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
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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 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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## 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.