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# SOIL-SOLUTION EQUILIBRATION PARAMETERS AND THEIR RELATIONSHIP TO THE ACCUMULATION OF POTASSIUM BY RYEGRASS

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A Dissertation

Presented to

the Graduate Council of

The University of Tennessee

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In Partial Fulfillment

of the Requirements for the Degree

Doctor of Philosophy

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by

Samuel Kincheloe

June 1973

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ABSTRACT

Three Tennessee soils (Hartsells, Maury and Grenada) were investigated with respect to the soil-solution equilibration parameters and the content of potassium in ryegrass grown in a greenhouse. The soils were fertilized with N, P and K which was varied from 0-100 ppm added to the soil. Two harvestings of ryegrass were made. The content of K, Ca and Mg in the ryegrass was measured. Soil samples were taken immediately following the first harvesting and subjected to the soil-solution equilibration technique. Two forms of equilibration curves resulted. Seven of the 33 equilibration curves were curvilinear in form, whereas the remaining 26 curves were linear. The form of the curves indicated that no release of fixed potassium occurred during the equilibration period. Liming had a significant effect on the $\Delta K$ values except for the Maury soil. The potassium buffering capacity was not affected by the K treatments for each soil; however, the buffering capacities were different for each soil. The K labile pools were significantly different due to K treatments for all soils except for the Grenada. The Maury soil had the largest K labile pool and the Grenada had the smallest.

The content of K in the first cutting of ryegrass ranged from 2.8 percent to 7.8 percent while the K content of the second cutting was considerably lower. Much greater variability in the K content was found in the first cutting of ryegrass. Various regression models were used to test the effects of soil parameters on the plant parameters. The

results indicated that when any two of the three soil-solution equilibration parameters were used together in a regression model, they accounted for the variability of plant K content as well as but no better than the single parameters of soil exchangeable K or the equilibrium solution K activity.

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# CHAPTER I

## INTRODUCTION

Soil testing is an invaluable tool for agriculturalists to use in evaluating the nutrient status of the soil in relation to crop production but testing methods continue to be controversial issues. Differences in location, soils, crops and cropping systems, and individual preferences are some of the factors which lead to use of different testing methods and extracting solutions in soil testing.

A statement which indicates the growing concern with the soil testing situation was made by Nye (37). He stated:

> Unless an approach . . . , capable of universal application, is adopted, the future of soil testing will consist of an endless series of fertilizer trials designed for correlation with an ever-increasing number of hit or miss extractions.

It is this kind of situation which may be instrumental in initiating a fresh approach to soil testing. The ideas presented by Schofield (42) and further developed by Beckett (6,7) are examples of a new approach. These workers and others began to realize that not only the amount of the "available" nutrient but also its degree of availability or intensity of supply would influence the amount at the disposal of the plants for uptake. The quantity-intensity approach which is derived from soil-solution equilibration techniques began to evolve. These ideas have been applied to the soil acidity, aluminum, phosphate and potassium status of the soil.

# I. OBJECTIVE OF THE STUDY

It was the objective of this study to apply the soil-solution equilibration technique proposed by Schofield and Beckett to three Tennessee soils having distinctly different parent materials and to study the relationships between the parameters of the soil-solution equilibration curves obtained and the potassium content of annual ryegrass.

# CHAPTER II

## SELECTIVE REVIEW OF LITERATURE

The concepts of the soil solution and equilibrium conditions between the soil and the soil solution were being firmly established as the focal point of interest in the early 1900's. Cameron and Bell (13) and Parker (38) concluded from their work and other previous work that the growing plant obtains its mineral nutrition directly from the aqueous solution formed by the soil moisture. They proposed the idea that the development of modern soil chemistry is dependent on the study of the soil solution. However, doubt was expressed that real equilibrium conditions would ever really exist but that the generalized statement is more or less closely approximated for some of the important nutrient elements.

Attempts at studying the soil solution created new problems, one of the most basic being the difficulty of obtaining sufficient quantities of solution for analysis without contamination. This aspect alone generated much investigation to develop techniques for extracting the soil solution. The composition of the soil solution and its relation to plant nutrition were of primary interest. At first, the amounts of the nutrient elements in solution were related to plant growth. Pursuit of this type of investigation led to the idea that nutrient elements supplied on the basis of amounts in the soil may not be entirely adequate for the desired plant growth but that a balance between certain elements was also necessary.

In 1938, Itallie (21) described some work in which a soil was treated with varying ratios of Ca, Mg, K and Na, and ryegrass was grown in pot cultures. It was found that there was no satisfactory relationship between the concentration of an ion in the soil and that in the plant. However, by giving the concentration values of each ion in the soil a special coefficient and taking the ratio of the soluble plus the exchangeable amount of each ion to the soluble plus exchangeable amounts of the other ions, soil values were obtained which gave a satisfactory correlation with the composition of the plants.

The ion ratio concept was further investigated by other workers (5,22,40), the general conclusion being that among the factors affecting plant uptake, the ratio of the major cations is a dominant factor. Bear and Toth (5) described optimum conditions for alfalfa plants relative to the cation balance on the soil exchange complex. They indicated that when 65 percent of the exchange complex is saturated with Ca, 10 percent by Mg, 5 percent by K and 20 percent by H, optimum conditions were approached.

## I. RATIO LAW

In a paper published in 1947, Schofield (42) formulated the "ratio law" that applies to equilibrium conditions between exchangeable cations and those in solution. The law was stated as follows:

> When cations in a solution are in equilibrium with a larger number of exchangeable ions, a change in the concentration of the solution will not disturb the equilibrium if the concentrations of all the monovalent ions are changed in one ratio,

> those of all the divalent ions in the square of that ratio and those of all the divalent ions in the square of that ratio [sic] and those of all the trivalent ions in the cube of that ratio.

Schofield verified this law experimentally over a limited range of concentrations for potassium, magnesium, calcium, hydrogen and aluminum ions for soil samples from the Rothamsted Park Grass Plots. Hydrogen did not obey the law in the case of one soil which carried nearly equal amounts of negative and positive charges. Conformity to the law requires the effective exclusion of anions from the sites where the exchangeable cations are situated. In this event, the equilibrium of the cations should not depend on the valency of the anions in the solution.

The basis for the development of the "ratio law" is indicated (42) to be the earlier work of Kerr (23), Vanselow (51) and Gapon (16), in which the law of mass action was being applied to cation exchange studies. From exchange equations based on the law of mass action, it was indicated that for a given proportion of exchangeable sodium to exchangeable potassium there should be a constant ratio of sodium to potassium in the solution, while for a given proportion of exchangeable sodium to exchangeable calcium there should be a constant ratio of sodium to the square root of the calcium concentration in the solution. The implications of these equations were not specifically tested and verified until these results were reported in 1947 by Schofield.

Since the original statement of the "ratio law", it has undergone considerable verification and investigation. When the $H/(Ca)^{1/2}$ ratio was investigated by Schofield and Taylor (43), it was found to be constant over a wide range of electrolyte concentrations. It was postulated that

constant values for the ratios of activities of bases may be observed in solutions in equilibrium with soils and may be used as a general measure of soil acidity. Taylor (46) carried the study further to observe the potassium and calcium relationship. This relation, $a_K/(a_{Ca})^{1/2}$ (a = activity), was found to strictly obey the "ratio law" only when the soil has a low potassium status. Variations from the "ratio law" were observed when soils had received large applications of potassium fertilizer. These variations were attributed to an exchange reaction by which the amount of potassium in readily exchangeable form was increased as the electrolyte concentration was raised.

It has been reported in 1947 and 1963 that dilution of a soil with water over the normal range for field moisture content does not affect the equilibrium conditions of the soil (30,42). Thus, the "ratio law" is independent of moisture content.

The "ratio law" had been confirmed for only a few soils and for several ion pairs prior to work reported by Beckett (7) in 1964. The ion pairs investigated up to this point were H-Na, H-K, H-Ca, H-Al, H-(Ca+Mg) and K-(Ca+Mg). However, workers were finding that some soils did not conform to the law. In an attempt to present a detailed confirmation of Schofield's "ratio law", Beckett found that within the accuracy of the method, and for the one soil chosen, it was evident that the ion pair K-(Ca+Mg) conformed to the "ratio law". The term (Ca+Mg) indicates a system where Ca and Mg are treated as one ionic species when used in the ratio expression. Subsequent measurements on a large number of soils (29,48) failed to reveal any exceptions to the "ratio law".

Taylor (46) reported that some soils failed to conform to the "ratio law". It was explained by Matthews and Beckett (29) that the lack of conformity for those soils was the result of a high release of fixed potassium and that the amounts released probably varied with the concentration of the solution.

Because Ca and Mg have the same valence and have been included as one ionic species in the activity ratio $a_K/a_{(Ca+Mg)}{}^{1/2}$, Beckett (7) wished to confirm that the activity ratio was not affected by the changes in the proportion of calcium to magnesium. His results indicated that for a soil otherwise uniform in all respects the activity ratio $a_K/a_{(Ca+Mg)}{}^{1/2}$ was independent of the ratio of $a_{Mg}/a_{(Ca+Mg)}$, at least over the range of 0.07 to 0.75.

## II. QUANTITY-INTENSITY RELATIONSHIPS

The "ratio law" formally stated by Schofield has been confirmed to be valid for numerous ion pairs in numerous soils. The significance of the "ratio law" lies in the fact that when a soil conforms to the law, the utilization of another relationship is permitted. This relationship is the activity ratio. The activity ratio is a unique property of the soil and not a function of the soil-solution concentration when the "ratio law" holds for the soil (7,12). They pointed out that the activity ratio and the "ratio law" are not the same thing.

The capacity of a soil to supply potassium is characterized by the total amount of the nutrient present and the energy level or intensity at which it is supplied. A relationship between these two parameters

may be determined by the quantity-intensity (Q/I) technique developed by Beckett and his coworkers (7,8,12,29).

The technique used to obtain the Q/I relationship or curve consists of equilibrating a number of subsamples of the same soil with a series of solutions containing variable amounts of KCl in 0.01M $CaCl_2$. For each suspension the difference between the potassium concentration in the initial and final equilibrated solution gives the amount by which the soil gains or loses potassium in reaching equilibrium, ($\pm\Delta K$). The $\Delta K$ value is the quantity factor. The activity ratio, $a_K/a_{(Ca+Mg)}^{1/2}$ or AR, is the intensity factor.

The form of the typical Q/I curve is characterized by an upper linear portion and a lower curved portion. This typical form is illustrated by curve A in Figure 1 with other parameters of the Q/I relationship (7,8,12,27,48,52). Zandstra (53) reported the linear form of the Q/I relationship (curve B, Figure 1), which illustrates a deviation from the typical curvilinear form. The curved lower part of the Q/I relationship has generally been attributed to a small number of sites that have a specific affinity for potassium (12). It was speculated that the sites specific for potassium were located on the edge or interlattice positions of the clay particles. The sites which account for the linear part of the curve were speculated to be located on the planar surfaces of the clay particles. The slope of the linear portion of the Q/I curve gives the amount of labile potassium that can be removed before the activity ratio falls by more than a given amount. This represents the Potential Buffering Capacity (PBC) of the soil for potassium. Curve B,

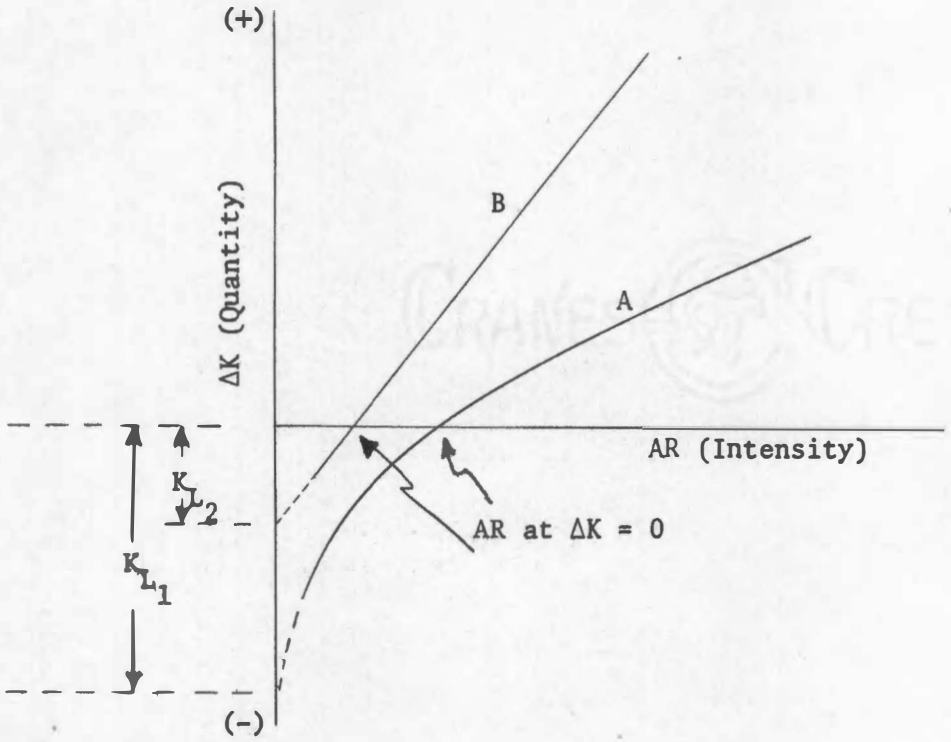


Figure 1. Some parameters of two theoretical Q/I relationships.

Figure 1, represents a soil which is more highly buffered than is the soil represented by curve A. The labile pool of potassium is defined as the amount of potassium present which is capable of ion exchange during the period allowed for the determination of the Q/I relation. The $K_{L1}$ and $K_{L2}$ symbols represent the measures of the K labile pool for the two curves in Figure 1. The soil represented by curve A has a much larger pool of labile potassium than the soil represented by curve B as indicated by the Q/I relationships. The value of the activity ratio, where $\Delta K = 0$, refers to the activity ratio where there is no loss or gain of potassium by the soil to the potassium-calcium solution added.

There is no uniform agreement among workers relative to the best indicator or measure of the labile pool of potassium. Beckett (12) and Tinker (48) ascribed the labile potassium pool to the intersection point of the lower curved portion of the Q/I relation at the Q-axis, where AR = 0. A portion of this labile pool was attributed as being less readily exchangeable due to specific potassium adsorption. In contrast, Le Roux and Sumner (27) used the linear portion of the Q/I relation extrapolated to AR = 0 as a measure of the labile pool. They also indicated that changes in the labile pool should be measured relative to the amount in the unchanged field soil and not against a zero state where the labile potassium had been removed prior to measuring.

In a review of "potassium potentials" published in 1971, Beckett (12) indicated that AR, pAR, and RTLnAR have been proposed as measures of the intensity factor of soil potassium. Each of these had been referred to as a potassium potential. He indicated that RTLnAR may be

thought to look more imposing than AR but that in fact not one of them was more fundamental than the others, nor was there any consistent evidence to show that the uptake of potassium by plants was more closely measured by one than the others.

In a series of papers published by Matthews and Beckett (29), Beckett (6,7,8), Beckett et al. (9,10) and Tinker (48,49), the form of the exchange isotherm as indicated by the Q/I relations of labile potassium to calcium plus magnesium was found to be independent of release or fixation of potassium. The forms of the Q/I relations of a number of soils were unaffected by the removal in crops of much of the labile potassium or by large changes in the proportions of labile potassium and calcium present. But, in contrast, it was found that Q/I relations of potassium-fertilized plots and potassium-depleted plots were not the same.

Moss (30,31,32) and Moss and Hodnett (33) in a series of papers presented some aspects of the cation status of soil moisture. Investigating the moisture content of soil in relation to the pAR form of the activity ratio, the pAR values were constant for one soil over the entire range of moisture content. For two other soils studied, the values were constant only over the field range of moisture. Once the field range of moisture was exceeded, the pAR values increased with dilution. This same series of papers showed that dilution and the increase of calcium ions can cause the release of potassium ions from the soils in excess of the exchangeable potassium value. When comparing fertilized and unfertilized plots under field conditions, they found

little or no difference between the pAR values of the wet and dry seasons.

Direct and indirect methods (34) of determining cation ratios of natural soil solutions were studied. It was found that potassium activity ratio values derived from ethyl-alcohol displaced soil solutions were in excellent agreement with values determined on the same soil by the Q/I relations. Le Roux and Sumner (26) found good correlation between the AR of high-pressure soil-solution extract and the AR value obtained from a similar sample using the Q/I technique.

The effect of sewage sludge on the ion activity in soils was investigated by Tan, King and Morris (45). It was noticed from the Q/I relationships that the linear part tended to be steeper for the sewage sludge treated soil than for the water treated soil. This fact indicated a larger buffering capacity against potassium depletion in the sludge-treated soil. The Q/I relation exhibited a regression line, which was less curved in the lower part, when the soil was treated with sludge. The greater curvature in the Q/I relation of the nontreated soil was attributed to potassium fixation by the wedge effect of weathered mica present in the soil.

Some general statements regarding errors in the Q/I technique have been made by Moss and Beckett (36). They indicated that errors may arise in the sampling, preparation and storage of the soil samples. Analysis of the samples as soon as possible after sampling, with no preparation other than gentle sieving was recommended. The Q/I procedure relies on certain implicit assumptions which will not strictly apply if

there is any major exchange between exchangeable cations and soluble salts or microbially-dissolved carbonates during determinations. In investigating sources of errors, they found that modified interpolation procedures designed to minimize errors from these causes appeared to introduce larger errors than they avoided.

## III. Q/I RELATIONSHIPS AND PLANTS

Currently used soil tests, at best, serve only as a workable index to what is actually available to the plant (25). In the course of time, workers such as Schofield (42) came to realize that not only the amount of the so-called available nutrient but its degree of availability or intensity would influence the amount available to the plant. Beckett (7) developed this approach further by the use of the quantity-intensity technique. The energy level or intensity (I) of potassium in the labile pool is related to the amount (Q) present.

Arnold (3) reported work in 1962 where the potassium status of some soils was considered as a function of energy relationships. The free energy parameter was calculated from the activity ratios of potassium and calcium. Sixty-four soils from 50 sites were cropped with perennial ryegrass in the greenhouse for about 36 days. Very low correlation ($r = 0.35$) was obtained between uptake by the ryegrass and the exchangeable potassium measured. The attempt to define the potassium status of the soils in terms of the difference in free energy between potassium and divalent ions was partially successful. For 54 of the 64 soils, free energy and ryegrass uptake of potassium were well correlated

($r = 0.89$). This parameter was inadequate, however, to define the potassium status of all 64 soils.

