The influence of calcium carbonate on the availability and plant uptake of potassium in Montana soils
by Thomas Glen Moore

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Soils
Montana State University
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Abstract:
Most soils in this region contain free $CaCO_3$. Reports in the literature do not agree concerning the nature of $CaCO_3$ influence on soil K availability and uptake.

Two separate greenhouse experiments, using barley as an indicator crop, were designed to examine whether $CaCO_3$ influences the availability and uptake of K. The first experiment utilized a slightly acidic soil to which different levels of reagent grade $CaCO_3$ were added. The second experiment utilized four regionally occurring soils from north-central Montana, each of which contained distinct differences in $CaCO_3$ content. In both experiments three separate factors (K source, K rate, $CaCO_3$ level) were examined to determine whether each had any influence on nutient availability (K, Ca, Mg) or on each other.

The level of $CaCO_3$ in the first experiment caused no differences in extractable soil K across all treatments. Differences in extractable soil K were found in experiment II however, and these differences corresponded to $CaCO_3$ level with K decreasing as $CaCO_3$ increased. However, a small R-squared between pre-plant K and percent $CaCO_3$ eq. suggests that only a small amount of the observed variation in extractable K was due to percent $CaCO_3$.

The effect of K rate in pre-plant soils was the same in both experiments; increasing levels of extractable K were found with increasing K application. Increasing rate of applied K resulted in increased levels of extractable K, Ca and Mg (post-harvest) in both experiments.

Soil variables used in experiment II resulted in no differences in plant concentration for K, Ca or Mg, or in response to source of applied K. Potassium chloride, in both experiments, produced greater fresh and dry matter yield compared to K_2SO_4 .

Plant concentration of K in both experiments was the same with both sources of applied K. No differences in K concentration across $CaCO_3$ treatments were observed in experiment I. Similar results are evident in experiment II.

Results of these experiments suggest that $CaCO_3$ in these soils, and in these quantities has limited direct influence on availability and plant uptake of K, Ca and Mg. This appears to be true where these elements are present in quantities which can minimize the effects of ionic competition between them.

THE INFLUENCE OF CALCIUM CARBONATE ON THE AVAILABILITY AND PLANT UPTAKE OF POTASSIUM IN MONTANA SOILS

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ABSTRACT

Most soils in this region contain free $CaCO_3$. Reports in the literature do not agree concerning the nature of $CaCO_3$ influence on soil K availability and uptake.

Two separate greenhouse experiments, using barley as an indicator crop, were designed to examine whether $CaCO_3$ influences the availability and uptake of K. The first experiment utilized a slightly acidic soil to which different levels of reagent grade $CaCO_3$ were added. The second experiment utilized four regionally occurring soils from north-central Montana, each of which contained distinct differences in $CaCO_3$ content. In both experiments three separate factors (K source, K rate, $CaCO_3$ level) were examined to determine whether each had any influence on nutient availability (K, Ca, Mg) or on each other.

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Plant concentration of K in both experiments was the same with both sources of applied K. No differences in K concentration across $CaCO_3$ treatments were observed in experiment I. Similar results are evident in experiment II.

Results of these experiments suggest that $CaCO_3$ in these soils, and in these quantities has limited direct influence on availability and plant uptake of K, Ca and Mg. This appears to be true where these elements are present in quantities which can minimize the effects of ionic competition between them.

INTRODUCTION

Calcium carbonate, or lime, is found extensively in the soils of the arid to semi arid western and plains states. Its accumulation in the soil, aside from parent material weathering, results from lack of sufficient precipitation to leach it from the profile. Where it does not occur naturally, (i.e. wherever there is sufficient moisture to leach lime from the profile) there is a greater tendency for soils to become or remain acid. In such situations lime is applied as an amendment to bring soils to neutral or near neutral pH to facilitate better plant growth and optimize nutrient availability.

The influence of lime on soil potassium has been debated since Liebig in 1847 first published his view that lime liberated K from the soil. Little agreement seems to exist among soil scientists and plant physiologists as to whether lime exerts positive, negative or even consistent effects upon the availability and uptake of K.

Early investigators (Jenny and Shade, 1934) observed that the addition of lime liberated K to the soil solution. Others (Volk, 1934; Curtin and Smillie, 1983) observed reduced solution K upon liming. In Montana, several investigators have found decreasing depth to $CaCO_3$ in the soil, and increasing extractable soil Ca, are negatively correlated to yield and K uptake in small grains (Schaff, 1979; Veeh, 1981; Burke, 1984; Larson, 1986).

The application of varying rates of K with lime has not always produced conclusive results, though overall higher K rates usually

result in greater K concentration in plant tissue. Thorp and Hobbs (1956) noted that K uptake by alfalfa was increased by liming, but felt this was due more to yield increase rather than a lime effect on K per se. Studies where increased uptake of P and K did not parallel an increase in crop growth support the theory that the percentage of a particular element in forage does not necessarily indicate the availability of that nutrient in the soil (Dunn, 1943; Allaway and Pierre, 1939).

Another important aspect of K availability and uptake with liming is that of K source. The anion component of K fertilizers has been found to be an important factor in the absorption of K as well as other macro and micronutrients (Younts and Musgrave, 1958a; Seatz et. al., 1958).

With these points in mind, greenhouse experiments were designed to investigate various facets of K availability and uptake as influenced by $CaCO_3$. Specifically, objectives included:

I. Determine the influence of $CaCO_3$ on:

- Soil K parameters which relate to plant availability of K
- Plant growth and K uptake

II. Measure related nutrients (in soils and plants) which interact with K (especially Ca and Mg) to help explain the influence of $CaCO_3$ on plant nutrient relations.

Two separate greenhouse experiments were initiated to investigate these factors and determine their influence upon plant K uptake. Experiment I dealt with the effects of $CaCO_3$ addition to a slightly

acid soil. Experiment II dealt with examination of how plant K uptake was affected by different levels of native $CaCO_3$ in several Montana soils.

LITERATURE REVIEW

The amount of exchangeable K in the soil at any one time is generally considered to be rather small, though more or less constant, being in equilibrium with nonexchangeable and solution K. Fixation of K is the conversion of the available forms, exchangeable and solution, to forms unavailable to plants, including nonexchangeable and mineral forms.

Although the exchangeable and nonexchangeable phases are in equilibrium, the rates of conversion are considerably different, the process of fixation generally occurring at a greater rate than that of release (York et. al., 1953; Wang, 1975). McLean (1949) examined the cationic activities in clays, and observed that increasing the base saturation of any soil by liming increased the availability of exchangeable K, but that it also may slow the conversion from nonexchangeable to exchangeable by slowing or halting the acid weathering of K bearing minerals.

Effect of Lime on K Adsorption

Peech and Bradfield (1943) examined the adsorption of K by clays saturated with Ca and Mg. In the reaction:

$$H^{+}[\overset{Ca^{++}}{Clay}] + 2KCl \Longleftrightarrow H^{+}[\overset{K^{+}\ K^{+}}{Clay}] + CaCl_2$$

added potassium replaces Ca^{++} more readily than H^{+} on the colloid due to the position of each ion in the lyotropic series. They felt that the direction in which the reaction would proceed depended upon the initial degree of Ca saturation of the clay. Potassium adsorption isotherms bore out their prediction. Added K was continually adsorbed onto clay colloids at Ca saturation percentages of 25, 50, 75, and up to 100%. However, in the presence of free $CaCO_3$, the reaction was driven to the left, freeing adsorbed K to the soil solution. Similar results were obtained using Mg.

Seatz and Winters (1943) found similar results. At high rates of K, no difference in release of K was found between H and Ca saturated clays, though at low K rates, much more K release occurred with Ca saturated clay.

Results of other studies on leaching soil with 0.5 N acetate solutions of different cations indicated that the amount of K released by different cations increased in the order: $Na > H > NH_4 > Mg > Ca > Ba$. The release of K by the whole soil or clay fraction was greatest in the presence of Ca rather than H (Merwin and Peech, 1950).

Pratt et al., (1962), upon analyzing extractions of soil incubated at various pH levels, found greater K release from nonexchangeable forms as pH increased. Extracts with various cations indicated higher K release with Ca, rather than H. At low pH values, it was suggested that Al, in either exchangeable or recently precipitated hydroxide form, may have blocked K release from nonexchangeable forms.

