The influence of selected soil physical properties, soil type and site characteristics, soil temperature, and soil moisture on the response of small grains to potassium on Montana soils

by Richard Harold Veeh

A thesis submitted in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE in Soils
Montana State University

Abstract:
Two hundred twenty-two small grain experiments established on 127 site locations throughout Montana were selected to study the influence of pertain soil physical properties, soil classification parameters, soil moisture and temperature, and site and soil profile characteristics on crop response to applied K fertilizer. From 2 to 5 rates of K, ranging from 0 to 134 kg K/ha, were applied in the experiments studied. Rates of N and P were held constant within an experiment but varied from one experiment to another. A total of 48 independent variables in various combinations were inserted into multiple linear stepwise regression programs. The dependent variables were average and maximum percent yield response (to added K) as well as actual crop yield. The variable relationships were analyzed over the whole data set as well as over part of the data file subdivided according to: 1) crop; 2) crop and geographic location; 3) crop, geographic location, and percent response class; and 4) K rate at which maximum percent response occurred. Over 60 regression analyses were performed. Fifty-one of the resultant regression equations produced significant R^2 values ranging from the .10 to .005 significance level. The variables entering the regression equations most often (and the number of times each appeared) were elevation (19), latitude (17), dry consistence of the B horizon (17), dry consistence of the Cca horizon (15), textural class (15), moisture regime (14), dry consistence of the Ap horizon (14), and aspect (14). The most consistently correlated (Simple R) variables to the dependent variables were the K-treatment (rate) variables, mean annual soil temperature, dry consistence of the B horizon, elevation, slope, and moisture regime. These latter variables were consistently positively correlated to percent crop response to applied' K. The results of this study indicate that crops grown on the soils associated with the warmer and drier site locations responded to a greater degree to applied K. However, low spring soil temperatures were also associated with greater crop response to added K. Increased crop response to applied K was also associated with the more fine textured soils. Rainfall, although not consistently correlated (Simple R) to crop response, had a marked influence on the effect of applied K.

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THE INFLUENCE OF SELECTED SOIL PHYSICAL PROPERTIES, SOIL TYPE AND SITE CHARACTERISTICS, SOIL TEMPERATURE, AND SOIL MOISTURE ON THE RESPONSE OF SMALL GRAINS TO POTASSIUM ON MONTANA SOILS

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

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ABSTRACT

Two hundred twenty-two small grain experiments established on 127 site locations throughout Montana were selected to study the influence of certain soil physical properties, soil classification parameters, soil moisture and temperature, and site and soil profile characteristics on crop response to applied K fertilizer. From 2 to 5 rates of K, ranging from 0 to 134 kg K/ha, were applied in the experiments studied. Rates of N and P were held constant within an experiment but varied from one experiment to another. A total of 48 independent variables in various combinations were inserted into multiple linear stepwise regression programs. The dependent variables were average and maximum percent yield response (to added K) as well as actual crop yield. The variable relationships were analyzed over the whole data set as well as over part of the data file subdivided according to: 1) crop; 2) crop and geographic location; 3) crop, geographic location, and percent response class; and 4) K rate at which maximum percent response occurred. Over 60 regression analyses were performed. Fifty-one of the resultant regression equations produced significant R^2 values ranging from the .10 to .005 significance level. The variables entering the regression equations most often (and the number of times each appeared) were elevation (19), latitude (17), dry consistence of the B horizon (17), dry consistence of the Cca horizon (15), textural class (15), moisture regime (14), dry consistence of the Ap horizon (14), and aspect (14). The most consistently correlated (Simple R) variables to the dependent variables were the K-treatment (rate) variables, mean annual soil temperature, dry consistence of the B horizon, elevation, slope, and moisture regime. These latter variables were consistently positively correlated to percent crop response to applied K. The results of this study indicate that crops grown on the soils associated with the warmer and drier site locations responded to a greater degree to applied K. However, low spring soil temperatures were also associated with greater crop response to added K. Increased crop response to applied K was also associated with the more fine textured soils. Rainfall, although not consistently correlated (Simple R) to crop response, had a marked influence on the effect of applied K.

Chapter 1

INTRODUCTION

Accurately predicting K-fertilizer recommendations for crops grown on Montana soils has been a recognized problem for several years. Research during the past decade has shown K-response by various crops to be unpredictable, and poorly related to soil test K ratings. Although a soil may test "high" in extractable K, a yield response to added K frequently occurs. Significant crop response also occurs regardless of yield level; this suggests that K may be yield-limiting independent of the status of other growing conditions (Skogley, 1976).

A coordinated statewide research effort was begun in 1971 to try to determine what factors were contributing to the variability in K-response. That K-fixation had long been associated with the presence of micaceous clays (particularly illite) led to a study in which clay type and amount of clay were related to crop response (Phillips, 1973). No significant relationships existed upon which a K-soil test could be based. Wang (1975) also studied K-fixation and release potential of selected soils incubated over various time periods. This research showed that after small additions of K, the level of extractable K could be greatly increased; this suggests that a type of K-release mechanism is operative in some soils.

Haby (1975) investigated the possibility of using a more reliable extraction procedure than the standard NH_4OAc extractable

K-soil test. Fifteen different extraction techniques were studied on a wide range of soil types. The results of this investigation showed that soil test values could at best only account for 40 percent of the variation in crop response. This strongly suggests the lack of a close functional relationship between extractable K (regardless of extraction procedure or method of expressing the results) and K availability to plants grown under the climatic and soils conditions of Montana. Some system which relates more closely to factors controlling K availability over time will need to be developed as a K soil test. Uptake of K by plant roots has been shown to be governed primarily by ion diffusion, accounting for a minimum of 80 percent of the K-supply. Mass flow and direct root contact can account for no more than 15-20 percent of the K supply (Barber, 1962; Beckett, 1964). Massee (1973) found a very good correlation between K-diffusion in a variety of soil types and crop response to added K under controlled conditions.

Developing a K soil test based on factors that influence K diffusion presents a complex problem. Not only is K diffusion related to numerous soil physical properties (e.g. texture and structure) but also to various climatic and weather-related factors such as moisture availability and temperature. These are extremely variable from year to year in Montana, as well as during any one growing season.

Shrader, et al (1957) hypothesized that soils should possess inherent characteristics which influence crop growth and are defined and/or expressed by the parameters used in soil classification. Schaff (1979) investigated this hypothesis on a number of soils which had been used during two years of soil fertility field research experiments with winter wheat. The soils were characterized as to their physical, chemical, and climatic properties and then correlated to winter wheat response to added K-fertilizer. Variables with the highest correlation (soil and site combined regression analysis) with percent yeild response were: 1) mean annual soil temperature at 50 cm.; 2) moist consistence of the Ap horizon; 3) moist consistence of the B horizon; 4) dry consistence of the B horizon; and 5) the clay content of the Ca horizon. These five variables produced an R^2 value of .88.

These results were very encouraging. To further investigate the hypothesis that genetic soil characteristics influence crop response to added K, the present study was conceived. The data base would be expanded to determine if significant correlations could be observed statewide, and for additional crops. Soils and sites were classified according to Soil Taxonomy (U.S.D.A., 1975) at selected locations at previous small grain soil fertility experiments (127 sites). The soil samples were analyzed by horizon (Ap, B, and Cca) to determine dry consistence and bulk density values; other selected soil and site properties which could be determined from the SCS soil series description for a particular site and for which a coding scheme could be devised were also included.

The objectives of this research project were to 1) determine if known or easily determined soil and site characteristics were significantly correlated to crop response to K fertilizer when a large number of sites from past experiments throughout the state was included, and 2) investigate the feasibility of developing a system for predicting future crop responses to K-fertilizer based on selected soil and site classification parameters.

Chapter 2

LITERATURE REVIEW

Crop responses to applied fertilizers and yield differences have been associated with soil type differences (Shrader et al., 1957; Olsen, 1977). Dass and Shankhayan (1979) reported that the dry matter production of wheat and response to added K differed significantly when the crop was grown on different soil types. Some of the soil and site properties which have been reported to be most important in this regard are discussed below.

Soil Texture and Clay Type

Liebhardt and Cotnoir (1979) studied 28 Delaware soil series ranging in texture from silt loam to loamy sand. Soils higher in sand content did not need as much K added to raise the soil test values as soils higher in silt and clay. Von Braunschweig (1980) found similar effects of clay content upon K-availability. On coarse textured soils with clay contents up to 12 percent, a K-saturation of the clay minerals from 1.7 to 2.5 mg. K/percent clay was necessary for adequate plant uptake of K. Soils with clay contents from 12 to 25 percent and greater than 25 percent required 1.2 - 1.7 mg K/percent clay and 1.1-1.4 mg K/percent clay, respectively, for adequate K uptake. Calculating these values in terms of mg K/100 g soil, it was apparent that the more clay the soil contained, the higher the exchangeable K content should be for adequate K nutrition.

The level of K available at the plant root is the critical factor governing plant K uptake. This involves a number of soil aspects. Potassium-fixing soils may show extreme variability in their K-supplying power. In one study it was observed that K-fixation values were relatively constant on the plots without or with low K-fertilization; after high K application, fixation values fluctuated much more (Burkart and Amberger, 1978). Also, the rise in the level of available K by fertilization was negatively correlated to soil clay content. In a similar study, the K concentration of a saturated paste extract was inversely related to soil clay content (Mengel and Aksoy, 1971). These experimental data support the concept that the K concentration of the soil solution influences the K-supply for plants and that the K concentration of the soil solution is influenced by the degree of K saturation of the clay minerals.

In a study of four Ohio soils with a wide range of K release capability, it was observed that the two soils highest in clay and total K content reacted in a significantly different manner to added K than did soils with less clay (Munn and McLean, 1975). Initial cropping decreased exchangeable K in all K-treated soils eliminating the effect of K treatments on exchangeable K. However, after initial cropping where no K was added, exchangeable K varied sixfold from the lowest (least percent clay) to the highest (greatest percent clay).

In the two soils highest in clay content, there was a tendency for prior cropping to increase K fixation and reduce the plant recovery of subsequently applied K.

Sparks et al. (1980) reported that soils with sandy surface horizons and clayey subsoils had a pronounced accumulation of K in the subsoil layers. The K in the clayey subsoil, probably a result of leaching of both applied K and that of genetic origin, was available to plants depending upon the ease of root penetration. The ability of the plant to extract subsoil K caused a lack of response to surface applied K.

Singh et al. (1977) observed higher K uptake by dryland wheat grown on a clay loam soil than on a loamy sand soil in a year of normal rainfall and profile storage. This difference was attributed to the higher water storage capacity of the clay loam soil. It is probable that the increased water supply in the clay loam soil is related to a greater potential for K ion diffusion.

Particle size within the clay fraction has been observed to influence the rate of weathering and K fixation and release of clay minerals. Potassium release has been shown to be more rapid as the particle size becomes smaller. However, at a certain point in decomposition at which the diameter and thickness of the clay particles approach equality, little or no K release is observed. This is probably due to the stable overall charge of the clay particle

(Sawhney, 1972). Particle size was also related to K-selectivity and to ease of collapse of the frayed edges of the particle. A greater area of collapsed central core relative to the edges of the particle was associated with greater ease of collapse of the edges. Beckett and Nafady (1967) also associated specific K sites with the edges or peripheral interstices of stacks of clay plates and the non-specific (Gapon) sites to their planar surfaces.

Soil Structure, Consistence, and Bulk Density

Soil structure can influence the percentage of total soil volume that can be utilized by roots. Soil consistence as well as permeability can be interrelated with many other physical properties. A hard dry consistence commonly implies slow permeability, low porosity, and high bulk density (Niekerk and Lambrechts, 1977). In a study of some Singapore soils, Wells and Leamy (1977) observed that the physical properties of the soils were different and could be related to the nature of the parent rock. For intensive market gardening, the moist soil consistence and grade of structure were both determined to be of major importance.

Soil consistence is a soil parameter which measures the force required to crush a soil ped. Consistence is probably an important parameter in that it is dependent upon various soil physical properties such as porosity, bulk density, and texture as they interrelate. Cone index (CI), defined as the force required to push a penetrometer into the soil divided by the cross-sectional area of the penetrometer cone, is a similar type of measurement. In a study to determine those factors which influence the CI value, it was observed that CI for each texture increased monotonically with decreasing soil water pressure, but no simple relationship between CI and texture was found (Byrd and Cassel, 1980). Regression equations relating CI to water content, percentage of sand, and the volume of pores greater than 150 μm in diameter explained 67 - 72 percent of the observed variation (.0001 probability level.). It was pointed out that the importance of roots in natural systems should not be overlooked as an influence in determining soil physical properties.

Reddy et al. (1978) observed that the hydraulic conductivity and water holding capacity of the soil had increased by 25 - 30 percent and 10 - 16 percent, respectively, under all of the cropped plots (42 kg. K/ha level) at the full flowering stage as compared to the control. The root weight of all crops had also increased by 25-40 percent with the increased K application.

Root growth has been shown to be one of the most important factors for improving soil structure; bulk density can be used as a sensitive index of soil structure. This suggests that the higher rates of hydraulic conductivity (associated with the lower bulk density values) observed under the 42 and 83 kg. K/ha treatments might be attributed to better root growth.

The relationship between root growth, bulk density and soil structure has been shown to be important. Schuurman (1971) observed that root weights, numbers, and rooting depth decreased with increasing soil density. In addition, uptake of water and minerals, particularly P and K, decreased. The yield of dry matter of wheat decreased in all soil series except one as the bulk density was increased from 1.02 to 1.52 g/cm^3 (Sharma and Verma, 1971). A similar trend was also observed for root growth, grain yield, and uptake of N, P, and K. In a related study, the compaction of soil to create a bulk density greater than 1.40 g/cm^3 proved harmful for plant growth in all soil series observed (Verma and Sharma, 1972). The harmful effect of compaction was again directly related to decreased nutrient uptake. It is probable that decreased nutrient uptake is related to decreased ion diffusion and increased soil matric potential associated with the higher bulk densities.

Soil physical parameters may also be important in the way that they can modify the biological-chemical nature of the soil environment. Samra and Goswami (1978) found that grain yield increased up to a bulk density of 1.6 and 1.75 at the 0 - 15 cm depth and 15 - 30 cm depth, respectively, after which yield dropped off. The interaction of bulk density and moisture content was observed to significantly affect the oxygen diffusion rate. Oxygen diffusion rate increased as yield increased to a point after which yield decreased. The same kind of parabolic relationship was observed between bulk density and grain yield and between soil resistance to penetration and grain yield.

In another study soil compaction was observed to decrease total porosity and the amount of macropores (> 50 μ). However, the amount of water holding pores (.20 - 10 μ) and fine capillary pores (< .20 μ) increased (Talha et al., 1979). Total dry matter production of maize and barley as well as K concentration and uptake was higher at all levels of fertilization in the compact soil and increased as K fertilization level increased. By compacting the soil an equilibrium was reached among water and air-filled pores. The potential existed for a negative effect on plant growth during moist years because the plants would suffer from an excessive CO_2/O_2 ratio (O_2 deficiency).

Tillage practices have been found to significantly affect K concentration and uptake of K. These effects have variously been associated with increased compaction of high moisture content (Fisher et al., 1975), differences in concentration gradients of K (Drew and Saker, 1978; Hodgson, et al., 1977), differences in moisture content and depth and abundance of rooting (Cannell et al., 1980; Drew and Saker, 1980), and differences in physical and chemical properties and activity of earthworms (Lal, 1976).

Soil Moisture

Sharda and Gupta (1975) point out that soil moisture affects the growth of plants by modifying soil aeration, mechanical impedance of the soil, the concentration of readily soluble nutrients and the heat conductivity of the soil. In their investigation an increase in oxygen diffusion rate with increasing soil moisture tension was indicated. Uptake of nutrients was found to decrease with increased moisture stress.

The interaction between soil moisture regime and nitrogen level has been found to be significant in respect to N, P, and K uptake (Varma et al., 1976; Varma, 1976). As soil moisture increased, the higher rates of nitrogen increased general growth and dry matter production. Better root growth, in particular, allowed the plants access to more soil which resulted in better water use efficiency. The influence of increasing moisture levels on N, P, and K uptake has been similarly observed in two other studies (Bajpai and Mertia, 1977; Fedak and Mack, 1977). Increasing moisture levels increased ash content of the grain and straw, increased grain and protein yield, and decreased grain protein content.