Tinker (48) has indicated that there was no fully satisfactory reason for assuming that availability to the plant depends on the chemical potential. Nevertheless, the potential of an ion in the soil must control the potential of that ion on the plant root exchange sites, and it seems likely that the chemical potential is a major factor in uptake. In work dealing with Nigerian Oil Palm, Tinker (49) reported that the results of a study related to AR and response to fertilizer potassium indicated a very poor relationship between response of the oil palm, fertilizer and activity ratios. He speculated activity ratios would possibly give excellent results under mildly acid, neutral or alkaline conditions. For the acid soils with which he was working, the activity of aluminum was introduced into the activity ratio. With this resulting change in the activity ratio, good correlation was found between the new activity ratio and yield response to potassium in field experiments on acid soils.

Magnesium availability to ryegrass in relation to cation activity ratios was investigated by Salmon (41). Perennial ryegrass was grown on two soil types, each with four Ca:Mg ratios at constant potassium levels. The magnesium concentration in the grass was linearally related to $(a_{Mg}/a_{Ca}+a_{Mg})^{1/2}$ in the equilibrium soil solution. When ryegrass was grown on a range of soils with different pH values and levels of magnesium, potassium and calcium, the magnesium in the grass was poorly correlated with exchangeable magnesium and the ratio $(a_{Mg}/a_{Ca}+a_{Mg})^{1/2}$ in solution. However, it was closely correlated with the ratio

$(a_{Mg})^{1/2}/a_{(Ca+Mg)}{}^{1/2}$ + B·aK + C·aH in solution. The constants B and C were determined experimentally. This relationship was used to explain some of the variations of magnesium availability in acid soils.

Eleven soils were studied in relation to activity ratios, buffering capacity and plant uptake by Acquaye and McLean (1). These soils were equilibrated in 0.02M $CaCl_2$ containing different amounts of KCl. The resulting equilibrium activity ratios showed a higher correlation with the portion of potassium uptake derived from the exchangeable form than with the total potassium uptake by plants. The activity ratio values together with estimates of the quantities of potassium released (-ΔK), as obtained from equilibration curves, were much more indicative of the total potassium uptake than AR values only. The ratio of -ΔK/AR, or potential buffering capacity, showed some relation to the amount of non-exchangeable potassium, which was an important source of potassium in most of the soils. The -ΔK values obtained where AR = 0 showed a good relationship with previously published amounts of potassium removed by plants.

A similar procedure was used by Acquaye, McLean and Rice (2) on 14 soils from Ghana. The activity ratio was found to be related to the amount of exchangeable potassium in $NH_4OAc$, and especially related to the uptake by oats of potassium derived from the initial level of exchangeable potassium measured at the time of seeding. The activity ratio alone did not appear to be an adequate measure of the potassium supply of these soils, which released potassium from the nonexchangeable form. Again, the potential buffering capacity was a useful measure of

the capacity of the soil to resist potassium depletion. The fact that activity ratio alone was not an adequate measure of potassium supply was explained more fully when the potential buffering capacity was taken into consideration.

Matthews and Beckett (29) had shown earlier that the form of the Q/I relation was unaffected by release or fixation of moderate quantities of potassium from soils agitated in dilute electrolyte solutions. But their evidence suggested that the Q/I relations may be altered by repeated depletion by crops. Consequently, Beckett et al. (9) attempted to verify that the form of the Q/I relation was unaffected by the removal of potassium in crops. They found that the forms of the Q/I curves for labile potassium in the soils studied were almost unaffected by potassium depletion by fixation on storage, or by the release or fixation of potassium by heating. Addition of very large amounts of potassium may cause transient changes, but these changes disappeared upon storing the soil. They concluded that depletion of potassium or calcium and magnesium by crops, and the addition of potassium in fertilizers, are unlikely to alter the form of the Q/I relationships of the labile potassium.

Exchangeable potassium, $CaCl_2$ exchangeable potassium and the change in free energy were methods compared by Feigenbaum and Hagin (15) for the evaluation of available potassium in soils. The evaluation was based on the potassium uptake by wheat in a greenhouse soil exhaustion experiment. The value for the change in free energy was best correlated with the potassium uptake by the wheat plants. Good correlation was

reported between the logarithm of the exchangeable potassium expressed as a percentage of the cation exchange capacity and the free energy values.

The ion pair of hydrogen and potassium was used by Davidescu et al. (14) to test the agronomic significance of activity ratios of soils. These workers found that the effect of potassium fertilizers on wheat and corn crops correlated well with the activity ratio of hydrogen ions to potassium ions. Therefore, the index pH minus pK could be used to estimate the probable effect of potassium fertilization on soils.

Field responses of oats, barley and corn and the potassium exchange equilibria in some Quebec soils were investigated by Zandstra and MacKenzie (53). To interpret crop response and potassium measurements on the soils, two types of information were required. These were the total amount of exchangeable potassium in the soil ($-\Delta K$ when $AR = 0$) and the amount that could be released per unit reduction in the relative activity of potassium on the exchange complex. The activity ratio was found not to be a satisfactory indication of the potassium fertility status of the soils and was poorly correlated to crop response. The potential buffering capacity for potassium did not change after intensive cropping for one growing season. The potential buffering capacity did not, however, indicate the fertility status of the soil. The product of the potential buffering capacity and the amount of exchangeable potassium ($-\Delta K$ when $AR = 0$) completely defined the potassium quantity-intensity relationship of the soils. The new potential was found to correlate more closely to crop response than the activity ratio measurement or the potential buffering capacity alone.

Wild (52) designed a study to determine whether activity ratios or concentrations of potassium were better measures of the potassium in solution for plants. A second aspect of the study was to determine the effect of magnesium on the uptake of potassium. The conclusions drawn from the study were that yields of dry matter and potassium uptake of ryegrass and flax depended on the concentration of potassium rather than on the activity ratio in solution. A magnesium concentration increase did not depress potassium uptake. Wild indicated that the concentration of potassium, in addition to the activity ratio, should be measured and reported.

Activity ratios (11) define the relative ease of removal of equivalent amounts of two cations from the soil but only insofar as the relative ease of removal is controlled by their relative amounts or by the way they are held in the soil. According to these authors, the activity ratios are more likely to provide useful measures of the availability of a particular nutrient when it is deficient or nearly so than when it is in adequate supply and uptake is mainly limited by deficiencies in other aspects of the root environment.

An attempt to evaluate the Q/I technique for defining the potassium availability to corn on a field basis was made by Koch, Orchard and Sumner (25). The relationship between potassium in the corn leaf and soil potassium is best described for this soil if the leaf potassium is considered as a function of the pool of labile potassium. It was shown that in a leached Oxisol, the labile pool of potassium is a good index of the amount available to corn. The labile pool of potassium was

superior to both the equilibrium activity ratio and the exchangeable potassium. The labile pool is not the important criterion as such, but through its effect on diffusion and mass flow of potassium, and thus on the rate of supply to the sites of entry on the growing root, the pool is most closely related to potassium uptake.

In 1970, Herlihy and Moss and Moss and Herlihy (19,35) published papers concerning the availability of potassium to ryegrass. Twenty-four unfertilized permanent pasture soils were treated with potassium fertilizer. The treated and untreated soils were depleted by repeated cropping in a greenhouse culture to determine the extent to which the measurements of labile and nonlabile soil potassium were correlated with potassium uptake and crop yield. The results indicated that the quantity measurements, either $NH_4OAc$ exchangeable potassium or the available exchangeable ($-\Delta K$ when $AR = 0$), were better related to the ryegrass uptake than was the activity ratio. Both quantity and intensity measurements decreased in their ability to account for the potassium uptake with successive cropping due to the depletion of the labile pool of potassium. The authors indicated that Beckett had suggested different soils, having the same activity ratio, may have different potassium buffering capacities for maintaining the activity ratio.

The second paper examined the importance of the buffering capacity of soils for describing the availability of potassium to ryegrass. The Q/I relationship was used to develop a sequential scheme of depletion of labile potassium. The potassium uptake was defined by the product of the buffering capacity and the change in the potassium activity

ratio over the cropping period. The approach to buffering capacity is somewhat different than that proposed by Beckett et al. (9) and adopted by numerous other authors. Beckett used the slope of the Q/I relation that was approximately linear as the measure for buffering capacity. These authors have indicated, however, that because of the curved nature of the Q/I relation there will not be a unique soil potassium buffering capacity but rather that it will increase as the activity ratio is reduced. The buffering capacity that is relevant during cropping is that associated with a particular change in activity ratio. It was indicated that if the change in activity ratio considered is that which occurred during cropping, then the buffering capacity effective over cropping can conveniently be defined as the slope of the chord between the intercepts on the Q/I curve at activity ratio values before and after cropping. If the source of potassium to the crop is entirely from the labile pool, the change in K ($d\Delta K$), should be the amounts made available to the crop. Crop uptake of K = $d(\Delta K) = BC_e \chi d(AR)$ where $BC_e$ is the effective buffering capacity. It was stated that this buffering capacity measurement would not be available initially for predictive purposes. Their results showed that the correlation between potassium uptake and activity ratio was considerably improved when the buffering capacity term was included. This occurred not only over the period of cropping involving the labile potassium pool, but also when nonlabile potassium was released.

Khasawneh (24) reported that a thorough study of most of the published work relative to the potassium activity ratio indicates that

this ratio suffers from a serious limitation. This limitation was clearly explained by its early proponents. They warned that the activity ratio should be used only as a comparative measure of potassium nutrition for soils having similar calcium status. In essence, Khasawneh stated that this made the activity ratio equal to the activity of potassium divided by a constant factor. The constant factor would be the activity of Ca+Mg of the soils that have similar calcium and magnesium status. He indicated that perhaps the potassium activity instead of the activity ratio should have been used all along. He further stated that the inherent suitability of the activity ratio as a measure of the intensity of potassium is questionable, especially since it was only an expression of the relative intensities rather than actual intensities.

# CHAPTER III

## EXPERIMENTAL PROCEDURES

This study consisted of soil-solution equilibrium investigations utilizing the soils from geographically different regions of Tennessee. The term soil-solution equilibration will be used in the same context throughout the remainder of this presentation as the Q/I relationship expression. Ryegrass was grown in soils in a greenhouse pot culture in an attempt to relate the concentration of potassium in the plants to the soil equilibrium parameters. The soils were from the Hartsells, Maury and Grenada series.

Limed and unlimed soils were established as separate series in the experimental phase of the study. The potassium content of each soil was then varied from 0 to 100 ppm of added potassium to each soil. A secondary series was established for the Hartsells soil in which the potassium content was held constant and the calcium and magnesium levels were varied.

All soils were fertilized with nitrogen and phosphorus, seeded in ryegrass and grown to the early maturity stage. Two harvests of the ryegrass were made.

Soil-solution equilibrium investigations were made in the laboratory on the soils in which the ryegrass was grown. Laboratory analyses were made on the harvested plant material.

Appropriate calculations and relationships were determined from the data, utilizing the University of Tennessee Computer Service and programs made available at the computer center.

## I. DESCRIPTIONS OF THE SOILS

The Hartsells series (44,50) is a member of a fine-loamy, siliceous, thermic family of Typic Hapludults. These soils have dark grayish brown to brown fine sandy loam A horizons and yellow-brown B2t horizons of fine sandy clay loam. Acid sandstone bedrock is at about 36 inches. The Hartsells soils occur in the Cumberland Plateau region of East Tennessee on broad smooth plateaus, mountain tops or hill tops. They are well drained, and runoff is medium. The soils are strongly acid, and the natural fertility is generally low.

The Maury series (44,50) is a member of a clayey, mixed, mesic family of Typic Paleudults. The upper part of the solum is believed to have developed in a silt mantle that was chiefly transported material. The lower part developed in the residuum of phosphatic limestones. The depth to bedrock varies from 3 to 12 feet. These soils are well drained and found in the Outer Central Basin of Middle Tennessee. The soils are generally slightly acid, and the natural fertility is high.

The Grenada series (44,50) is a member of the fine-silty, mixed, thermic family of Glossic Fragiudalfs. These soils have silt-loam A horizons, yellowish-brown heavy silt-loam upper B horizons, and distinct A'2 horizons which have tongues or interfingers of gray silt-loam into

an underlying horizon. The combined thickness of horizons having less than 10 percent sand is more than 48 inches. The soils are moderately well drained, runoff is medium to slow and the reaction is slightly acid. The setting is in West Tennessee, on nearly level to sloping uplands and stream terraces, and the soils have formed from beds of silty loess material more than 48 inches thick. The natural fertility is generally moderate to low.

Some properties of the three soils used in this study are summarized in Table 1.

## II. SOIL TREATMENTS

Samples representing the Hartsells, Maury and Grenada soils were taken from the surface to a depth of eight inches. The soils were passed through a 1/4 inch mesh screen, air dried and mixed individually in the greenhouse.

For the greenhouse phase of the study, 3500 grams of soil were weighed into a one-gallon size paper container with a plastic liner. The limed series was accomplished by adding 23.6 meq of $CaCO_3$ to each container for the Hartsells soil, 6.1 meq of $CaCO_3$ for the Maury soil and 18.1 meq $CaCO_3$ for the Grenada soil. Potassium was the variable in both the limed and unlimed series. The potassium treatments were made in triplicate, and KCl was added to each pot to achieve the following range of added potassium: 0, 0.064, 0.128, 0.192, and 0.256 meq/100g soil. The potassium treatments expressed as ppm potassium added are as follows: 0, 25, 50, 75, and 100. The secondary series involved

TABLE 1

SOME PROPERTIES OF THE HARTSELLS, MAURY AND GRENADA SOILS

| Soil Properties[1] | Soils | | |
|---|---|---|---|
| | Hartsells | Maury | Grenada |
| pH (39): | | | |
| Water | 5.15 | 6.07 | 5.52 |
| 0.01 M $CaCl_2$ | 4.67 | 5.87 | 5.07 |
| Field Cap. Moisture | | | |
| Approx. percent by dry wt. basis | 22.70 | 27.70 | 26.90 |
| Exchangeable Bases and Acidity as me/100g soil (28): | | | |
| K | 0.37 | 0.34 | 0.13 |
| Ca | 2.27 | 5.79 | 2.69 |
| Mg | 0.33 | 0.76 | 0.32 |
| Na | 0.05 | 0.04 | 0.05 |
| Sum of Bases | 3.03 | 6.93 | 3.19 |
| Acidity | 2.76 | 0.72 | 1.93 |
| CEC (By Summation Method) | 5.79 | 7.65 | 5.12 |
| Percent Base Saturation | 52.30 | 90.60 | 62.40 |
| Lbs/A K ($NH_4OAc$ Extractable) | 292 | 270 | 104 |

[1]Numbers in parentheses indicate references for laboratory procedures.

the Hartsells soil only, and the potassium content was held constant while the calcium and magnesium contents were varied. The ratio of added calcium plus magnesium on a weight basis was 3:1 and the following amounts were added: 0, 0.25 meq Ca/100g and 0.14 meq Mg/100g, 0.625 meq Ca/100g and 0.34 meq Mg/100g added to the soil as $CaCl_2$ and $MgCO_3$. These treatments expressed as ppm were: 0, 200 ppm Ca and 67 ppm Mg, and 500 ppm Ca and 167 ppm Mg. This secondary series was prepared in triplicate. The potassium and calcium plus magnesium treatment levels were established on the basis of results of preliminary investigations and previous unpublished data.

All soils were treated with $NH_4H_2PO_4$ and $NH_4NO_3$ in amounts equivalent to 112 kg/ha (100 lbs/A) of nitrogen and 168 kg/ha (150 lbs/A) of $P_2O_5$ in addition to the chemical treatments described above.

The chemical treatments were added to the individually potted soils at one time and mixed thoroughly. Mixing was accomplished by utilizing an "elbow-type", twin-shell, dry blender, which revolved at approximately 32 rpm for a period of five minutes for each container of soil.

The treated soils were repotted, moisture content brought to field capacity and placed in the greenhouse to equilibrate for eight days before seeding the ryegrass. The field capacity moisture content was determined for each soil in the laboratory prior to the greenhouse phase of the study.

## III. GREENHOUSE CROP PRODUCTION

After the eight-day equilibration period, 40 seeds of Wintergreen Annual Ryegrass were sown in each of the prepared containers of soil on October 26, 1971. Ten days after emergence, each container was thinned to 30 ryegrass seedlings and grown to the early maturity stage before harvesting. The soil moisture content was adjusted daily, or as needed, to maintain the approximate field capacity moisture content throughout the growing period. The ryegrass was harvested 60 days after seeding at a height of 1.5 inches above the soil surface. A second crop was allowed to grow, and it was harvested 94 days after seeding.

## IV. PLANT ANALYSIS

The harvested plant material was dried in an oven at 70°C. for 24 hours. A Wiley mill with a No. 20 screen was used to grind the plant material. A modification of the wet oxidation procedure reported by Gieseking, Snider and Getz (18) was used to digest all plant tissue for K, Ca and Mg analyses. Details of this procedure are outlined in Appendix A. The measurement of Ca, K and Mg concentrations in the ryegrass was made by the use of the Perkin-Elmer 303 Atomic Absorption Spectrophotometer.

## V. SOIL-SOLUTION EQUILIBRIUM

One day following the first harvest, soil samples were removed from the containers in which the ryegrass was growing. Three 1/2 inch

cores of soil extending to the full depth of the containers were taken from each container to be utilized in the soil-solution equilibrium studies. The soil was passed through a nine-mesh sieve, dried at 60°C. overnight and stored at room temperature.

The soils were equilibrated (7,27) in a solution for two hours by agitating constantly in a reciprocating-type shaker. A 1:4 soil to solution ratio was used throughout the investigation. A portion of soil from each container, representing each soil treatment in triplicate, was equilibrated with a 0.005M $CaCl_2$ solution containing each of the following potassium concentrations: 0, 10, 20, 30, 40, 50, 60, and 70 ppm.

At the end of the equilibration period with each of the different solutions, the soil-solution suspensions were centrifuged at high speed for approximately five minutes in the Model K International Centrifuge to separate the clear solution from the soil. The soils equilibrated with the solutions containing $CaCl_2$ flocculated easily, and the clear supernatants were decanted. The Ca, K and Mg concentration determinations were made on the solutions, utilizing the Perkin-Elmer 303 Atomic Absorption Spectrophotometer.

## VI. ACTIVITY RATIO DETERMINATIONS

Activity ratios (AR) were determined from the equation $AR = a_K/a_{(Ca+Mg)}^{1/2}$, where a is the activity of the cations in solution. Activities of the cations in solution were derived from the expression: $a = \gamma c$, where c is the molar concentration of the cations in solution

and $\gamma$ is the activity coefficient: the activity coefficient is a result of the extended Debye-Huckel (17) equation:

$$-\log\gamma = 0.509Z^2(I)^{1/2}/1 + \propto\beta(I)^{1/2} \text{ at } 25^{o}C.$$

The symbol $\propto$ is the hydrated diameter of the ion in solution; $\beta$ is the dielectric constant for water; I is the ionic strength of the solution and is equal to $1/2\ \Sigma\ cZ^2$; Z is the valence of the ion. The experimental values of $\propto$ for Ca, K and Mg are $6.0 \times 10^{-8}$cm, $3.0 \times 10^{-8}$cm and $8.0 \times 10^{-8}$cm respectively (17). The value of $0.3281 \times 10^{8}$ was used for $\beta$ in the Debye-Huckel equation (17).