Murdock and Rich (1965) observed NH_4 increased K availability when soils were limed to pH 7.0. At high soil pH, plant uptake of K was significantly greater when the N source was NH_4NO_3, compared to $Mg(NO_3)_2$. Ammonium, being smaller than Mg, is thought to be more efficient at displacing K from "fixed" positions, than is Mg. They felt that greater fixation at higher pH may be due to less H available for site competition. In a greenhouse study they found yields, as well as K uptake, were decreased by liming at high lime rates, though where the N sources were NH rather than Mg, these decreases were less.

Stanford et. al. (1941) examined some unproductive high lime soils in Iowa, some having as much as 25% $CaCO_3$ equivalent. They found relatively high exchangeable K on these soils. However, high Ca+Mg:K ratios in corn plants were thought to account for poor growth and indicated hindered K absorption. Allaway and Pierre (1939), working on these same soils, found similar circumstances; high levels of exchangeable K, but low plant uptake. They implicated high Ca:K ratios in the soil.

Sears (1930) found that unproductive high lime soils in Illinois contained excessive amounts of NO_3, and thought the formation of large amounts of $Ca(NO_3)_2$ had occurred, resulting in large increases in soluble calcium, again producing high Ca:K soil ratios.

Brown and Albrecht (1947) approached the same problem from a different direction. They took a representative calcareous soil and to it added increasing amounts of an acidic subsoil clay. As $CaCO_3$ was solubilized by acidification, more Ca dominated the exchange complex

(80-98%) and fertility problems were not alleviated until other nutrients were added to displace Ca.

Effect of pH on CEC and K Relations

Another approach to the question of K availability has been to examine the effects of pH on the exchange complex. Recent studies have focused more on how CEC changes with liming and pH, and how this in turn, affects exchangeable K.

The two components of CEC are permanent charge and pH dependent charge. Permanent charge is developed in layer silicates due to isomorphous substitution within the crystal lattice and broken bonds at edges, and is for the most part considered to be unaffected by the environment (Bohn et al., 1979). pH dependent charge varies with the pH of the soil environment. The primary source of this charge is considered to be the gain or loss of H^+ from functional groups on layer silicates, oxides, hydrous oxides, and organic colloids. Common functional groups include hydroxyl, carboxyl, phenolic, and amine groups. The ambient soil pH dictates the degree of protonation or deprotonation of these groups. At low pH, protonation increases the H^+ saturation, eliminating negative charge sites for cation exchange (Bohn, et. al., 1979),(Bartlette and McIntosh, 1969).

Nemeth and Grimme (1972), working with a soil which was predominately illite, found the CEC of the clay fraction decreased with decreasing pH. At a given K saturation, the K concentration in the extract increased distinctly with decreasing pH. They interpreted

this as less strong bonding at low pH, presumably due to increasing competition from Al and hydroxy-Al compounds which lead to a blocking of the K selective exchange sites.

Using the equation pH - 1/2p(Ca + Mg) = 2, Magdoff and Bartlette (1980) calculated the amounts of K which must be added to the soil to maintain solution K from low pH to high pH. Their findings were consistent with those of other investigators in that solution K decreased with liming and this appears to result from the increased "pull" on solution K by new CEC sites which were formerly blocked by Al at low pH. Perhaps most important, however, was the fact that they found no evidence that these new sites have a greater selectivity for K as opposed to Ca. In a selectivity experiment, soil samples with a high degree of pH dependent CEC were leached with KCl and $CaCl_2$ solutions and the percent absorption of each was determined. The new CEC sites were found to actually have a greater selectivity for Ca, at the expense of K.

Upon examination of "semi-permanent" charge, in the interlayer areas of expanding 2:1 silicate clays, Murdock and Rich (1965), Rich (1968),and Rich and Black,(1964) found that at low pH selection for K was quite low, but at higher pH the selection for K, even in solutions having high concentrations of Ca and Mg, was very high. This is attributed to a physical selectivity based on cation size, which occurs in the "wedge zones" of weathered mica-vermiculite minerals. In the absence of these wedge zones (true vermiculite), a large concentration of K is necessary to collapse the layers. Once this

process begins, wedge zones form and fixation can be quite high.

Influence of K Application on K Availability

Based on the literature, it appears that the main antagonistic effects among cations are between Ca, Mg and K, and that the direction of influence is dependent upon the relative concentrations of each. Hence, there has been a great deal of study on cation ratios in both the soil and in plants.

Potassium is absorbed by plants in greater quantities than any other cation, though it is usually present in the soil in much smaller quantities than either Ca or Mg (Barber, 1968). Healthy plant tissue commonly contains ten times as much K as Ca, yet many soils contain approximately opposite concentration of the two nutrients. With these relationships in mind, the importance of an adequate supply of K becomes apparent.

Doll, et. al. (1959) observed that small, annual applications of K resulted in greater depletion of soil K than did a single heavy application. Fixation of a portion of the large application was thought to provide a more or less steady supply of K over several years to a grass - legume pasture, without much danger of K depletion.

With neutral or near neutral soils, increasing exchangeable K often results in depressed uptake of both Ca and Mg. Various cation ratios have been used over the years in an attempt to express which nutrient relationships are important, both in the plant and in the soil (Bear et al., 1948; Lucas and Scarseth, 1947; Sorensen and Ologunde (1982).

High application rates of K have generally been shown to depress Mg uptake to a high degree and Ca uptake as well, though to a lesser extent. McLean and M.O. Carbonell (1972) found a drastic reduction in Mg content of plant tissues with increasing soil K. Omar and Kobbia (1966) using sand culture medium and several ratios of K and Mg, found a distinct one-way competition between the two, with Mg absorption being depressed significantly by small increases in nutrient K, whereas K absorption was not affected by any level of added Mg. Added K was found to greatly reduce Ca uptake in corn (Maas, 1969) and in millet and alfalfa (McLean and Carbonell, 1972).

Lucas and Scarseth (1947) found that increasing the level of K, for any given saturation of Ca, caused a lowering of Mg and Ca uptake in plants and felt that the ratio of Ca+Mg/K should be considered, since many K deficiencies have been associated with a high ratio of this type. McLean and Carbonell (1972) in a study using two K rates and five Ca/Mg ratios, found neither plant yields nor exchangeable K was affected by these ratios.

Bear and Toth (1948) examined the growth of alfalfa in relation to exchangable Ca/K ratios in the soil. They found that alfalfa could adjust very well over wide Ca/K ratios between 100:1 and 1:1. Ratios in the soil of 32:1 resulted in plant ratios of 3:1, making the absorption of K almost 10 times that of Ca. Without further additions of either element, plant ratios in subsequent crops rose from 3.9 to 11.1. Yields were found to decrease when the ratio exceeded 4.0, however, no K deficiencies were observed until ratios of 8.0 occurred.

They concluded that the plant tends to take up more K than needed unless soil Ca/K ratios become fairly high (12 or 13).

This last study, however, illustrates one important aspect of the Ca - K - lime research that has been conducted over the years: different crop species will show markedly different responses depending upon their nutrient needs. Many investigators in the past have approached this area of research, using different crops.

Bower and Pierre (1944) looked at seven different crops, having different K/Ca+Mg requirements, to determine the response to added K on high lime soils. They observed that those crops which require high K/Ca+Mg ratios, (corn, alfalfa, sorghum) showed greatest response to added K, whereas those with low K/Ca+Mg ratios, (sweetclover, buckwheat, soybeans) showed little or no response.

Influence of K Source on K Availability

Results of studies comparing sources of K fertilizer have not been consistent. This may be due partly to associated anions. Aside from its suspected role in reducing the incidence of certain diseases, chloride has long been thought to influence plant growth by indirectly affecting plant nutrition (Fixen et al.,1986).

Terman et al., (1975) compared responses of corn to KNO_3, KCl and K_2SO_4. Varying concentrations of applied Cl or SO_4 had little effect on yields or cation concentrations in the plant tissue. Higher KCl rates resulted in decreased sulfur concentrations in the plant tissue. Harward et al., (1956) in greenhouse experiments to compare

SO_4 and Cl response of potatoes, found greater tuber yields from SO_4, and greater vine yields from Cl. Chloride also resulted in greater concentrations of Ca and Mg in leaves and stems, though greater K uptake in tubers was found with SO_4 treatments. Harward also found that SO_4 treatments resulted in greater leaf N. This result is fairly well documented, and arises from the fact that Cl may substitute, to some extent, to spare nitrate.