Hoyt and Rice (1977) found that efficiency of moisture use was generally more than doubled by the fertilizer and fertilizer plus manure treatments versus the control (no applied fertilizer or manure). Petinov et al. (1977) also observed that the higher the level of N, P, and K, the more pronounced the positive response of the plants to soil moisture.

Soil moisture, as it fluctuates, may also affect exchange relations and, therefore, soil solution concentrations of K. Raney and Hoover (1946) reported that alternate wetting and drying of some soils caused a rapid fixation of K in a non-replaceable form and that very little fixation of this kind took place under the soils kept continually moist. However, Scott and Smith (1957) found that the exchangeable K in the surface and subsoil was doubled upon drying and that K uptake by plants was always less on soils kept continually moist than from soils that had been dried and rewetted. Potassium uptake, in particular, from the non-exchangeable K fraction, was impaired by a dry soil medium (Mengel and Wiechens, 1979). The release rate of non-exchangeable K was more important for crop production than the level of exchangeable soil K. Beckett and Nafady (1967) also observed that the rate of release of K from a non-labile pool decreased as the non-labile pool became exhausted.

Soil moisture will influence the concentration of ions in the soil solution both by the effect of dilution and by the relative effect on ions of different charge. Karlen et *al*. (1978) found that as soil moisture was increased, Ca and Mg concentrations in leaf tissues were depressed while K concentrations increased or remained unchanged. It was felt that this differential change in cation composition of wheat grown under wet soil conditions could be explained by changes in ion activities in accord with Donnan Equilibrium Theory. This theory shows that the availability of monovalent ions increases while the availability of divalent ions decreases as soils become more nearly saturated with water.

There is much evidence that K concentrations in soil solutions are decreased and that K absorption on exchange sites is increased by liming. These Ca:K interactions explained the decreased yield of potatoes in a study conducted at Rothamsted (Bolton, 1977). Jankovic and Nemeth (1978) observed that owing to K and P fertilization, the Ca concentration of the soil solution increased as a result of exchange processes in the soil. Simple ion concentrations were determined to be more suitable than the potentials for defining nutrient dynamics changed by fertilizer application.

The concentration of cations in solution and pH have also been shown to influence K release from micaceous clays. Marked complementary ion effects on K and Ca displacement occurred when the exchange was from pH-dependent charges. At 30 percent K saturation (70 percent Ca), complementary ion effects were small. However, at 10 percent K saturation (90 percent Ca), the different complementary cations caused more than a fourfold difference in the K displaced from illite (McLean and Bittencourt, 1974). Mattson (1973) found that the uptake of P and K was lowest, and the uptake of Ca highest toward the dry end of the treated soils. Again, the implication here is that moisture is important in that it modifies both the relative ionic concentrations and ion diffusion.

Soil Temperature

At any one moment, temperature varies from soil horizon to soil horizon. It fluctuates with the hour of the day and with the season of the year, and the fluctuations may be large or small according to the environment. Seasonal fluctuations in soil temperature are affected by latitude, soil moisture, groundwater, air movement near the ground, clouds, rain, and ground cover. The influence of latitude is dominant over most of the United States. Daily fluctuations are affected by all of these except latitude, and the influence of moisture is dominant (Smith and Newhall, 1964). The importance of slope and aspect can also be very pronounced on adjacent soils, especially in the higher latitudes.

Daily changes in air temperature have a significant effect on the temperature of surface-soil horizons to a depth of about 50 cm. This is particularly so in soils of dry climates where moisture can be exceedingly important in reducing fluctuations in soil temperature. Oliveira et al. (1979), in attempting to estimate soil temperature at 2 cm from air temperatures, found that on rainy days the measured soil temperature was always lower than the estimated soil temperature because the rainwater cooled the soil surface more rapidly than the air.

Willis and Power (1975) point out that water viscosity and surface tension are inversely related to temperature, and relative hydraulic conductivity increases as temperature increases. A dry soil will freeze more quickly and to a greater depth than a wet soil, and thawing of the dry soil occurs much more rapidly in the spring.

As the soil profile cools or warms, the water table drops or rises in response to the known fact that a cold soil holds more water than a warm soil and loses water more slowly. Frost may remain in the soil profile for a significant time after the surface has thawed, thus forcing plant roots to grow into soil colder than the surface.

Soil temperature has been shown to significantly affect K-uptake and the K-requirement. Boatwright et al. (1976) found that fertilization of spring wheat with N, P, and K appeared to partially alleviate the detrimental effect of low surface soil temperatures. In a similar study, N, P, and K concentrations were observed to be higher in grain from plants grown under reduced soil aeration and 25° C soil temperature than in grain produced at lower soil temperatures (Labanauskas et al., 1975).

Wicke (1973) also observed that the K requirement was greatest at the lower soil temperature and that the response to added K was smaller at high root-zone temperatures than at low root-zone temperatures. Kabu and Toop (1970) found that high soil temperature (23.9° C and higher) could be contributing to the problem of K-induced

Mg deficiency by increasing the potassium uptake.

Mack (1971) confirms this in his report on yields of bromegrass. An increase in concentration of the major nutrients (N, P, K) in the plants coincided with the greater herbage growth on the warm soil. The changes in uptake for N, P, and K per 1° C change of seasonal temperature were 8.7, 10.4, and 7.1 percent, respectively, and the associated Q_{10} values were 1.5, 1.6, and 1.4 at 9.2° C.

Temperature influences may also be related to different exchange relations which exist among potassium-bearing micas. The heating of various micas caused marked differences in K-exchangeability. Although the maximum degree of K exchange was generally unaltered by heating, major changes in the rate of exchange occurred (Scott, et al., 1972). Heat treated muscovite showed a marked increase in the rate of exchange, whereas biotite and lepidomelane showed a decrease in the rate of K release.

Chapter 3

MATERIALS AND METHODS

Selection and Location of Plot Sites

Between 1968 and 1980, numerous field soil fertility research studies were conducted by Montana Agricultural Experiment Station researchers, Extension Service Soil Scientists, and USDA-ARS scientists in Montana. Results of recent research suggested that these sites could provide valuable information for developing a system for predicting crop response to K fertilizer. Because crop yield and response data were already available from previously conducted research, only the site and soil characteristics (which are basically constant over the years) needed to be obtained. To do this, only those research sites which included small grains (winter wheat, spring wheat, barley, and oats) as the experimental crop and upon which various rates of K fertilizer were applied as a variable in the experiment were selected. The total number of sites sampled based on these criteria was 127. Because many of the sites had several experimental plots established on them over the years, the site data could be applied to more than one set of experimental data (i.e. yield data, etc.). For this reason, the total number of experiments (cases) included in this study was 222.

In most cases site location was determined from the legal descriptions as reported by the various researchers in the Montana

Agricultural Experiment Station Annual Report. Actual location in the field of the old plot sites was accomplished with the aid of someone who was directly involved in the research when the plot was established and/or with the help of the cooperators themselves. In all cases, care was taken to insure that the sample taken was in close proximity to the old fertility plot site to insure the same soil type (series level). See Appendix I for site numbers, cooperators, legal descriptions, and soil series names.

Fertility Plot Sampling

Soil samples were taken as near the center of the old fertility plot as could be determined. A Giddings probe was used to take soil samples to a depth of approximately four feet. The core sample was then divided into plow layer (Ap) horizon, B horizon, based on structural and textural differences induced by clay accumulation, and a Cca horizon, as determined by reaction with dilute hydrochloric acid. Samples from each horizon at each site were then placed in a sampling bag labelled as to cooperator, years in which the plot was used, and horizon name and depth.

In several cases, because of the method of sampling, soil type differences, or previous erosion, it was not possible to distinguish three distinct horizons. In a few cases, the presence of a Cca horizon was not detected to the maximum depth of sampling.

Percent slope and aspect of the plot area were also recorded. Aspect was introduced into the analysis by the following coding scheme in which a number from 1 to 8 was assigned to correspond with the general site aspect (Figure 1).

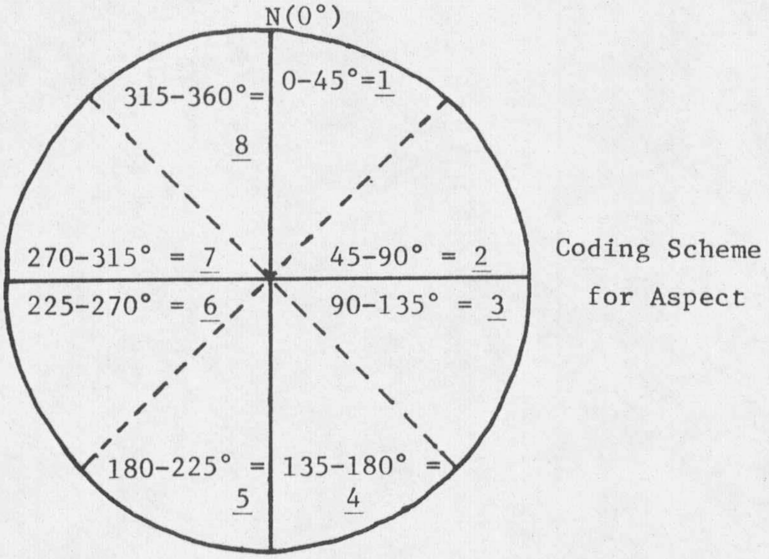

Figure 1.

Dry Consistence and Bulk Density Determination

Traditionally, dry consistence in the field is determined by placing a soil ped between the thumb and forefinger (and/or between the hands) and exerting a force sufficient to crush the ped. On the basis of the force applied, one of six semi-quantitative values is assigned, ranging from loose to extremely hard.

To obtain a more quantitative (less subjective) measure of dry consistence, a pocket penetrometer (CL-700; Soiltest, Inc.) with the foot attached was used to determine the point of failure or force required to crush the ped. Five peds from each horizon at each site were sampled and the dry consistence measurements recorded in kg/cm^2.

In addition to the latter measurements, the thickness of each ped was measured and recorded. This was done to subsequently determine if a significant relationship existed between ped thickness and the consistence measurement itself. If necessary, corrections could then be made later for those horizons with either small or large average ped thicknesses. However, care was taken to try to eliminate this potential problem by selecting five peds of similar range in size for each horizon at each site. Ped thicknesses ranged from 10 - 25 mm. If the force required to crush the ped exceeded 4.5 kg/cm^2 (maximum value on the penetrometer scale), a value of 5.0 was recorded.

Bulk density determination was accomplished by using the clod method (Black, 1965). Saran was used as the water seal or coating medium. This method was chosen because in many cases an intact core was not preserved through handling. Three large-sized peds were sampled from each horizon for each site. The average bulk density of the three peds sampled was entered as the value used in the statistical analysis.

Determination of Soil Series

The soil series present at a site was determined in one of two ways. The soil series name was obtained in many cases from the researcher as reported in the Montana Agricultural Experiment Station Annual Report. If not given, then the legal description of the fertility plot was used in conjunction with the appropriate Soil Conservation Service county soil survey to determine the soil series present at a site. Not all counties in Montana have been mapped, so the soil series present at some sites is not known. The inclusion of the variables derived from the soil series description was not possible for these sites (See Appendix II).

Variables Determined from the Soil Series Description and Taxonomic Classification

The soil classification and profile description system (U.S.D.A., 1951; U.S.D.A., 1975) used in the United States makes use of soil physical criteria as well as climatic parameters to distinguish one soil type from another. In the present study, some of the variables used in the statistical analysis were derived from these physical and climatic criteria. These include: 1) mean annual soil temperature (MAST); 2) soil structure; 3) textural class; 4) textural family; 5) temperature regime; and 6) moisture regime.

Mean annual soil temperature was introduced as a variable in the analysis by calculating the average of the range of values presented in the soil series description for a given site. If a specific temperature was obtainable as <u>the</u> MAST in the soil series description, then that value was used in the analysis.

Soil structure, textural class, textural family, temperature regime, and moisture regime were all introduced as variables in the regression analysis according to various coding schemes. The coding schemes were devised so that the number sequence would reflect a logical order. For example, textural family determination was coded from coarse-textured to fine-textured; structural grade was coded from weak to strong.

Moisture regime determination for a given soil series was derived from the classification of that series at the subgroup level. A soil with a cryic temperature regime was assumed to possess a udic moisture regime in that the ustic moisture regime could not technically apply at the subgroup level of classification (U.S.D.A., 1975). A soil with a frigid temperature was considered to have an ustic moisture regime unless the subgroup modifier indicated some other moisture regime (intergrade). Any soil series in this study classified as an aridisol always possessed an ustic intergrade in the subgroup modifier. See Table 1 and Table 2, respectively, for moisture regime and temperature regime coding schemes.

Soil structure was introduced as a three-digit variable in the

Table 1

Coding Scheme for Moisture Regime

Moisture Regime	Coded Value
Udic	1
Ustic	2
Ustic - aridic	3
Aridic - ustic	4

Table 2

Coding Scheme for Temperature Regime

Temperature Regime	Coded Value
Cryic	1
Frigid	2
Mesic	3

analysis composed of three coded 1-digit numbers for grade, size, and type, respectively (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
				Sub-angular blocky	5
				Granular	6
				Massive	7
				Single grain	8

Textural class always refers to that texture dominant at the surface of a given soil series and is that texture usually associated with the soil series name. Textural family is that parameter associated with the control section of a particular soil series at the family level of classification (Hopkins, 1979; U.S.D.A., 1975). Table 4 and Table 5 contain the coding schemes for textural class and textural family, respectively. Soil series names and their respective moisture

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

Table 5

Coding Scheme for Textural Family

Textural Family	Coded Value
Coarse-loamy	1
Fine-loamy	2
Fine-silty	3
Fine-montmorillonitic	4

and temperature regimes, as well as textural classifications can be found in Appendix II.

Variables Determined from the Montana Agricultural Experiment Station Annual Reports

Variables obtained from the annual reports that were used in the statistical analysis included: 1) type of crop; 3) year of the experiment; 3) yield data; 4) K-rates applied; 5) rainfall; 6) soil temperature data; and 7) soil moisture data.

The coding scheme for crop type is given in Table 6.

Table 6

Coding Scheme for Crop Type

Crop Type	Coded Value
Winter Wheat	1
Spring Wheat	2
Barley	3
Oats	4

"Year" was introduced as a variable in the analysis by recording the last two digits of the year the experiment was conducted. Yield data (kg/ha) were obtained from the annual reports only for those treatments in which nitrogen and phosphorus were considered to be adequate and in which the N and P rates were constant across the various rates of K. Thus, N and P rates were constant within an experiment for the yield data recorded but were variable from one experiment to another.

Rates of applied K varied from experiment to experiment. In some cases, only two rates of K were applied (e.g. 0 and 56 kg K/ha). In a number of cases, five rates of K were applied. In all cases, the number of yield variables corresponded to the number of rate variables. The control was always the same at 0 kg K/ha.

Rainfall (cm.) was introduced as a single variable in the analysis. The value recorded was that of total rainfall reported during the growing season with no regard being given to the distribution.

Temperature data taken throughout the growing season were used in calculating an average monthly temperature for April, May, June, and July. Four variables were thus introduced into the analysis.

Spring soil moisture was introduced to the analysis in the form of seven variables. These variables represented the total moisture content to 183 cm. (V43) as well as the moisture content of the soil profile taken in 30 cm. increments from the surface to 183 cm. (6 variables - V44 through V49). At a later date, sixe more variables were introduced from these data as a modification of the six variables just mentioned. Whereas the first six variables (V44 through V49) measured soil moisture within a given 30 cm. increment, the latter six variables (V52 through V57) measured the cumulative soil moisture from the surface to a specified depth (e.g. 0-30cm., 0-60cm., 0-90cm,etc.).

Temperature, moisture, and rainfall data were missing from the annual reports in many cases, complicating the statistical analysis. Because of the missing data for these variables, care must be taken in interpreting the significance of some of the regression results, particularly those in which the dependent variable was a yield variable (V6 through V10). More will be said about this problem in the section on statistical methods. Table 7, which presents all of the variables used in the analysis, also details the severity of missing data for each variable.

Determination of Latitude, Elevation, and Geographical Location

Latitude and elevation of each site were both determined by obtaining the appropriate topographical map which could be used in conjunction with the legal description of a particular site. Latitude was introduced into the analysis as a four-digit number recorded to the nearest minute. Elevation, in most cases, was determined ± 7.5 meters.