# CHAPTER IV

# RESULTS AND DISCUSSION

## I. THE RATIO LAW

As evidenced in the review of literature, a large number of different soils have been shown to conform to the "ratio law", with only a very few soils reported as not conforming. Schofield (42) and Beckett (7) explained that soils which have nearly equal amounts of positive and negative charges would not be expected to conform to the "ratio law". The assumption that most soils conform to the "ratio law" would be valid when based on the results of previous work done in this regard. However, the three soils utilized in this study were subjected to equilibration with solutions which contained zero to 0.2M $CaCl_2$ for determining activity ratios and verifying conformity to the "ratio law". The procedure was similar to that used by Beckett (7) to confirm the "ratio law". The Grenada, Maury and Hartsells soils had activity ratios, $a_K/a_{(Ca+Mg)}^{1/2}$, that were esentially constant for equilibration solutions containing approximately 0.00025M to 0.05M $CaCl_2$ and were established as conforming to the "ratio law". This establishes the basis for using the activity ratio as a soil parameter for evaluating the potassium nutrient status of the soil. The activity ratio can then be considered a characteristic property of the soil and not a function of the ionic strength of the soil solution.

# II. SOIL-SOLUTION EQUILIBRATION

Thirty-three soil-solution equilibration curves were obtained from the five potassium treatments made to the limed and unlimed Hartsells, Maury and Grenada soils used to grow annual ryegrass in the greenhouse. From these curves, the general form of the curve, the slope, the y-intercept and the activity ratio, $a_K/a_{(Ca+Mg)}^{1/2}$, are parameters utilized in studying the relationship between the potassium fertility status of the soil and the concentration of potassium in the ryegrass plants. The regression equations and $R^2$ values for the soil-solution equilibration curves are tabulated in Table B-1, Appendix B.

## Form of the Soil-Solution Equilibration Curve

The form of the curves for the unlimed and limed Hartsells soils are shown in Figures 2 and 3. Only one of the ten equilibration curves deviated from the linear form. The family of curves for the unlimed Hartsells soil treated with five different amounts of potassium are linear in form. The limed Hartsells soil that received no potassium treatment resulted in an equilibration curve that was quadratic in form. The curves for the four other potassium treatments were linear.

The Maury soil resulted in equilibration curves that were linear for both the limed and unlimed condition. These curves are shown in Figures 4 and 5.

The unlimed Grenada soil yielded curves of the linear form as shown in Figure 6. However, the quadratic form was obtained from the limed Grenada soil for all five of the potassium treatments, Figure 7.

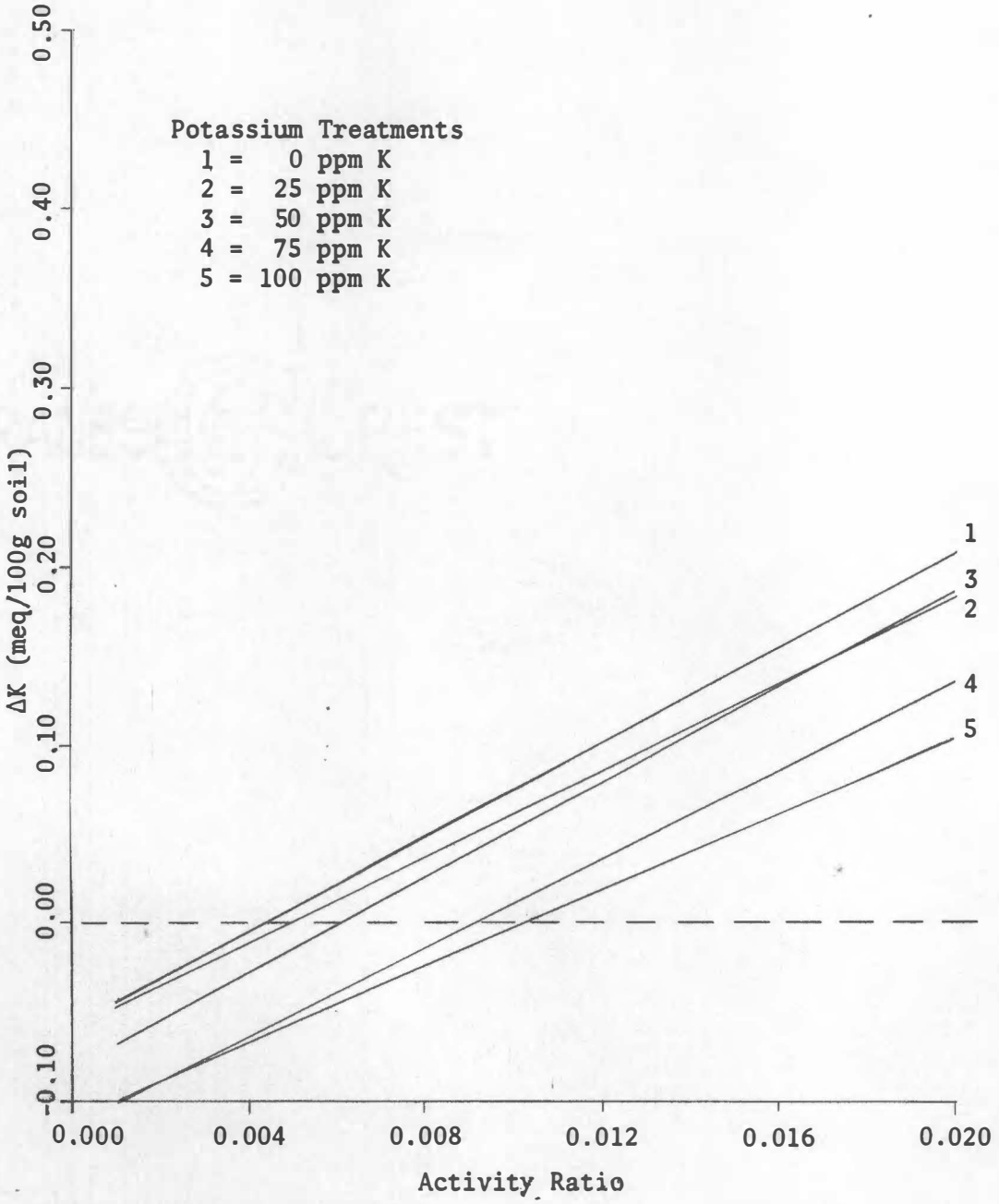


Figure 2. Relationship between ΔK and activity ratios of the soil-solution equilibration of the potassium-treated unlimed Hartsells soil.

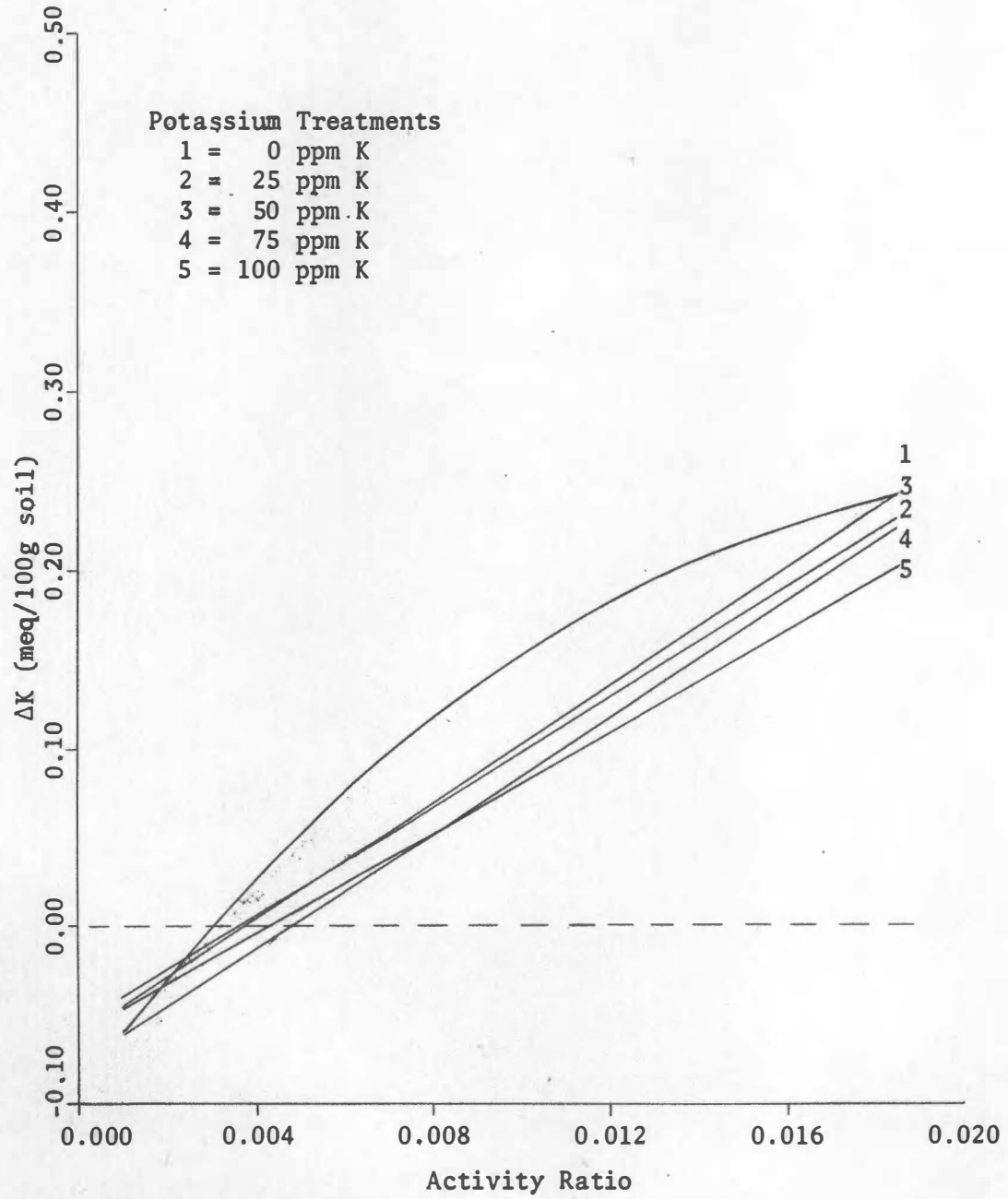


Figure 3. Relationship between ΔK and activity ratios of the soil-solution equilibration of the potassium-treated limed Hartsells soil.

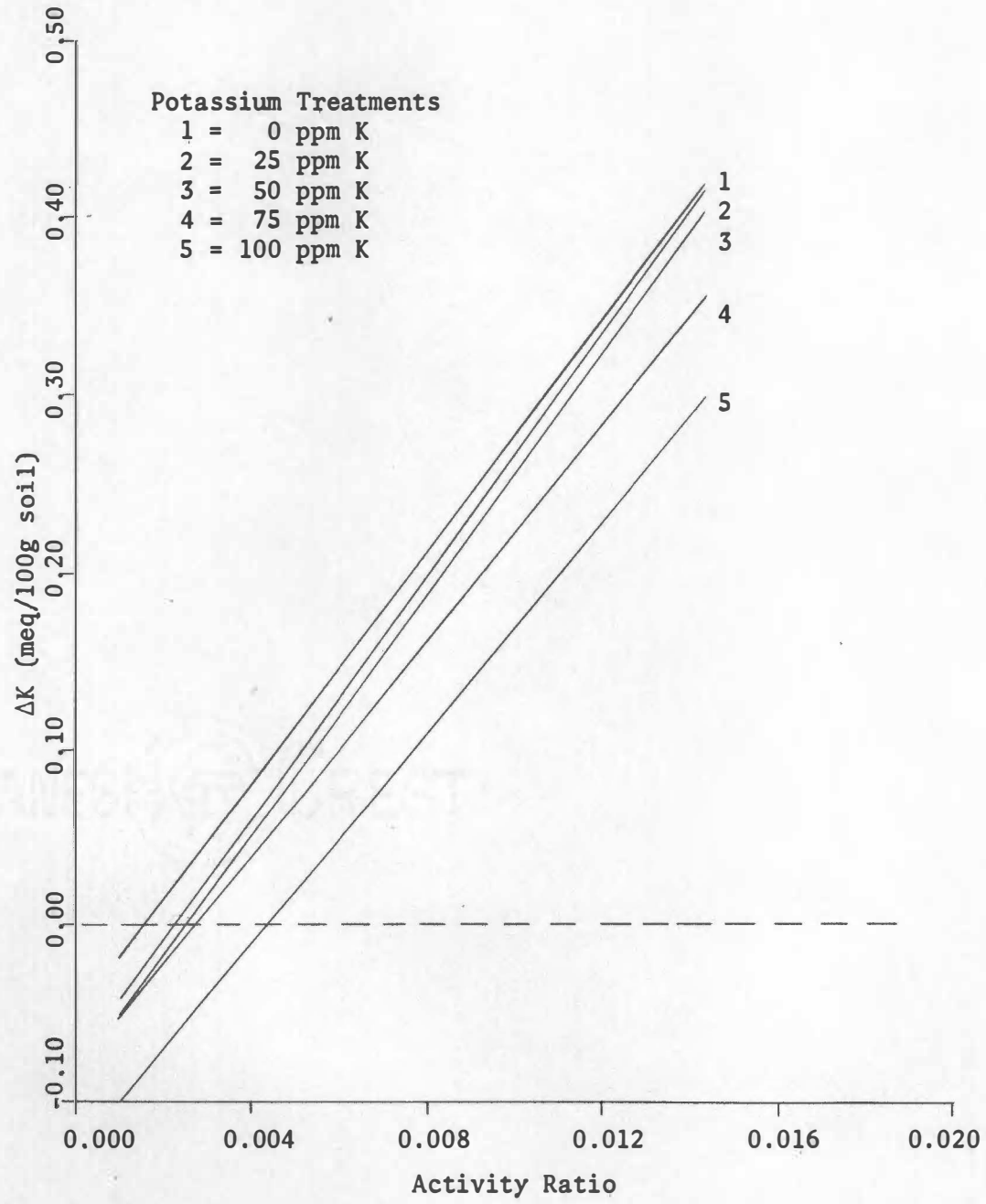


Figure 4. Relationship between ΔK and activity ratios of the soil-solution equilibration of the potassium-treated unlimed Maury soil.

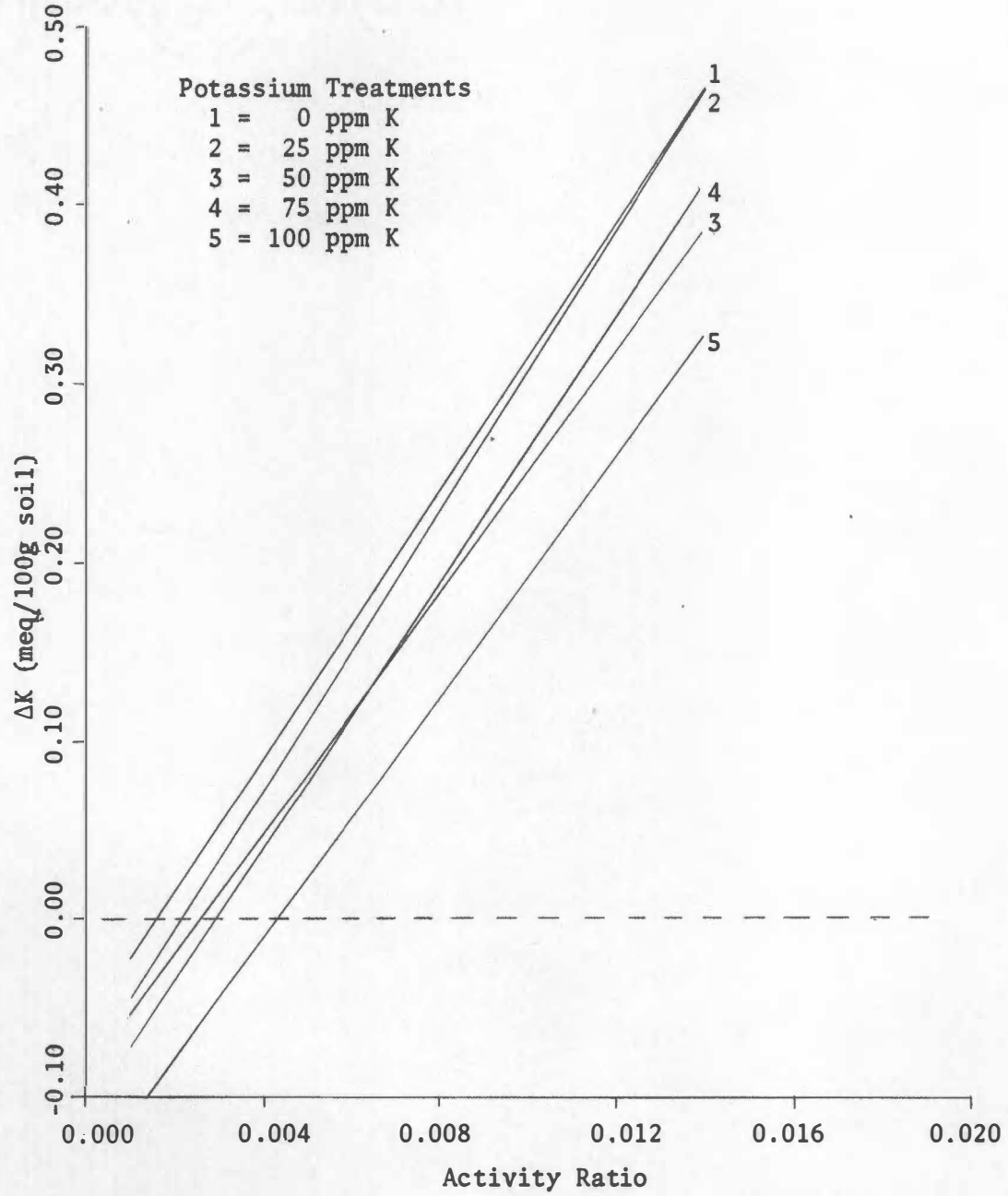


Figure 5. Relationship between ΔK and activity ratios of the soil-solution equilibration of the potassium-treated limed Maury soil.