Kretschmer et al., (1953) found, when comparing Cl and SO_4 effects on nutrient absorption, that greater yields and numbers of marketable Lima beans were consistently produced by Cl treatments. They also observed that SO_4 in the plant tissue never followed SO_4 concentrations in solution or soil/sand mixtures, whereas Cl concentrations and accumulation were closely related to the quantity in the substrate, independent of substrate or plant species.

In studies examining KCl, K_2SO_4 and KPO_4 fertilizers in pot experiments, Younts and Musgrave (1958a) found K_2SO_4 resulted in greater fresh and dry weight, though these differences were significant only at the highest levels of N and P.

Source of K thus seems to produce highly variable results, and studies on comparison of sources differ with crop species as well as geographic (soil types) location, with very little indication of consistent trends.

MATERIALS AND METHODS/EXPERIMENT I

Two experiments were conducted to examine the effect of $CaCO_3$ on K availability. The soil used for the first experiment is a silty clay loam, and was obtained from the Glenn Kraft farm approximately 2.5 miles south of Bozeman, Montana. Transects were made across the field and, using a portable pH meter, areas were staked where the soil pH was found to be 6.0 or less. It was felt at this pH, little or no $CaCO_3$ would be present in the soil as free carbonates.

Samples were then collected to a depth of 15 cm at sites with pH readings of 6.0 or less; pH was again measured in the laboratory with a pH electrode. The lowest pH values obtained were approximately 5.9. Bulk soil samples (approximately 350 kg) for greenhouse research were then taken from the 15 cm depth at the sites corresponding to the areas of lowest pH. The soil was dried for about one week at 55° C, ground, thoroughly mixed, and a subsample taken to determine initial fertility status.

Lime Requirement

The initial lime levels established as treatments were determined using the procedure described by McLean et al., (1978). This method was utilized to provide a guideline in establishing

suitable lime increments and was not intended to arrive at exact soil pH values.

The bulk soil sample was then split into eight subsamples to be treated with seven different amounts of reagent grade $CaCO_3$ (7 treatments and one check). After adding lime and thoroughly mixing, the soils were placed into large fiberglass tubs lined with heavy plastic, and brought up to 25% moisture by weight. They were maintained at 25% moisture by regular watering and mixing. Soil samples were maintained at 5° C to facilitate $CaCO_3$ dissolution, and to minimize biological activity.

Soil Preparation

After twelve weeks of incubation, the soils were placed into a large rotary mixer, one lime treatment at a time, to which was added potting sand (70% by weight). Nitrogen and P were added at the equivalent of 112 kg/ha each, with N being applied as Urea (46-0-0), and N and P as ammonium polyphosphate (11-55-0). This soil/sand mixture was then potted, with 1.7 kg per pot. Potassium was applied as KCl or K_2SO_4 at 0, 112, 224 and 448 kg K/ha, as solution. Pots were placed into two complete factorial designs - KCl in one factorial, K_2SO_4 in another, each replicated four times. Upon addition of K, soils were allowed to equilibrate for 48 hours prior to sampling for pre-plant soil analysis. Samples were collected from each pot (approx. 100g), bagged, dried at 55° C for 2-3 days, and set aside for analysis.

Immediately after sampling, barley (Hordeum vulgare L. var. "Clark") was seeded at a rate of 50 seeds per pot. Malathion was applied by spraying to control infestation of aphids several weeks after initiation of the experiment. Several days later, though the aphids were no longer a problem, foliage burn was evident on most of the plants, presumably due to the malathion. In an effort to remedy the foliage burn, additional N and P were applied with the same sources and rates as used at the start of the experiment. Subsequently, the plants experienced an outbreak of powdery mildew (Erysiphe graminis). Apparently, the addition of nitrogen, combined with the foliage injury and the high humidity of the greenhouse, provided the optimum environment for this fungus. A sulfur burner was rotated throughout the experiment for approximately 10 days, after which foliage burn, powdery mildew, and aphids had disappeared, and the entire plant population appeared healthy. Plants were harvested at flag leaf (Feekes scale: stage 9) by cutting at the soil surface using razor blades. The entire above ground portion of the plant material was collected, placed in paper bags, and weighed for fresh weight. The number of plants per pot was recorded, and plants were then dried for 3 days at 60°C, and reweighed for dry matter yield. Samples were ground, bagged, and set aside for analysis. Post harvest soil samples (approx. 100g) were collected from each pot, dried, seived to eliminate root material and ground to <2 mm.

Soil Analysis

Both pre-plant and post-harvest soils were analyzed for extractable K, Ca and Mg. Each element was determined by atomic absorption spectrophotometry, using the 1N NH_4OAc extraction procedure (Appendix C). These results were recorded as ppm in solution and converted to meq./100g soil by the appropriate factors and used for statistical analysis and discussion (Appendix C).

Plant Tissue Analysis

All plant tissue was analyzed for K, Ca and Mg concentration in the entire above ground portion of the plants. Potassium, Ca, and Mg were determined by the dry ash method (Chapman and Pratt, 1961) and were recorded as percent of plant tissue as well as total nutrient uptake by multiplying percent nutrient in plant tissue by total dry matter yield per pot. Nutrient uptake was also expressed as meq./100g of dry matter.

MATERIALS AND METHODS/EXPERIMENT II

To examine the influence of native lime levels on K availability and uptake, a second experiment was undertaken. Five soil series were obtained from several locations throughout Choteau county in north central Montana. Approximately 50 kg of each soil was collected and analyzed to determine differences in extractable K, Ca and Mg, using atomic absorption spectrophotometry. The elements of interest were significantly different in four of the five soils, and these four soils were selected for this study. The four soil series, Zahill, Vida, Hillon and Scobey, are common series in the north central part of the state. Table 1 summarizes the extractable levels of K, Ca, Mg, and $\%CaCO_3$ equivalent of each soil, and legal descriptions of the sampled sites. Detailed chemical and physical properties of the soils are presented in Appendix A, Table 40.

Table 1. Extractable K, Ca, Mg, $\%CaCO_3$ Eq., Experiment I and II Soils

	(ppm in solution)				
Soil Series	Ca	Mg	K	$\%CaCO_3$ Eq.	Legal Description
Bozeman	11.22	7.02	0.90	1.10	SE1/4, SE1/4, Sec.10 R4E, T7N
Zahill	23.01	1.85	1.49	5.62	SW1/4, NE1/4, Sec.5 R12E, T21N
Vida	14.66	1.77	3.25	4.78	SW1/4, NE1/4, Sec.5 R12E, T21N
Hillon	21.58	1.54	1.99	1.88	NE1/4, NE1/4, Sec. 28, R5E, T24N
Scobey	5.92	1.53	2.99	1.06	NE1/4, NE1/4, Sec. 28, R5E, T24N

Each of the soils are considered distinct treatments in Experiment II, that is, the four soils are considered as four lime levels, similar to Experiment I, though the lime in this case is

native lime. These soils obviously vary in many other respects since they are four distinct series. Each of the soils were separately placed into a large rotary mixer, with potting sand added at 70% by weight. The sand used in this experiment is neutral or near neutral silica sand, different from the greenhouse potting sand used in Experiment I. Nitrogen and P were again added at approximately 112 kg/ha. As in the first experiment, 1.7 kg of soil-sand mixture was potted and placed into a complete factorial design, replicated four times, and occupied one bench in the greenhouse. Potassium chloride or K_2SO_4 was applied to the soil at 0, 112, 224 and 448 kg K/ha as solution. After 48 hours of equilibration, pre-plant soil samples (100g) were collected from each pot, bagged, dried at 55°C for 2-3 days, and set aside for analysis. Barley (var. "Clark") was seeded at 50 seeds per pot. Greenhouse conditions were maintained similar to those in the first experiment, except that plants were thinned to 30 plants per pot in Experiment II. Thus, no differences in stand development were considered in this experiment. As the barley neared flag leaf stage, aphids once again appeared, this time, however, malathion was applied at half the recommended rate, and the aphids were controlled, with no foliage injury. When the majority of the plants (70%) were showing flag leaf (Feekes scale: stage 9) the plants were harvested and treated as described in Experiment I. Post harvest soils were immediately collected and treated as described for Experiment I.

Soil Analysis

As in the first experiment, pre-plant and post harvest-soils were analyzed for extractable K, Ca and Mg using the 1N NH_4OAc extraction procedure (Appendix C) and atomic absorption spectrophotometry. Values for this analysis were obtained as ppm in solution and later converted to meq/100g.