Geographical location was an arbitrarily derived variable used in the analysis. Its derivation originated from the desire to separate the plot sites according to the area of the state of Montana in which they were established. These areas were defined on the basis of the proximity of the sites to one another and according to known growing season differences, such as usual time of harvest and general climatic conditions. Four areas were thus delineated and a number (1-4) used as the assigned coded value for the variable (Figure 2).

Determination of Percent K Response

For those experiments with five treatments of applied K fertilizer including the control (0 kg K/ha), a quadratic multiple regression analysis was used to obtain the calculated maximum percent K response. This method of percent response determination was described by Schaff (1979). The equation obtained from the regression analysis is as follows:

$$\hat{Y} = a + b_1 X + b_2 X^2$$

where;

$\hat{Y}$ = calculated maximum yield

a = intercept of the Y axis; X = 0

b_1 = linear regression coefficient

b_2 = quadratic regression coefficient

X = rate of applied K fertilizer

If the derivative of the original equation is calculated, the rate of K fertilizer needed for maximum yield can be determined. The

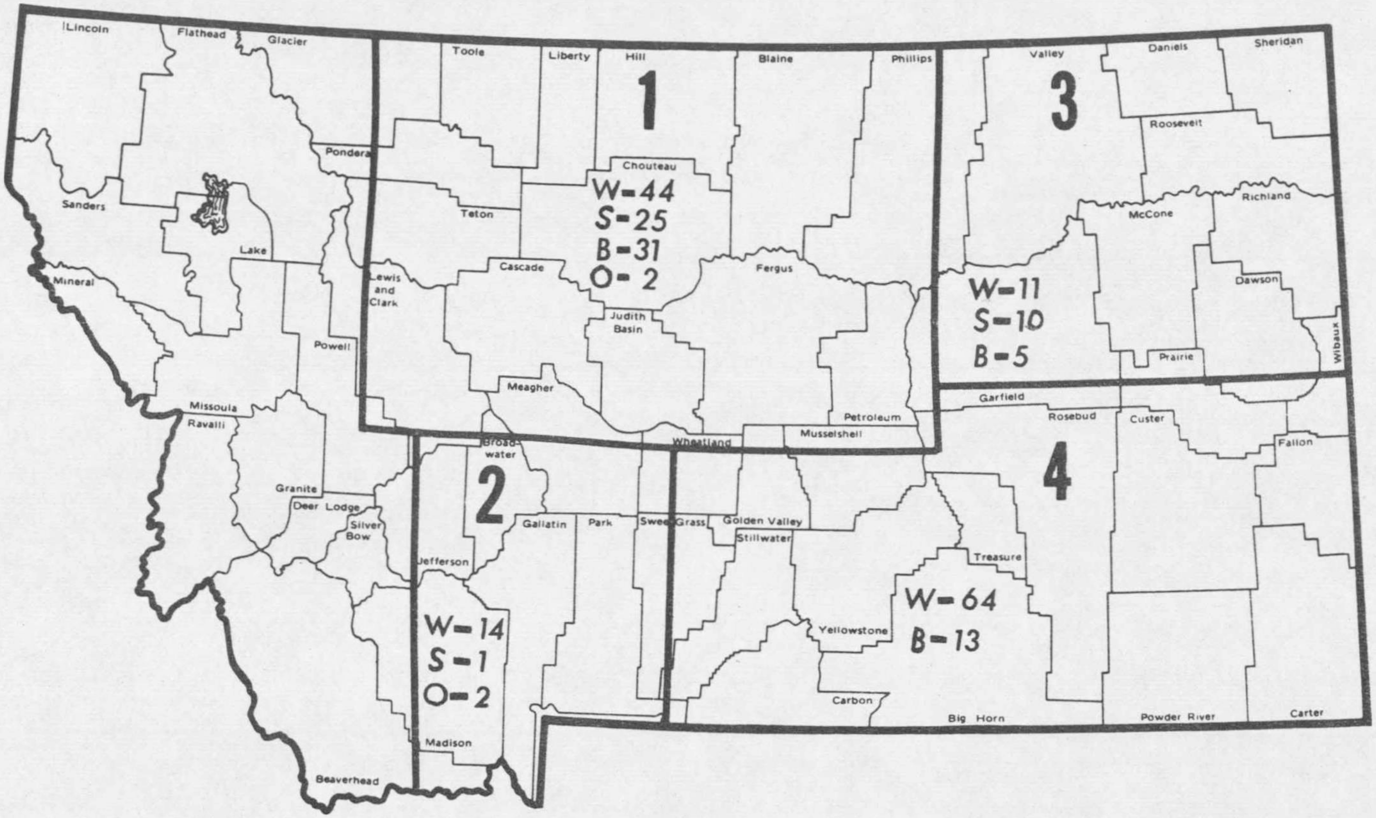

Figure 2. Delineation of geographic location (V27) and the number of experiments according to crop in each. W = winter wheat, S = spring wheat, B = barley, O = oats.

equation becomes:

$$\hat{Y} = b_1 + 2\ b_2\ X$$

By setting $\hat{Y} = 0$ and solving for X:

$$2\ b_2\ X + b_1 = 0$$

$$X = -b_1/2\ b_2$$

where; X = rate of K fertilizer to obtain maximum yield response.

By substituting this value of X into the original equation, one can then solve for maximum yield ($\hat{Y}$). After the maximum yield is determined, then a simple ratio ($\hat{Y}$/a) provides Y, or the percent change in yield (response).

For those sites with only 2, 3, or 4 treatments of K fertilizer including the control (0 kg/ha K), a second method was used to calculate percent K response. This method was used as an alternative because quadratic multiple regression analysis becomes more meaningless as the number of points to which a curve is adjusted decreases. In other words, a perfect-fit quadratic curve will always result in instances of the presence of only three points.

This second method of determining percent K response is less involved. The yield at each rate of K application (other than the control) was divided by the yield at the control rate (0 kg K/ha). These percent response values were then added together and divided by the number of values so determined. This value conveys the average percent K response.

The following equation describes the procedure. Assume an experiment in which 0, 22, and 48 kg/ha added K were the treatments used, then:

$$\left[\left(\frac{Y_{22}}{Y_0}\right) + \left(\frac{Y_{48}}{Y_0}\right)\right] \div 2 = \%\ K_{res}$$

where: Y_{22} = yield at 22 kg/ha K

Y_{48} = yield at 48 kg/ha K

Y_0 = yield of the control

$\%K_{res}$ = average percent K response

These two methods of percent K response determination were assumed to provide similar values and were used as the same dependent variable (V42) in the subsequent multiple stepwise linear regression analysis.

A third determination of percent K response utilized a method similar to the second. In this case, the greatest yield value for a given experiment (other than the control yield) was divided by the yield value of the control. This value was termed "maximum percent K response." This method was used over all of the experiments (222) and the results introduced into the analysis as a second dependent variable (V50). Appendix III presents site number, experiment number, average percent K response, maximum percent K response, and the K rate corresponding to maximum percent K response.

Statistical Methods

The variables used in the analysis (Table 7) were inserted into an SPSS multiple stepwise linear regression program (Nie et al., 1975). This regression program was chosen because it contained an option which could manage cases with missing data for a given variable. Therefore, a case (experiment) with missing data for certain variables was not completely eliminated from the analysis; and the data base was preserved for those variables for which data were present.

Because of the large amount of missing spring soil moisture, soil temperature, and rainfall data, for example, the data base would have been reduced drastically had not this approach been taken. However, because this approach was chosen, care must be taken in interpreting the results with regard to variables for which only minimum data existed.

The analysis of R^2 values and the interpretation of significant F-values should be based on the number of sites with complete data. Results including variables with missing values will tend to inflate the R^2 value for the equation; the degrees of freedom used in determining the significance of the F-value will also tend to be inflated. For example, if data are missing for a given variable at "n" number of sites, then the R^2 for that variable is based on the total number of sites minus "n." The overall regression equation R^2 value, however, is based on the total number of sites analyzed. More restrictive

Table 7. Variables used in Multiple Stepwise Linear Regression Analysis

Variable Number	Variable Name	Units	Card #	Format	Cases with Missing Data
1	Site	a number (1-127)	1,2,3	F 3.0	0
2	Site-Experiment Separation Number	a number (1-4)	1,2, & 3	F 1.0	0
3	Crop	Coded Value[2/]	1,2, & 3	F 1.0	0
4	Year	a number (68-80)	1,2, & 3	F 2.0	0
5	Card Number	a number (1-3)	1,2, & 3	F 1.0	0
6[1/]	Yield 1	Kg/ha	1	F 4.0	0
7[1/]	Yield 2	Kg/ha	1	F 4.0	0
8[1/]	Yield 3	Kg/ha	1	F 4.0	16
9[1/]	Yield 4	Kg/ha	1	F 4.0	135
10[1/]	Yield 5	Kg/ha	1	F 4.0	119
11	K-Trt. 1	Kg/ha	1	F 1.0	0
12	K-Trt. 2	Kg/ha	1	F 2.0	0
13	K-Trt. 3	Kg/ha	1	F 3.0	16
14	K-Trt. 4	Kg/ha	1	F 2.0	135
15	K-Trt. 5	Kg/ha	1	F 3.0	119
16	Dry Consistence A	Kg/cm^2	1	F 2.1	0
17	Dry Consistence B	Kg/cm^2	1	F 2.1	20
18	Dry consistence Cca	Kg/cm^2	1	F 2.1	4
19	Bulk Density A	g/cm^3	1	F 3.2	0
20	Bulk Density B	g/cm^3	1	F 3.2	20
21	Bulk Density Cca	g/cm^3	1	F 3.2	4
22	Structure A	Coded value[2/]	1	F 3.0	42
23	Structure B	Coded value[2/]	1	F 3.0	56
24	Structure Cca	Coded value[2/]	1	F 3.0	42
25	Textural class	Coded value[2/]	1	F 2.0	36
26	Textural family	Coded value[2/]	1	F 2.0	37
27	Geographic Location	Coded value[2/]	1	F 1.0	0
28	Thickness of B	cm	1	F 2.0	20
29	Depth to Ca	cm	1	F 2.0	4
30	Elevation	meters	2	F 4.0	0
31	Slope	percent	2	F 2.1	0
32	Aspect	Coded value[2/]	2	F 2.0	10
33	Latitude	degrees (°) and minutes (')	2	F 4.2	0
34	Mean annual soil Temperature (MAST)	°C	2	F 3.1	36
35	Temperature Regime	Coded value[2/]	2	F 1.0	0
36	Temperature (April)	°C	2	F 2.0	194
37	Temperature (May)	°C	2	F 2.0	179
38	Temperature (June)	°C	2	F 2.0	176
39	Temperature (July)	°C	2	F 2.0	177
40	Rainfall	cm.	2	F 3.1	150
41	Water Regime	Coded value[2/]	2	F 2.0	37
42[1/]	Average % K response	percent	2	F 3.0	0
43	Total Spring Soil H_2O	cm.	2	F 4.1	94
44	Spring Soil H_2O (0-30)	cm.	2	F 3.1	99
45	Spring Soil H_2O (30-60)	cm.	2	F 3.1	99
46	Spring Soil H_2O (60-90)	cm.	2	F 3.1	100
47	Spring Soil H_2O (90-122)	cm.	2	F 3.1	107
48	Spring Soil H_2O (122-152)	cm.	2	F 3.1	145
49	Spring Soil H_2O (152-183)	cm.	2	F 3.1	172
50[1/]	Maximum % K response	percent	3	F 3.0	0
51	K-rate for max. response	kg/ha	3	F 3.0	0
52	Spring Soil H_2O (0-30)	cm.	3	F 4.0	99
53	Spring Soil H_2O (0-60)	cm.	3	F 4.0	99
54	Spring Soil H_2O (0-90)	cm.	3	F 4.0	99
55	Spring Soil H_2O (0-122)	cm.	3	F 4.0	99
56	Spring Soil H_2O (0-152	cm.	3	F 4.0	99
57	Spring Soil H_2O (0-183)	cm.	3	F 4.0	99

[1/] Used as a dependent variable in the regression analysis.

[2/] Coded value; See Tables 1-7 for coding schemes used to introduce the variables into the analysis.

options of analysis were used later in the investigation to try to remedy this situation and to insure statistical validity in the results. These are described in the Results and Discussion section.

Due to the fact that over 60 separate regressions were conducted and because of the large number of independent variables, the number of variables allowed to enter the equation, the F-value, and tolerance level were set at 5, 1.0, and .10, respectively. This was done in order to restrict the length of the resulting regression equation and to give some assurance of the significance of the results. The level of statistical significance was determined from standard F-tables (Steel and Torrie, 1960).

Chapter 4

RESULTS AND DISCUSSION

Two preliminary investigations were performed prior to the multiple regression analyses which involved yield and percent response as the dependent variables. First, an analysis of variance (ANOV) was conducted with bulk density as the dependent variable. The bulk density values were grouped both on site and horizons within a site. This analysis was done to determine if statistically significant differences between plot locations existed for one of the variables (bulk density) that would be used later as an independent variable in the regression analyses.

The ANOV produced an F-value of 9.15 when comparing one site to another. At 1 and 126 degrees of freedom, these results are significant at the .005 significance level. An F-value of .20 resulted when comparing horizon bulk densities at a given site. At 1 and 2 degrees of freedom, this was not statistically significant. These results establish that horizon differences at a site are <u>not</u> apparent, but that differences in bulk density between sites are pronounced.

The second preliminary investigation was conducted to establish if ped thickness was an important factor influencing the dry consistence measurements. This was done to establish whether or not corrections in the dry consistence values would have to be made for horizons with either low or high mean values for ped thickness.

A regression analysis was performed using consistence values as the dependent variable and ped thickness as the independent variable. The F-value produced from this regression was 130.8, significant at the .005 level. However, the R^2 value resulting from the regression equation was only .07. These results indicate that ped thickness does influence the consistence measurement but that it does not account for a very large amount of the observed variability. If the pocket penetrometer was to be used in the field to measure consistence, uniform ped thickness would be desirable. Because care was taken to select ped sizes of a comparable range of thicknesses for each horizon and because other factors obviously influence the consistence values, it was determined that correction of the dry consistence data because of ped thickness was not necessary.

The discussion of results which follows in this chapter is organized by the order in which the regression analyses were run. In each regression analysis, data were organized differently to reveal independent variable relationships with different dependent variables. Divisions of the data file by crop, geographical location (see Figure 2), percent response class, and by K-rate at which maximum response occurred are explained at the beginning of each discussion section dealing with a specific group of regression equations. Each group of regression equations was organized and separated on the basis of how the data file divisions were made.

Each regression table presented in the following discussion sections was organized in a similar manner. In the column located on the extreme left of each table (refer to Table 8, pg 41), the regression number and the dependent variable and the independent variables used in the analysis were given. Also, when it applied, the part of the data file included in the regression analysis was identified in this column. The coding schemes used for crop (Table 6, pg. 27) and geographical location (Figure 2, pg. 31) were used to identify the part of the data file in which the regression equation applied. The division of the data into percent response classes and according to K-rate at which maximum response occurred (V51), when applicable, were also designated in the extreme left hand column of the table. Also included in this column in some instances are the number of cases (experiments) to which the regression equation applies.

A complete list of the variables used in the analyses can be found in Table 7 (pg. 35). It will need to be referred to in interpreting the regression analysis results presented in Table 8 through Table 17 and the summary tables (Table 18 through 20).

Because of the large number of variables used in this study, some limitations were applied to each regression analysis. One of these limitations was to allow only a set number of variables to enter each regression equation. In regression No. 1 through No. 14, ten variables were allowed to enter the equation. In regression No. 15 through No. 51, a maximum of five variables were allowed to enter the equation. It was felt that this limitation would still allow for identification of all important relationships.

Table No. 11, Regression No. 15 (pg. 60), can be used as an example of how the actual regression equation would be constructed from the table using step number, constant, and beta values. This equation would read:

$$Y - 78.82 - .186\ X_1 + .145X_2 + .164X_3 + .147X_4$$

where:

Y = maximum percent yield response (V50)

X_1 = value of V28

X_2 = value of V17

X_3 = value of V30

X_4 = value of V19

Regressions No. 1 - No. 5: Yield as the Dependent Variable

The following regression analyses were conducted using V06 through V10 (actual crop yield at the various K rates) as the dependent variables. In this group of analyses, ten variables were allowed to enter each of the regression equations. The independent variables for each analysis were the same and included those variables which were listed in the table of the regression results (Table 8). The

Table 8. Regression No. 1 - No. 5; Actual Crop Yield (V06-V10) as the Dependent Variable; Data File not Subdivided; Independent Variables not Restricted.