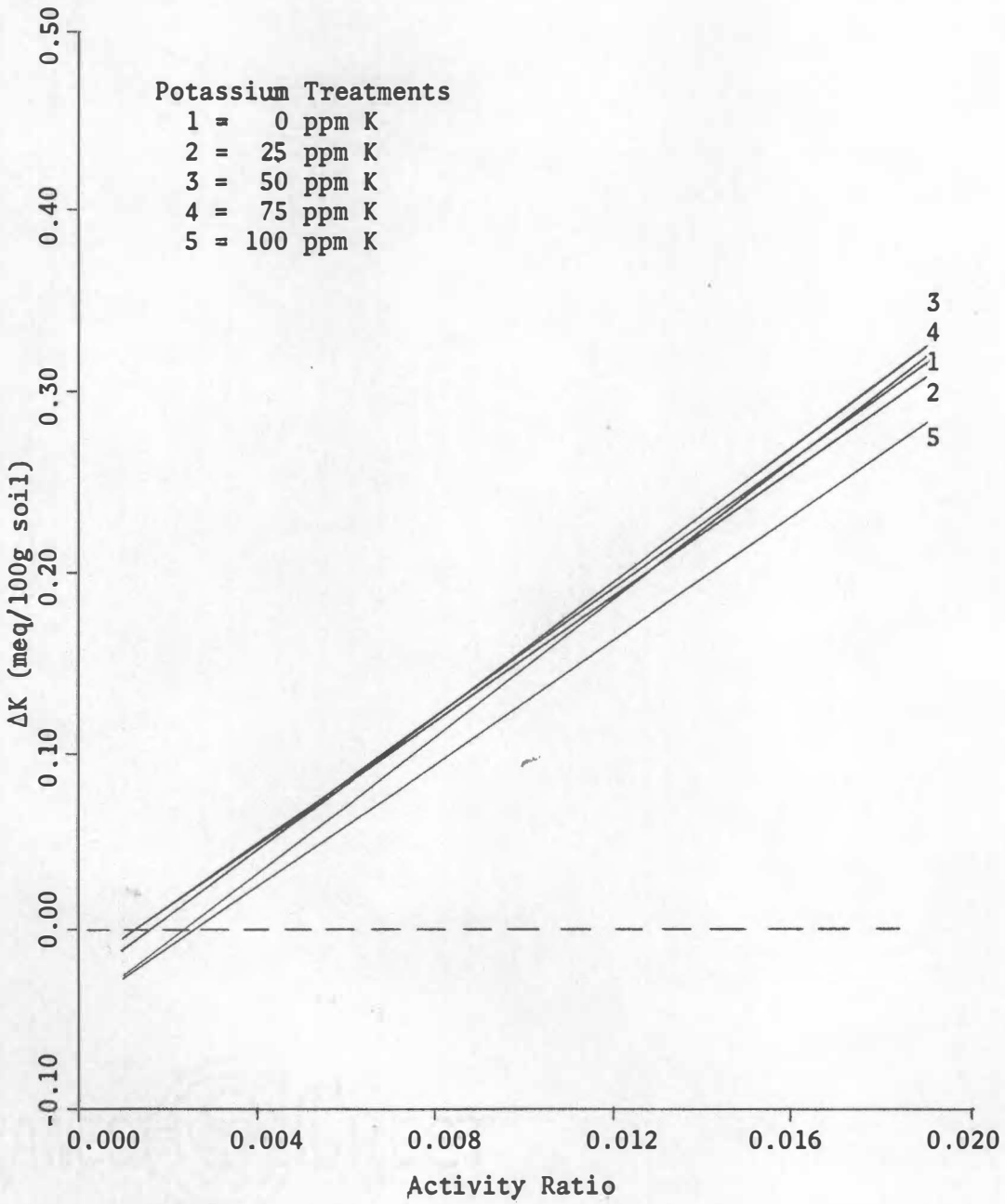


Figure 6. Relationship between ΔK and activity ratios of the soil-solution equilibration of the potassium-treated unlimed Grenada soil.

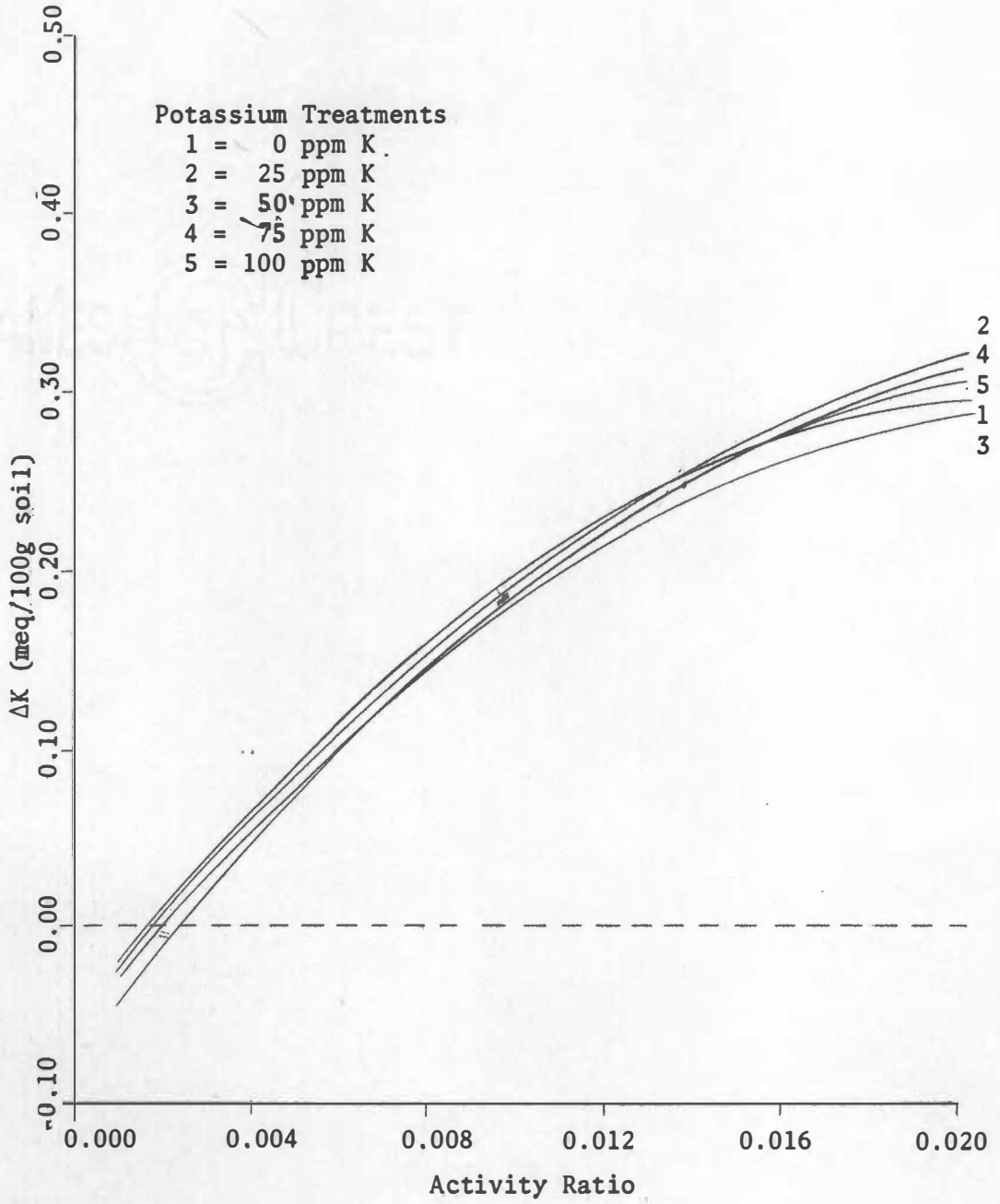


Figure 7. Relationship between ΔK and activity ratios of the soil-solution equilibration of the potassium-treated limed Grenada soil.

From the Hartsells soil that was treated with varying amounts of calcium and magnesium, the zero treatment resulted in a curve of the quadratic form. The two remaining curves of that family were linear. These curves are shown in Figure 8.

Beckett (12) has indicated that the lower portion of the curvilinear equilibration curve has generally been attributed to a relatively small number of exchange sites with a more specific affinity for potassium than that exhibited by the remainder of the exchange surfaces. According to Beckett, the specific exchange sites for potassium have been attributed to edge of interlattice positions, and the sites which account for the linear part of the curve lie on the planar surfaces of the clay plates. The lower curved portion of the curve would, in fact, indicate the release of fixed potassium.

The linear form of the soil-solution equilibration curves for the Hartsells, Maury and Grenada soils indicates that potassium fixation was not a significant factor under the conditions of this investigation. For the seven curves that were not linear, the lower portion of the quadratic form of the curves was judged to be sufficiently close to the linear form to indicate that potassium fixation was, again, not a significant factor.

## Liming and Soil-Solution Equilibration

Unlimed Hartsells, Maury and Grenada soils and the same three soils limed with $CaCO_3$ in amounts to adjust the pH to 7.0 were used as separate series of the investigation. To determine the effects of liming, the

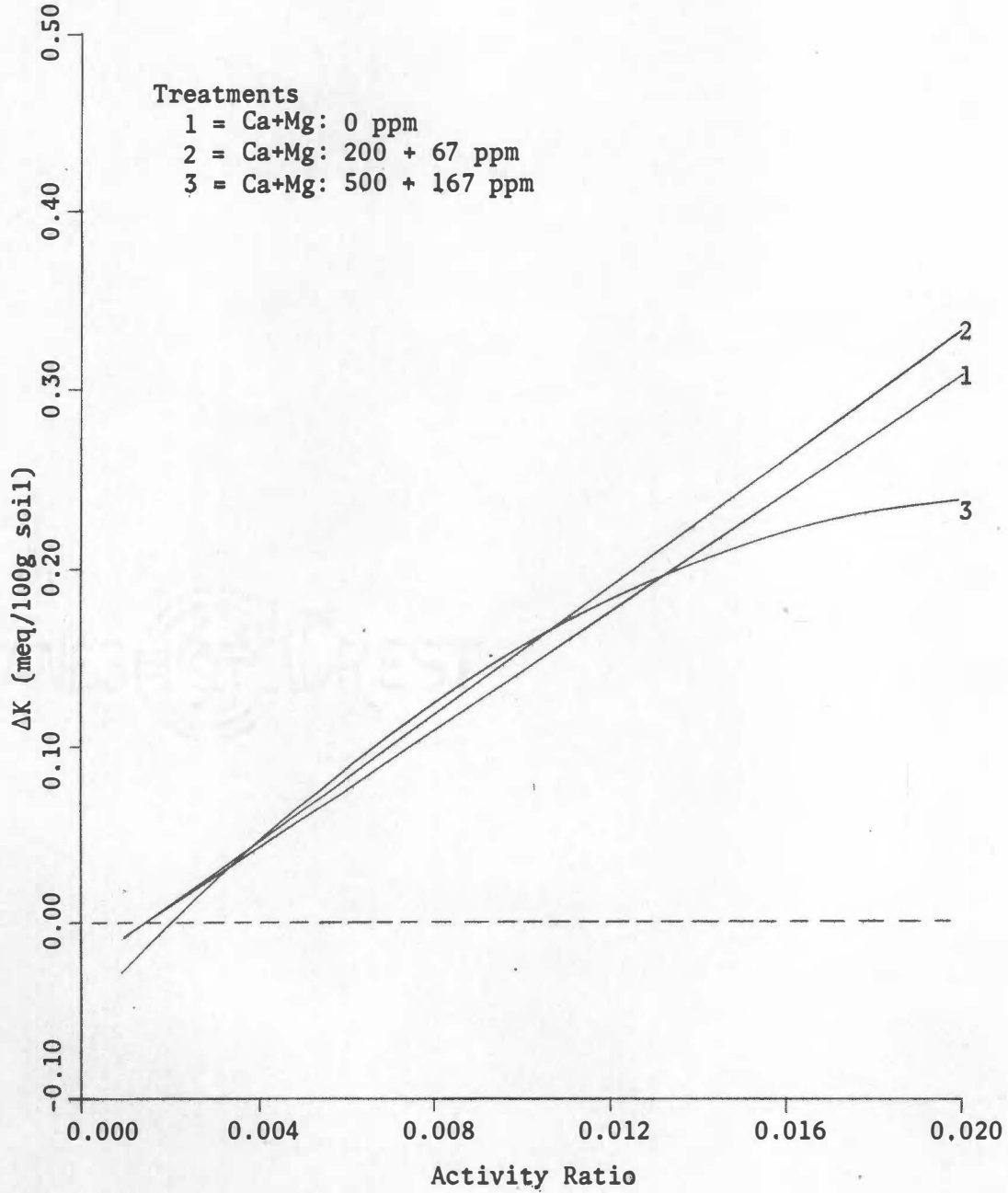


Figure 8. Relationship between ΔK and activity ratios of the soil-solution equilibration of the calcium and magnesium-treated Hartsells soil.

effect of liming on the ΔK values obtained from the soil-solution equilibration was statistically examined. When the analysis was made across all soils, an F-value of 23.38 resulted, indicating that the ΔK values derived from the limed soils were significantly different from the unlimed at the 1 percent probability level. The regression analysis was made for the effect of liming on ΔK between the three soils. Both the Hartsells and Grenada resulted in F-values (47.68 and 8.48, respectively) that were significant at the 1 percent probability level. However, the Maury soil yielded an F-value of 1.97, which was not significant at the 10 percent level of probability. From Table 1 on page 25, the Maury soil is shown to have a higher pH, cation exchange capacity, percent base saturation and exchangeable calcium than the Hartsells and Grenada soils. Consequently, the addition of liming materials would be expected to have less pronounced effect on the Maury soil than on the Hartsells and Grenada soils. This situation may account for the fact that there were no significant differences between the ΔK values for the limed and unlimed Maury soil.

Slopes of the Soil-Solution Equilibration Curves

A test for the homogeneity of regression coefficients was utilized to determine whether the slopes of the soil-solution equilibration curves were significantly different due to the potassium treatments within each soil. Since not all of the equilibration curves were linear and since the regression coefficient of a linear equation is the same value as the slope of the curve of that equation, a reference point was needed to make

such a comparison. Consequently, the test for the homogeneity of the slopes of the equilibration curves was made at the soil-solution equilibrium point on the curves where $\Delta K$ was equal to zero.

A summary of the values for the slopes of the soil-solution equilibration curves at $\Delta K = 0$ is shown in Table 2.

At the 10 percent level of probability, the slopes of the soil-solution equilibration curves for each of the limed and unlimed Hartsells, Maury and Grenada soils were not significantly different due to the five potassium fertilizer treatments. The results of the homogeneity test are shown in Table C-1, Appendix C.

The slope of the soil-solution equilibration curve has been previously defined as the soil buffering capacity for potassium. The soil buffering capacities for the three limed and unlimed soils used in this investigation are unchanged by the five potassium fertilization treatments, as indicated by the results of the homogeneity test. The buffering capacity would not be expected to change as a result of potassium treatments. Beckett (12) explained that generally the buffering capacity of a soil depends on the extent of the planar surfaces of clays on which potassium and calcium exchange may take place. Additionally, the buffering capacity is dependent on the charge density of the surfaces, which affects the relative affinity for potassium. Potassium additions to the soil do not appreciably influence these properties. However, if the average of the five slope values for the equilibration curves of the limed Hartsells, which are not significantly different, are compared with the average for the unlimed Hartsells, there is an

TABLE 2

Y-INTERCEPTS, SLOPES AT $\Delta K = 0$, AND ACTIVITY RATIOS AT $\Delta K = 0$ OF THE SOIL-SOLUTION EQUILIBRATION CURVES FOR HARTSELLS, MAURY AND GRENADA SOILS

| Soil | Treatment | Y-Intercept (Labile Pool) | Slope at $\Delta K = 0$ | AR at $\Delta K = 0$ |
|---|---|---|---|---|
| Limed Hartsells | 0 ppm K | -0.0885 | 27.0800 | 0.00301 |
| | 25 ppm K | -0.0562 | 15.3900 | 0.00365 |
| | 50 ppm K | -0.0614 | 16.4092 | 0.00374 |
| | 75 ppm K | -0.0790 | 16.3509 | 0.00483 |
| | 100 ppm K | -0.0612 | 14.2242 | 0.00429 |
| Limed Maury | 0 ppm K | -0.0615 | 37.7993 | 0.00162 |
| | 25 ppm K | -0.0848 | 39.3196 | 0.00215 |
| | 50 ppm K | -0.0892 | 34.0853 | 0.00261 |
| | 75 ppm K | -0.1099 | 37.4573 | 0.00293 |
| | 100 ppm K | -0.1478 | 34.1255 | 0.00424 |
| Limed Grenada | 0 ppm K | -0.0535 | 30.5600 | 0.00168 |
| | 25 ppm K | -0.0513 | 28.3600 | 0.00174 |
| | 50 ppm K | -0.0586 | 28.4500 | 0.00196 |
| | 75 ppm K | -0.0771 | 30.2700 | 0.00240 |
| | 100 ppm K | -0.0591 | 28.2500 | 0.00200 |
| Unlimed Hartsells | 0 ppm K | -0.0585 | 13.4096 | 0.00255 |
| | 25 ppm K | -0.0627 | 11.8912 | 0.00527 |
| | 50 ppm K | -0.0860 | 13.3468 | 0.00644 |
| | 75 ppm K | -0.1144 | 12.1461 | 0.00942 |
| | 100 ppm K | -0.1112 | 10.8875 | 0.01021 |
| Unlimed Maury | 0 ppm K | -0.0517 | 32.8516 | 0.00157 |
| | 25 ppm K | -0.0773 | 34.3599 | 0.00224 |
| | 50 ppm K | -0.0861 | 34.1560 | 0.00252 |
| | 75 ppm K | -0.0843 | 30.6830 | 0.00274 |
| | 100 ppm K | -0.1302 | 29.9404 | 0.00434 |

TABLE 2 (continued)

| Soil | Treatment | Y-Intercept (Labile Pool) | Slope at $\Delta K = 0$ | AR at $\Delta K = 0$ |
|---|---|---|---|---|
| Unlimed Grenada | 0 ppm K | -0.0233 | 17.8881 | 0.00130 |
| | 25 ppm K | -0.0214 | 17.3609 | 0.00123 |
| | 50 ppm K | -0.0298 | 18.7125 | 0.00159 |
| | 75 ppm K | -0.0446 | 19.1529 | 0.00232 |
| | 100 ppm K | -0.0446 | 17.2664 | 0.00258 |
| Unlimed Hartsells | 0 ppm Ca, 0 ppm Mg | -0.0253 | 16.7379 | 0.00151 |
| | 200 ppm Ca, 67 ppm Mg | -0.0268 | 18.0526 | 0.00148 |
| | 500 ppm Ca, 167 ppm Mg | -0.0550 | 25.0000 | 0.00208 |

indication that the slopes are different. Further evidence of this difference was discussed in the previous section.

The average slope for the five soil-solution equilibration curves for limed Hartsells was 17.88, and the average for the unlimed Hartsells was 12.34. In the limed Maury soil, the average slope of the equilibration curves was 36.56, compared with 32.40 for the unlimed Maury soil. The limed Grenada equilibration curves were of the quadratic form, and the unlimed Grenada curves were linear. Consequently, the slopes at the point on the curves where $\Delta K$ was equal to zero were compared. The limed Grenada equilibration curves averaged 29.18, and the unlimed Grenada curves averaged 18.08.

