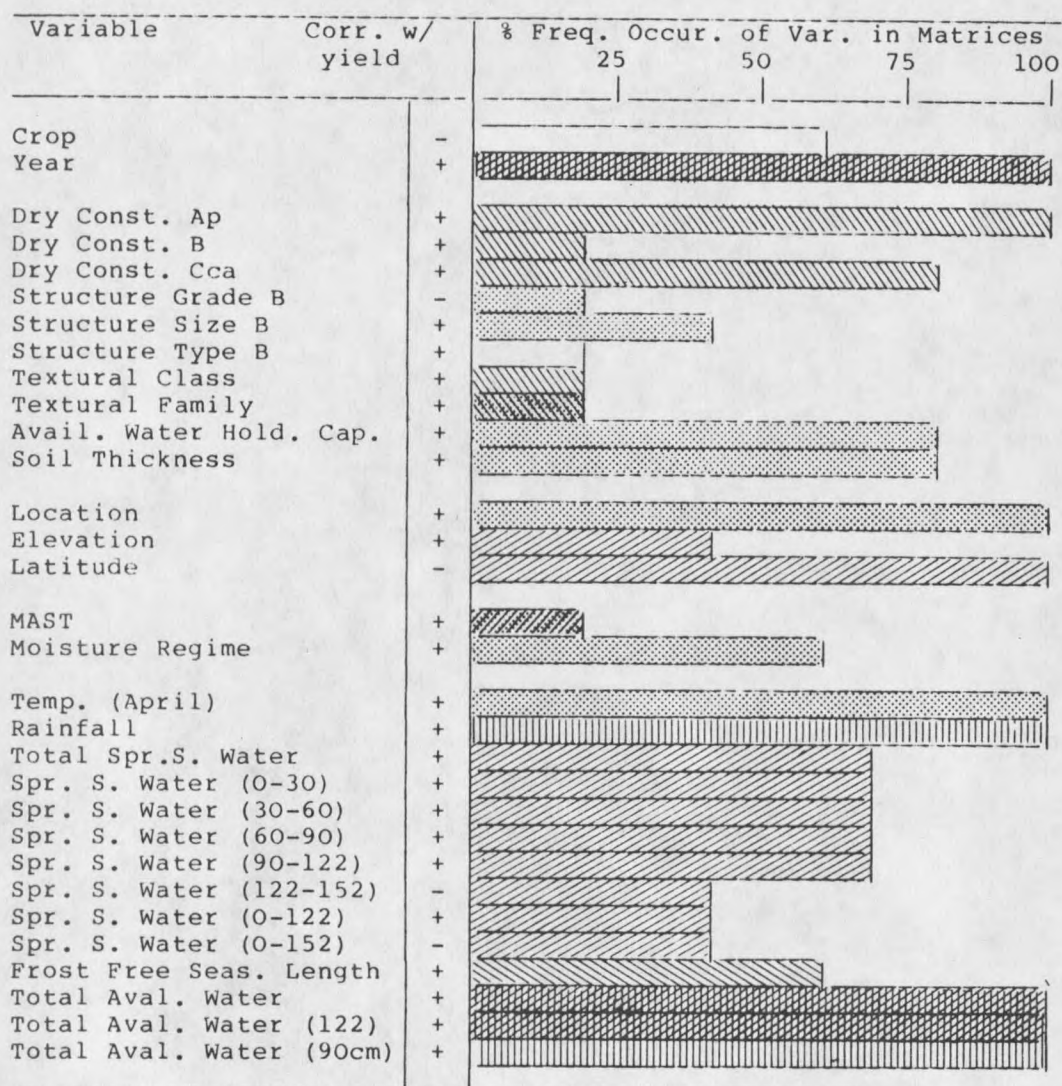
Appendix G1. Frequency (%) of Variables significantly directly correlated with yield ($p=.05$); all crops and locations.

▨ = Avail. Water Holding Cap. (V53) related

▤ = Rainfall (V38) related

▧ = Dry Consistence Cca (V10) related

▩ = Spring Soil Water to 122 cm (V50) related



Appendix G2. Frequency (%) of variables significantly directly correlated with yield ($p=.05$); winter wheat - all locations.

|||| = Total Avail. Water (to 122cm) related

|||| = Depth to Cca related

|||| = Structure Size Ap related

|||| = Avail. Water Holding Cap. related

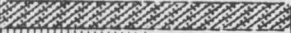
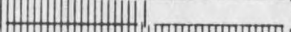
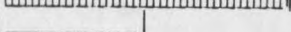
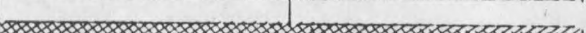
Variable	Corr. w/ yield	% Freq. Occur. of Var. in Matrices			
		25	50	75	100
Year	+				
Dry Const. Ap	+				
Dry Const. Cca	+				
Structure Size Ap	+				
Depth to Cca	+				
Avail. Water Hold. Cap.	+				
Soil thickness	+				
Elevation	+				
Rainfall	+				
Spr. S. Water Total	+				
Spr. S. Water (0-30)	+				
Spr. S. Water (30-60)	+				
Spr. S. Water (60-90)	+				
Spr. S. Water (90-122)	+				
Spr. S. Water (0-122)	+				
Total Aval. Water	+				
Total Aval. Water (122)	+				

Appendix G3. Frequency (%) of variables significantly directly correlated with yield ($p=.05$); spring wheat - location 1,3.