Regression No.	Step into eq.	Variable Name	Variable Number	Constant	Beta	Simple R	R^2	F-sig. level
1 Dependent Var. V06 Independent Vars. V01, V03, V04, V11, V16, to V41, V43 to V49	1	Struc. B	V23	2450.19	.161	.41	.17	.005
	2	MAST	V34		.353	.39	.21	.005
	3	Crop	V03		-.217	-.27	.24	.005
	4	Dry Con. A	V16		.100	.16	.26	.005
	5	Temp.cls.	V35		-.248	-.01	.28	.005
	6	Temp.(May)	V37		-.288	-.04	.30	.005
	7	Dry Con. C	V18		.235	.13	.31	.005
	8	Bulk Den.C	V21		-.160	.03	.33	.005
	9	Rainfall	V40		.121	.21	.34	.005
	10	Soil H_2O (90-122)	V47		.133	.06	.35	.005
2 Dependent Var. V07 Independent Vars. V01, V03, V04, V12, V16 to V41, V43 to V49	1	Struc. B	V23	2306.73	.129	.43	.18	.005
	2	Dry Con. A	V16		.201	.20	.22	.005
	3	Crop	V03		-.172	-.29	.26	.005
	4	MAST	V34		.288	.39	.29	.005
	5	K-trt. 2	V12		-.181	-.22	.30	.005
	6	Thickness of B	V28		.095	.13	.32	.005
	7	Soil H_2O (0-30)	V44		.303	.16	.34	.005
	8	Temp.(May)	V37		-.300	-.09	.36	.005
	9	Temp. cls.	V35		-.167	.04	.37	.005
	10	Soil H_2O (152-183)	V49		-.145	-.04	.38	.005

Table 8, Continued. Regression No. 1 - No. 5; Actual Crop Yield (V06-V10) as the Dependent Variable; Data File not Subdivided; Independent Variables not Restricted.

Regression No.	Step into eq.	Variable Name	Variable Number	Constant	Beta	Simple R	R^2	F-sig. level
3 Dependent Var. V08 Independent Vars. V01, V03, V04, V13, V16 to V41, V43 to V49	1	Bulk Den.A	V19	-1386.72	-.611	-.44	.19	.005
	2	Struc. B	V23		.172	.30	.30	.005
	3	Crop	V03		-.251	-.26	.36	.005
	4	Rainfall	V40		.238	.22	.40	.005
	5	Dry Con.A	V16		.210	-.10	.42	.005
	6	Temp. (June)	V38		-.191	.03	.44	.005
	7	MAST	V34		.234	.29	.46	.005
	8	Tex. cls.	V25		-.181	.13	.47	.005
	9	Year	V04		.231	.14	.48	.005
	10	Site	V01		-.165	-.03	.49	.005
4 Dependent Var. V09 Independent Vars. V01, V03, V04, V14, V16 to V41, V43 to V49	1	K-trt-4	V14	4285.93	.844	.84	.70	.005
	2	Bulk Den.A	V19		-.251	-.18	.76	.005
	3	Water Reg.	V41		.089	.16	.77	.005
	4	Dry Con.A	V16		.103	.01	.78	.005
	5	Temp.(June)	V38		-.080	-.32	.79	.005
	6	Site	V01		.150	.04	.79	.005
	7	Geog. loc.	V27		-.093	-.15	.80	.005
	8	Struc.C	V24		.062	.02	.80	.005
	9	Dry Con.B	V17		.061	-.01	.81	.005
	10	Year	V04		-.074	.06	.81	.005

Table 8, Continued. Regression No 1. - No. 5; Actual Crop Yield (V06-V10) as the Dependent Variable; Data File not Subdivided; Independent Variable not Restricted.

Regression No.	Step into eq.	Variable Name	Variable Number	Constant	Beta	Simple R	R^2	F-sig. level
5								
Dependent	1	K-trt.5	V15		.664	.69	.48	.005
Var. V10	2	Bulk Den. A	V19		-.468	-.42	.68	.005
Independent	3	Water Reg.	V41		.180	.29	.70	.005
Vars. V01,	4	Aspect	V32		-.080	.01	.72	.005
V03, V04,	5	Rainfall	V40	3932.32	.135	.03	.73	.005
V15, V16 to	6	Temp.(May)	V37		-.278	-.05	.73	.005
V41, V43 to	7	Dry Con.A	V16		.124	-.09	.74	.005
V49	8	Soil H_2O (152-183)	V49		-.184	.07	.75	.005
	9	Soil H_2O (90-122)	V47		.267	.19	.76	.005
	10	Soil H_2O (0-30)	V44		-.111	-.10	.76	.005

analyses were conducted over the entire data set so that the results were based on 222 cases, the total number of experiments included in this study.

Regression No. 4 and No. 5 (actual crop yield as the dependent variable) produced the highest R^2 values, .81 and .76, respectively. The F-significance level of the results was .005 at each step in <u>all</u> five of the regression equations. This was somewhat surprising and probably misleading. It was pointed out in the Materials and Methods section that R^2 values and F-significance levels tend to be inflated by including variables with missing data into the regression analysis. The variables for which this was particularly true were those associated with the seasonal temperature data (V36, V37, V28, V39), rainfall data (V40), and spring soil moisture data (V43 through V49). Although other variables which appeared in the regression equations also had missing data, the severity was not as pronounced (See Table 7 for the number of missing cases for each variable.

Simple correlations (Simple R), however, for each of the variables in the equation indicated valid relationships to the dependent variable.

It is important to note the strong positive correlation between structure of the B horizon (V23) and yield in regression No. 1, No. 2, and No. 3. This indicated that higher yields were associated with the more strongly structured soils. Thickness of the B horizon (V28) was also positively correlated with yield in regression No. 2.

Mean annual soil temperature (MAST) was positively correlated to yield in regression No. 1, No. 2, and No. 3. This suggested that lower soil temperatures associated with some soils may have been yield-limiting.

Yield (V09 and V10) in regression No. 4 and No. 5 showed a strong positive correlation to the rate of applied K (V14 and V15, respectively). This indicates that availability of native soil K and/or low rates of applied K are not adequate in many cases.

Dry consistence of the Ap horizon (V16) was the only variable to appear in all five of the regression equations. Its correlation (Simple R) to yield ranged from slightly positive to slightly negative. However, bulk density of the Ap horizon (V19) showed a consistently strong negative correlation to yield in regression No. 3, No. 4, and No. 5. The literature generally supported this observation in that increased bulk densities were associated with decreased root penetration and nutrient uptake. In the surface horizon (Ap) high bulk densities may also have been associated with increased difficulty of seedling emergence.

Rainfall (V40) was positively associated with yield in regression No. 1, No. 3, and No. 5; yet moisture regime (V41), which was coded wet to dry, was also positively correlated to yield in regression No. 4 and No. 5. This latter relationship of moisture regime to yield seems to be in agreement with the positive association between

MAST and yield.

In regression No. 51, MAST and moisture regime were highly positively correlated to one another. The warmer soils (> MAST) would be expected to be associated with the drier moisture regimes in that soil moisture would have exerted a profound buffering influence on soil temperature.

Temperature in May (V37) in regression No. 1, No. 3, and No. 5 as well as temperature in June (V38) in regression No. 4 showed a strong negative correlation with yield. This at first seemed to have contradicted the relationship between MAST and yield. However, the value of the MAST was determined from long-term temperatue data and so was an average. That low early growing season temperatures are correlated with greater yields could be explained by the fact that low soil temperatures have been associated with greater stored soil moisture.

Crop differences existed with regard to yield. This was shown by the fact that crop (V03) was an important variable in regresison No. 1, No. 2, and No. 3. Varietal and crop differences with regard to nutrient uptake may be due to differences in root membrane activity; the selectivity for certain ion absorption may be an inherited trait (Mattson, 1974). Lal and Sharma (1974) found that two varieties of dwarf wheat differed significantly in their ability to extract N, P, and K. Their experimental results were consistent over three levels of soil moisture and five rates of applied N.

Regressions No. 6 - No. 10: Average Percent Yield Response (V42) as the Dependent Variable.

The regression analyses were performed separately for each crop (regression No. 6 for winter wheat, No. 7 for spring wheat, No. 8 for barley and No. 10 for winter wheat) and combined over all crops (regression No. 9). The data subfile for oats was not analyzed separately throughout the regression analysis because there were only four experiments with oats as the experimental crop.

Regression No. 6 and No. 10 differ only in that V01 and V04 (site and year) were removed as independent variables in regression No. 10. The removal of V01 and V04 from regression No. 10 and subsequent regression analyses was done because it was decided that no explicit meaningful information could be derived from their inclusion in the regression equation.

Crop (V03) was also removed as an independent variable from these and subsequent regression analyses as the data were divided and analyzed according to crop.

The highest R^2 values were obtained for spring wheat and barley (regression No. 7 and No. 8). The R^2 values were .57 and .45, respectively. However, the highest F-significance level (.005) was attained for winter wheat (regression No. 6 and No. 10) and in

Table 9. Regressions No. 6 - No. 10; Average Percent Response (V42) as the Dependent Variable; Data File Subdivided on Crop; Independent Variables <u>not</u> Restricted.

Regression No.	Step into eq.	Variable Name	Variable Number	Constant	Beta	Simple R	R^2	F-sig. level
6 Dependent Var. V42 Independent Vars. V01, V04, V11 to V41, V43 to V49 Subfiles: Divided on crop; winter wheat (133 cases)	1	Latitude	V27	93.03	.241	.26	.07	.005
	2	Rainfall	V40		.210	.20	.08	.005
	3	Dry Con.B	V17		.313	.14	.10	.005
	4	Bulk Den.B	V20		-.244	.04	.11	.005
	5	Site	V01		-.285	-.01	.13	.005
	6	Struc.A	V22		.285	.13	.14	.005
	7	Struc.B	V23		-.196	.06	.15	.005
	8	Slope	V31		-.099	-.04	.16	.005
	9	Temp.(May)	V37		-.207	.01	.17	.005
	10	K-trt.2	V12		.264	.09	.19	.005
7 Dependent Var. V42 Independent Vars. V01, V04, V11 to V41, V43 to V49 Subfiles: Divided on crop; spring wheat (36 cases)	1	Latitude	V33	284.78	-.163	-.23	.05	----
	2	Soil H_2O (30-60)	V45		-1.461	-.15	.09	----
	3	Dry Con.A	V16		-.566	-.16	.14	----
	4	Slope	V31		.713	.06	.20	----
	5	Bulk Den.C	V21		-.380	-.14	.25	----
	6	Thickness of B	V28		.458	.10	.31	.10
	7	Rainfall	V40		-1.058	-.17	.33	.10
	8	K-trt.4	V14		.916	.04	.39	.10
	9	Bulk Den.A	V19		.627	-.10	.48	.025
	10	Soil H_2O (90-122)	V47		.885	-.09	.57	.01

Table 9, Continued. Regressions No. 6 - No. 10; Average Percent Response (V42) as the Dependent Variable; Data File Subdivided on Crop; Independent Variable not Restricted.

Regression No.	Step into eq.	Variable Name	Variable Number	Constant	Beta	Simple R	R^2	F-sig. level
8								
Dependent	1	K-trt.3	V13		.540	.29	.08	.05
Var. V42	2	K-trt.5	V15		.380	.26	.15	.025
Independent	3	Temp.(July)	V39		.486	.13	.25	.005
Vars. V01,	4	Dry Con.B	V17		.151	.05	.29	.005
V04, V11 to	5	Elevation	V30	221.47	.238	.10	.31	.01
V41, V43 to	6	Year	V04		-.347	-.17	.34	.01
V49	7	Site	V01		.235	-.19	.38	.005
Subfiles:	8	Aspect	V32		-.173	.07	.39	.01
Divided on crop; barley	9	Soil H_2O (122-152)	V48		-.547	-.10	.41	.01
(49 cases)	10	Soil H_2O (152-183)	V49		.471	.10	.45	.01
9								
Dependent	1	K-trt.5	V15		.371	.13	.02	.10
Var. V42	2	K-trt.3	V13		.254	.11	.06	.005
Independent	3	Dry Con.B	V17		.241	.11	.08	.005
Vars. V01, V04, V11 to	4	Soil H_2O (0-30)	V44		.376	.08	.09	.005
V41, V43 to V49	5	Soil H_2O (90-122)	V47	141.19	-.486	-.04	.12	.005
Subfiles:	6	Year	V04		-.165	-.03	.14	.005
Divided on	7	Bulk Den.B	V20		-.157	.08	.14	.005
crop: over-all (222	8	Soil H_2O (60-90)	V46		.632	.02	.15	.005
cases)	9	Soil H_2O (30-60)	V45		-.483	.002	.16	.005
	10	Temp.(July)	V39		.091	.04	.17	.005

Table 9, Continued. Regressions No. 6 - No. 10; Average Percent Response (V42) as the Dependent Variable; Date File Subdivided on Crop; Independent Variable not Restricted.

Regression No.	Step into eq.	Variable Name	Variable Number	Constant	Beta	Simple R	R^2	F-sig. level
10								
Dependent	1	Geog. loc.	V27		.162	.19	.04	.05
Var. V42	2	Dry Con.B	V17		.356	.19	.06	.025
Independent	3	Bulk Den.B	V20		-.167	.08	.08	.01
Vars. V11 to	4	Depth to Ca	V29		-.121	-.07	.09	.025
V41, V43 to	5	Soil H_2O						
V49.		(0-30)	V44	92.99	.079	.15	.10	.025
Subfiles:	6	Temp.(May)	V37		-.997	.02	.11	.025
Divided on	7	Temp.(June)	V38		.738	.09	.15	.005
winter wheat	8	Soil H_2O						
(133 cases)		(152-183)	V49		-.320	-.06	.16	.005
	9	Soil H_2O						
		(122-152)	V48		.335	-.008	.18	.005
	10	K-trt.2	V12		.192	.14	.19	.005

the case of the overall regression analysis (regression No. 9).

Again, it is stressed that when variables with missing data are included in the analysis the R^2 and F values are probably inflated. Spring soil moisture (V43 to V49), rainfall (V40), and temperature (V36 to V39) variables appeared in all the regression equations. The presence of these variables in the regression equations meant they were subject to misinterpretations.

It was somewhat contradictory that rainfall (V40) was positively correlated to percent yield response in regression No. 6 and negatively correlated in regression No. 7. This difference could possibly be explained by assuming that the addition of water to the soil may have produced variable influences on crop response to added K under different soil conditions. If the soil was dry so that no K diffusion could take place, then rainfall should have had a positive influence on crop response. Under adequate soil moisture conditions in which diffusion of native K to the plant root is sufficient, the general cooler climatic conditions (cloud cover, - etc.) associated with rainfall may possibly have acted to depress crop response to added K. Distribution of rainfall and soil permeability may also have been important factors in the explanation of these results.

Both dry consistence of the B horizon (V17) and bulk density of the B horizon (V20) were positively correlated to percent response in all cases in which they appeared in the regression equations. High bulk densities are usually associated with less plant available water. This is due to the increased matric potential.

If high bulk densities were restricting diffusion of native K, one would have expected the observed positive correlation between bulk density and crop response to added K. Dry consistence probably increases as clay content increases. The B horizon is the major zone of clay accumulation. The higher CEC values associated with increasing clay content (especially considering that 2:1 clays are dominant in Montana soils) may also be associated with restricting diffusion of native K. These results were in accord with observations presented in the Literature Review section.

In the one case in which thickness of the B horizon (V28) was included in the regression equation (regression No. 7), it was also positively correlated to crop response. Structure of the B horizon (V23) was also positively correlated to winter wheat response (regression No. 6). This relationship between strongly structured soils and positive crop response to added K may be due to the fact that strongly structured soils are usually associated with soils that have an abundance of clay and experience a definite dry period during any given year. Both of these factors would tend to cause slower or more tortuous diffusion of K in the soil.

The K-rate variables (V12, V13, V15) were positively correlated to crop response in regression No. 6 through No. 10. This again suggested that, in many cases, the availability of native K was not adequate.

Although subsoil moisture was somewhat variable in its correlation to crop response, spring soil moisture in the surface 30 cm. (V44) was positively correlated with crop response (regression No. 9 and No. 10). This indicated that adequate surface soil moisture may have been a prerequisite in order for added K to have had a positive effect.