In each of the three soils, the limed soil had the highest value for soil buffering capacity for potassium. The Maury soil was the most highly buffered, followed by Grenada, and then by the Hartsells soil. Beckett (12) has indicated that any treatments that obscure parts of the planar surfaces of the soil particles may reduce the buffering capacity of the soil. Polymerized aluminum and iron hydroxides have been shown to block portions of the cation exchange capacity, and increases in exchangeable hydrogen and aluminum may also reduce the buffering capacity. Thus, the soil buffering capacity is indicated to be directly proportional to soil pH. Consequently, raising the pH of an acid soil should lower the positive charges of the aluminum and iron polymers on planar surfaces, increase the exchangeable calcium and magnesium, and increase the buffering capacity of the soil. Since liming has been shown to have little or no effect on the Maury soil,

the buffering capacity values for potassium would not be expected to be different between the limed and unlimed conditions. The converse is true for the Hartsells and Grenada soils whose pH values were lower, and consequently liming had significant effects on the ΔK values.

## Y-Intercepts or Potassium Labile Pool

The families of curves resulting from the soil-solution equilibration of the three soils treated with five levels of potassium generally appeared to be displaced vertically. The displacement of the curves within the family is such that the curve for the sample with no potassium added is the uppermost curve on the graph. Then, increasing additions of potassium to the soils cause a displacement of the curves downward on the graphs.

Beckett (12) and other workers have stated that increased labile potassium in the soil, whether it is caused by potassium fertilizer additions or the release of fixed potassium, results in a family of curves for a soil where each curve will be transposed vertically. They used ΔK as a measure of the amount of potassium cations in the double layer and indicated that ΔK would be a good measure as long as the additions or releases of labile potassium were not followed by fixation.

The y-intercept of the soil-solution equilibration curve has previously been defined as a measure of the potassium labile pool. Vertical displacement of the curves and the y-intercepts indicates that potassium fertilization results in changing the size of the labile pool of potassium. A multiple regression model of ΔK as the dependent

variable and the equilibrium activity ratio and the potassium fertilizer treatments as the continuous independent variables was made. The potassium treatments, as a continuous independent variable, have a major effect on $\Delta K$ due to their effect on the activity ratio. Table 3 summarizes the results of this analysis.

Liming the Hartsells soil resulted in significant differences between the size of the labile pools of potassium at the 10 percent probability level for the curves due to the five potassium treatments. However, it is indicated from the appearance of the curves shown in Figure 3, page 33, that the significant difference may be due primarily to the zero potassium treatment curve since it is of the quadratic form. The remaining four curves of that family are linear and show very little vertical displacement. In contrast, the unlimed Hartsells soil yielded a family of curves with y-intercepts which were significantly different at the 1 percent probability level.

It has been shown in the previous section that liming had no significant effect on the Maury soil. From Table 2, page 42, it can been seen that the y-intercepts or the labile pools for the limed and unlimed Maury soil are very similar. However, in both families of curves for the Maury soil, the y-intercepts are displaced vertically, indicating an increase in the size of the potassium labile pool due to the increase in potassium treatments. The labile pools for both the limed and unlimed Maury soil are significantly different at the 1 percent probability level.

TABLE 3

F-VALUES FOR THE REGRESSION ANALYSIS OF POTASSIUM TREATMENTS AS THE MAJOR EFFECT ON ΔK FOR THE SOIL-SOLUTION EQUILIBRATION CURVES OF HARTSELLS, MAURY AND GRENADA SOILS

| Soil | F-Value |
|---|---|
| Limed Hartsells | 2.22* |
| Limed Maury | 5.43*** |
| Limed Grenada | 0.32n.s. |
| Unlimed Hartsells | 9.04*** |
| Unlimed Maury | 6.80*** |
| Unlimed Grenada | 1.31n.s. |
| Ca+Mg Treated Hartsells | 1.46n.s. |

***Significant at $P_{0.01}$.

** Significant at $P_{0.05}$.

* Significant at $P_{0.10}$.

n.s. Not significant at $P_{0.10}$.

The Grenada soil presents a situation somewhat different from the Hartsells and Maury soils with respect to the potassium labile pool. The limed and unlimed Grenada soils differ in the form of the soil-solution equilibration curves. The effect of liming is significant at the 1 percent level of probability. However, there is no significant difference between the size of the potassium labile pools for the different equilibration curves at the 10 percent level of probability. The soil-solution equilibration curves are not sufficiently displaced vertically to be significant at the 10 percent level of probability, as shown in Table 3.

The limed Hartsells soil that did not receive a potassium treatment and all of the limed Grenada soils yielded equilibration curves that were of the quadratic curvilinear form in contrast to the linear curves. It is speculated that liming and the potassium content of the equilibration solution influenced the potassium selectivity of the soil particles such that the buffering capacity values for potassium continually changed as the solution potassium content was increased.

Although the size of the labile pools (y-intercepts) are different and are displaced downward as the potassium treatments are increased, the differences are not proportionate between treatments. Table 2, page 42, summarizes the values for the potassium labile pool in meq/100g of soil. The size of the labile pools are relatively small in terms of meq/100g of soil and the resulting vertical displacement due to each potassium fertilization treatment may be sufficiently small to be within the range of experimental error. This situation could account for the

variability of displacement of the equilibration curves within a soil even though the overall effect indicated significant differences.

When the largest value for the potassium labile pool or the lowest value for the y-intercept is used to compare the soils, the Grenada soil provided the smallest pool of potassium. The Maury soil provides the largest pool of labile potassium.

## III. CONTENT OF POTASSIUM IN RYEGRASS

Two harvestings were made of the annual ryegrass grown in the greenhouse. Both crops were grown to early maturity when growth was approximately two feet high. The physical appearance of the first and second cuttings of ryegrass was similar.

Table D-1, Appendix D contains the average percentages of calcium, potassium and magnesium found in the ryegrass plants grown on the limed and unlimed Hartsells, Maury and Grenada soils when potassium fertilizer was varied.

Figures 9 and 10 illustrate graphically the relationship of the percent potassium in the ryegrass plant and the concentration of potassium in the soil due to fertilization. General observations that can be made from the curves from Figures 9 and 10 are that the percentages of potassium in the ryegrass are high with respect to that normally found in grasses under field conditions. Then, there is a sharp contrast between the general level of potassium in the first cutting of ryegrass and the second cutting of ryegrass. The potassium content in the plants from the second cutting is approximately 40 percent lower for all soils

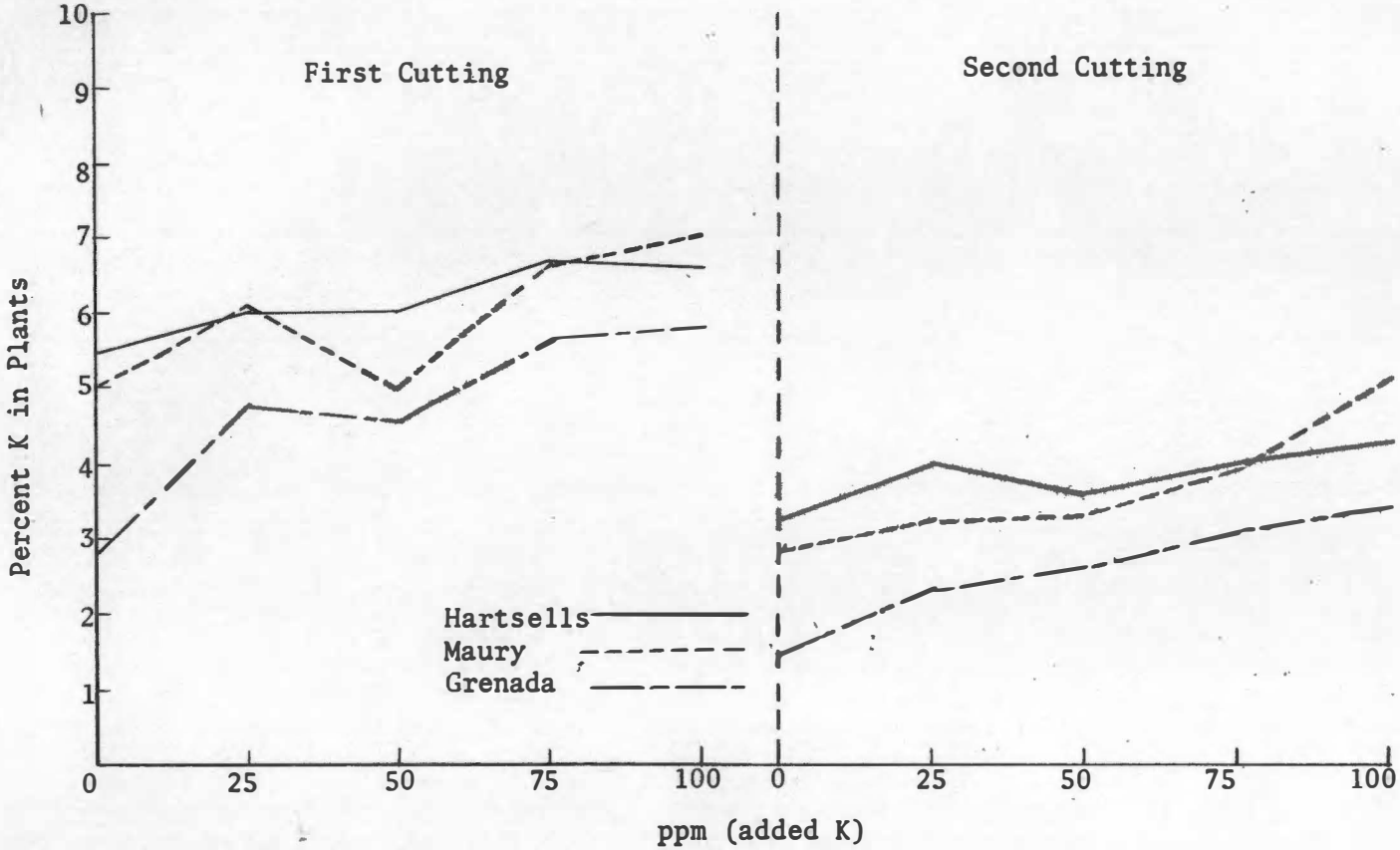


Figure 9. Relationship between the percent potassium in the first and second cuttings of ryegrass plants and the concentration of potassium of the limed Hartsells, Maury and Grenada soils.

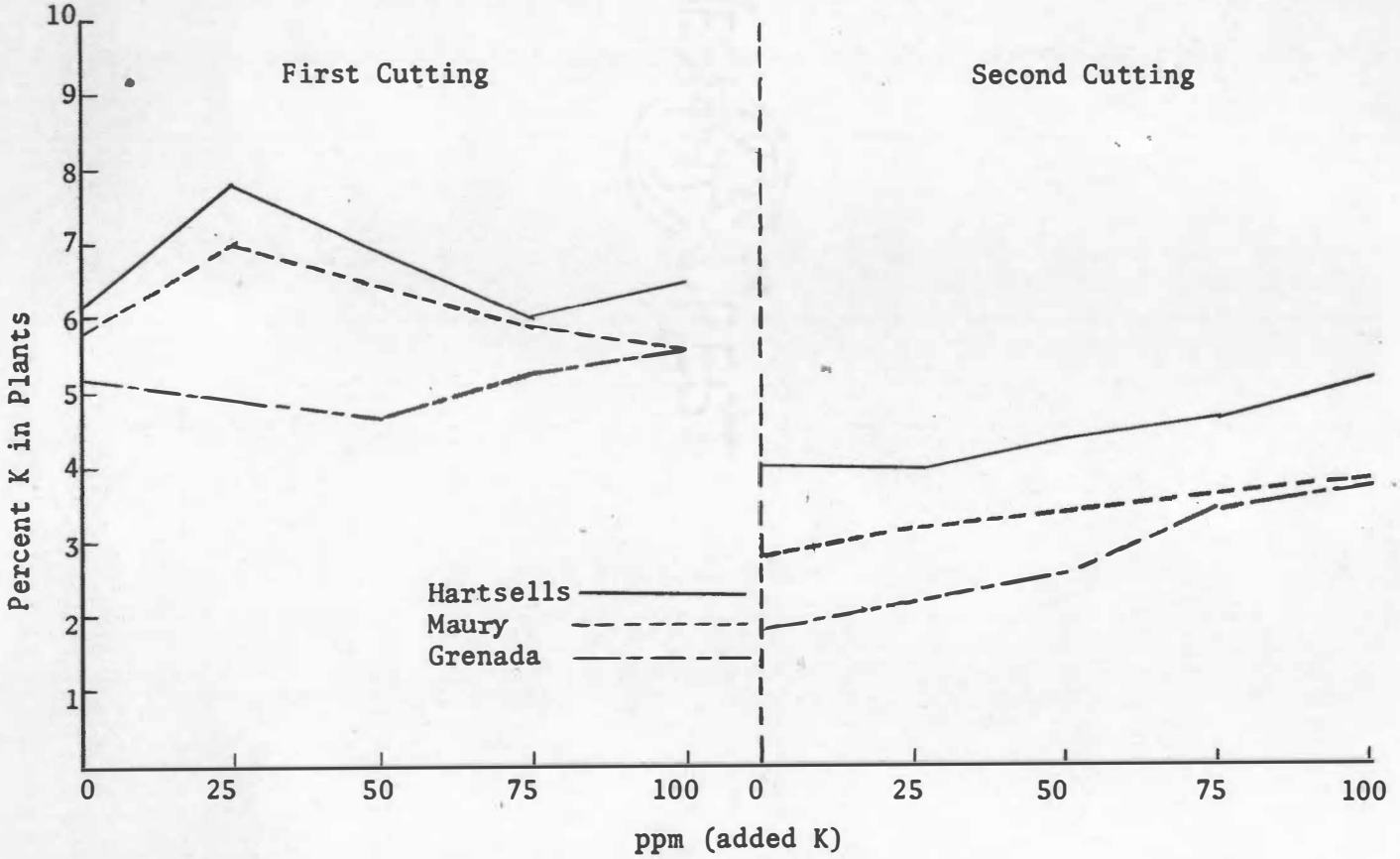


Figure 10. Relationship between the percent potassium in the first and second cuttings of ryegrass plants and the concentration of potassium of the unlimed Hartsells, Maury and Grenada soils.

and for limed and unlimed conditions than that found in the first cutting. Also, more variability exists in the potassium concentration of the plants from the first cutting than in the second cutting. A more definite increasing trend exists in the second cutting in relation to the increasing additions of potassium to the soil.

The high percentages of potassium are attributed to high levels of potassium in the soil. In Table 1, page 25, it is shown that the amount of potassium as pounds per acre in the soil initially was high except for Grenada which was low. Then, additional potassium fertilizations were made in the greenhouse to raise the potassium levels even higher. Concentrations of potassium in ryegrass of this magnitude are not uncommon under appropriate conditions, as illustrated by the work of Hylton, Ulrich and Cornelius (20), in which potassium concentrations in excess of 8 percent were obtained by a nutrient solution technique for growing ryegrass.

This author speculates that a combination of two situations may account, at least in part, for the sharp reduction of potassium concentration in the second cutting of ryegrass. Since the uptake of potassium is generally attributed to the metabolic process of the plant, a reduction in the metabolic rate of the plant may result in a lower concentration in the plant when sufficient amounts of potassium are potentially available to the plant. Nitrogen was applied to the soil at the rate of 100 pounds per acre approximately 20 days after seeding. No additional nitrogen was applied after that time. It would be reasonable to expect that less nitrogen would be available to the second cutting of ryegrass

than to the first cutting. And, since nitrogen is directly associated with the metabolic rate of the plants, the influence of metabolic processes may be associated with the reduction of the concentration of potassium in the second cutting of ryegrass.

In conjunction with the reduction in the metabolic rate of the plant, the soil potassium may be less readily available than was the case in the first cutting. This may be especially true if the root system did not continue to develop appreciably during the growth of the second cutting and "explore" significantly greater volumes of soil where the potassium was just as available to the plant as it was for the first cutting.

The explanation given for the greater variability of the concentration of potassium in the plants in the first cutting than in the second cutting is that the time for an equilibrium to exist between the added potassium fertilizer and the soil was inadequate during the growth of the first cutting, and luxury consumption by the plants resulted due to the very high levels of potassium in the soils.

The concentrations of calcium and magnesium in the plants did not vary appreciably when potassium was increased in the soils. Generally, the plant calcium concentrations were somewhat higher in the limed soils than in the unlimed soils. Magnesium in the plant was not appreciably affected by liming the soils (see Table D-1, Appendix D, for specific values).

The effect of liming was apparently not reflected in the concentration of potassium in the ryegrass plants. There was very little

difference in the percent potassium in the plants for the limed and unlimed soils even though the ΔK values of the equilibration curves were significantly different between limed and unlimed conditions of the Hartsells and Grenada soils.

## IV. POTASSIUM CONCENTRATION OF RYEGRASS AND SOIL POTASSIUM

The relationship between the concentration of potassium in ryegrass and the level of exchangeable soil potassium is the most important aspect of this investigation. The soil-solution equilibration technique was utilized to obtain equilibration curves characteristic of the individual soils from which their parameters may be related to the potassium concentration in plants grown on the soils.

Soil parameters obtained from the equilibration curves used in this investigation and which have been defined previously are the potassium labile pool, the soil buffering capacity for potassium and the activity ratio when ΔK is equal to zero. In addition, combinations of these parameters and the activity of potassium in the equilibration solution were related by regression analysis to the potassium content of the plant.

It was desired to express the concentration of potassium in the plants as a function of the soil parameters. The plant concentration was expressed as the equivalents of potassium per 100g of plant material and as a ratio of the equivalents of potassium per 100g to the square root of the equivalents per 100g of calcium plus magnesium.

Various regression models were used to test the effect of the plant parameters on the soil parameters. Table 4 summarizes the regression models and $R^2$ values for each model. Analysis of variance tables for each regression model, except for those models utilizing the plant parameter $eq_K/eq_{(Ca+Mg)}$, are included in Tables E-1 through E-20, Appendix E. These analysis of variance tables were omitted since the values were so similar to the plant parameter $eq_K/eq_{(Ca+Mg)}{}^{1/2}$. The regression analysis was made across all soils, liming and potassium treatments.

A sharp contrast between the $R^2$ values of the first and second cutting of ryegrass is readily observable from the data in Table 4. The $R^2$ values for the second cutting are appreciably higher than those for the first cutting of ryegrass. The fact that the percent potassium in the ryegrass is higher in the first cutting but that much greater variation exists in the first cutting has been discussed previously and illustrated in Figures 9 and 10 (pages 50 and 51, respectively).

This variability in potassium concentration in the plants of the first cutting and sharp contrast between the first and second cuttings are, again, illustrated by Figures 11 and 12. The concentration of potassium in the plants as meq K/100g of plant material is plotted against meq/100g of exchangeable soil potassium in Figure 11 and Figure 12. The soil exchangeable potassium is the sum of the $NH_4OAc$ extractable potassium of the soil before treatment and the potassium added as fertilizer.