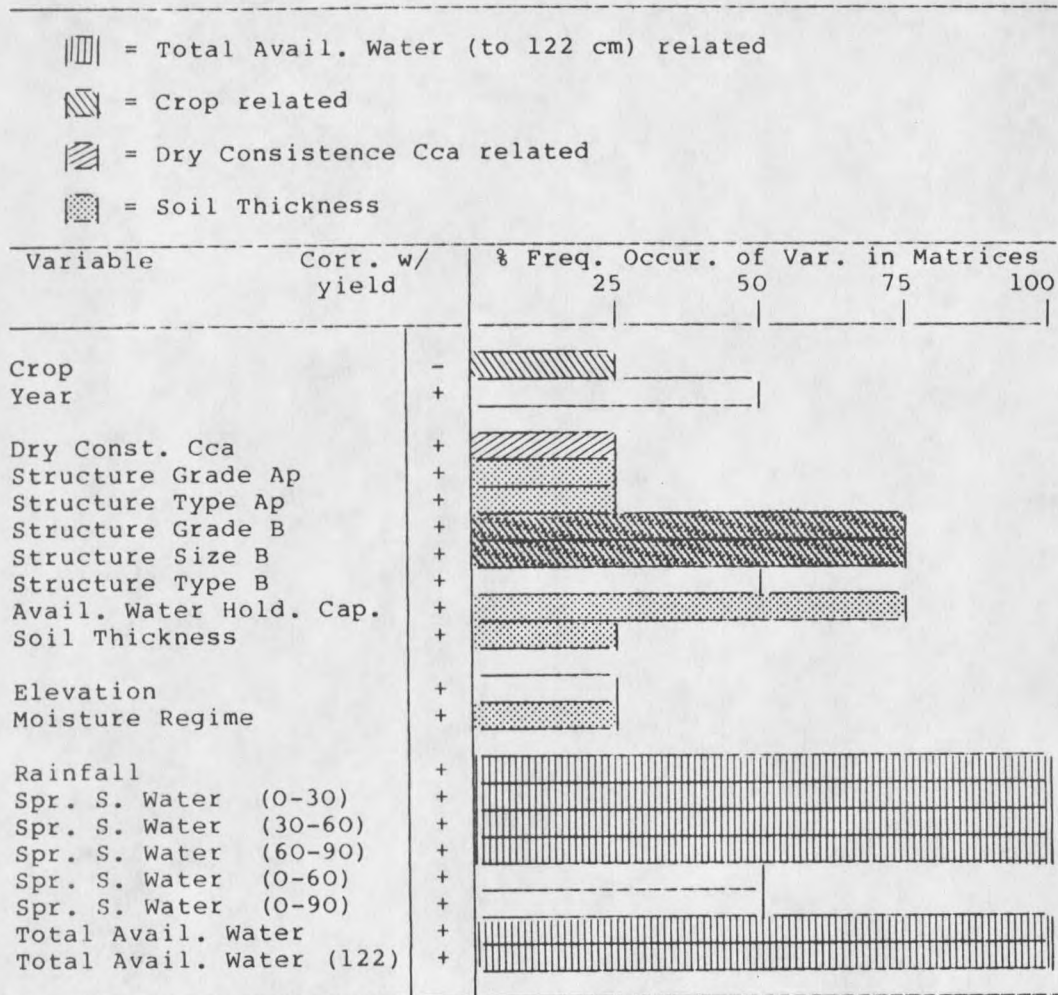
= Rainfall related					
Variable	Corr. w/ yield	% Freq. Occur. of Var. in Matrices			
		25	50	75	100
Dry Const. Cca	+	<			

Appendix G4. Frequency (%) of variables significantly directly correlated with yield ($p=.05$); barley - locations 1,3,4.