The strong negative correlation of latitude (V33) to crop response is of interest in regression No. 7. Soils in the higher latitudes generally warm up more slowly in the spring. The potassium requirement of small grains is high early in the growing season. If temperature was the limiting factor, a positive correlation between latitude and crop response would be expected. However, other factors may have influenced the effect of latitude. Perhaps low temperature was still the limiting factor in that the effects of applied K were not realized in the colder soils. Also, higher rates of K application may have been required in colder soils to provide a crop yield increase.

Regressions No. 11 - No. 14: Maximum Percent Yield Response (V50) as the Dependent Variable.

These regression analyses were conducted separately for each

Table 10. Regressions No. 11 - No. 14; Maximum Percent Response (V50) as the Dependent Variable; Data File Subdivided on Crop; Independent Variable V01-V15 Not Included.

Regression No.	Step into eq.	Variable Name	Variable Number	Constant	Beta	Simple R	R^2	F-sig. level
11 Dependent Var. V50 Independent Vars. V16 to V41, V43 to V49, V51 Subfiles: Divided on crop; winter wheat (133 cases)	1	Rainfall	V40	101.48	.182	.20	.04	.025
	2	Elevation	V30		.093	.16	.06	.025
	3	K-rate for max. res.	V51		.189	.14	.08	.025
	4	Struc. B	V23		-.155	-.10	.10	.01
	5	Soil H_2O (90-122)	V47		-.158	-.04	.12	.005
	6	Thickness of B	V28		-.116	-.17	.14	.005
	7	Dry Con.B	V17		.221	.08	.15	.01
	8	Bulk Den.B	V20		-.168	-.02	.15	.01
	9	Temp.(May)	V37		-.802	.03	.16	.01
	10	Temp.(June)	V38		.789	.10	.19	.005
12 Dependent Var. V50 Independent Vars. V16 to V41, V43 to V49, V51 Subfiles: Divided on crop: spring wheat (36 cases)	1	Temp.(June)	V38	184.17	-1.803	-.29	.08	.10
	2	Slope	V31		-.011	.26	.21	.025
	3	Elevation	V30		-.245	-.20	.28	.025
	4	Water Reg.	V41		1.508	.15	.31	.025
	5	Tex.cls.	V25		-1.436	-.08	.39	.01
	6	Dry Con.A	V16		.837	.03	.46	.005
	7	Bulk Den.A	V19		-.805	-.15	.55	.005
	8	K-rate for max. res.	V51		.306	.20	.61	.005
	9	Temp.(July)	V39		1.671	-.28	.64	.005
	10	Soil H_2O (30-60)	V45		-.176	-.10	.66	.005

Table 10, Continued. Regressions No. 11 - No. 14; Maximum Percent Response (V50) as the Dependent Variable; Data File Subdivided on Crop; Independent Variable V01-V15 Not Included.

Regression No.	Step into eq.	Variable Name	Variable Number	Constant	Beta	Simple R	R^2	F-sig. level
13 Dependent Var. V50 Independent Vars. V11 to V41, V43 to V49, V51 Subfiles: Divided on crop: barley (49 cases)	1	K-trt.5	V15		.491	.40	.16	.005
	2	K-trt.3	V13		.389	.31	.26	.005
	3	Elevation	V30		.460	.19	.32	.005
	4	K-trt.2	V12		.326	-.04	.41	.005
	5	K-rate for max. res.	V51	-155.51	.207	.33	.45	.005
	6	Temp.(June)	V38		.242	.01	.49	.005
	7	Geog. loc.	V27		.220	-.19	.49	.005
	8	Latitude	V33		.219	.13	.50	.005
	9	Soil H_2O (122-152)	V48		-.373	.04	.51	.005
	10	Soil H_2O (152-183)	V49		.355	.25	.53	.005
14 Dependent Var. V50 Independent Vars V16 to V41, V43 to V49, V51 Subfiles: Divided on crop: overall (222 cases)	1	K-rate for max. res.	V51		.251	.21	.04	.005
	2	Struc. B	V23		-.154	-.12	.06	.005
	3	Elevation	V30		.295	.11	.08	.005
	4	Rainfall	V40		.130	.07	.09	.005
	5	Soil H_2O (90-122)	V47	-50.16	-.196	-.04	.10	.005
	6	Soil H_2O (152-183)	V49		.116	.03	.11	.005
	7	Dry Con.C	V18		.104	.03	.11	.005
	8	Latitude	V33		.233	-.01	.12	.005
	9	Geog. Loc.	V27		.151	-.03	.12	.005
	10	Thickness of B	V28		-.051	-.08	.13	.005

crop as in the previous section (regression No. 11 for winter wheat, No. 12 for spring wheat, and No. 13 for barley). Regression No. 14 was the combined overall regression and corresponded to regression No. 9 in the previous group of regressions. The inclusion of V51 (the K-rate at which maximum response occurred) into these regression analyses was done because the dependent variable (V50) was the one with which it was associated. The other K-rate variables were excluded from these regressions except for in regression No. 13.

Regression No. 12 (spring wheat) and No. 13 (barley) produced the highest R^2 values, .66 and .53, respectively. These values were higher than the corresponding regression R^2 values in the prior group (regression No. 7 and No. 8). The F-significance levels of these regressions were also higher overall, each regression equation being significant at the .005 level. Care must be taken in interpreting the significance of these results as the R^2 and F-values were probably inflated due to the inclusion of variables with missing data into the analysis. However, results indicated a good potential for utilizing certain of these independent variables to predict crop response to K fertilizer.

The K-rate variables (V51, V13, V15) again showed a pronounced positive correlation to the dependent variable. Variable 51 (K rate at which maximum response occurred) was postively correlated in all four regressions. Variable 15 and V13 (high and moderate rates of

K application) in regression No. 13 had Simple R values of .40 and .31, respectively, with the dependent variable (V50).

Rainfall was positively correlated to maximum percent response in both cases in which it appeared in the regression equation (regression No. 11 and No. 14). Elevation (V30) was also positively correlated to percent response in three of the four regression equations. Elevation may have been an important factor with regard to crop response to added K in the way that it may have modified the climatic environment. Elevation may have influenced soil moisture and soil temperature in that wind, rain, and storm patterns may have been affected.

Average temperature in May (V37) and June (V38) were only slightly positively correlated to percent response in regression No. 11 and No. 13. There was a much stronger negative correlation between V38 and average temperature in July (V39) in regression No. 12.

Soil temperature probably influenced crop response to added K differently depending on other existing soil conditions. A positive correlation would be expected to exist between soil temperature and crop response under conditions of adequate soil moisture. Increasing soil temperature in this case would have probably increased ion diffusion of applied K. On the other hand, a negative correlation would have existed between soil temperature and crop response (particularly later in the growing season) if soil moisture was inadequate. In this case, greater soil temperatures could have been associated with drying of the soil profile so that diffusion was reduced. Another aspect of soil temperature is that diffusion of K would normally increase with increasing temperature, allowing native soil K to be more available, thus decreasing the response to supplemental K.

Spring soil moisture (V45, V47, V48, V49) was <u>not</u> consistently correlated to crop response. The greatest correlation, which was .25 between deep soil moisture (V49) and maximum percent response, appeared in regression No. 13. Although spring soil moisture variables appeared in all of the regression equations, they generally entered toward the end of the equation and increased the R^2 values very little.

Structure of the B horizon (V23) was negatively correlated to crop response in regression No. 11 and No. 14. This contradicted results from previous regression groups. It was difficult to explain the effect of soil structure on crop responses, especially considering the way in which the soil structure variables were derived and coded. First, it was impossible to know if grade, size, or type of structure was the dominant influence on crop response. Second, because the structure variables were derived from the SCS soil series description, it was possible that the coding scheme was misleading for these particular soil sites. Horizon depths and designations in the soil series description usually did not correspond to the method of horizon naming and sampling that was done in the field during this study. Also, the soil series description usually described horizon soil structures in terms of a range of structures (e.g. moderate medium angular blocky to strong medium prismatic). It was doubtful that a meaningful interpretation could be derived from the structure variables as they were used in these analyses. For these reasons, structure as an independent variable was removed from subsequent analyses.

Adams and Wilde (1976) added some insight into this problem. They studied the variability in 16 morphological soil properties in a soil mapping unit mapped as one soil series. Maximum variability was observed in structure grade and size and wet consistence. Data showing the variability within soil mapping units should be included in all soil surveys to give users a better understanding of the limits of their ability to generalize. This may be very important when making fertilizer recommendations for areas where limited sampling has led to generalized soil mapping.

Regressions No. 15 - No. 19; V50 or V42 as the Dependent Variable.

Regression No. 15 through No. 19 were different from the previous regressions in that the three structure variables, the average

Table 11. Regression No. 15 - No. 19; Maximum (V50) and Average (V42) Percent Response as the Dependent Variables; Data File Subdivided on Crop; V01 - V15 and Soil Temperature, Rainfall, and Soil Moisture Variables Not Included as Independent Variables.

Regression No.	Step into eq.	Variable Name	Variable Number	Constant	Beta	Simple R	R^2	F-sig. level
15 Dependent Var. V50 Subfiles: Divided on crop: Winter Wheat (133) Independent Var.V16 to V21, V25, V26, V28 to V35, V41	1	Thickness of B	V28		-.186	-.17	.03	.05
	2	Dry Con.B	V17		.145	.08	.05	.05
	3	Elevation	V30	73.82	.164	.16	.07	.05
	4	Bulk Den.A	V19		.147	.12	.09	.025
16 Dependent Var. V42 Subfiles: Divided on crop: Winter wheat (133) Independent Vars. V16 to V21, V25, V26, V28 to V35, V41	1	Dry Con.B	V17		.436	.19	.03	.05
	2	Bulk Den.B	V20	153.89	-.312	.08	.06	.025
	3	Latitude	V33		-.122	-.15	.07	.025

Table 11, Continued. Regression No. 15- No. 19; Maximum (V50) and Average (V52) Percent Response as the Dependent Variables; Data File Subdivided on Crop; V01 - V15 and Soil Temperature, Rainfall, and Soil Moisture Variables Not Included as Independent Variables.

Regression No.	Step into eq.	Variable Name	Variable Number	Constant	Beta	Simple R	R^2	F-sig. level
17 Dependent Var V50 Subfiles: Divided on crop; Spring wheat (36) Independnet Vars. V16 to V21, V25, V26, V28 to V35, V41	1	Slope	V31		.276	.26	.07	----
	2	Elevation	V30		-.003	-.20	.12	----
	3	Water Reg.	V41	94.62	1.256	.15	.19	.10
	4	Tex. cls.	V25		-1.086	-.08	.28	.05
	5	Dry Con.A	V16		.330	.03	.36	.025
18 Dependent Var. 42 Subfiles: Divided on crop: Spring Wheat (36) Independent Vars: V16 to V21, V25, V26, V28 to V35, V41	1	Thickness of B	V28		.485	.32	.10	.10
	2	Aspect	V32		-.511	-.31	.26	.01
	3	Water Reg.	V41	99.46	.293	.12	.32	.01
	4	Slope	V31		.219	.03	.36	.01

Table 11, Continued. Regression No. 15- No. 19; Maximum (V50) and Average (V42) Percent Response as the Dependent Variables; Data File Subdivided on Crop; V01 - V15 and Soil Temperature, Rainfall, and Soil Moisture Variables Not Included as Independent Variables.

Regression No.	Step into eq.	Variable Name	Variable Number	Constant	Beta	Simple R	R^2	F-sig. level
19 Dependent Var. V42 Subfiles: Divided on crop; overall (222) Independent Vars: V16 to V21, V25, V26, V28 to V35, V41	1	Dry Con.B	V17		.100	.11	.01	.10
	2	Latitude	V33	145.09	-.094	-.11	.02	.10

monthly temperature data, the spring soil moisture data, and the rainfall data were excluded from the analyses. This was done to try to increase the statistical validity of the subsequent regression equations, due to extensive missing data in each of these parameters.

Regression No. 15 and No. 16 differ only in that the dependent variable was V50 (maximum percent K response) in the first case and V42 (average percent K response) in the second case for winter wheat. The R^2 and F-significance level indicated very little difference in using V50 or V42 as the dependent variables. Only four variables in the first case and three in the second were significantly ($P = .10$) related to crop yield responses. Dry consistence of the B horizon (V17), however, was the only variable common to both equations. Of the seven variables included in both equations, four of them are related to B horizon characteristics. In both equations and in regression No. 19 as well, bulk density and dry consistence were positively correlated to percent yield response. Increased bulk density probably resulted in a reduction of plant available water, reduced root proliferation, and restriction of native K diffusion. Higher values of dry consistence can be associated with decreased root penetration and utilization of native K, so that a positive response to added K resulted.

A higher R^2 value (.36) was obtained from the spring wheat sites (regression No. 17 and No. 18). But, in regression No. 18

the F-value was more highly significant (.01) than that for regression No. 17 (.025) with V50 as the dependent variable.

Thickness of the B horizon (V28) was positively correlated to crop response in regression No. 18 and negatively correlated in regression No. 15. Again, the effect of the thickness of the B horizon on crop response to added K may have been determined by other factors which modified its effect (e.g. clay content, stored soil moisture).

Water regime was positively correlated to crop response in both cases in which it appeared in the regression equation. This suggests that the soil types which are normally associated with the drier sites tend to show a greater crop response to added K.

Elevation was positively correlated to crop response in regression No. 15 and negatively correlated in regression No. 17. This indicated that elevation, by itself, was not a good parameter for predicting crop response. Its effect on crop response was probably realized by the way in which it interrelated with other factors.

The negative correlation of latitude to crop response in regression No. 16 and No. 19 suggests that temperature in the more northern latitudes may be limiting crop response to added K. Slope was positively correlated to crop response in regression No. 17 and No. 18. Areas with greater slopes are usually associated with drier sites in that groundwater tends to move downslope. If the site aspect was oriented to the south, this drying effect associated with greater slope would be maximized.

Regressions No. 20 - No. 31: V50 or V42 as the Dependent Variable.

Geographic location (V27) appeared as a variable in several of the previously discussed regression groups. It was not clear, however, because of the coding scheme employed, exactly for what reason this variable was important to crop response. In order to try to determine this "reason", the data for the present set of regressions was divided and analyzed both in terms of crop type (V03) and geographic location (V27).

The regression equations for this analysis were grouped in pairs so that each pair concerned the same data set (identified in the regression tables). The only difference was that in the first case of a given pair the dependent variable was maximum percent response (V50), and in the second case it was average percent response (V42).

Regression No. 30 and No. 31 yielded the highest R^2 values, .86 and .72, respectively. For regression No. 30 (maximum percent response as the dependent variable) the F-statistic was more highly significant at the .01 level. Both equations concerned barley experiments in the southeastern part of Montana. Generally these soils tend to be warmer during the growing season, and this is the

Table 12. Regression No. 20 - No. 31; Maximum (V50) and Average (V42) Percent Response as the Dependent Variables; Data File Subdivided on Crop and Geographic Location; Independent Variables Restricted as in Table 11.

Regression No.	Step into eq.	Variable Name	Variable Number	Constant	Beta	Simple R	R^2	F-sig. level
20 Dependent Var. V50 Subfiles: Divided on: Crop -1 Geog. loc.-1 (44) Independent Vars: - same as Regression #15	1	Bulk Den.C	V21	168.73	-.319	-.37	.14	.025
	2	Aspect	V32		-.267	-.17	.18	.025
	3	Dry Con.A	V16		-.274	-.01	.21	.025
	4	Depth to Ca	V29		-.251	-.33	.25	.025
21 Dependent Var. V42 Subfiles: Divided on: Crop - 1 Geog. loc.-1 (44) Independent Vars: - same as Regression #15	1	Bulk Den.C	V21	159.27	-.317	-.35	.12	.025
	2	Dry Con.A	V16		-.431	-.14	.17	.025
	3	Aspect	V32		-.185	-.09	.22	.025
	4	Depth to Ca	V29		-.287	-.26	.25	.05
	5	Dry Con.B	V17		.221	.12	.29	.025

Table 12, Continued. Regression No. 20 - No. 31; Maximum (V50) and Average (V42) Percent Response as the Dependent Variables; Data File Subdivided on Crop and Geographic Location; Independent Variables Restricted as in Table 11.