TABLE 4

$R^2$ VALUES FOR VARIOUS MODELS OF REGRESSION OF PLANT PARAMETERS ON SOIL PARAMETERS

| Regression Model | | $R^2$ Values: First Cutting | $R^2$ Values: Second Cutting |
|---|---|---|---|
| Plant K Conc.[a] | = K labile pool + BC + AR | 0.36 | 0.76 |
| | = K labile pool + BC | 0.36 | 0.75 |
| | = AR | 0.27 | 0.62** |
| | = K labile pool | 0.26 | 0.49** |
| | = BC | 0.02 | 0.06** |
| | = K activity | 0.46 | 0.77 |
| | = Exchangeable K | 0.51 | 0.81 |
| | = K labile pool + BC + K act. | 0.47 | 0.82 |
| | = K labile pool + K act. | 0.47 | 0.78 |
| | = BC + K activity | 0.47 | 0.80 |
| Plant Ratio[b] | = K labile pool + BC + AR | 0.47 | 0.81 |
| | = K labile pool + BC | 0.44 | 0.76 |
| | = AR | 0.42 | 0.72 |
| | = K labile pool | 0.19 | 0.37 |
| | = BC | 0.11 | 0.16 |
| | = K activity | 0.48 | 0.73 |
| | = Exchangeable K | 0.42 | 0.68 |
| | = K labile pool + BC + K act. | 0.55 | 0.83 |
| | = K labile pool + K act. | 0.52 | 0.75 |
| | = BC + K activity | 0.54 | 0.82 |
| Plant Ratio[c] | = K labile pool + BC + AR | 0.47 | 0.81 |
| | = K labile pool + BC | 0.43 | 0.74 |
| | = AR | 0.43 | 0.74 |
| | = K labile pool | 0.12 | 0.28 |
| | = BC | 0.17 | 0.22 |
| | = K activity | 0.40 | 0.64 |
| | = Exchangeable K | 0.30 | 0.55 |
| | = K labile pool + BC + K act. | 0.52 | 0.80 |
| | = K labile pool + K act. | 0.48 | 0.69 |
| | = BC + K activity | 0.52 | 0.80 |

[a]Plant conc. as eq/100g plant material.

[b]Plant ratio as $eq_K/eq_{(Ca+Mg)}^{1/2}$.

[c]Plant ratio as $eq_K/eq_{(Ca+Mg)}$.

**Significantly different from exchangeable K model at $P_{0.05}$.

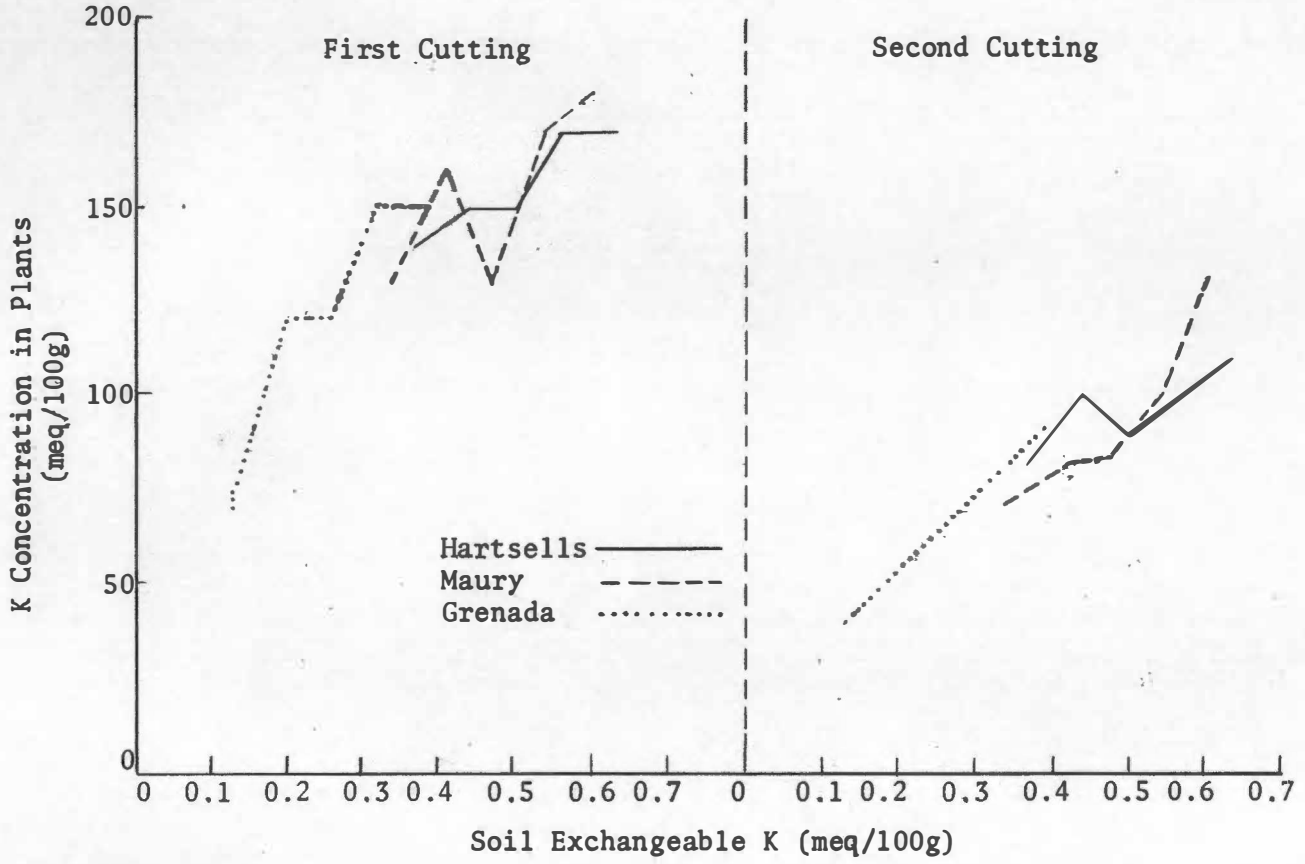


Figure 11. Relationship between the concentration of potassium in the first and second cuttings of ryegrass and the exchangeable potassium in the limed Hartsells, Maury and Grenada soils.

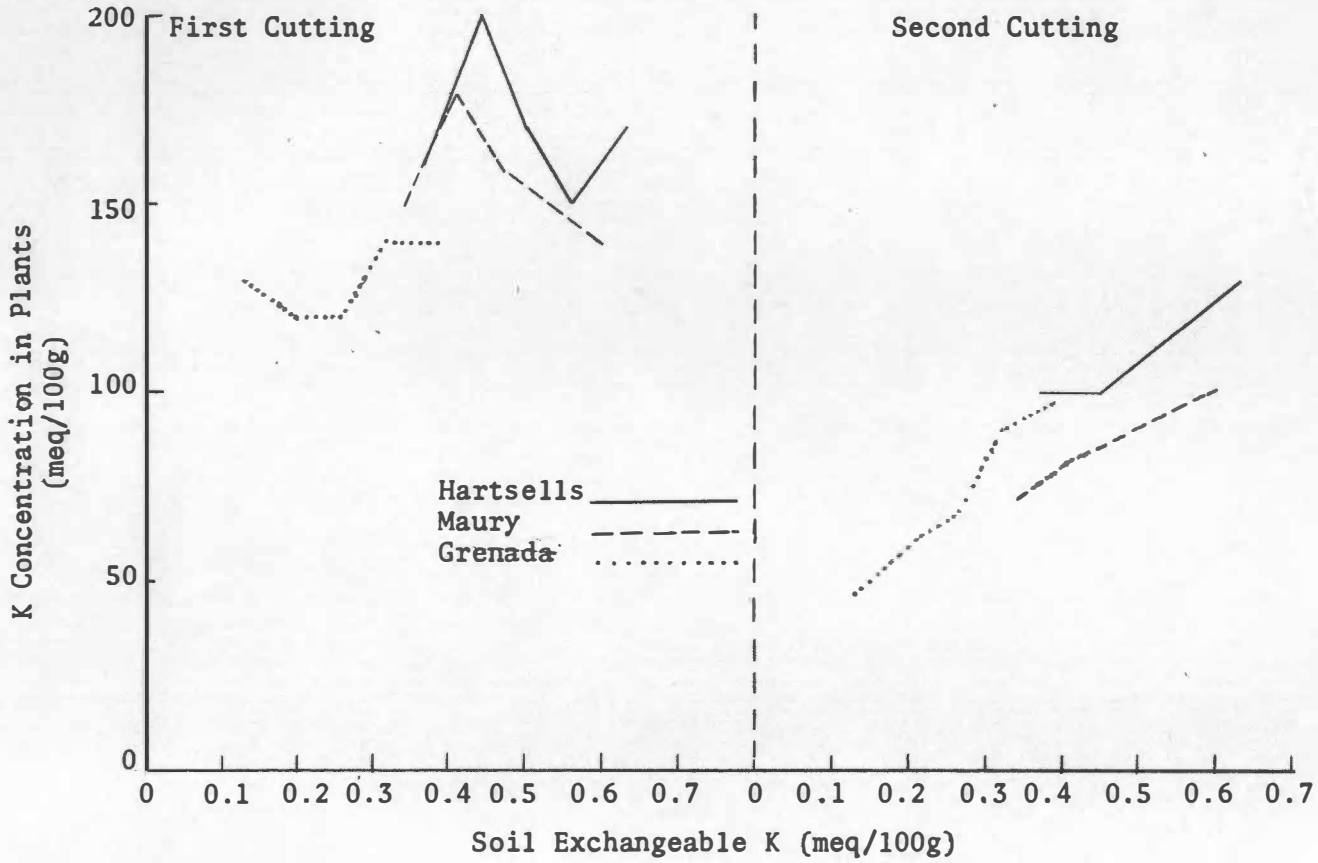


Figure 12. Relationship between the concentration of potassium in the first and second cuttings of ryegrass and the exchangeable potassium in the unlimed Hartsells, Maury and Grenada soils.

Herlihy and Moss (19) recently reported results of a study concerning the availability of soil potassium to ryegrass and soil-solution equilibration measurements. No relationship was found between the initial exchangeable soil potassium content and potassium uptake in the first cutting. According to Herlihy and Moss, the lack of correlation was due partly to inadequate equilibrium of added potassium with the soil prior to measurement and partly to the high levels of potassium, resulting in luxury consumption by the plants.

This author speculates that a situation similar to that described by Herlihy and Moss may have existed for the first cutting of ryegrass in this investigation and may explain the great variability of the potassium concentration found in the plants and the very low $R^2$ values obtained for the first cutting.

Due to the variability of the concentration of potassium in the plants and the low $R^2$ values from the regression analysis of the first cutting, only the results of the second cutting of ryegrass will be discussed in relating the soil parameters to the concentration of potassium in the plants.

The concentration of potassium in the plants may be taken to mean either the $eq_K/100g$ of plant material or $eq_K/eq_{(Ca+Mg)}^{1/2}$ of the plants in the following discussion due to the similarity of the results of the regression analysis (Table 4).

## Soil Exchangeable Potassium and Plant K Concentration

The exchangeable potassium regression model was used to represent the standard or conventional technique for relating soil potassium to the concentration of potassium in plants.

In the regression analysis for the effect of soil parameters on the concentration of potassium in the plant, the exchangeable potassium model resulted in the highest $R^2$ value (Table 4) of all other single source models. The analysis of variance tables for this model are in Tables E-1 and E-2, Appendix E. Although this soil parameter appears to be the best expression for relating the concentration of potassium in plants as a function of the soil potassium, it has been determined by a test for equality of regression coefficients that six other models used are not statistically different from the exchangeable potassium model at the 10 percent probability level. Those models that are significantly different from the exchangeable potassium have been indicated as such in Table 4.

The regression analysis was made across all soils and treatments. However, plots of the concentration of potassium in the ryegrass and the exchangeable potassium of the soil for the various treatments are shown in Figures 11 and 12, pages 57 and 58, respectively. These plots are examples of the kind of relationships existing for the individual soils and would be similar to plots using other soil parameters.

Activity Ratio at $\Delta K = 0$ and Plant K Concentration

The activity ratio at $\Delta K = 0$ was not one of the better indicators for the concentration of potassium in ryegrass plants in this investigation relative to the other models utilized. The $R^2$ value for the activity ratio model was significantly lower than that of the soil exchangeable potassium when the plant content was expressed as $eq_K/100g$ plant material, Table 4, page 56. When the plant content was expressed as the ratio $eq_K/eq_{(Ca+Mg)}^{1/2}$, the $R^2$ value was somewhat higher and not significantly different from the exchangeable potassium model at the 5 percent probability level. Wild (52) has indicated recently that the uptake of potassium by plants is dependent on the concentration in the soil rather than the activity ratio at the point on the equilibration curve that indicates the soil has neither lost nor gained potassium. Several other workers reported findings which indicated that the activity ratio as a single soil parameter does not sufficiently describe the availability of potassium to plants as did the present investigation. Analysis of variance tables for this model are shown in Tables E-3 and E-4, Appendix E.

Potassium Labile Pool and Plant K Concentration

The amount of potassium that is potentially available to plants as measured during the soil-solution equilibration period and indicated by the y-intercept of the equilibration curve has been termed the potassium labile pool for this investigation. This definition is consistent with that of Beckett (12), Koch (25) and others. Koch has

reported that the relationship between the potassium in the corn leaf and soil potassium is best described if the potassium in the leaf is considered as a function of the labile pool of potassium. He suggested that the labile pool of potassium is not the important criterion as such but that through its effect on diffusion and mass flow of potassium and thus on the rate of supply to sites of entry on the growing root, the pool is most closely related to potassium uptake.

The results of this investigation indicate the relationship between the potassium labile pool and the concentration of potassium in the plants is highly significant (Tables E-5 and E-6, Appendix E), but it is significantly lower than the soil exchangeable potassium in accounting for the variability of potassium in the plant (Table 4, page 56).

Soil Buffering Capacity and Plant K Concentration

The soil buffering capacity for potassium or the slope of the equilibration curve at the point where $\Delta K = 0$ was used as a soil parameter in relating the concentration of potassium in the plant to the soil potassium. The slope of the curve at soil-solution equilibrium when $\Delta K = 0$ was utilized because seven of the 33 equilibration curves were of the quadratic curvilinear form. Through the use of the slopes of the linear and curvilinear curves at the point where $\Delta K = 0$, the curves of different forms could then be compared.

The soil buffering capacity was not statistically significant at the 10 percent probability level for describing the potassium concentration

in the plant, Tables E-7 and E-8, Appendix E. It was significant at the 5 percent probability level for the plant ratio form of the expression for plant potassium. Yet, in both cases, they were significantly lower than the exchangeable potassium model. In fact, the $R^2$ value, Table 4 on page 56, for the soil buffering capacity models as individual sources were the lowest of all models used. Under the conditions of this investigation, it appears that the buffering capacity as a single soil parameter is a poor indicator of the available potassium for plant growth. This result should be anticipated since the buffering capacity does not measure quantities of available potassium but only its resistance to change in relation to the activity ratio.

Potassium Activity and Plant K Concentration

The potassium activity of the solution in equilibrium with the soil that had been treated with potassium fertilizer was used in a regression model to test its effect on the plant potassium concentration. As shown in Tables E-9 and E-10 of Appendix E, the potassium activity was highly significant in its relationship with the plant concentration and accounted for the variability of the plant potassium concentration equally well as did the exchangeable potassium of the soil (Table 4). Khasawneh (24) has indicated in his review of work done on this subject, that the potassium activity should have been used all along instead of the activity ratio. However, the results of this study indicated that as a single soil parameter, the potassium activity accounts for the potassium variability of plant as well as other parameters, but is it no better than others investigated.

Multiple Soil Parameters and Plant K Concentration

The activity ratio at $\Delta K = 0$, the potassium labile pool, the buffering capacity, and the potassium activity were used together in various combinations to determine the additive effect in a multiple regression analysis. These regression models and their $R^2$ values are tabulated in Table 4, page 56, and the analysis of variance tables are in Tables E-11 through E-20 of Appendix E.

In every case, when the various soil parameters are combined and are related to the potassium in the ryegrass plants, the $R^2$ values (Table 4) from the regression analysis are comparable to that of soil exchangeable potassium. Each of the models is significant at the 1 percent probability level but is not significantly different from the soil exchangeable potassium model at the 5 percent level of probability.

The activity ratio, potassium labile pool and the buffering capacity had correlation coefficients that were significantly lower than the standard regression model of exchangeable potassium; however, in some combined forms, they described the soil potassium in relation to plant uptake as well as did the exchangeable potassium but were no better than the exchangeable potassium model.

The results indicate that a measure of the quantity of available or potentially available potassium with a measure of the ability of the soil to release potassium, or buffering ability of the soil, can adequately describe the potassium concentration of the plant as a

function of exchangeable soil potassium utilizing the soil-solution equilibration technique.

# CHAPTER V

## SUMMARY AND CONCLUSIONS

The primary objective of this study was to investigate the parameters of the soil-solution equilibration relationships of three different soils with respect to the concentration of potassium in ryegrass. To facilitate this investigation, the soils were used to grow ryegrass in the greenhouse with varying amounts of potassium fertilization in limed and unlimed conditions. The soils were then subjected to the soil-solution equilibration technique described by Schofield and Beckett for evaluating the fertility status of the soils for potassium.

The soils were fertilized with nitrogen and phosphorus, and the potassium fertilization was varied from 0 to 100 ppm of added potassium. Ryegrass was seeded in the Hartsells, Maury and Grenada soils and grown to early maturity. Soil-solution equilibrium determinations were made on the soils in which the ryegrass had grown, and analyses for potassium, calcium and magnesium contents were made on the plant material.

In the soil-solution phase of the investigation, two forms of equilibration curves resulted. Seven of the 33 equilibration curves resulted in the quadratic curvilinear form, whereas the remaining 26 curves were linear. The limed Hartsells that received no potassium fertilization and the family of limed Grenada curves resulted in the curvilinear form. However, the lower portion of the quadratic form curves approximates a straight line. Due to the linear nature of the

lower portion of all curves, it was speculated that there had been no release of fixed potassium during the equilibration period.

When the effect of liming on $\Delta K$ for the soils was determined, the results indicated that liming significantly affected the $\Delta K$ values except for the Maury soil. Generally, the $\Delta K$ values for the limed soils were somewhat higher than for the unlimed soils.

The slopes of the soil-solution equilibration curves at $\Delta K = 0$ which were defined as a measure of the potassium buffering capacity of the soils, were not affected by adding potassium as fertilizer treatments within each soil. However, the limed condition of each soil resulted in a higher potassium buffering capacity than the unlimed condition. The Maury soil was most highly buffered, followed by Grenada, and then by the Hartsells soil.

The labile pools of potassium as measured by the y-intercepts of the equilibration curves generally were displaced downward on the graph as the potassium fertilizer additions were increased. However, in the specific case of the Grenada soil, there were no significant differences in the size of the potassium labile pools due to fertilization. The Maury soil provided the largest pool of labile potassium, and the Grenada provided the smallest pool.