Plant Tissue Analysis

Plant tissues were analyzed for K, Ca and Mg using the dry ash procedure described in Chapman and Pratt (1961).

Statistical Analysis

Analysis of variance (AOV) was used to examine which treatments and/or treatment combinations and interactions produced significant differences. Multiple regression analysis was used to provide summary statistics, correlation matrices, and multiple regressions. All statistical programming was obtained through MSUSTAT, developed by R. E. Lund (1983).

In order to facilitate the discussion which follows, major emphasis is placed on those treatments or factors which produced significant differences in the parameters measured, with only brief descriptions and references to other correlation and regression results which are presented in full detail in the appendices.

RESULTS AND DISCUSSION/EXPERIMENT I

Examination of post harvest soils from Experiment I, revealed large increases in extractable Ca from all pots compared to the original soils. This problem was traced to the greenhouse potting sand used in the soil/sand mixture, which was found to contain almost 6.7% $CaCO_3$ equivalent (eq.). Because the potting mixture contained 70% by weight of this sand, differences in $CaCO_3$ eq. of less than 0.1% existed between some treatments. Table 2 presents the treatments as designed, compared to $CaCO_3$ levels actually existing following addition of sand (post - harvest analysis).

Table 2. Effect of Calcareous Sand on Lime Treatments

Without Sand		With Sand	
Trt. No.	$CaCO_3$ Eq.,%	Trt. No.	$CaCO_3$ Eq.,%
1	1.10	1	2.28
2	1.20	7	2.30
3	1.30	5	2.36
4	1.39	6	2.41
5	1.74	8	2.55
6	1.74	4	2.72
7	1.60	3	2.83
8	1.86	2	2.93

In addition to narrowing the effective range of $CaCO_3$ eq., the treatments became un-ordered. This result was thought due to the

poorly sorted nature of the sand, or its wide variation in particle size and associated $CaCO_3$ Eq. Five particle size fractions were split from a sample of sand by sieving, and each fraction analyzed to determine $\%CaCO_3$ eq. of that fraction. Table 3 summarizes the results:

Table 3. Various Size Fractions of Potting Sand Used in Exp. I.

Fraction No.	Sieve Size*	mm	$\%CaCO_3$ Eq.
1	2	9.50	6.69
2	4	4.76	5.19
3	10	2.00	4.37
4	20	0.85	3.37
5	40	0.42	4.45

* refers to U.S. Standard Sieve size

It is assumed that, despite soil/sand mixing time of about 1/2 hour, several treatments received more of one size fraction of sand than others, thereby altering the final level of $CaCO_3$ eq. into a somewhat random arrangement. The actual range in $CaCO_3$ eq. from "check" to "high" $\%CaCO_3$ eq. was only about 0.65% $CaCO_3$ eq. which is slightly less than the intended range of 0.76%. To adjust for this discrepancy, treatments were re-ordered according to the amount of $CaCO_3$ present in post harvest soil analysis. Results are presented using the reordering and consecutive numbering to reflect the influence of increasing "levels" of $CaCO_3$ on the measured parameters.

It should also be noted that the original treatments were designed to study the influence of $\%CaCO_3$ eq. in the 1-2% range, as this has been generally considered the range over which the largest influences occur. The presence of $CaCO_3$ in the sand places all

treatments (including the check) over 2% $CaCO_3$ eq., thus a major objective of the study could not be accomplished, and fewer significant differences were found in this experiment than would likely have occurred had the intended $CaCO_3$ levels been realized.

Soil samples from Experiment I were collected 48 hours after addition of K, prior to seeding and again after harvest. Even though the treatments involving KCl and K_2SO_4 were set up as separate experiments, results are presented together so that comparative treatment effects from these two K sources can be observed.

Influence of $CaCO_3$ Level on Extractable Soil K, Plant Growth, and Plant Uptake of K

Influence of $CaCO_3$ Level on Extractable Soil K

Where KCl was used as the K source, examination of pre-plant extractable soil K showed a negative response to added $CaCO_3$, though the only significant difference was found between the check (level 1; 2.28% $CaCO_3$) and level 8 (2.93% $CaCO_3$), Where a decrease of 0.07 meq. of K was observed. Other differences were more or less random, and not significant (Table 4.)

Where K_2SO_4 was applied as the K source, a less clear response was seen, with $CaCO_3$ eq. levels 2, 6 and 7 all showing significantly greater amounts of K over the highest level. No significant difference was found between the check and highest $CaCO_3$ eq. treatments (Table 4).

Soils analyzed after harvest showed no detectable patterns and no significant differences with regard to extractable K. This was true for both sources of applied K (Table 4). Similar results were found upon examination of delta K values (dK), which represent the change in extractable K from pre-plant to post-harvest soils.

No apparent trends with regard to dK values were found to correspond with $CaCO_3$ eq. treatments. It would appear then, that at least over the range of $\%CaCO_3$ eq. in Experiment I, added $CaCO_3$ had little, if any, influence upon extractable soil K.

Table 4. Mean Values for Extractable Soil K As Influenced by $CaCO_3$ Level- Averaged Across K Rates

	(meq./100g soil)			
	- Pre-plant Soils -		- Post-harvest Soils -	
Source:	KCl	K_2SO_4	KCl	K_2SO_4
$\%CaCO_3$ Eq.:				
2.28	0.55b*	0.54ab	0.42ab	0.40a
2.30	0.49ab	0.61b	0.40ab	0.37a
2.36	0.52ab	0.54ab	0.38a	0.39a
2.41	0.51ab	0.52ab	0.43b	0.37a
2.55	0.50ab	0.52ab	0.39ab	0.38a
2.72	0.52ab	0.62b	0.41ab	0.37a
2.83	0.50ab	0.60b	0.43ab	0.38a
2.93	0.48a	0.50a	0.41ab	0.39a

* means within the same column followed by the same letter are not significantly different by LSD at p=0.05.

Influence of $CaCO_3$ Level on Extractable Soil Ca and Mg

Extractable Ca levels were found to be somewhat surprising in

that they were found to be strongly associated with added $CaCO_3$ (R =.90), though not with $\%CaCO_3$ eq. Table 5 presents this result more clearly:

Table 5. Comparison of Extractable Ca by Added $CaCO_3$ and $\%CaCO_3$ eq. Averaged Over Both K Sources

Treatments arranged by increasing additions of $CaCO_3$ (R=.90)		Treaments arranged by increasing $CaCO_3$ Eq. (R=n.s.)	
Trt.	Ca (meq./100g)	Trt.	Ca (meq./100g)
1	10.92a*	1	10.92a
2	13.03b	2	14.88de
3	13.53b	3	14.26c
4	14.13c	4	14.37cd
5	14.26cd	5	15.26e
6	14.37cd	6	14.13c
7	14.88de	7	13.53b
8	15.26e	8	13.03b

* means within columns followed by the same letter are not significantly different by LSD at p=0.05.

This effect occurred for both K sources. These results suggest that although the various size fractions of the sand may have contributed differing amounts of Ca to that which existed in the soils previously, the added $CaCO_3$ was more soluble than that in the sand. Alternatively, the sand may have increased the CO_3 eq. without increasing Ca, namely with $MgCO_3$. Post-harvest soils did show a significant increase in extractable Ca over pre-plant soils as might be expected from effects of cropping on $CaCO_3$ dissolution in the soil (Table 6).

Extractable Mg levels with both K sources showed significant decreases with added $CaCO_3$. The checks, where no $CaCO_3$ was added,

showed the highest extractable Mg (Table 7). This suggests that the sand did not contain significant quantities of $MgCO_3$. Where $CaCO_3$ was added, extractable Mg decreased, though relatively independently of $CaCO_3$ level.

Table 6. Mean Values for Extractable Soil Ca as Influenced by $CaCO_3$ Level- Averaged Across K Rates

	(meq./100g soil)			
	- Pre-plant Soils -		- Post-harvest Soils -	
K Source:	KCl	K_2SO_4	KCl	K_2SO_4
%$CaCO_3$ Eq.:				
2.28	10.92a*	11.28a	14.09a	16.66a
2.30	14.88de	15.50c	20.24e	20.76f
2.36	14.26c	14.36b	17.59cd	19.60ed
2.41	14.37cd	14.14b	18.15d	20.02fe
2.55	15.26e	16.03c	20.24e	20.35f
2.72	14.13c	14.27b	17.04c	19.16cd
2.83	13.53b	13.91b	16.74cb	18.37b
2.93	13.03b	13.74b	15.67b	18.61cb

* means within columns followed by the same letter are not significantly different by LSD at p=0.05.