Regression No.	Step into eq.	Variable Name	Variable Number	Constant	Beta	Simple R	R^2	F-sig. level
22								
Dependent	1	Latitude	V33		.434	.33	.11	----
Var. V50	2	Dry Con.C	V18		-.764	-.32	.27	.05
Subfiles:	3	Bulk Den.A	V19	-306.00	-.899	-.30	.44	.01
Divided on:	4	Aspect	V32		-.657	-.27	.73	.005
Crop-2	5	Water Reg.	V41		-.431	.13	.79	.005
Geog.loc.-1								
(25)								
Independent								
Vars: same as								
Regression #15								
23								
Dependent	1	Aspect	V32		-.829	-.40	.16	.05
Var. V42	2	Bulk Den.A	V19		-.037	-.01	.28	.025
Subfiles:	3	Dry Con.C	V18	121.34	-.749	-.31	.39	.025
Divided on:	4	Depth to Ca	V29		.781	.07	.54	.005
Crop -2	5	Slope	V31		.347	-.02	.60	.005
Geog.loc.-1								
(25)								
Independent								
Vars.: same as								
Regression #15								

Table 12, Continued. Regression No. 20 - No. 31; Maximum (V50) and Average (V42) Percent Response as the Dependent Variables; Data File Subdivided on Crop and Geographic Location; Independent Variables Restricted as in Table 11.

Regression No.	Step into eq.	Variable Name	Variable Number	Constant	Beta	Simple R	R^2	F-sig. level
24 Dependent Var. V50 Subfiles: Divided on: Crop - 1,2,3 Geog. loc.-3 (26) Independent Vars.: same as Regression #15	1	Bulk Den.C	V21		.655	.32	.10	----
	2	Latitude	V33	978.91	-.434	-.07	.21	.10
	3	Aspect	V32		.231	.08	.26	.10
25 Dependent Var. V42 Subfiles: Divided on: crop - 1,2,3 Geog. loc. - 3 (26) Independent Vars: same as Regression #15	1	MAST	V34		.745	.30	.08	----
	2	Tex.Fam.	V26		.474	.13	.25	.05
	3	Bulk Den.A	V19		.231	.11	.30	.05
	4	Slope	V31	-39.99	.331	.07	.33	.10

Table 12, Continued. Regression No. 20 - No. 31; Maximum (V50) and Average (V42) Percent Response as the Dependent Variables; Data File Subdivided on Crop and Geographic Location; Independent Variables Restricted as in Table 11.

Regression No.	Step into eq.	Variable Name	Variable Number	Constant	Beta	Simple R	R^2	F-sig. level
26								
Dependent	1	Elevation	V30		.385	.23	.05	.05
Var. V50	2	Tex. cls.	V25	93.93	-.265	-.002	.07	.10
Subfiles:	3	Dry Con.B	V17		.154	.03	.09	.10
Divided on:								
Crop - 1,3								
Geog. loc. -4								
(77)								
Independent								
Vars: same as								
Regression #15								
27								
Dependent	1	Elevation	V30		.448	.15	.02	----
Vars. V42	2	Tex. cls.	V25		-.355	-.05	.05	----
Subfiles:	3	Dry Con.B	V17	-71.15	.358	.14	.11	.05
Divided on:	4	Latitude	V33		.151	-.06	.13	.05
Crop - 1,3								
Geog. loc.-4								
(77)								
Independent								
Vars: same as								
Regression #15								

Table 12, Continued. Regression No. 20 - No. 31; Maximum (V50) and Average (V42) Percent Response as the Dependent Variables; Date File Subdivided on Crop and Geographic Location; Independent Variables Restricted as in Table 11.

Regression No.	Step into eq.	Variable Name	Variable Number	Constant	Beta	Simple R	R^2	F-sig. level
28								
Dependent	1	Elevation	V30		.421	.24	.06	.10
Vars. V50	2	Tex. cls.	V25	92.79	-.307	-.01	.08	.10
Subfiles:	3	Dry Con.B	V17		.208	.05	.11	.10
Divided on: Crop - 1 Geog.loc.-4 (64) Independent. Vars: same as Regression #15								
29								
Dependent	1	Elevation	V30		.396	.17	.03	----
Var. V42	2	Dry Con.B	V17	89.54	.336	.15	.06	----
Subfiles:	3	Tex. cls.	V25		-.374	-.04	.13	.05
Divided on: Crop - 1 Geog. loc. - 4 (64) Independent Vars: same as Regression #15								

Table 12, Continued. Regression No. 20 - No. 31; Maximum (V50) and Average (V42) Percent Response as the Dependent Variables; Data File Subdivided on Crop and Geographic Location; Independent Variables Restricted as in Table 11.

Regression No.	Step into eq.	Variable Name	Variable Number	Constant	Beta	Simple R	R^2	F-sig. level
30								
Dependent	1	Latitude	V33		.603	.63	.39	.025
Var. V50	2	Aspect	V32		-.392	-.52	.64	.01
Subfiles:	3	Depth to Ca	V29	-403.72	.555	.40	.73	.01
Divided on:	4	Tex. cls.	V25		.392	.06	.80	.01
Crop - 3	5	Bulk Den.B	V20		-.258	-.11	.86	.01
Geog. loc.-4								
(13)								
Independent								
Vars: same as								
Regression #15								
31								
Dependent	1	Depth to Ca	V29		.181	.47	.22	----
Var. V42	2	Temp. Reg.	V35		-.954	-.43	.40	.10
Subfiles:	3	Latitude	V33	98.30	-.014	.37	.57	.05
Divided on:	4	Dry Con.B	V17		.500	.41	.63	.10
Crop - 3	5	Water Reg.	V41		.845	.03	.72	.10
Geog. loc. -4								
(13)								
Independent								
Vars: same as								
Regression #15								

only part of Montana that has soil types with a mesic temperature regime.

Depth to the ca (V29) was positively correlated to crop response in these equations. This indicated that as the horizon of calcium accumulation approached the surface, there was a decreased response to applied K. Perhaps the greater calcium concentration associated with a ca horizon was interfering in some way with K uptake. The literature supports this as a possibility.

Elevation (V30) was a very important variable in this group of regression equations. It was positively correlated to crop response in regression No. 26 through No. 29, which deal with winter wheat and barley and winter wheat alone in geographic location 4. Because elevation did not enter regression No. 30 and No. 31 (barley alone), this effect can be attributed to the winter wheat sites. The possible effects of elevation have already been discussed.

Textural class (V25) entered the regression equations five times (regression No. 26 through No. 30). No consistent correlation to crop response appeared to exist.

Dry consistence of the B horizon (V17) was positively correlated to crop response in all cases in which it appeared in an equation; it also appeared most often in the regression equations. However, dry consistence and bulk density of the Ap (V16 and V19) and Cca horizons (V18 and V21) were most often negatively correlated to crop response. This negative correlation of the Ap horizon to crop response could have involved the possibility that textural differences at the surface of a soil could have governed the effectiveness of broadcast application of K. Hard dry consistence and high bulk densities may not have allowed penetration of surface-applied K.

Aspect (V32) also appeared in six of the regression equations and was negatively correlated to crop response in all cases except one. The interpretation of the effect of aspect on crop response was difficult because of the coding scheme devised. The effect of aspect was no doubt related to how it modified the effect of slope and incidence of incoming radiation (soil temperature). If this was the relationship that existed, then one would have expected a positive correlation between aspect and crop response if most of the experimental sites pertaining to the regression equation had northeast to southeast exposures. One would have expected the opposite correlation if most of the experimental sites had northwest to southwest exposures. This was due to the coding scheme employed (see Figure 1).

Regression No. 22 and No. 23 (spring wheat in geographic location 1) produced the most highly significant results (.005 level). It is interesting to note that the equations have only three variables in common and they appear in a different order. This points out that the nature of the dependent variable exerts some kind of unexplainable influence on the factors which relate to the variability in crop response.

Regressions No. 32 - No. 43: Average Percent Response (V42) as the Dependent Variable.

Some of the percent response (V42) data clearly indicated that a negative response to added K occurred. In some cases there was clearly a strong positive response to applied K. In order to determine what factors might be responsible for this variation in response to added K, the data file for the present set of regressions was divided not only by crop type and geographic location but also be response class (V42). Three response classes were created on the following basis: Subfile 1) 95 percent response and less = negative response; Subfile 2) 96 - 105 percent response = no response; Subfile 3) 106 percent response and greater = positive response.

Regression No. 41, which described the analysis of the spring wheat experiments in geographic locations 1, 2, and 3 in the "no response" class, yielded the highest R^2 value (.93). This was significant at the .005 level. Regression No. 33 produced an R^2 value of .20, also significant at the .005 level. This latter equation described the analysis for all crops in subfile 2 (no response) over all of the geographic locations.

Response class 2 (no response) was described by regressions No. 33, No. 36, No. 39, and No. 41. All of the regression equations

Table 13. Regression No. 32 - No. 43; Average Percent Response (V42) as the Dependent Variable; Data File Subdivided on Crop, Geographic Location, and Percent Response Class; Independent Variables as in Table 11.

Regression No.	Step into eq.	Variable Name	Variable Number	Constant	Beta	Simple R	R^2	F-sig. level
32								
Dependent	1	Depth to Ca	V29		.171	.24	.06	----
Var. V42	2	Latitude	V33		-.503	-.16	.09	----
Subfiles:	3	Tex. Fam.	V26	231.56	-.340	-.13	.15	.10
Divided on:	4	Aspect	V32		.240	.14	.18	.10
Crop - 1,2,3	5	Elevation	V30		-.234	-.08	.22	.10
Geog.loc-1,2,3,4								
%-res. - 1								
(45)								
Independent								
Vars: same as								
Regression #15								
33								
Dependent	1	Elevation	V30		.202	.32	.10	.005
Var. V42	2	Slope	V31		.239	.23	.13	.005
Subfiles:	3	Dry Con.C	V18	97.05	.148	.11	.16	.005
Divided on:	4	Water Reg.	V41		-.295	-.11	.18	.005
Crop, 1,2,3,	5	Tex. cls.	V25		.253	.11	.20	.005
4. Geog.								
loc. - 1,2,3,4								
% res.-2								
(85)								
Independent								
Vars: Same as								
Regression #15								

Table 13, Continued. Regression No. 32 - No. 43; Average Percent Response (V42) as the Dependent Variable; Data File Subdivided on Crop, Geographic Location, and Percent Response Class; Independent Variables as in Table 11.

Regression No.	Step into eq.	Variable Name	Variable Number	Constant	Beta	Simple R	R^2	F-sig. level
34								
Dependent	1	Tex. cls.	V25		.536	.13	.02	----
Var. V42	2	Tex. Fam.	V26		-.493	.06	.04	----
Subfiles:	3	Water Reg.	V41	116.59	.553	.13	.06	----
Divided on:	4	MAST	V34		-.448	.02	.10	.10
Crop-1,2,3	5	Dry Con.C	V18		.278	.11	.12	.10
Geog.Loc-	6	Bulk Den.C	V21		-.198	-.05	.15	.05
1,2,3,4								
% res.-3								
(89)								
Independent								
Vars: Same as								
Regression #15								
35								
Dependent	1	Elevation	V30		-.571	-.43	.19	.05
Var. V42	2	Aspect	V32		-.366	-.31	.25	.05
Subfiles:	3	Bulk Den.A	V19	119.31	-.251	-.14	.35	.05
Divided on	4	Temp.Reg.	V35		-.318	-.05	.39	.05
Crop-1	5	Water Reg.	V41		.230	.09	.43	.10
Geog.Loc.								
1,2,3,4								
%res. -1								
(24)								
Independent								
Vars:Same as								
Regression #15								

Table 13, Continued. Regression No. 32 - No. 43; Average Percent Response (V42) as the Dependent Variable; Data File Subdivided on Crop, Geographic Location, and Percent Response Class; Independent Variables as in Table 11.

Regression No.	Step into eq.	Variable Name	Variable Number	Constant	Beta	Simple R	R^2	F-sig. level
36								
Dependent	1	Depth to Ca	V29		-.292	-.23	.05	.10
Var. V42	2	Latitude	V33		-.303	-.22	.09	.10
Subfiles:	3	Water Reg.	V41	143.01	-.279	-.15	.13	.10
Divided on:	4	Dry Con.C	V18		.240	.02	.16	.10
Crop - 1	5	Dry Con.A	V16		-.187	-.06	.19	.10
Geog.loc.-1,2,3,4								
% res.-2								
(57)								
Independent								
Vars: Same as								
Regression #15								
37								
Dependent	1	Water Reg.	V41		.581	.20	.04	----
Var. V42	2	MAST	V34		-.514	.07	.08	----
Subfiles	3	Dry Con.B	V17	153.41	.219	.19	.13	.10
Divided on:	4	Bulk Den.A	V19		.201	.19	.17	.10
Crop -1	5	Latitude	V33		-.201	-.15	.19	.10
Geog. loc.-								
1,2,3,4								
% res.-3								
(52)								
Independent Vars:								
Same as Regression #15								

Table 13, Continued. Regression No. 32 - No. 43; Average Percent Response (V42) as the Dependent Variable; Data File Subdivided on Crop, Geographic Location, and Percent Response Class; Independent Variables as in Table 11.

Regression No.	Step into eq.	Variable Name	Variable Number	Constant	Beta	Simple R	R^2	F-sig. level
38								
Dependent	1	Dry Con.B	V17		.534	.45	.20	.10
Var. V42	2	Tex. Fam.	V26		.008	-.40	.30	.10
Subfiles:	3	Dry Con.A	V16	123.95	-.247	-.08	.41	.10
Divided on:	4	Dry Con.C	V18		-.546	-.13	.47	.10
Crop-1	5	Tex.cls.	V25		-.703	-.32	.55	.10
Geog.loc.-1								
% res.-3								
(18)								
Independent Vars:								
Same as Regression #15								
39								
Dependent	1	Latitude	V33		-.615	-.27	.08	----
Var. V42	2	Dry Con.A	V16		-.432	-.18	.16	.10
Subfiles:	3	Water Reg.	V41	253.04	-.334	-.14	.25	.05
Divided on:	4	Dry Con.C	V18		-.255	-.03	.30	.05
Crop - 1								
Geog. loc.-4								
% res.-2								
(31)								
Independent Vars:								
Same as Regression #15								

Table 13, Continued. Regression No. 32 - No. 43; Average Percent Response (V42) as the Dependent Variable; Data File Subdivided on Crop, Geographic Location, and Percent Response Class; Independent Variables as in Table 11.

Regression No.	Step into eq.	Variable Name	Variable Number	Constant	Beta	Simple R	R^2	F-sig. level
40								
Dependent	1	Dry Con.C	V18		.521	.27	.07	----
Var. V42	2	Latitude	V33		.888	.15	.11	----
Subfiles:	3	Dry Con.B	V17	-972.77	1.599	.13	.16	----
Divided on:	4	Elevation	V30		1.728	.04	.28	----
Crop - 1	5	Tex. cls.	V25		-1.400	.05	.48	.025
Geog.loc.-4								
% res.-3								
(27)								
Independ. Vars.:								
Same as Regression #15								
41								
Dependent	1	Dry Con.C	V18		.649	.78	.61	.005
Var. V42	2	Elevation	V30		.246	.75	.79	.005
Subfiles:	3	Bulk Den.B	V20	96.33	-.589	-.31	.89	.005
Divided on:	4	Bulk Den.C	V21		.319	.34	.91	.005
Crop - 2	5	Water Reg.	V41		.157	-.33	.93	.005
Geog.loc.-1,2,3								
% res. - 2								
(16)								
Independent Vars.:								
Same as Regression #15								

Table 13, Continued. Regression No. 32 - No. 43; Average Percent Response (V42) as the Dependent Variable; Data File Subdivided on Crop, Geographic Location, and Percent Response Class; Independent Variables as in Table 11.

Regression No.	Step into eq.	Variable Name	Variable Number	Constant	Beta	Simple R	R^2	F-sig. level
42								
Dependent	1	Depth to Ca	V29		-.482	-.51	.26	.01
Var. V42	2	Elevation	V30	99.33	.359	.34	.34	.01
Subfiles:	3	Aspect	V32		.307	.22	.43	.01
Divided on:								
Crop -3								
Geog.loc.-1,3,4								
% res.-3								
(25)								
Independ. Vars.:								
Sames as Regression #15								
43								
Dependent Var. V42	1	Thickness of B	V28	130.08	-.551	-.55	.30	.05
Subfiles:								
Divided on:								
Crop - 3								
Geog. loc.-1								
% res. - 3								
(16)								
Independ. Vars.:								
Same as Regression #15								

included dry consistence of the Cca horizon (V18) and moisture regime (V41). Moisture regime was consistently negatively correlated to crop response. This suggests that added K may not produce as great a response on soils that normally are of the drier regimes.