The content of potassium in the ryegrass plants was high with respect to that normally found in grasses under field conditions. The first cutting resulted in potassium contents ranging from 2.8 percent to 7.8 percent. The second cutting had a considerably lower potassium content. The percentages of the second cutting ranged from 1.4 percent

to 5.2 percent potassium. In addition, much greater variability was found in the first cutting potassium contents. This variability and high potassium content were believed to be due to the very high soil potassium levels and the lack of adequate equilibrium between the potassium fertilizer added and the soil during the growing period for the first cutting. The concentration of calcium and magnesium did not vary appreciably when potassium was increased in the soil. The effects of liming were apparently not reflected by the potassium percentages found in the ryegrass plants. However, this may not be the case at lower potassium levels.

Various regression models were used to test the effect of the soil parameters on the plant parameters. Exchangeable soil potassium used as a single source in the regression model gave the highest $R^2$ value ($R^2 = 0.81$) of all the other single sources used. The potassium activity as a single source regression model gave an $R^2$ value ($R^2 = 0.77$) slightly lower than the exchangeable potassium model but was not statistically different from the exchangeable potassium model. Other single source soil parameters (AR at $\Delta K = 0$, potassium labile pool, or buffering capacity) accounted for less of the variability of potassium in the plant than the exchangeable potassium and the potassium activity parameters.

However, when any two of the three soil-solution equilibration parameters were used together in a regression model, they accounted for the variability of plant potassium content no better than the single parameters of exchangeable potassium or the potassium activity.

The results of this investigation indicated that the soil-solution equilibration (Q/I) technique adequately describes the potassium fertility status of the soil in relation to the potassium content of plants grown on the soil. It was not better than the conventional method of exchangeable soil potassium measurements, and it does demand some additional effort beyond that of the conventional method. However, the soil-solution equilibration technique, in addition to accounting for the variability of potassium in the plant as does the conventional method, provides other parameters (K labile pool, K buffering capacity, and AR at $\Delta K = 0$) that may be useful in further delineating the potassium fertility status of the soil.

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## LITERATURE CITED


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# APPENDIXES

## APPENDIX A

## PROCEDURE FOR THE WET DIGESTION OF RYEGRASS FOR POTASSIUM, CALCIUM AND MAGNESIUM ANALYSIS BY THE ALUMINUM HEATING BLOCK METHOD

1. Dry plant tissue at 70°C., grind into fine particles, and store in airtight containers.

2. Weigh a 0.5000 gram portion of each sample and place into a 50 ml glass tube.

3. Add two or three small glass beads and 3 ml of concentrated nitric acid to each sample. Place a small funnel in the mouth of each glass tube to act as a condenser.

4. Place tubes into the aluminum heating block and let the samples digest at room temperature overnight.

5. Place aluminum block on hotplate and raise the temperature to 150°C. Digest at this temperature for one hour.

6. Add 2 ml of 60 to 70 percent perchloric acid to each tube and digest at 235°C. for two hours. The liquid in each sample should be clear at this point. If not, continue digestion until clear.

7. Cool the aluminum block to room temperature and add 1 ml of concentrated hydrochloric acid. Digest at 150°C. for 15 to 20 minutes.

8. Transfer cooled samples into 100 ml volumetric flasks and make to volume with distilled water.

9. Shake the flask thoroughly and let stand overnight.

10. At this point the samples are ready for analysis for Ca, K and Mg content.

APPENDIX B

TABLE B-1

REGRESSION EQUATIONS AND $R^2$ VALUES FOR SOIL-SOLUTION EQUILIBRATION CURVES FOR THE HARTSELLS, MAURY AND GRENADA SOILS

| Soil | Treatment | Equation of Soil Equilibration Curve | $R^2$ |
|---|---|---|---|
| Limed Hartsell | 0 ppm K | $y = -0.0885 + 31.58x - 749.3x^2$ | 0.92 |
| | 25 ppm K | $y = -0.0562 + 15.39x$ | 0.75 |
| | 50 ppm K | $y = -0.0614 + 16.41x$ | 0.85 |
| | 75 ppm K | $y = -0.0790 + 16.35x$ | 0.90 |
| | 100 ppm K | $y = -0.0616 + 14.22x$ | 0.78 |
| Unlimed Hartsells | 0 ppm K | $y = -0.0585 + 13.41x$ | 0.79 |
| | 25 ppm K | $y = -0.0627 + 11.89x$ | 0.70 |
| | 50 ppm K | $y = -0.0860 + 13.35x$ | 0.89 |
| | 75 ppm K | $y = -0.1144 + 12.15x$ | 0.87 |
| | 100 ppm K | $y = -0.1112 + 10.89x$ | 0.70 |
| Limed Maury | 0 ppm K | $y = -0.0615 + 37.80x$ | 0.94 |
| | 25 ppm K | $y = -0.0848 + 39.32x$ | 0.94 |
| | 50 ppm K | $y = -0.0892 + 34.08x$ | 0.90 |
| | 75 ppm K | $y = -0.1100 + 37.46x$ | 0.93 |
| | 100 ppm K | $y = -0.1477 + 34.13x$ | 0.78 |
| Unlimed Maury | 0 ppm K | $y = -0.0517 + 32.85x$ | 0.94 |
| | 25 ppm K | $y = -0.0773 + 34.36x$ | 0.96 |
| | 50 ppm K | $y = -0.0861 + 34.16x$ | 0.93 |
| | 75 ppm K | $y = -0.0843 + 30.68x$ | 0.91 |
| | 100 ppm K | $y = -0.1302 + 29.94x$ | 0.90 |

TABLE B-1 (continued)

| Soil | Treatment | Equation of Soil Equilibration Curve | $R^2$ |
|---|---|---|---|
| Limed Grenada | 0 ppm K | $y = -0.0534 + 33.21x - 783.8x^2$ | 0.94 |
| | 25 ppm K | $y = -0.0516 + 30.42x - 589.9x^2$ | 0.93 |
| | 50 ppm K | $y = -0.0586 + 31.14x - 687.4x^2$ | 0.97 |
| | 75 ppm K | $y = -0.0771 + 33.80x - 727.4x^2$ | 0.94 |
| | 100 ppm K | $y = -0.0591 + 30.59x - 594.3x^2$ | 0.94 |
| Unlimed Grenada | 0 ppm K | $y = -0.0233 + 17.89x$ | 0.88 |
| | 25 ppm K | $y = -0.0214 + 17.36x$ | 0.90 |
| | 50 ppm K | $y = -0.0298 + 18.71x$ | 0.94 |
| | 75 ppm K | $y = -0.0446 + 19.15x$ | 0.93 |
| | 100 ppm K | $y = -0.0446 + 17.27x$ | 0.90 |
| Unlimed Hartsells | 0 ppm Ca, 0 ppm Mg | $y = -0.0253 + 16.74x$ | 0.86 |
| | 200 ppm Ca, 67 ppm Mg | $y = -0.0268 + 18.05x$ | 0.92 |
| | 500 ppm Ca, 167 ppm Mg | $y = -0.0549 + 27.70x - 684.5x^2$ | 0.91 |

APPENDIX C

TABLE C-1

TEST FOR HOMOGENEITY OF REGRESSION COEFFICIENTS OF THE SOIL-SOLUTION EQUILIBRATION CURVES FOR POTASSIUM-TREATED HARTSELLS, MAURY AND GRENADA SOILS

| Soil | Fertilizer Treatment | Error Sum of Squares | d.f. | Mean Square | F-Value[a] |
|---|---|---|---|---|---|
| Limed Hartsells | 0 ppm K | 0.016201 | 21 | | |
| | 25 ppm K | 0.050550 | 22 | | |
| | 50 ppm K | 0.030026 | 22 | | |
| | 75 ppm K | 0.019587 | 22 | | |
| | 100 ppm K | 0.040607 | 22 | | |
| | Pooled Error SS | 0.168806 | 114 | | |
| | Σ Error SS | 0.156970 | 109 | 0.001440 | |
| | Difference | 0.011836 | 5 | 0.002367 | 1.64 |
| Limed Maury | 0 ppm K | 0.026370 | 22 | | |
| | 25 ppm K | 0.028183 | 22 | | |
| | 50 ppm K | 0.039338 | 22 | | |
| | 75 ppm K | 0.028791 | 22 | | |
| | 100 ppm K | 0.094066 | 22 | | |
| | Pooled Error SS | 0.223112 | 114 | | |
| | Σ Error SS | 0.216784 | 110 | 0.001974 | |
| | Difference | 0.076901 | 4 | 0.001581 | 0.80 |
| Limed Grenada | 0 ppm K | 0.015930 | 21 | | |
| | 25 ppm K | 0.017785 | 21 | | |
| | 50 ppm K | 0.006275 | 21 | | |
| | 75 ppm K | 0.016376 | 21 | | |
| | 100 ppm K | 0.015304 | 21 | | |

TABLE C-1 (continued)

| Soil | Fertilizer Treatment | Error Sum of Squares | d.f. | Mean Square | F-Value[a] |
|---|---|---|---|---|---|
| | Pooled Error SS | 0.076900 | 117 | | |
| | Σ Error SS | 0.071670 | 105 | 0.000682 | |
| | Difference | 0.005230 | 12 | 0.000436 | 0.64 |
| Unlimed Hartsells | 0 ppm K | 0.036405 | 22 | | |
| | 25 ppm K | 0.047322 | 22 | | |
| | 50 ppm K | 0.016100 | 22 | | |
| | 75 ppm K | 0.017050 | 22 | | |
| | 100 ppm K | 0.043781 | 22 | | |
| | Pooled Error SS | 0.164321 | 114 | | |
| | Σ Error SS | 0.160658 | 110 | 0.001460 | |
| | Difference | 0.003662 | 4 | 0.000915 | 0.63 |
| Unlimed Maury | 0 ppm K | 0.022802 | 22 | | |
| | 25 ppm K | 0.017329 | 22 | | |
| | 50 ppm K | 0.027734 | 22 | | |
| | 75 ppm K | 0.033905 | 22 | | |
| | 100 ppm K | 0.033861 | 22 | | |
| | Pooled Error SS | 0.141065 | 114 | | |
| | Σ Error SS | 0.135634 | 110 | 0.001233 | |
| | Difference | 0.005431 | 4 | 0.001357 | 1.10 |
| Unlimed Grenada | 0 ppm K | 0.026534 | 22 | | |
| | 25 ppm K | 0.022268 | 22 | | |
| | 50 ppm K | 0.014591 | 22 | | |
| | 75 ppm K | 0.017347 | 22 | | |
| | 100 ppm K | 0.022718 | 22 | | |

TABLE C-1 (continued)

| Soil | Fertilizer Treatment | Error Sum of Squares | d.f. | Mean Square | F-Value[a] |
|---|---|---|---|---|---|
| | Pooled Error SS | 0.105203 | 114 | | |
| | Σ Error SS | 0.103458 | 110 | 0.000941 | |
| | Difference | 0.001745 | 4 | 0.000436 | 0.46 |
| Unlimed Hartsells | 0 ppm Ca, 0 ppm Mg | 0.028882 | 22 | | |
| | 200 ppm Ca, 67 ppm Mg | 0.015266 | 22 | | |
| | 500 ppm Ca, 167 ppm Mg | 0.016388 | 21 | | |
| | Pooled Error SS | 0.064618 | 68 | | |
| | Σ Error SS | 0.060536 | 65 | 0.000930 | |
| | Difference | 0.004082 | 3 | 0.001360 | 1.46 |

[a]Regression coefficients are equal when F-value equals zero. F-values > 2.22 are significant at P = 0.10.

APPENDIX D

TABLE D-1

PERCENT CALCIUM, POTASSIUM AND MAGNESIUM IN RYEGRASS GROWN ON HARTSELLS, MAURY AND GRENADA SOILS WITH VARIOUS POTASSIUM FERTILIZER TREATMENTS

| Soil | Treatment | First Cutting | | | Second Cutting | | |
|---|---|---|---|---|---|---|---|
| | | Ca | K | Mg | Ca | K | Mg |
| Limed Hartsells | 0 ppm K | 1.37 | 5.43 | 0.48 | 1.13 | 3.18 | 0.41 |
| | 25 ppm K | 1.28 | 6.01 | 0.49 | 1.16 | 4.01 | 0.39 |
| | 50 ppm K | 1.54 | 6.02 | 0.48 | 1.19 | 3.57 | 0.36 |
| | 75 ppm K | 1.40 | 6.72 | 0.50 | 1.10 | 4.04 | 0.37 |
| | 100 ppm K | 1.71 | 6.59 | 0.46 | 1.01 | 4.29 | 0.34 |
| Limed Maury | 0 ppm K | 2.12 | 5.00 | 0.51 | 1.69 | 2.83 | 0.44 |
| | 25 ppm K | 2.01 | 6.11 | 0.49 | 1.72 | 3.16 | 0.45 |
| | 50 ppm K | 2.23 | 5.01 | 0.48 | 2.07 | 3.28 | 0.42 |
| | 75 ppm K | 1.92 | 6.60 | 0.47 | 1.68 | 3.90 | 0.39 |
| | 100 ppm K | 1.99 | 7.01 | 0.49 | 1.64 | 5.07 | 0.38 |
| Limed Grenada | 0 ppm K | 2.09 | 2.78 | 0.58 | 1.23 | 1.41 | 0.41 |
| | 25 ppm K | 2.05 | 4.76 | 0.58 | 1.20 | 2.29 | 0.40 |
| | 50 ppm K | 1.82 | 4.58 | 0.48 | 1.25 | 2.55 | 0.39 |
| | 75 ppm K | 1.92 | 5.72 | 0.51 | 1.27 | 3.07 | 0.36 |
| | 100 ppm K | 1.97 | 5.79 | 0.52 | 1.32 | 3.39 | 0.37 |
| Unlimed Hartsells | 0 ppm K | 1.08 | 6.07 | 0.43 | 0.86 | 3.96 | 0.39 |
| | 25 ppm K | 1.07 | 7.83 | 0.43 | 0.94 | 3.93 | 0.38 |
| | 50 ppm K | 1.97 | 6.75 | 0.43 | 0.91 | 4.43 | 0.36 |
| | 75 ppm K | 1.84 | 6.02 | 0.42 | 0.97 | 4.72 | 0.36 |
| | 100 ppm K | 0.97 | 6.52 | 0.39 | 0.94 | 5.15 | 0.34 |

TABLE D-1 (continued)

| Soil | Treatment | First Cutting | | | Second Cutting | | |
|---|---|---|---|---|---|---|---|
| | | Ca | K | Mg | Ca | K | Mg |
| Unlimed Maury | 0 ppm K | 2.38 | 5.80 | 0.57 | 1.72 | 2.80 | 0.52 |
| | 25 ppm K | 3.09 | 6.96 | 0.60 | 1.50 | 3.24 | 0.43 |
| | 50 ppm K | 2.40 | 6.45 | 0.47 | 1.38 | 3.35 | 0.39 |
| | 75 ppm K | 2.40 | 5.94 | 0.52 | 1.52 | 3.71 | 0.39 |
| | 100 ppm K | 2.38 | 5.65 | 0.47 | 1.51 | 3.90 | 0.38 |
| Unlimed Grenada | 0 ppm K | 2.46 | 5.17 | 0.71 | 1.47 | 1.82 | 0.48 |
| | 25 ppm K | 2.16 | 4.94 | 0.61 | 1.53 | 2.32 | 0.50 |
| | 50 ppm K | 2.05 | 4.68 | 0.52 | 1.40 | 2.55 | 0.47 |
| | 75 ppm K | 1.27 | 5.32 | 0.54 | 1.31 | 3.48 | 0.43 |
| | 100 ppm K | 1.38 | 5.59 | 0.49 | 1.35 | 3.80 | 0.40 |
| Unlimed Hartsells | 0 ppm Ca, 0 ppm Mg | 2.88 | 4.40 | 0.48 | 1.40 | 2.64 | 0.44 |
| | 200 ppm Ca, 67 ppm Mg | 3.26 | 4.76 | 0.67 | 2.38 | 2.46 | 0.63 |
| | 500 ppm Ca, 167 ppm Mg | 2.52 | 4.93 | 0.71 | 2.32 | 2.82 | 0.62 |

APPENDIX E

TABLE E-1

ANALYSIS OF VARIANCE FOR THE EFFECT OF THE EXCHANGEABLE SOIL POTASSIUM ON THE RATIO OF THE CONCENTRATION OF POTASSIUM TO THE SQUARE ROOT OF THE CONCENTRATION OF CALCIUM PLUS MAGNESIUM IN THE RYEGRASS PLANTS GROWN ON HARTSELLS, MAURY AND GRENADA SOILS

| Source | d.f. | Mean Square | F-Value |
|---|---|---|---|
| | First Cutting | | |
| Exchangeable K | 1 | 0.00111050 | 20.72*** |
| Error | 28 | 0.00005360 | |
| | Second Cutting | | |
| Exchangeable K | 1 | 0.00154224 | 60.45*** |
| Error | 28 | 0.00002551 | |

***Significant at $P_{0.01}$.

** Significant at $P_{0.05}$.

* Significant at $P_{0.10}$.

n.s. Not significant at $P_{0.10}$.

TABLE E-2

ANALYSIS OF VARIANCE FOR THE EFFECT OF THE EXCHANGEABLE SOIL POTASSIUM ON THE CONCENTRATION OF POTASSIUM IN THE RYEGRASS PLANTS GROWN ON HARTSELLS, MAURY AND GRENADA SOILS

| Source | d.f. | Mean Square | F-Value |
|---|---|---|---|
| | First Cutting | | |
| Exchangeable K | 1 | 0.00000090 | 29.36*** |
| Error | 28 | 0.00000003 | |
| | Second Cutting | | |
| Exchangeable K | 1 | 0.00000122 | 123.23*** |
| Error | 28 | 0.00000001 | |

***Significant at $P_{0.01}$.

** Significant at $P_{0.05}$.

* Significant at $P_{0.10}$.

n.s. Not significant at $P_{0.10}$.

TABLE E-3

ANALYSIS OF VARIANCE FOR THE EFFECT OF THE SOIL EQUILIBRIUM ACTIVITY RATIO ON THE CONCENTRATION OF POTASSIUM IN THE RYEGRASS PLANTS GROWN ON HARTSELLS, MAURY AND GRENADA SOILS

| Source | d.f. | Mean Square | F-Value |
|---|---|---|---|
| | First Cutting | | |
| Activity Ratio | 1 | 0.00000054 | 11.73*** |
| Error | 31 | 0.00000005 | |
| | Second Cutting | | |
| Activity Ratio | 1 | 0.00000100 | 50.79*** |
| Error | 31 | 0.00000002 | |

***Significant at $P_{0.01}$.

** Significant at $P_{0.05}$.

* Significant at $P_{0.10}$.

n.s. Not significant at $P_{0.10}$.