Significant decreases in Mg occurred only between the check and all other $CaCO_3$ levels. This relationship held true for both pre-plant and post-harvest soils (Table 7).

As with extractable soil K, $CaCO_3$ levels had no apparent consistent relationship with dCa or dMg values (data not shown) when comparing post-harvest soils to pre-plant soils.

Table 7. Mean Values for Extractable Soil Mg as Influenced by $CaCO_3$ Level- Averaged Across K Rates

	(meq./100g soil)			
	- Pre-plant Soils -		- Post-harvest Soils -	
K Source:	KCl	K_2SO_4	KCl	K_2SO_4
%$CaCO_3$ Eq.:				
2.28	2.74c*	2.89b	3.03b	3.17c
2.30	2.45b	2.58a	2.70a	2.63a
2.36	2.36ab	2.47a	2.57a	2.68ab
2.41	2.40ab	2.44a	2.62a	2.65ab
2.55	2.34a	2.50a	2.63a	2.63a
2.72	2.41ab	2.58a	2.57a	2.67ab
2.83	2.35ab	2.50a	2.70a	2.63a
2.93	2.31a	2.50a	2.63a	2.76b

* means within columns followed by the same letter are not significantly different by LSD at p=0.05.

Influence of Added $CaCO_3$ Level on Plant Growth

In Experiment I, several parameters associated with plant growth were examined to determine which, if any, treatments produced responses in plant growth. Parameters of interest include: germination (stand); fresh harvest weight; dry matter yield and percent dry matter.

Germination

As mentioned previously, no thinning was done on seedlings in Experiment I. Thus, all seeds which germinated and matured were harvested and analyzed. Lime treatments did not produce any changes in stand count (Table 8). Some significant differences were found,

especially with the K_2SO_4 source of applied K, but were not related to $CaCO_3$ levels.

Table 8. Mean Values for Harvest Data - Experiment I Averaged Across K Rates

$CaCO_3$ Treatment:	Plants/pot	Fresh Wt.(g)	Dry Matter(g)	%Dry Matter
	K Source: KCl			
1	33.1a	25.83a	7.20a	28.20a
2	33.5a	28.11	7.78abc	28.02a
3	34.9a	31.74b	8.71cd	27.72a
4	35.5a	28.83ab	7.83abc	27.33a
5	34.6a	31.82b	9.00d	28.74a
6	33.8a	29.57ab	8.26bcd	28.11a
7	34.6a	29.38ab	8.33bcd	28.67a
8	35.8a	26.77a	7.70ab	27.81a
	K Source: K_2SO_4			
1	32.5a	17.88a	5.54a	32.39a
2	34.6abc	21.61ab	6.44abc	29.81a
3	34.9abc	23.38b	6.82bc	29.59a
4	36.6bc	24.26b	7.32bc	31.19a
5	34.8abc	22.65b	6.96bc	31.10a
6	36.5bc	23.42b	7.14bc	30.72a
7	33.1ab	21.13ab	6.14ab	30.09a
8	37.1c	24.28b	7.45c	32.39a

* means within columns followed by the same letter are not significantly different by LSD at p=0.05

Fresh Harvest Weight

Under both K sources a significant increase in fresh weight was found from the check up to lime level 3 or 4 depending upon K source. However, over the entire range of $CaCO_3$ level, no significant relationships were seen.

Dry Matter Yield and Percent Dry Matter

As with fresh harvest weight, consistent and significant increases in dry matter yield were found under both K sources for the first 3 to 4 lime levels (Table 8). However, no consistent trends were observed across the entire range of $CaCO_3$ levels. Percent dry matter of the plants showed no response to $CaCO_3$ levels.

Influence of $CaCO_3$ Level on Plant Uptake of K, Ca and Mg

Results of the dry ash analyses of plant tissue are presented in Table 9. These values are given as percent of plant tissue dry matter. Munson (1968) referred to the fact that plant uptake expressed as percentages tends to minimize variations for Mg, while enhancing variations in K, due to the difference in equivalent weights of these two elements. He suggested converting values to meq./100g of tissue to obtain a better comparison among elements. Percent of an element based on dry matter content in plant material is converted to meq./100 grams by multiplying the percent by the reciprocal of the meq. weight of the element. Conversion factors used for K, Ca and Mg are as follows:

% of plant tissue x conversion factor = meq./100g plant tissue

K	25.57
Ca	49.90
Mg	82.24

However, for both Experiment I and Experiment II, no differences

resulted in the AOV or correlation matrices between plant uptake expressed as meq./100g or as straight percentage of total dry plant tissue. This was true across an entire experiment as well as within each K source experiment (Appendix A). Therefore, results of plant concentration of K, Ca and Mg, are discussed as percentages of plant dry matter yields. Though the check lime treatment with KCl showed the highest plant K, no significant differences in plant concentration of K were found across $CaCO_3$ levels (Table 9).

Table 9. Mean Values for Plant Tissue K, Ca and Mg as Influenced by $CaCO_3$ Level- Averaged Across K Rates

(Percent of Plant Tissue)						
	K		Ca		Mg	
K Source:	KCl	K_2SO_4	KCl	K_2SO_4	KCl	K_2SO_4
$\%CaCO_3$ Eq.:						
2.28	2.92b*	2.72ab	0.62ab	0.64a	0.32a	0.33ab
2.30	2.83ab	2.96b	0.67cd	0.69a	0.32a	0.36b
2.36	2.85ab	2.78ab	0.65abcd	0.64a	0.32a	0.32a
2.41	2.88ab	2.92ab	0.64abc	0.67a	0.32a	0.34ab
2.55	2.68a	2.72ab	0.69d	0.69a	0.33a	0.34ab
2.72	2.69a	2.70a	0.61a	0.65a	0.31a	0.33a
2.83	2.76ab	2.79ab	0.66bcd	0.68a	0.33a	0.34ab
2.93	2.87ab	2.85ab	0.65abcd	0.65a	0.32a	0.33a

* means within columns followed by the same letter are not significantly different by LSD at p=0.05.

In addition, plant K concentration was not correlated with CaCO level under either K source (Appendix B). Plant K concentrations were found to be significantly correlated only to soil K levels. Perhaps the most important point to note here is that no noticeable decrease in plant K uptake occurred as $\%CaCO_3$ eq. increased from 2.28% to 2.9%.

Calcium carbonate treatments did not produce any consistent significant differences in plant Ca concentration between the check and 2.9% $CaCO_3$ (Table 9).

The addition of $CaCO_3$ had no effect on plant Mg levels, under either K source experiment (Table 9). It is assumed, since the applied $CaCO_3$ was reagent grade with little or no Mg contamination (<0.005%), no additional Mg was put into the soil system. While added $CaCO_3$ did not enhance Mg uptake, neither did it lower it. Plant concentrations of Mg at high $CaCO_3$ levels were equal to those found in the check treatments. Any ionic competition for uptake between Mg and Ca, which have similar properties, was not evident.

Influence of Rate of Applied K on Soil K, Ca and Mg, Plant Growth, and Plant Uptake of K, Ca and Mg

As expected, highly significant increases in extractable soil K were found with increased K application (Table 10). This was true of both pre-plant and post-harvest soils, and with both sources of added K. Delta K (dK) values, the difference between pre-plant and post-harvest extractable K, increased significantly with increasing K application. This suggests that as more K was supplied, more was taken up by plants or fixed in non-extractable forms (data not shown).

Table 10. Mean Values for Extractable Soil K as Influenced by Applied K- Averaged Across $CaCO_3$ Levels

(meq./100g soil)

	- Pre-plant Soils -		- Post-harvest Soils -	
K Source:	KCl	K_2SO_4	KCl	K_2SO_4
K Rate:				
Check	0.37a*	0.44a	0.36a	0.33a
112 kg/ha	0.44b	0.49a	0.38a	0.35b
224 kg/ha	0.50c	0.60b	0.43b	0.38c
448 kg/ha	0.71d	0.70c	0.47c	0.45d

* means within columns followed by the same letter are not significantly different by LSD at p=0.05.

The effect of added K on extractable soil Ca was different for the two K sources applied. Increasing application rates of KCl lowered the amount of extractable soil Ca (Table 11) and was true for both pre-plant and post-harvest soils.