Dry consistence of the Cca horizon was positively correlated to crop response in three of the four regressions. In regression No. 41, bulk density of the Cca horizon was also positively correlated to crop response. Perhaps this indicates that in soils with more easily penetrable subsoils, a response to added K is not likely to occur. This may be due to the fact that native soil K was utilized more readily from the subsoil horizons.

Latitude (V33) was negatively correlated to crop response in regression No. 36 and No. 39. The reason that the "no response" class is negatively correlated to latitude is open for speculation. It could be that the effect of latitude was temperature related. At any rate, it was interesting that latitude was more negatively correlated in the "no response" class (regression No. 36 and No. 39) and negative response class (regression No. 32) and positively correlated in the positive response class (regression No. 40).

Another trend appeared with respect to the depth to the Cca horizon (V29). In the negative response class (regression No. 32), V29 was strongly positively correlated to crop response. However, in the no response class (regression No. 36) and positive response class (regression No.42), there was a strong negative correlation between crop response and depth to the Cca. This relationship suggested that added K fertilizer was more likely to cause a positive response under conditions of high $CaCO_3$ accumulation nearer to the soil surface.

The positive response class was described by regression No. 34, No. 37, No. 38, No. 40, No. 42, and No. 43. In this class, moisture regime (V41) and MAST (V34) were both positively correlated to crop response. This again indicated that soils which tended to be warmer and drier throughout the year showed a greater positive response to added K.

Textural class (V25) and textural family (V26) appeared to be inconsistently correlated to crop response between regression equations in response class 3 (e.g. regression No. 34 vs. No. 38). However, both variables were consistently correlated within a regression equation. This perhaps indicated that other factors were responsible for modifying the effects of texture and that crop response was dependent on these other factors as well. Dry consistence of the B horizon (V17) was again positively correlated to crop response in all three regression equations (No. 37, No. 38, and No. 40) in which it appeared. The implications of this relationship have already been discussed.

Regression No. 43 included only one significant variable (V28).

Thickness of the B horizon was strongly negatively correlated to crop (barley) response, and this variable alone accounted for 30 percent of the observed variation in response.

Regressions No. 44 - No. 47: Maximum Response (V50) as the Dependent Variable.

The data file for regressions No. 44 through No. 47 was divided according to the K rate at which the maximum crop response occurred. This was done to investigate whether different factors were important to response depending on rate of applied K.

The data subfiles were created as follows : Subfile 1) 11-39 kg K/ha; Subfile 2) 45-67 kg K/ha; Subfile 3) 81-96 kg K/ha; Subfile 4) 112-128 kg K/ha; and Subfile 5) 134 kg K/ha. None of the regression equations corresponded to subfile 2 (which included only those experiments in which maximum percent response was attained at 45-67 kg K/ha applied K) since no significant results were obtained.

The regression equation (No. 47) dealing with the highest rate of added K produced the highest R^2 value (.40). The highest F-significance level (.025) in this equation was actually achieved in step 4 (R^2 = .36). Regression No. 45 and No. 46, which dealt with subfile 3 and subfile 4, respectively, as explained above, also were significant at the .025 level.

Textural class (V25) appeared in three of the four regression

Table 14. Regression No. 44 - No. 47; Maximum Percent Response (V50) as the Dependent Variable; Data File Subdivided on K-rate at Which Maximum Response Occurred (V51); Independent Variables as in Table 11.

Regression No.	Step into eq.	Variable Name	Variable Number	Constant	Beta	Simple	R^2	F-sig. level
44 Dependent Var. V50 Subfiles: Divided on V51 (S1) cases: 43 Independent Vars: V16 to V21, V25, V26, V28 to V35, V41	1	Elevation	V30		.453	.34	.12	.05
	2	Dry Con.C	V18		.115	.05	.18	.025
	3	Thickness of B	V28	37.26	-.354	-.26	.21	.05
	4	Tex. cls.	V25		-.274	.06	.25	.05
	5	Bulk Den.C	V21		.242	.15	.27	.05
45 Dependent Var. V50 Subfiles: Divided on V51 (S3) cases: 41 Independent Vars: V16 to V21, V25, V26, V28 to V35, V41	1	Latitude	V33		.631	.31	.10	.05
	2	Tex.cls.	V25		.592	.05	.16	.05
	3	Aspect	V32	-323.36	-.305	-.14	.22	.05
	4	Bulk Den.C	V21		.312	.12	.28	.025
	5	Dry Con.A	V16		.203	.03	.31	.025

Table 14, Continued. Regression No. 44 - No. 47; Maximum Percent Response (V50) as the Dependent Variable; Data File Subdivided on K-rate at Which Maximum Response Occurred (V51); Independent Variables as in Table 11.

Regression No.	Step into eq.	Variable Name	Variable Number	Constant	Beta	Simple R	R^2	F-sig. level
46 Dependent Var. V50 Subfiles: Divided on V51 (S4) cases: 42 Independnet Vars: V16 to V21, V25, V26, V28 to V35, V41	1	Water Reg.	V41	101.50	.242	.38	.15	.025
	2	Temp. Reg.	V35		-.020	.003	.20	.025
	3	Aspect	V32		.208	.19	.23	.025
	4	Tex. Fam.	V26		.349	.36	.26	.025
	5	Dry Con.C	V18		-.290	-.15	.30	.025
47 Dependent Var. V50 Subfiles: Divided on V51 (S5) cases: 29 Independent Vars: V16 to V21, V25, V26, V28 to V35, V41	1	Latitude	V33	-29.70	.270	.27	.07	----
	2	Tex. cls.	V25		1.282	.21	.17	.10
	3	Tex. fam.	V26		-1.036	-.03	.33	.025
	4	Temp. Reg.	V35		.224	.14	.36	.025
	5	Slope	V31		.205	.02	.40	.05

equations and was most strongly positively correlated to crop response at the highest rate of applied K. Textural family (V26) was also strongly positively correlated to crop response in regression No. 46 which was also concerned with the higher rates of applied K. This indicates that the more finely textured soils show a more positive response to high rates of applied K.

Bulk density and dry consistence of the Cca horizon appeared in regression No. 44, No. 45 and No. 46. Both of these variables seemed to be more positively correlated to crop response at the lower rates of applied K. In regression No. 46 (higher K rate class), dry consistence of the Cca was negatively correlated to response. This suggests that perhaps the lower rates of applied K have more of a positive effect on response as the subsoil horizons become more impenetrable.

Temperature regime (V35) and moisture regime (V41) appeared in the regression equations (No. 46 and No. 47) at the higher rates of applied K. The general positive correlation of these variables to crop response indicates that the higher rates of K are more effective on the warmer and drier soil types.

Aspect (V32) appeared in regression No. 45 and No. 46 (maximum percent response as the dependent variable) as an important variable. It was negatively correlated to crop response in one case and positively correlated in the other. The problem, as discussed earlier, with regard to the coding scheme for aspect, could explain this phenomenon.

It should be pointed out that one class or rate of applied K did not dominate the determination of the maximum response variable (V50). This indicates that factors such as soil type and/or soil conditions may dictate the most effective rate of K application.

Regression No. 48: Average Percent Response (V42) as the Dependent Variable.

The fact that much of the growing season temperature data, rainfall data, and spring soil moisture data were missing, indicated that statistical validity of previous results in which they were included in the regression equation was questionable. To determine a more accurate interpretation of the importance of these variables to crop response, a regression analysis option was used to include only those cases which had a complete set of data for these variables. Only growing season temperature data (V37, V38, V39), rainfall (V40), and cumulative spring soil moisture to 122 cm. (V52), V53), V54, V55) were included as independent variables in the analyses.

The results showed that only average temperature in May (V37) and rainfall (V40) entered the regression equation. Temperature in May by itself produced an R^2 value of .17 and was strongly negatively correlated to crop response. This indicated that low soil temperatures early in the growing season may have limited uptake of native K. One

Table 15. Regression No. 48; Average Percent Response (V42) as the Dependent Variable; Data File Restricted to Include Only Cases With Complete Data; Independent Variables Restricted to Soil Temperature, Rainfall, and Cumulative Soil Moisture Variables.

Regression No.	Step into eq.	Variable Name	Variable Number	Constant	Beta	Simple R	R^2	F-sig. level
48 Dependent Var. V42 Subfiles: All; cases: 41 Independent Vars: V37 to V40, V52 to V55	1	Temp.(May)	V37		-.467	-.42	.17	.01
	2	Rainfall	V40	126.37	-.172	-.03	.20	.025

would probably have observed a positive response to added K if this was the case. These results were in accord with observations discussed earlier by Boatwright *et al.* (1976).

Regressions No. 49 or No. 50; Maximum (V50) and Average (V42) Percent Response as the Dependent Variable.

The same regression analysis was performed with a different dependent variable in each case (V50 and V42, respectively). The set of independent variables was the same in both cases. The independent variable set included all of those variables used in regression No. 48 with the addition of those variables (V16 to V21, V25, V26, and V28 to V35) used in the majority of the regression analyses. A more statistically valid regression analysis option was again used to only include those cases for which there was a complete data set for the variables included.

Dry consistence of the Cca horizon (V18), temperature in May (V37), and rainfall (V40) appeared in both regression equations. Both equations were significant at the .05 level. The R^2 values for both equations were similar at .33 and .34, respectively.

All of the variables that entered the two equations which were related to soil physical properties, dry consistence of the Cca horizon, bulk density of the Ap horizon, textural family, and thickness of the B horizon (V18, V19, V26, and V28, respectively) were all positively correlated to percent response. These results

Table 16. Regression No. 49 and No. 50; Maximum (V50) and Average (V42) Percent Response as the Dependent Variables; Data File Restricted to Include Only Cases With Complete Data; Independent Variables as in Table 11 and Table 15 Combined.

Regression No.	Step into eq.	Variable Name	Variable Number	Constant	Beta	Simple R	R^2	F-sig. level
49								
Dependent Var. V50 Subfiles: All, cases: 32 Independent Vars.- V16 to V21, V25, V26, V28 to V35, V37 to V40, V41, V52 to V55	1	Dry Con.C.	V18		.317	.37	.13	.05
	2	Bulk Den.A	V19		.367	.11	.17	.10
	3	Rainfall	V40	53.12	-.315	-.05	.23	.10
	4	Thickness of B	V28		.278	.29	.29	.05
	5	Temp.(May)	V37		-.240	-.33	.33	.05
50								
Dependent Var. V42 Subfiles: All, cases: 32 Independent Vars. - V16 to V21, V25, V26, V28 to V35, V37 to V40, V41, V52 to V55	1	Dry Con.C	V18		.596	.41	.17	.025
	2	Tex. Fam.	V26		-.380	.11	.22	.05
	3	Temp.(May)	V37	102.36	-.223	-.41	.26	.05
	4	Rainfall	V40		-.344	-.03	.30	.05
	5	Soil H_2O (0-90)	V54		.244	.12	.34	.05

suggest that as clay content increases (associated with hard consistence of the Cca, greater thickness of the B horizon, and a positive correlation to textural family as coded coarse to fine), a more positive response to added K results.

The negative correlation of temperature in May (V37) to percent response was consistent with regression No. 48 and has been discussed. The fact that cumulative soil moisture to 90 cm. (V54) appeared in regression No. 50 indicated that soil moisture was important with regard to crop response to added K. The positive correlation of this moisture variable to response suggests that without adequate moisture diffusion of applied K to the plant root will not occur. Rainfall, another moisture variable, was not clearly correlated to crop response; but its appearance in both equations proved that it did account for some of the variability in response to added K.

Regression No. 51: MAST (V34) as the Dependent Variable.

Schaff (1979) determined that MAST was the most important variable in relating to percent change in yield of winter wheat to applied K fertilizer. This factor alone accounted for 56 percent of the observed variability in percent change in yield.

Because of the importance of this variable in Schaff's regression analyses, it was of interest to try to determine why MAST did not

Table 17. Regression No. 51; MAST (V34) as the Dependent Variable; Data File Subdivided on Crop; Independent Variables Restricted as in Table 11.

Regression No.	Step into eq.	Variable Name	Variable Number	Constant	Beta	Simple R	R^2	F-sig. level
51								
Dependent	1	Water Reg.	V41		.511	.82	.68	.005
Var. V34	2	Latitude	V33		-.133	-.51	.73	.005
Subfiles:	3	Tex. Fam	V26	15.56	.299	.65	.75	.005
Divided on:	4	Temp. Reg.	V35		.243	.47	.77	.005
Crop - 1	5	Dry Con. C	V18		-.162	.03	.79	.005
Cases : 133								
Independent Vars. Same as Regression #15								

appear more often in the regression equations in this study. Regression No. 51 was performed with MAST (V34) as the dependent variable. The independent variable set was that utilized in the majority of the regression analyses, in other words, that set which excluded variables with a large amount of missing data.

MAST was highly positvely correlated with moisture regime (V41), textural family (V26), and temperature regime (V35). It was also highly negatively correlated to latitude (V33). The regression equation showed that these four variables alone accounted for 77 percent of the observed variability in MAST (.005 significance level). Because of this relationship, it was not surprising that MAST did not appear more often in the regression equations. Other independent variables, particularly water regime (V41), probably accounted for the same variability in crop response as MAST.

Regression Equations - Summary

Table 18 summarizes the correlations (Simple R) of each independent variable used in the regression equations with the dependent variables, which are yield (V06 to V10) and average (V42) and maximum (V50) percent response. Table 18 also summarizes the relative overall importance of each independent variable, based on the number of times that each of them enters a regression equation and the frequency of entry (number of times included as an independent variable divided by the number of times of entry into the equation).

Table 18. Overall Correlations of the Independent Variables with the Dependent Variables - Yield (V06 - V10) and Maximum (V50) and Average (V42) Percent Yield Response.

Variable Name	Variable Number	Simple R (+)	Simple R (-)	No. of Regressions included as a Variable	No. Times Variable Entered Regression	Entry Frequency into Regression Equation (%)
Site	V01	1	3	9	4	44
Crop	V03		3	5	3	60
Year	V04	2	2	9	4	44
K-rate 2	V12	2	2	7	4	57
K-rate 3	V13	3		7	3	43
K-rate 4	V14	2		7	2	29
K-rate 5	V15	4		7	4	57
Dry Con. A	V16	6	8	50	14	28
Dry Con. B	V17	16	1	50	17	34
Dry Con. Cca	V18	10	5	50	15	30
Bulk Den. A	V19	4	8	50	12	24
Bulk Den. B.	V20	4	3	50	7	14
Bulk Den.Cca	V21	5	4	50	9	18
Struc. A	V22	1		15	1	7
Struc. B	V23	4	2	15	6	40
Struc. Cca	V24	1		15	1	7
Tex. cls.	V25	9	6	50	15	30
Tex. Fam.	V26	4	3	50	7	14
Geog. Loc.	V27	2	3	15	5	33
Thickness B	V28	4	5	50	9	18
Depth to Ca	V29	4	5	50	9	18
Elevation	V30	15	4	50	19	38
Slope	V31	7	2	50	9	18
Aspect	V32	6	8	50	14	28
Latitude	V33	7	10	50	17	34
MAST	V34	6		49	6	12
Temp. Regime	V35	3	3	50	6	12
Temp. (May)	V37	3	6	18	9	50
Temp. (June)	V38	4	2	18	6	33
Temp. (July)	V39	2	1	18	3	17
Rainfall	V40	6	4	18	10	56
Water Regime	V41	11	4	50	15	30
Soil H_2O (0-30)	V44	3	1	15	4	27
Soil H_2O (30-60)	V45	1	2	15	3	20
Soil H_2O (60-90)	V46	1		15	1	7
Soil H_2O (90-122)	V47	2	4	15	6	40
Soil H_2O (122-152)	V48	1	2	15	3	20
Soil H_2O (152-183)	V49	4	2	15	6	40
K-rate of Max. Response	V51	4		4	4	100
Soil H_2O (0-90)	V54	1		3	1	33

The variables entering the regression equations most often were elevation (V30 - 19 times), latitude (V33) and dry consistence of the B horizon (V17 - 17 times), dry consistence of the Cca horizon (V18), textural class (V25), and dry consistence of the Ap horizon (V16) and aspect (V32 - 14 times). The most consistently correlated variables in the regression equations were the K-4ate variables (V13, V14, V15, V51), MAST (V34), dry consistence of the B horizon (V17), elevation (V30), slope (V31), and moisture regime (V41).