TABLE E-4

ANALYSIS OF VARIANCE FOR THE EFFECT OF THE SOIL EQUILIBRIUM ACTIVITY RATIO ON THE RATIO OF THE CONCENTRATION OF POTASSIUM TO THE SQUARE ROOT OF THE CONCENTRATION OF CALCIUM PLUS MAGNESIUM IN THE RYEGRASS GROWN ON HARTSELLS, MAURY AND GRENADA SOILS

| Source | d.f. | Mean Square | F-Value |
|---|---|---|---|
| | First Cutting | | |
| Activity Ratio | 1 | 0.00132842 | 22.65*** |
| Error | 31 | 0.00005864 | |
| | Second Cutting | | |
| Activity Ratio | 1 | 0.00186737 | 81.74*** |
| Error | 31 | 0.00002284 | |

***Significant at $P_{0.01}$.

** Significant at $P_{0.05}$.

* Significant at $P_{0.10}$.

n.s. Not significant at $P_{0.10}$.

TABLE E-5

ANALYSIS OF VARIANCE FOR THE EFFECT OF THE LABILE POOL OF POTASSIUM IN THE SOIL ON THE CONCENTRATION OF POTASSIUM IN THE RYEGRASS PLANTS GROWN ON HARTSELLS, MAURY AND GRENADA SOILS

| Source | d.f. | Mean Square | F-Value |
|---|---|---|---|
| | First Cutting | | |
| K Labile Pool | 1 | 0.00000052 | 11.10*** |
| Error | 31 | 0.00000005 | |
| | Second Cutting | | |
| K Labile Pool | 1 | 0.00000079 | 30.03*** |
| Error | 31 | 0.00000003 | |

***Significant at $P_{0.01}$.

** Significant at $P_{0.05}$.

* Significant at $P_{0.10}$.

n.s. Not significant at $P_{0.10}$.

TABLE E-6

ANALYSIS OF VARIANCE FOR THE EFFECT OF THE LABILE POOL OF THE SOIL ON THE RATIO OF THE CONCENTRATION OF POTASSIUM TO THE SQUARE ROOT OF THE CONCENTRATION OF CALCIUM PLUS MAGNESIUM IN THE RYEGRASS PLANTS GROWN ON HARTSELLS, MAURY AND GRENADA SOILS

| Source | d.f. | Mean Square | F-Value |
|---|---|---|---|
| | First Cutting | | |
| K Labile Pool | 1 | 0.00060109 | 7.32*** |
| Error | 31 | 0.00008210 | |
| | Second Cutting | | |
| K Labile Pool | 1 | 0.00095933 | 18.40*** |
| Error | 31 | 0.00005214 | |

***Significant at $P_{0.01}$.

** Significant at $P_{0.05}$.

* Significant at $P_{0.10}$.

n.s. Not significant at $P_{0.10}$.

TABLE E-7

ANALYSIS OF VARIANCE FOR THE EFFECT OF THE BUFFERING CAPACITY OF THE SOIL ON THE CONCENTRATION OF POTASSIUM ON THE RYEGRASS PLANTS GROWN ON HARTSELLS, MAURY AND GRENADA SOILS

| Source | d.f. | Mean Square | F-Value |
|---|---|---|---|
| | First Cutting | | |
| Soil Buffering Capacity | 1 | 0.00000003 | 0.54n.s. |
| Error | 31 | 0.00000006 | |
| | Second Cutting | | |
| Soil Buffering Capacity | 1 | 0.00000010 | 2.12n.s. |
| Error | 31 | 0.00000005 | |

***Significant at $P_{0.01}$.

** Significant at $P_{0.05}$.

* Significant at $P_{0.10}$.

n.s. Not significant at $P_{0.10}$.

TABLE E-8

ANALYSIS OF VARIANCE FOR THE EFFECT OF THE BUFFERING CAPACITY OF THE SOIL ON THE RATIO OF THE CONCENTRATION OF POTASSIUM TO THE SQUARE ROOT OF THE CONCENTRATION OF CALCIUM PLUS MAGNESIUM IN THE RYEGRASS PLANTS GROWN ON HARTSELLS, MAURY AND GRENADA SOILS

| Source | d.f. | Mean Square | F-Value |
|---|---|---|---|
| | First Cutting | | |
| Soil Buffering Capacity | 1 | 0.00035062 | 3.89* |
| Error | 31 | 0.00009018 | |
| | Second Cutting | | |
| Soil Buffering Capacity | 1 | 0.00040392 | 5.76** |
| Error | 31 | 0.00007005 | |

***Significant at $P_{0.01}$.

** Significant at $P_{0.05}$.

* Significant at $P_{0.10}$.

n.s. Not significant at $P_{0.10}$.

TABLE E-9

ANALYSIS OF VARIANCE FOR THE EFFECT OF THE SOIL EQUILIBRIUM ACTIVITY OF POTASSIUM ON THE CONCENTRATION OF POTASSIUM IN THE RYEGRASS PLANTS GROWN ON HARTSELLS, MAURY AND GRENADA SOILS

| Source | d.f. | Mean Square | F-Value |
|---|---|---|---|
| | | First Cutting | |
| K Activity | 1 | 0.00000092 | 26.92*** |
| Error | 31 | 0.00000003 | |
| | | Second Cutting | |
| K Activity | 1 | 0.00000125 | 107.50*** |
| Error | 31 | 0.00000001 | |

***Significant at $P_{0.01}$.

** Significant at $P_{0.05}$.

* Significant at $P_{0.10}$.

n.s. Not significant at $P_{0.10}$.

TABLE E-10

ANALYSIS OF VARIANCE FOR THE EFFECT OF THE SOIL EQUILIBRIUM ACTIVITY OF POTASSIUM ON THE RATIO OF THE CONCENTRATION OF POTASSIUM TO THE SQUARE ROOT OF THE CONCENTRATION OF CALCIUM PLUS MAGNESIUM IN THE RYEGRASS PLANTS GROWN ON HARTSELLS, MAURY AND GRENADA SOILS

| Source | d.f. | Mean Square | F-Value |
|---|---|---|---|
| | | First Cutting | |
| K Activity | 1 | 0.00149917 | 28.22*** |
| Error | 31 | 0.00005313 | |
| | | Second Cutting | |
| K Activity | 1 | 0.00187141 | 82.39*** |
| Error | 31 | 0.00002271 | |

***Significant at $P_{0.01}$.

** Significant at $P_{0.05}$.

* Significant at $P_{0.10}$.

n.s. Not significant at $P_{0.10}$.

TABLE E-11

ANALYSIS OF VARIANCE FOR THE EFFECT OF LABILE POOL OF POTASSIUM BUFFERING CAPACITY OF THE SOIL AND ACTIVITY RATIO ON THE CONCENTRATION OF POTASSIUM IN RYEGRASS PLANTS GROWN ON HARTSELLS, MAURY AND GRENADA SOILS

| Source | d.f. | Mean Square | F-Value |
|---|---|---|---|
| | First Cutting | | |
| K Labile Pool | 1 | 0.00000052 | 12.03*** |
| Soil Buffering Capacity | 1 | 0.00000019 | 4.47** |
| Activity Ratio | 1 | 0.00000001 | 0.11n.s. |
| Error | 29 | 0.00000004 | |
| | Second Cutting | | |
| K Labile Pool | 1 | 0.00000079 | 59.87*** |
| Soil Buffering Capacity | 1 | 0.00000041 | 31.22*** |
| Activity Ratio | 1 | 0.00000002 | 1.59n.s. |
| Error | 29 | 0.00000001 | |

***Significant at $P_{0.01}$.

** Significant at $P_{0.05}$.

* Significant at $P_{0.10}$.

n.s. Not significant at $P_{0.10}$.

TABLE E-12

ANALYSIS OF VARIANCE FOR THE EFFECT OF LABILE POOL OF POTASSIUM, BUFFERING CAPACITY OF THE SOIL AND ACTIVITY RATIO ON THE RATIO OF THE CONCENTRATION OF POTASSIUM TO THE SQUARE ROOT OF THE CONCENTRATION OF CALCIUM PLUS MAGNESIUM IN THE RYEGRASS PLANTS GROWN ON HARTSELLS, MAURY AND GRENADA SOILS

| Source | d.f. | Mean Square | F-Value |
|---|---|---|---|
| | First Cutting | | |
| K Labile Pool | 1 | 0.00060109 | 10.42*** |
| Soil Buffering Capacity | 1 | 0.00079144 | 13.72*** |
| Activity Ratio | 1 | 0.00008111 | 1.41n.s. |
| Error | 29 | 0.00005768 | |
| | Second Cutting | | |
| K Labile Pool | 1 | 0.00095933 | 55.62*** |
| Soil Buffering Capacity | 1 | 0.00101009 | 58.57*** |
| Activity Ratio | 1 | 0.00010596 | 6.14** |
| Error | 29 | 0.00001725 | |

***Significant at $P_{0.01}$.

** Significant at $P_{0.05}$.

* Significant at $P_{0.10}$.

n.s. Not significant at $P_{0.10}$.

TABLE E-13

ANALYSIS OF VARIANCE FOR THE EFFECT OF LABILE POOL OF POTASSIUM AND THE BUFFERING CAPACITY OF THE SOIL ON THE CONCENTRATION OF POTASSIUM IN THE RYEGRASS PLANTS GROWN ON HARTSELLS, MAURY AND GRENADA SOILS

| Source | d.f. | Mean Square | F-Value |
|---|---|---|---|
| | First Cutting | | |
| K Labile Pool | 1 | 0.00000052 | 12.39*** |
| Soil Buffering Capacity | 1 | 0.00000019 | 4.61** |
| Error | 30 | 0.00000004 | |
| | Second Cutting | | |
| K Labile Pool | 1 | 0.00000079 | 58.72*** |
| Soil Buffering Capacity | 1 | 0.00000041 | 30.62*** |
| Error | 30 | 0.00000001 | |

***Significant at $P_{0.01}$.

** Significant at $P_{0.05}$.

* Significant at $P_{0.10}$.

n.s. Not significant at $P_{0.10}$.

TABLE E-14

ANALYSIS OF VARIANCE FOR THE EFFECT OF LABILE POOL OF POTASSIUM AND BUFFERING CAPACITY OF THE SOIL ON THE RATIO OF THE CONCENTRATION OF POTASSIUM TO THE SQUARE ROOT OF THE CONCENTRATION OF CALCIUM PLUS MAGNESIUM IN THE RYEGRASS PLANTS GROWN ON HARTSELLS, MAURY AND GRENADA SOILS

| Source | d.f. | Mean Square | F-Value |
|---|---|---|---|
| | First Cutting | | |
| K Labile Pool | 1 | 0.00060109 | 10.28*** |
| Soil Buffering Capacity | 1 | 0.00079144 | 13.54*** |
| Error | 30 | 0.00005846 | |
| | Second Cutting | | |
| K Labile Pool | 1 | 0.00095933 | 47.48*** |
| Soil Buffering Capacity | 1 | 0.00101009 | 49.99*** |
| Error | 30 | 0.00002020 | |

***Significant at $P_{0.01}$.

** Significant at $P_{0.05}$.

* Significant at $P_{0.10}$.

n.s. Not significant at $P_{0.10}$.

TABLE E-15

ANALYSIS OF VARIANCE FOR THE EFFECT OF LABILE POOL OF POTASSIUM, THE BUFFERING CAPACITY OF THE SOIL AND THE SOIL EQUILIBRIUM ACTIVITY OF POTASSIUM ON THE CONCENTRATION OF POTASSIUM IN THE RYEGRASS PLANTS GROWN ON HARTSELLS, MAURY AND GRENADA SOILS

| Source | d.f. | Mean Square | F-Value |
|---|---|---|---|
| | First Cutting | | |
| K Labile Pool | 1 | 0.00000052 | 14.34*** |
| Soil Buffering Capacity | 1 | 0.00000019 | 5.33** |
| K Activity | 1 | 0.00000021 | 5.70** |
| Error | 29 | 0.00000004 | |
| | Second Cutting | | |
| K Labile Pool | 1 | 0.00000079 | 78.61*** |
| Soil Buffering Capacity | 1 | 0.00000041 | 40.99*** |
| K Activity | 1 | 0.00000011 | 11.16** |
| Error | 29 | 0.00000001 | |

***Significant at $P_{0.01}$.

** Significant at $P_{0.05}$.

* Significant at $P_{0.10}$.

n.s. Not significant at $P_{0.10}$.

TABLE E-16

ANALYSIS OF VARIANCE FOR THE EFFECT OF LABILE POOL OF POTASSIUM, THE SOIL BUFFERING CAPACITY AND THE SOIL EQUILIBRIUM ACTIVITY OF POTASSIUM ON THE RATIO OF THE CONCENTRATION OF POTASSIUM TO THE SQUARE ROOT OF THE CONCENTRATION OF CALCIUM PLUS MAGNESIUM IN THE RYEGRASS PLANTS GROWN ON HARTSELLS, MAURY AND GRENADA SOILS

| Source | d.f. | Mean Square | F-Value |
|---|---|---|---|
| | First Cutting | | |
| K Labile Pool | 1 | 0.00060109 | 12.22*** |
| Soil Buffering Capacity | 1 | 0.00079144 | 16.09*** |
| K Activity | 1 | 0.00032737 | 6.66** |
| Error | 29 | 0.00004918 | |
| | Second Cutting | | |
| K Labile Pool | 1 | 0.00095933 | 64.75*** |
| Soil Buffering Capacity | 1 | 0.00101009 | 68.18*** |
| K Activity | 1 | 0.00017648 | 11.91*** |
| Error | 29 | 0.00001482 | |

***Significant at $P_{0.01}$.

** Significant at $P_{0.05}$.

* Significant at $P_{0.10}$.

n.s. Not significant at $P_{0.10}$.

TABLE E-17

ANALYSIS OF VARIANCE FOR THE EFFECT OF THE LABILE POOL OF POTASSIUM AND THE SOIL EQUILIBRIUM ACTIVITY OF POTASSIUM ON THE CONCENTRATION OF POTASSIUM IN THE RYEGRASS PLANTS GROWN ON HARTSELLS, MAURY AND GRENADA SOILS

| Source | d.f. | Mean Square | F-Value |
|---|---|---|---|
| | First Cutting | | |
| K Labile Pool | 1 | 0.00000052 | 14.82*** |
| K Activity | 1 | 0.00000040 | 11.38*** |
| Error | 30 | 0.00000004 | |
| | Second Cutting | | |
| K Labile Pool | 1 | 0.00000079 | 66.09*** |
| K Activity | 1 | 0.00000046 | 38.23*** |
| Error | 30 | 0.00000001 | |

***Significant at $P_{0.01}$.

** Significant at $P_{0.05}$.

* Significant at $P_{0.10}$.

n.s. Not significant at $P_{0.10}$.

TABLE E-18

ANALYSIS OF VARIANCE FOR THE EFFECT OF THE LABILE POOL OF POTASSIUM AND SOIL EQUILIBRIUM ACTIVITY OF POTASSIUM ON THE RATIO OF THE CONCENTRATION OF POTASSIUM TO THE SQUARE ROOT OF THE CONCENTRATION OF CALCIUM PLUS MAGNESIUM IN THE RYEGRASS PLANTS GROWN ON HARTSELLS, MAURY AND GRENADA SOILS

| Source | d.f. | Mean Square | F-Value |
|---|---|---|---|
| | First Cutting | | |
| K Labile Pool | 1 | 0.00060109 | 11.95*** |
| K Activity | 1 | 0.00103612 | 20.60*** |
| Error | 30 | 0.00005030 | |
| | Second Cutting | | |
| K Labile Pool | 1 | 0.00095933 | 43.94*** |
| K Activity | 1 | 0.00096119 | 44.02*** |
| Error | 30 | 0.00002183 | |

***Significant at $P_{0.01}$.

** Significant at $P_{0.05}$.

* Significant at $P_{0.10}$.

n.s. Not significant at $P_{0.10}$.

TABLE E-19

ANALYSIS OF VARIANCE FOR THE EFFECT OF THE SOIL BUFFERING CAPACITY AND THE SOIL EQUILIBRIUM ACTIVITY OF POTASSIUM ON THE CONCENTRATION OF POTASSIUM IN THE RYEGRASS PLANTS GROWN ON HARTSELLS, MAURY AND GRENADA SOILS

| Source | d.f. | Mean Square | F-Value |
|---|---|---|---|
| | First Cutting | | |
| Soil Buffering Capacity | 1 | 0.00000003 | 0.96n.s. |
| K Activity | 1 | 0.00000089 | 25.18*** |
| Error | 30 | 0.00000004 | |
| | Second Cutting | | |
| Soil Buffering Capacity | 1 | 0.00000010 | 9.73*** |
| K Activity | 1 | 0.00000119 | 111.92*** |
| Error | 30 | 0.00000001 | |

***Significant at $P_{0.01}$.

** Significant at $P_{0.05}$.

* Significant at $P_{0.10}$.

n.s. Not significant at $P_{0.10}$.

TABLE E-20

ANALYSIS OF VARIANCE FOR THE EFFECT OF THE SOIL BUFFERING CAPACITY AND THE SOIL EQUILIBRIUM ACTIVITY OF POTASSIUM ON THE RATIO OF THE CONCENTRATION OF POTASSIUM TO THE SQUARE ROOT OF THE CONCENTRATION OF CALCIUM PLUS MAGNESIUM IN THE RYEGRASS PLANTS GROWN ON HARTSELLS, MAURY AND GRENADA SOILS

| Source | d.f. | Mean Square | F-Value |
|---|---|---|---|
| | First Cutting | | |
| Soil Buffering Capacity | 1 | 0.00035062 | 7.35** |
| K Activity | 1 | 0.00136526 | 28.63*** |
| Error | 30 | 0.00004768 | |
| | Second Cutting | | |
| Soil Buffering Capacity | 1 | 0.00040392 | 26.33*** |
| K Activity | 1 | 0.00171146 | 111.58*** |
| Error | 30 | 0.00001534 | |

***Significant at $P_{0.01}$.

** Significant at $P_{0.05}$.

* Significant at $P_{0.10}$.

n.s. Not significant at $P_{0.10}$.

# VITA

Samuel Kincheloe was born September 4, 1938 on his parents' farm near Church Hill, Tennessee. The local elementary school and Church Hill High School were attended. Having graduated from high school, he entered the University of Tennessee and received a B.S. degree in Agriculture in March, 1961.

In May of 1961, he entered the U. S. Naval Officers Candidate School at Newport, Rhode Island. Having received a commission as a U. S. Naval Officer, he served three years aboard ships home based on the West Coast.

The Master of Science degree with a major in soil chemistry was received from the University of Missouri in August of 1966. Employment with the University of Tennessee Agricultural Extension Service as Assistant County Agent in Washington County followed graduation from the University of Missouri. He was employed with the Extension Service until August 15, 1969 when he then entered graduate school at the University of Tennessee. His Doctor of Philosophy degree in Plant and Soil Science was received in June, 1973.

He and his wife, Carol, have one daughter, Jan Cameron.