Table 11. Mean Values for Extractable Soil Ca as Influenced by Applied K- Averaged Across $CaCO_3$ Levels

(meq./100g soil)

	- Pre-plant Soils -		- Post-harvest Soils -	
K Source:	KCl	K_2SO_4	KCl	K_2SO_4
K Rate:				
Check	13.97b*	14.38a	17.76b	19.37a
112 kg/ha	13.88ab	13.96a	17.63ab	19.29a
224 kg/ha	13.85ab	14.17a	17.59ab	19.11a
448 kg/ha	13.50a	14.11a	16.95a	19.00a

* means within columns followed by the same letter are not significantly different by LSD at p=0.05.

This further illustrates the well documented phenomenon of ionic competition between these two ions. With applied K_2SO_4, however, no

consistent decrease in soil Ca was observed in pre-plant soils. Post-harvest soils by contrast, did show a consistent decrease in soil Ca levels corresponding to increasing applications of K. None of these differences were statistically significant however. Extractable soil Mg behaved in an almost identical manner to that of Ca, though the magnitude of observed differences was much smaller. A consistent decrease in soil Mg occurred as K rate increased when KCl was applied. Similar to soil Ca, only the highest rate of applied K produced a significant decrease of Mg related to the check (Table 12).

When K_2SO_4 was used as the K source, no such consistency was observed (Table 12). Post-harvest soil analysis did show a significant decrease in Mg where the highest rate of K_2SO_4 was applied, similar to that for KCl.

Table 12. Mean Values for Extractable Soil Mg as Influenced by Applied K- Averaged Across $CaCO_3$ Levels

	(meq./100g soil)			
	- Pre-plant Soils -		- Post-harvest Soils -	
K Source:	KCl	K_2SO_4	KCl	K_2SO_4
K Rate:				
Check	2.46b*	2.59a	2.73b	2.76b
112 kg/ha	2.42ab	2.55a	2.72b	2.73ab
224 kg/ha	2.41ab	2.56a	2.72b	2.74ab
448 kg/ha	2.38a	2.54a	2.57a	2.68a

* means within columns followed by the same letter are not significantly different by LSD at p=0.05.

Influence of K Application on Plant Growth

The same parameters of plant growth discussed under $CaCO_3$ influence are considered here in an attempt to determine the influence of rate of K application on fresh harvest weight, dry matter yield, and percent dry matter.

Fresh Harvest Weight

Significant differences in fresh harvest weight of barley plants were found not only between rates of applied K, but between K source as well. Increased application rates of KCl produced increasingly greater harvest weights (Table 13), but this was not true with K_2SO_4 as the source of K. These differences are illustrated in Table 13. The response of fresh harvest weight to KCl shows consistent response, though the lack of any significant correlation to applied K suggests other factors are influencing growth to a greater degree.

Dry matter yield increased with increasing rates of KCl, similar to fresh harvest weight (Table 13). Again, lack of a consistent relation to rate of applied K suggests that while plants did respond to increased K, other factors were predominant in controlling growth.

Table 13. Mean Values for Harvest Data - Experiment 1 Averaged Across $CaCO_3$ Levels

K Rate	Plants/pot	Fresh Wt.(g)	Dry Matter(g)	%Dry Matter
		K Source: KCl		
Check	32.7 a*	24.72a	7.02a	28.56b
112 kg/ha	35.0b	27.86b	8.00b	28.94b
224 kg/ha	34.5ab	30.84c	8.29b	26.55a
448 kg/ha	35.8b	32.60c	9.09c	28.26ab
		K Source: K_2SO_4		
Check	35.0a	21.15a	6.36a	30.84a
112 kg/ha	33.8a	21.46a	6.53a	31.92a
224 kg/ha	36.3a	23.73a	7.07a	30.05a
448 kg/ha	35.0a	22.96a	6.94a	30.83a

* means within columns followed by the same letter are not significantly different by LSD at p=0.05.

Dry Matter Yield and Percent Dry Matter

Percent dry matter under KCl was essentially constant. Dry matter yield under K_2SO_4 did not respond consistently to increasing K application and this was also true of percent dry matter.

Influence of Applied K on Plant Concentration of K, Ca and Mg

Increasing the rate of applied K resulted in greater plant concentration of K. While such a response is expected, it should be noted that the only significant increase was that between the check and all other rates, where KCl was applied. Where K_2SO_4 was used, only the two highest rates of K application resulted in significantly higher K concentration over the check (Table 14).

Table 14 illustrates a slight response to added K for both sources. Lack of a strong correlation coefficient also suggests that plant K uptake, in this case, was dependent upon applied K to only a limited degree. As shown in table 10, definite differences in extractable K are evident at each application rate. Where K_2SO_4 was the source, K uptake from the check to the highest rate resulted in an increase of 0.47% K. This compares to a 0.31% gain where the K source was KCl.

Table 14. Mean Values for Plant Tissue K as Influenced by Applied K- Averaged Across $CaCO_3$ Levels

	(Percent of Plant Tissue)					
	K		Ca		Mg	
K Source:	KCl	K_2SO_4	KCl	K_2SO_4	KCl	K_2SO_4
K Rate:						
Check	2.62a*	2.56a	0.70b	0.69b	0.34c	0.35c
112 kg/ha	2.82b	2.75ab	0.67b	0.68b	0.33cb	0.34bc
224 kg/ha	2.86b	2.88bc	0.62a	0.64ab	0.31b	0.33ab
448 kg/ha	2.93b	3.03c	0.60a	0.63a	0.30a	0.32a

* means within columns followed by the same letter are not significantly different by LSD at p=0.05.

Where soil analysis has shown inconclusive evidence of K-Ca competition, plant uptake of Ca expressed as tissue concentration was clearly found to have been diminished by the addition of K (Table 14), as either KCl or K_2SO_4.

Plant Ca concentrations were found to decrease as application rates and soil K increased. While little or no decrease in soil Ca occurred from increased K application, significant decreases in plant tissue Ca are observed. This seems to agree with other literature

citing K interference with accumulation of other cations.

Plant Mg concentrations also decreased directly with increasing K application (Table 14), from both forms of added K. Greater Mg differences were found in plant tissue compared to soil concentrations, again suggesting that additional K suppressed, or in some way decreased plant uptake of Mg. The level of statistical significance of these differences in plant Mg exceeds that of Ca, lending some credence to the idea of many researchers (McLean and Carbonell, 1972; Omar and Kobbia, 1966) that Mg uptake is more affected by K levels than is Ca. Plant Mg, like Ca, was negatively correlated to soil K as well as applied K for KCl treatments. For K_2SO_4 only applied K produced a significant negative correlation (Appendix B).

Plant Cation Ratios

Nutrient ratios in plant tissue are perhaps more indicative of what is considered "normal" plant growth and development than simply the percentage of nutrients. Based on the literature, it is apparent that plants take up nutrients in different proportions from those that exist in the soil. No single expression appears to be superior or universally employed to describe proper cation balance. The approach used in this analysis of plant cation ratios is to examine those ratios in which the K balance of the plant may be influenced by the two factors of interest (K rate and $CaCO_3$ level).

The ratios reported here include only K/Ca and K/Mg. Some other

commonly used ratios, namely the intensity value for K, K/ Ca + Mg, and the activity ratio $(Ak/ACa)^{1/2}$ were not found to conform to any detectable pattern with regard to applied K and $CaCO_3$. Moreover, some investigators (Barber, 1968) feel there is little evidence to indicate the activity ratio of K to the square root of (Ca + Mg) is the governing factor in determination of the rate of K absorption by the root .

Influence of Added Lime on Plant Cation Ratios K/Ca and K/Mg

Examination of plant K/Ca over lime treatments showed the highest K/Ca with the check (2.28 $\%CaCO_3$ eq.), though no apparent trend was obvious (Table 15). As the amount of Ca in the system increases, one might expect plant K/Ca to drop. However, no consistent relationship was found between $\%CaCO_3$ eq. and plant tissue K/Ca concentrations (Appendix A), nor with either source of applied K (Table 15).

Generally, K/Mg ratios were about twice those found for K/Ca. This has been reported by others (Omar and Kobbia, 1966). No significant decrease in K/Mg across the entire range of CaCO treatments was seen, either in soil analysis or plant tissue analysis (Table 15), for either K source.