The K-rate variables were consistently positively correlated to crop response, indicating that applied K generally caused increased yields. MAST and moisture regime were also consistently positively correlated to crop response, suggesting that applied K was generally more effective on soil types associated with the warmer and drier sites.

Slope was also consistently positively correlated to crop response. This relationship may be related to moisture availability (drier sites) or to a slope-aspect interaction in which the incidence of incoming radiation may have affected soil temperature trends.

Overall, dry consistence and bulk density throughout the soil profile seemed to be very important with regard to crop response to added K. Dry consistence of the B horizon (V17) was the most important factor relating to crop response and was also the most consistently correlated variable (Simple R) to crop response. Dry consistence of the B and Cca horizons are generally positively correlated to crop response whereas dry consistence and bulk density of the A horizon appear slightly negatively correlated to crop response.

If one assumes that increased dry consistence values can be associated with greater clay contents and decreased ease of K diffusion, root penetration, and exploitation of native soil K reserves, then the positive correlation between crop response and the harder subsoil horizons seems reasonable. The fact that bulk density and dry consistence of the Ap horizon appeared more negatively correlated to crop response perhaps suggests that the effectiveness of applied K (usually broadcast) was limited by compacted surface horizons which would have retarded diffusion of applied K into the soil profile.

Table 19 summarizes the responses to applied K by crop and geographic location for all of the experiments included in this study. Although oats showed the highest percentage of experiments with a positive response to applied K, there were only four experiments which used oats as the experimental crop. The other three crops are similar in the percentage of experiments of each which responded positively to applied K.

Winter wheat experiments in geographic location 4 had the

Table 19. Summary of Small Grain Response to Applied K Fertilizer, Montana Statewide Study, 1968-1980.

Crop	No. of Experiments	No. with Positive K-Response	% Positive Response	No. with Negative K-Response	% Negative Response	Range of % K Response	Geo. Loc. (V27)	Average % K - Response
Winter Wheat	133	90	68	43	32	81-122	1	102
						85-121	2	101
						88-117	3	101
						83-153	4	106
Spring Wheat	36	22	61	14	39	80-115	1	100
						110	2	110
						96-120	3	106
							4	
Barley	49	31	63	18	37	61-146	1	106
							2	
						90-118	3	104
						89-118	4	104
Oats	4	4	100	0	0	102-109	1	106
						108-110	2	109
							3	
							4	

Table 20. Number of Experiments at the Various Rates of Applied K at Which Maximum Percent K Response Occurred.

Rate at Which Maximum K-Response Occurred (V51)	Number of Experiments
- kg K/ha -	
11	3
13	2
22	12
27	2
28	22
34	1
39	1
45	37
48	11
54	2
56	11
57	4
67	2
81	2
90	32
96	7
112	32
115	9
128	1
134	29
	222

highest average percent K response (106 percent) for that crop. Spring wheat showed a higher average percent response in geographic location 3 (106 percent) than in geographic location 1 (100 percent). Barley showed a greater average percent response in geographic location 1 (106 percent) yet also showed a much greater variability in response in this area (61 - 146 percent).

Table 20 shows the number of experiments which produced maximum percent K response at each rate of applied K. It was interesting to note that in about half of the experiments the crops responsed to their maximum at applied K rate of 90 kg K/ha and above. This is conclusive evidence that in many cases availability of native soil K is not adequate for the nutrition of small grains. It further points out that crop responses to added K fertilizers may not be measured in many field experiments due to inadequate rates of application in the experiments.

Chapter 5

SUMMARY AND CONCLUSIONS

From 1968 to 1980, numerous small grain soil fertility experiments in which applied K fertilizer treatments were involved were established around the State of Montana. Two hundred twenty-two of these experiments established on 127 different site locations were selected to study the influence of soil profile and site characteristics and soil classification parameters on yield and crop response to applied K fertilizer. From two to five rates of K, ranging from 0 (control) to 134 Kg K/ha, were applied in the experiments studied.

Sites were classified as to their soil series using the legal description of the site along with the appropriate SCS county soil survey, or by using the series name associated with an experiment as reported in the Montana Agricultural Experiment Station Annual Report. Eight variables (classification parameters) were included in the regression analyses as determined from the SCS soil series description.

Soil samples from each of three horizons identified as the Ap, B, and Cca horizons were taken at each of the 127 sites. Dry consistence and bulk density measurements were obtained for each soil horizon sample. Site characteristics including slope, aspect, elevation and latitude were also recorded and introduced as variables in the regression analyses.

Spring soil moisture data, rainfall data, and soil temperature data were obtained from the Montana Agricultural Experiment Station Annual Report and introduced as variables in the regression analyses. However, many of the experiments did not include soil moisture and temperature data.

A total of 48 independent variables in varying combinations were inserted into multiple linear stepwise regression programs with actual crop yield or percent change in yield as the dependent variable. Percent change in yield was determined both as an average and maximum percent figure.

Over 60 regression analyses were performed with varying combinations of independent and dependent variables. The data file was divided in many cases so that the regression equations usually only pertained to a selected part of the data file. The data file was subdivided according to: 1) crop (winter wheat, spring wheat, barley, and oats); 2) crop and four geographic locations (see Figure 2); 3) crop, geographic location and percent response class (see Results and Discussion section - page 74 under Regressions No. 32 - No. 43); and 4) K rate at which maximum response occurred (V51). Fifty-one of these regression equations produced significant results ranging from .10 to .005 significance level. These regression equations are presented in the Results and Discussion Section of this thesis in Table No. 8 through Table No. 17.

Regression equations No. 1 through No. 5, which utilized actual crop yield as the dependent variable and included ten variables each, all produced R^2 values significant at the .005 level.

Regression equations No. 6 through No. 10 (average percent response as the dependent variable) and regression equations No. 11 through No. 15 (maximum percent response as the dependent variable) also included ten variables each; and the regression equations also all produced R^2 values significant at the .005 level. The significance of these results is probably inflated due to the inclusion of spring soil moisture, rainfall, and soil temperature variables which had extensive amounts of missing data. Regression No. 4 and No. 5 (actual crop yield as the dependent variable) are of special interest, though, in that the first two variables into the equation (K-treatment and bulk density of the Ap horizon) by themselves produced R^2 values of .76 and .68, respectively.

Regression No. 15 through No. 17 are similar in that the same restricted set of independent variables was used in these analyses. The set of independent variables was restricted in that soil moisture (V43 - V49 and V52 - V55), soil temperature (V36 - V39) and rainfall (V40) variables were removed from the analyses due to the large amount of missing data for these variables. The dependent variables used in these analyses were either the average (V42) or maximum (V50) percent response. The most significant results (.005 level) were produced by regression equations: No. 22, which measured the relationship of maximum percent response of spring wheat in geographic location 1[1/]; No. 23, which measured the relationship of average percent response of spring wheat in geographic location 1; No. 33, which measured the relationship of average percent response in experiments which included all four crops over all four geographic locations and that had average percent response values between 96 and 105; and No. 41, which measured the relationship of average percent response in experiments which dealt with winter wheat in geographic locations 1, 2, and 3 that had average percent response values between 96 and 105. These regression equations produced R^2 values of .79, .60, .20, and .93, respectively, with five variables included in each equation. The only variable to appear in <u>all</u> of these equations was dry consistence of the Cca horizon (V18).

Regression No. 49 and No. 50 (V50 and V42 as the dependent variable, respectively) were produced with a restricted regression program option in which only those cases (experiments) with a complete data set were included in the analysis. The independent variable set was again expanded to include soil temperature, rainfall, and cumulative spring soil moisture variables. These regression equations produced R^2 values of .33 and .34 respectively (.05

[1/] See Figure 2.

significance level). Dry consistence of the Cca horizon (V18), rainfall (V40), and average soil temperature in May (V37) were the only variables to appear in both regression equations.

Elevation (V30) entered the regression equations more than any other variable and was most often positively correlated to crop response to applied K. The effect of elevation on crop response may be related to its influence on climatic factors such as moisture and temperature, but ascertaining its importance at this point is merely speculative.

Dry consistence of the B horizon (V17) is consistently positively correlated to crop response to added K. This relationship may have to do with the decreased ability of roots to penetrate into subsoil horizons with a hard dry consistence or for native soil K to readily diffuse to crop roots. If this is so, then the plant's ability to utilize native soil K would be limited and a response to added K would be likely.

Consistence is no doubt a measurement that integrates the effects of other factors such as clay content, clay type, and bulk density. It will be important in the future to quantitatively determine exactly how these various factors interact to influence the consistence measurement.

Schaff (1979) determined that clay content of the ca horizon was one of the five most important factors influencing winter wheat response to added K. The importance of the dry consistence of the Cca horizon (V18) in the present study corroborates his observation and gives credence to the idea that clay content and consistence are directly related to one another.

The relationship of soil structure to crop response to added K is not clearly defined in this study. However, the structure of the B horizon (V23) appears to be very important with regard to yield variability. In regression No. 1, No. 2 and No. 3, it is strongly positively correlated to actual crop yield, which was the dependent variable in these regression equations.

Because of the coding scheme used for the soil structure variables, it was difficult to ascertain the exact effect of soil structure on yield; but the indication was that greater yields were associated with the stronger, more coarsely structured soils. Perhaps this effect was related to better root penetration and exploitation of the soil environment along the planes of separation between adjacent peds associated with well structured soils.

Other soil classification parameters accounted for much of the variability in crop response to added K. Moisture regime and mean annual soil temperature were two classification parameters that were consistently positively correlated to crop response. That is, the warmer and drier soils were associated with greater response to added K. Temperature regime was also an important soil classification parameter that appeared in the regression equations, but it was not as consistently correlated to crop response.

Textural class and textural family both were significantly related to crop response to applied K in a number of the regression equations. The general trend was for the fine textured soils to respond to a greater degree than the more coarse textured soils. This was consistent with most of the literature which indicated that as clay content of the soil increased, more total soil K was required for adequate supply to the plant to be maintained.

The above soil classification parameters may be easily determined in the field or from a soil series description. The indication was that all or some of these parameters could be incorporated into a reliable K soil test procedure.

The K rate variables were the most consistently correlated variables to crop response. The high positive correlation of K rate to crop response indicated that, in many soils, adequate availability of native soil K did not exist. However, approximately one-third of the total number of experiments in this study either showed no response or a negative response to applied K. In some cases the negative response was pronounced. This suggested that for a given set of existing soil conditions, there was an optimum rate of K which should be applied to achieve maximum crop response. If the availability of native soil K was adequate, it is possible that added K may have interfered with the uptake of some other nutrient. It is important to know when and where this type of adverse effect is likely to occur.

Schaff (1979) found a positive correlation between the concentration of extractable Ca^{++} in both the 1st and 2nd horizons and percent yield response. It was the most highly related chemical factor to percent yield response of winter wheat to K fertilizer. In the present study, depth to the Cca horizon (V29) was an important factor relating to crop response to applied K. It is possible that the calcium concentration in the soil solution may have affected diffusion of soil K by influencing the ionic concentration of K.

A high calcium concentration may have interfered with other primary nutrients also. Phosphorus, for example is considered to be more limiting for small grains than potassium. Calcium is known to convert phosphorus into forms unavailable to plants and, thus, could indirectly influence plant K needs as well. This indirect influence may be related to decreased demand and uptake of K with decreased phosphorus availability.

Rainfall during the growing season was also important with regard to crop response to applied K. Rainfall was not consistently correlated to yield response because its influence was probably modified by other existing soil conditions, such as amount of spring soil moisture. The time and distribution of rainfall was also probably important and could explain variations in response to applied K. These considerations were not part of this study.

Soil temperature and moisture were important with regard to crop response to added K. Temperature in May (V37) was most often negatively correlated to crop response, suggesting that low spring temperatures controlled and probably retarded diffusion of native soil K to the plant root. Added K would have increased the soil solution K concentration and increased K diffusion under these circumstances.

Rather than soil moisture or temperature being the primary influence on crop response by itself, it was probably an interaction of these two factors which partially governed the effect of added K. An abundance of soil moisture would tend to prolong low spring soil temperatures by increasing the specific heat of the soil. On the other hand, the absence of adequate soil water would allow the positive effect of temperature on diffusion to be realized yet may have adversely affected the K concentration in the soil solution and limited K diffusion.

This study has shown the importance of soil temperature and moisture upon crop response to added K. However, significance of these relationships were limited by the fact that many of the experiments did not include soil moisture, rainfall, and soil temperature data collection. All future experiments should include the collection of these data as part of the standard experimental procedure. These factors are critical to dryland agriculture in Montana, and indications are that these factors highly influence crop response to added K fertilizer.

The effects of soil moisture and temperature on crop response will undoubtedly also be influenced by soil texture and other soil physical properties. Clay content, clay type, and bulk density are known to influence ion diffusion in soils. It is the interaction of _all_ of these factors which will ultimately determine crop response to added K.

It is essential that future studies be directed toward quantitatively determining the nature of these interrelationships. The relative importance of each of these factors will vary, and each of them could probably be considered to be limiting K diffusion and crop response depending on a given _set_ of soil conditions. The regression equations substantiate this conclusion in that the correlation (simple R) between crop response and these climatic and physical factors varied from one regression to another in many cases.

It is important to realize that this study was limited in that many factors which could affect crop response to added K were _not_ considered or included as variables. Management techniques, for example, may have a direct influence on crop response. The fact that bulk density of the Ap horizon was an important variable in many of the regression equations suggested that compaction problems on some soils may have existed as a result of time, amount, and kind of cultivation employed. Also, time of fertilizer application (spring vs. fall) and seeding date are two important variables which were not considered in this study.

Raychaudhuri (1976) found that in high potassium-fixing soils, recovery of applied K by the crop was appreciably lower from broadcast than from band application. Application of K in two or three split doses was found to be superior to a single basal dressing, depending on the soil texture and predominant clay type. Method and time of K fertilizer application, as well as type of K fertilizer applied (e.g. KCl vs. K_2SO_4), were variables not included in this study.

Kowalenko and Ross (1980) observed that the presence of K^+ depresses NH_4^+ fixation, and that fixed ammonium established some kind of equilibrium with exchangeable NH_4^+ over time. It is known that NH_4^+ and K^+ act similarly in the soil environment under certain circumstances. This is due to the fact that the ions are of equal valence and approximate ion size. The type and amount of N fertilizer was variable from one experiment to another in this study, and the influence of this difference was unknown.

McLean (1976) made some interesting observations with regard to K fixation and release. Potassium release, which became progressively smaller in magnitude with time, was eventually exceeded greatly by the capacity of the clay to fix added K in non-exchangeable form. He believed both processes occurred simultaneously, and it was not always known which predominated for a given soil. Therefore, there was always uncertainty as to how to take them into account when making a K recommendation based on soil tests. He concluded that it was particularly the fine textured alluvial or lakebed soils with a predominance of micaceous illitic clay that varied the most in K release and fixation, depending on the degree of original weathering and recent cropping conditions.

The weathering of clay particles probably varies from year to year in Montana in that soil moisture, snow cover, and the depth to which a soil freezes vary. Temperature effects have been shown to be important with regard to K fixation and release. A better understanding of these mechanisms will enhance the predictability of crop response to added K.

Willis and Power (1975) point out that soil temperature has a dominant influence on plant growth, both directly and indirectly. Whether temperature has a direct or indirect effect is, however, a moot question, particularly because we are primarily interested in some yield function; and the plant acts as an integrator of many individual factors.

Diffusion is the primary mechanism by which K reaches the plant root. Diffusion of K in the soil environment is no doubt governed by the interaction of many important factors. This study has established that known or easily determined soil and site characteristics are significantly correlated to crop response to K fertilizer and do indeed influence the process of diffusion.

The results of this study indicate that many of the significant variables could be incorporated for use in a K soil test. The parameters which accounted for much of the variation in crop response to applied K fertilizer can be easily determined in the field, from a soil series description, or from a soil sample taken for limited laboratory analysis.

Moisture content and soil temperature are known to influence diffusion. The way in which site characteristics (e.g. slope and aspect) and soil physical properties, such as bulk density, consistence, structure, and texture, modify the influence of moisture and temperature will allow for better understanding the soil environment in which K diffusion must occur.

APPENDICES

APPENDIX I