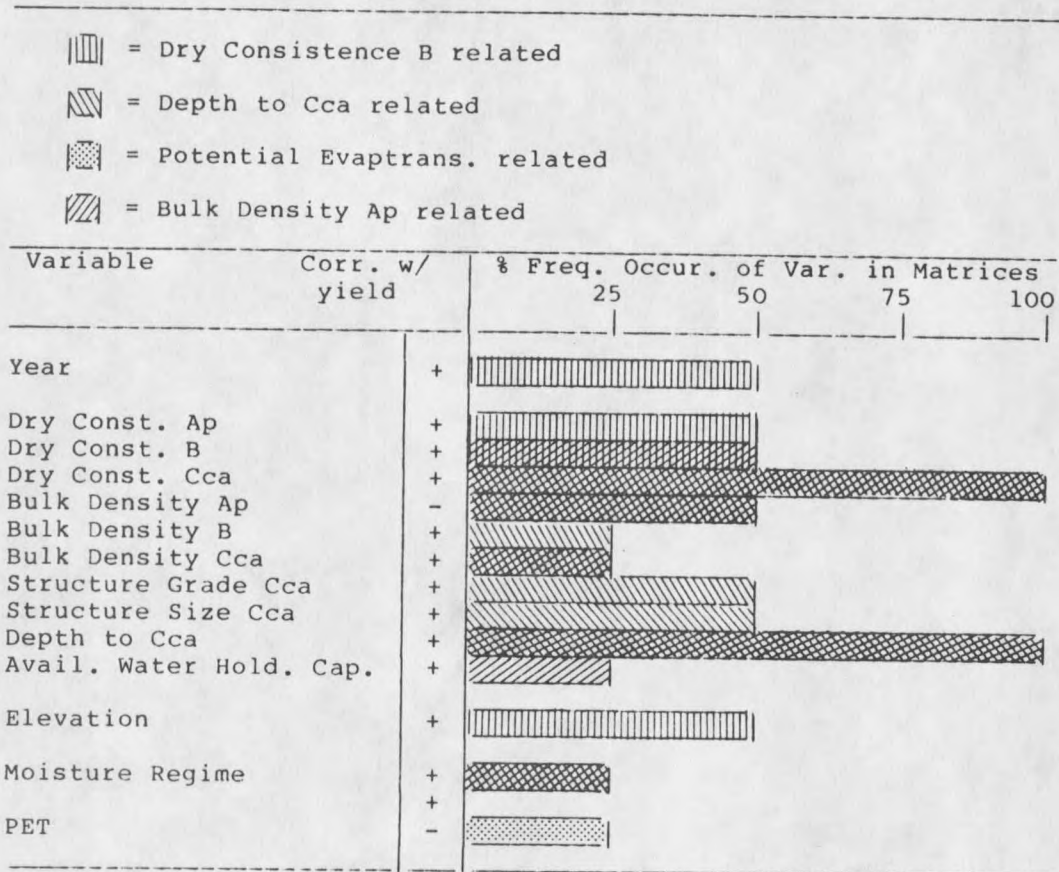
-  = Structure Type Cca related
 = Structure Size B related
 = Total Avail. Water (to 90 cm) related
 = Structure Size Cca related

Variable	Corr. w/ yield	% Freq. Occur. of Var. in Matrices			
		25	50	75	100
Year	+				
Structure Size Ap	-				
Structure Grade B	+				
Structure Size B	+				
Structure Type B	+				
Structure Type Cca	-				
Avail. Water Hold. Cap.	+				
Soil Thickness	+				
Rainfall	+				
Frost Free Seas. Length	+				
Total Aval. Water (90)	+				

Appendix G5. Frequency (%) of variables significantly directly correlated with yield ($p=.05$); north-central Montana.



Appendix G6. Frequency (%) of variables significantly directly correlated with yield ($p=.05$); Gallatin- Madison counties.



Appendix G7. Frequency (%) of variables significantly directly correlated with yield ($p=.05$); north-eastern Montana.

Variable	Corr. w/ yield	% Freq. Occur. of Var. in Matrices			
		25	50	75	100
Crop	+				
Year	-				
Bulk Density Ap	+				
Bulk Density B	-				
Bulk Density Cca	-				
Structure Size Ap	+				
Structure Type Ap	-				
Structure size B	+				
Structure type Cca	-				
Textural Class	+				
Textural Family	+				
Thickness of B	-				
Depth to Cca	+				
Avail. Water Hold. Cap.	+				
Slope	+				
Aspect	+				
Latitude	-				
PET	-				
Frost Free Seas. Length	+				

Appendix G8. Frequency (%) of variables significantly directly correlated with yield ($p=.05$); south-eastern Montana.

|||| = Total Avail. Water (to 122 cm) related

//// = Slope related

Variable	Corr. w/ yield	% Freq. Occur. of Var. in Matrices			
		25	50	75	100
Dry Const. Ap	+				
Bulk Density Ap	+				
Structure Grade B	-				
Structure Type B	-				
Structure Type Cca	+				
Slope	-	////			
Rainfall	+				
Spr. S. Water (60-90)	+				
Spr. S. Water (90-122)	+				
Spr. S. Water (0-122)	+				
Frost Free Seas. Length	+	////			
Total Avail. Water	+				
Total Avail. Water (122)	+				

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