Table 15. Mean Values for Plant K/CA and K/Mg Ratios as Influenced by $CaCO_3$ Level- Averaged Across K Rates

	K/Ca		K/Mg	
K Source:	KCl	K_2SO_4	KCl	K_2SO_4
%$CaCO_3$ Eq.:				
2.28	4.80c*	4.36a	9.12b	8.28a
2.30	4.31ab	4.39a	8.86ab	8.36a
2.36	4.46bc	4.40a	8.93ab	8.66a
2.41	4.56bc	4.50a	9.12b	8.56a
2.55	3.94a	4.02a	8.12a	7.92a
2.72	4.47bc	4.17a	8.67ab	8.16a
2.83	4.20ab	4.22a	8.39ab	8.11a
2.93	4.38abc	4.38a	8.82ab	8.59a

* Means within columns followed by the same letter are not significantly different by LSD at p=0.05.

Influence of Added K on Plant Cation Ratios - K/Ca and K/Mg

In contrast to added $CaCO_3$, increasing the rate of applied K resulted in a positive linear increase in tissue K/Ca concentrations (Appendix B). Increasing K application resulted in a linear increase in K/Mg ratios in plant tissue with both K sources. As might be expected, K/Mg ratios correlated well with applied K rates, and to a lesser extent with soil K levels (Appendix B).

RESULTS AND DISCUSSION/EXPERIMENT II

Influence of Native Lime on Soil K, Ca, Mg, Plant Growth and Plant Uptake of K, Ca and Mg

Soil K, Ca and Mg

The four soils chosen for this study represent well defined levels of naturally occurring $CaCO_3$. Whereas Experiment I consisted of two separate factorials, each with a different K source, Experiment II consisted of one factorial, with both K sources as main treatments. Thus, it was possible with Experiment II to make comparisons not only between $CaCO_3$ level and K rate, but also between K sources.

While the entire range of $CaCO_3$ treatments in the first experiment was only about 0.7% (2.28% $CaCO_3$ eq. to 2.93%), the soils in Experiment II range from 1.00% $CaCO_3$ eq. (Scobey) to 5.60% $CaCO_3$ eq. (Zahill), almost a six-fold increase.

Extractable soil K was greatest in the Scobey and Vida soils, 1.0% and 1.8% $CaCO_3$ eq., respectively. The Hillon series (4.7% $CaCO_3$ eq.) yielded less extractable K, with Zahill (5.6% $CaCO_3$ eq.) yielding the least (Table 16).

Extractable soil K was negatively correlated to %$CaCO_3$ eq. under both K sources for both pre-plant and post-harvest soils. While

differences in extractable K in pre-plant soils were relatively large, these differences were considerably less when comparing post-harvest soils (Table 16).

Though all differences in post-harvest extractable K are significant, K levels do not closely correspond to $\%CaCO_3$ eq., as was true in pre-plant soils. The Vida soil, containing almost twice the $\%CaCO_3$ eq. as Scobey, had significantly higher levels of extractable K than Scobey.

Table 16. Mean Values for Extractable K as Influenced by soil Type - Averaged Across K Levels

	(meq./100 g soil)			
	- Pre-plant Soils -		- Post-harvest Soils -	
K Source:	KCl	K_2SO_4	KCl	K_2SO_4
Soil/$\%CaCO_3$ Eq.:				
Scobey/1.06	1.43c*	1.44c	0.48b	0.48a
Vida/1.88	1.41c	1.39c	0.78a	0.78d
Hillon/4.78	1.07b	1.00b	0.55c	0.55b
Zahill/5.60	0.84a	0.80a	0.70a	0.70c

* means within columns followed by the same letter are not significantly different at p=0.05.

The Hillon and Zahill soils, containing greater $\%CaCO_3$ eq., yielded less extractable K in pre-plant soils. This was reversed in post-harvest soils. Scobey and Vida soils, which originally had similar levels of extractable K, had large differences post-harvest. This indicates a difference in the ability of these soils to maintain or "buffer" the level of plant-available K during the growing season. Differences in extractable Ca were evident as $\%CaCO_3$ eq. increased with soil series (Table 17). Correlation between extractable Ca and

%$CaCO_3$ eq. produced coefficients of .98 and .99 for pre-plant and post-harvest soils, respectively (Appendix B). This was not surprising given the wide differences in %$CaCO_3$ eq. of the soils. It does however, show that the procedure for extractable Ca does solubilize some of the native $CaCO_3$ in relative proportion to the level of $CaCO_3$.

Table 17. Mean Values for Extractable Ca as Influenced by Soil Type - Averaged Across K Levels

	(meq./100 g soil)			
	- Pre-plant Soils -		- Post-harvest Soils -	
K Source:	KCl	K_2SO_4	KCl	K_2SO_4
Soil/$CaCO_3$ Eq.:				
Scobey/1.06	4.48a*	4.51a	4.88a	4.51a
Vida/1.88	9.80b	10.34b	9.87b	9.89b
Hillon/4.78	19.49c	19.49c	20.97c	21.97c
Zahill/5.60	20.93d	21.09d	24.44d	22.80e

* means within columns followed by the same letter are not significantly different by LSD at p=0.05.

Extractable Mg levels were similar between the soils. Small differences in extractable Mg that did exist did not correspond to %$CaCO_3$ eq. (Table 18). This was true in soils prior to planting as well as after harvest. This suggests that native lime in these soils may be primarily of calcitic origin, containing little or no Mg.

Table 18. Mean Values for Extractable Mg as Influenced by Soil Type - Averaged Across K Levels

	(meq./100 g soil)			
	- Pre-plant Soils -		- Post-harvest Soils -	
K Source:	KCl	K_2SO_4	KCl	K_2SO_4
Soil/%$CaCO_3$ Eq.:				
Scobey/1.06	1.80a*	1.79a	2.31a	2.29a
Vida/1.88	1.84a	2.07b	2.20a	2.32a
Hillon/4.78	1.86a	1.91a	2.30a	2.19a
Zahill/5.60	2.12b	2.06b	2.33a	2.23a

* means within columns followed by the same letter are not significantly different by LSD at p=0.05.

Plant Growth

All pots were thinned to 30 seedlings in Experiment II, so no analysis of stand count was made. The plant growth characteristics examined here include fresh harvest weight, dry matter yield and percent dry matter.

Fresh Harvest Weight

Highest fresh harvest weights occurred on the Vida soil, with lowest fresh weights on the Zahill for both K sources (Table 19). Differences in fresh harvest weights appeared to correspond more to soil K levels, rather than %$CaCO_3$ eq.

Table 19. Mean Values for Harvest Data - Experiment II as Influenced by Soil Type- Averaged Across K Rates

Soil/%$CaCO_3$ Eq.:	Fresh Wt.(g)	Dry Matter(g)	%Dry Matter
	K Source: KCl		
Scobey/1.06	31.83a*	6.77ab	21.39b
Vida/1.88	36.69b	7.25b	20.11a
Hillon/4.78	32.05a	7.03ab	21.95b
Zahill/5.60	29.80a	6.48a	21.90b
	K Source: K_2SO_4		
Scobey/1.06	31.63cb	6.55b	20.87ab
Vida/1.88	33.69c	6.87b	20.77a
Hillon/4.78	30.14b	6.60b	22.11a
Zahill/5.60	24.88a	5.74a	23.41b

* means within columns followed by the same letter are not significantly different by LSD at p=0.05.

The Vida soil consistently ranked highest in fresh weight, and contains almost twice the $CaCO_3$ of Scobey. Data also revealed no significant difference in fresh plant weight between Scobey and Hillon soils, although a difference in $CaCO_3$ level of more than four-fold exists.

Dry Matter Yield and Percent Dry Matter

Dry matter yield appeared to not be influenced by %$CaCO_3$ eq. of the soil (Table 19). Depending upon K source, a four- or five-fold increase in %$CaCO_3$ eq. resulted in no significant differences in dry matter. The Vida soil again produced the greatest dry matter, and

Zahill the least. Differences in dry matter production among soils were statistically similar between K sources as evidenced by Table 19, although yield was greatest with KCl as the K source on all soils.

Percent dry matter, as with the previous yield parameters, displayed no clear response to increasing $\%CaCO_3$ eq. (Table 19). Overall, production on the Vida soil was greatest and produced plants with higher moisture content plants over the entire experiment.

Plant K, Ca and Mg Uptake

Differences in plant K concentrations between soils were significant, but they were not generally related to $\%CaCO_3$ eq. of the soils (Table 20). Plants grown on the Vida soil had the highest K concentration, and this soil is intermediate in $CaCO_3$ content. No significant difference in plant K concentration was observed between Scobey, Hillon and Zahill soils, though a five-fold difference in $\%CaCO_3$ eq. exists (Table 20). It would appear from these data that plant concentration of K over this range of $\%CaCO_3$ eq. was not significantly influenced by $CaCO_3$.

Data in Table 21 reveal that the wide range of $CaCO_3$ in the soils had little influence on the plant Ca concentration. Plants on the Vida series (1.8% $CaCO_3$ eq.) under both sources of K, had as much or more Ca concentration as plants grown on soils with 4.7-5.6% $CaCO_3$ eq. (Table 21).

Table 20. Mean Values for Plant Tissue K - Experiment II Averaged Across K Rates

	(Percent of plant tissue)	
K Source:	KCl	K_2SO_4
Soil/%$CaCO_3$ Eq.:		
Scobey/1.06	3.71b*	3.78ab
Vida/1.88	4.17b	4.27b
Hillon/4.78	3.97b	3.48a
Zahill/5.60	3.10a	3.54a

* means followed by the same letter are not significantly different by LSD at p=0.05.

Reasons for the reduced Ca concentration of plants grown on the Scobey soil are not apparent however. Amounts of Ca on exchange sites and in soil solution ("available Ca") are apparently more important than $CaCO_3$ level of the soil. Many factors besides $CaCO_3$ can influence "available" Ca.

Only plants grown on the Zahill soil with K SO as the K source had significantly greater Mg concentration (Table 22). Plant Mg concentrations were not related to the level of native soil lime over this range of $CaCO_3$.

Table 21. Mean Values for Plant Tissue Ca - Experiment II as Influenced by Soil Type- Averaged Across K Rates

	Ca (Percent of plant tissue)	
K Source:	KCl	K_2SO_4
Soil/%$CaCO_3$ Eq.:		
Scobey/1.06	0.38a*	0.40a
Vida/1.88	0.69b	0.65c
Hillon/4.78	0.71b	0.55b
Zahill/5.60	0.64b	0.77d

* means followed by the same letter are not significantly different by LSD at p=0.05.

Table 22. Mean Values for Plant Tissue Mg - Experiment II as Influenced by Soil Type- Averaged Across K Rates

	Mg (Percent of plant tissue)	
K Source:	KCl	K_2SO_4
Soil/%$CaCO_3$ Eq.:		
Scobey/1.06	0.17a*	0.17a
Vida/1.88	0.20ab	0.19a
Hillon/4.78	0.22b	0.17a
Zahill/5.60	0.19ab	0.23b

* means followed by the same letter are not significantly different by LSD at p=0.05.

Influence of Rate of Applied K on Soil K, Plant Growth and Plant Uptake of K

Influence of Applied K on Extractable Soil K

Consistent with expectations and results obtained in Experiment I, differences in extractable soil K were generally found to be significantly greater with increasing rate of applied K (Table 23). This was true of both K sources as well as pre-plant and post-harvest soils. Examination of changes in extractable K, from pre-plant to post-harvest soils (dK), revealed that dK increased significantly with increasing rate of K application, suggesting as in Experiment I, that as more K is applied, more is taken up or converted to non-extractable forms.

Table 23. Mean Values for Extractable Soil K as Influenced by Applied K- Averaged Across Soils

	(meq./100 g soil)			
	- Pre-plant Soils -		- Post-harvest Soils -	
K Source:	KCl	K_2SO_4	KCl	K_2SO_4
K Rate:				
Check	0.76a*	0.84a	0.52a	0.54a
112 kg/ha	1.06b	1.02b	0.60b	0.59b
224 kg/ha	1.27c	1.15c	0.63b	0.68b
448 kg/ha	1.66d	1.63d	0.77c	0.75c

* means followed by the same letter are not significantly different by LSD at p=0.05.

Each soil exhibited significant increases in extractable K as greater amounts of K were applied (Table 24). The Scobey, Vida and Hillon soils all responded positively to increased K application. Each increment of added K resulted in significantly greater amounts of extractable K. Post-harvest soil analysis of all three responded in a similar way, though to a lesser extent. Three of four increments of added K produced significant increases in extractable soil K. The Zahill soil, in contrast, showed only one significant increase in soil K, that being between the check and the other treatments. The Zahill post-harvest soils showed a significant increase in soil K only at the highest rate of applied K (Table 24).

Delta K values,(dK) over all four soils, increased with increasing rate of applied K. As with pre-plant and post-harvest soils, the Scobey, Vida and Hillon soils all produced significantly higher dK values with three of four increments of applied K, while

Zahill had significantly higher dK values between the check and added K treatments only. Both pre-plant soil K and dK means decreased in the order Scobey, Vida, Hillon, Zahill, whereas post-harvest soil K means decreased in order of Vida, Scobey, Hillon, Zahill. These data for pre-plant soil K and dK suggest the Scobey and Vida soils have greater K supplying capacity, followed by Hillon and Zahill soils. Data for plant K concentration are also presented in Table 24 to view whether these differences in levels of extractable soil K had an influence on plant K. Few differences were found, suggesting that in all soils, except perhaps Zahill, adequate K was available with or without the addition of K. These relationships are discussed in more detail in a later section.

Influence of Applied K on Extractable Ca and Mg

Applied K did not significantly change levels of extractable Ca or Mg for either K source, or between pre-plant and post-harvest soils (Tables 25,26).

Table 24. Influence of Applied K on Soil K and Plant K by Soil Type - Averaged Across K Sources

Soil	Pre-plant Soil K (meq/100g)	Post-harvest Soil K (meq/100g)	dK (meq/100g)	Plant K Concentration
		(Across K Source)		
Scobey				
K Rate:				
Check	1.03a*	0.58a	0.45a	3.97a
112 kg/ha	1.24b	0.66ab	0.58a	3.40a
224 kg/ha	1.47c	0.70b	0.77b	3.94a
448 kg/ha	1.99d	0.81c	1.17c	3.67a
Vida				
K Rate:				
Check	1.01a	0.63a	0.37a	4.21ab
112 kg/ha	1.27b	0.75b	0.51ab	4.34ab
224 kg/ha	1.48c	0.84bc	0.63b	3.75a
448 kg/ha	1.86d	0.91c	0.95c	4.57b
Hillon				
K Rate:				
Check	0.67a	0.47a	0.20a	3.67a
112 kg/ha	0.83b	0.53b	0.30a	3.59a
224 kg/ha	0.98c	0.54b	0.44b	3.90a
448 kg/ha	1.64d	0.73c	0.91c	3.74a
Zahill				
K Rate:				
Check	0.50a	0.44a	0.05a	2.96a
112 kg/ha	0.82b	0.43a	0.38b	3.18ab
224 kg/ha	0.89b	0.54ab	0.35b	3.41bc
448 kg/ha	1.07b	0.59b	0.48b	3.73c

* means followed by the same letter are not significantly different by LSD at p=0.05.

Table 25. Influence of Applied K on Soil and Plant Ca By Soil Type - Averaged Across K Sources

Soil	Pre-plant Soil Ca meq./100g	Post-harvest Soil Ca meq./100g	dCa meq./100g	Plant Ca Concentration (%)
Scobey				
K Rate:				
Check	4.51a*	5.11a	-0.60a	0.44a
112 kg/ha	4.41a	4.68a	-0.27a	0.37a
224 kg/ha	4.56a	4.47a	-0.08a	0.38a
448 kg/ha	4.50a	4.51a	-0.01a	0.36a
Vida				
K Rate:				
Check	9.82a	9.68a	0.13a	0.75b
112 kg/ha	10.51a	10.09a	0.42a	0.73b
224 kg/ha	10.01a	10.01a	0.00a	0.56a
448 kg/ha	9.93a	9.75a	0.18a	0.64ab
Hillon				
K Rate:				
Check	20.01a	21.78a	-1.76a	0.73b
112 kg/ha	19.50a	20.96a	-1.46a	0.63ab
224 kg/ha	19.15a	20.84a	-1.68a	0.61ab
448 kg/ha	19.30a	22.33a	-3.02a	0.56a
Zahill				
K Rate:				
Check	20.38a	22.01a	-1.63a	0.78a
112 kg/ha	20.40a	24.13a	-2.28a	0.68a
224 kg/ha	21.28a	24.78a	-3.50a	0.69a
448 kg/ha	21.99a	23.58a	-1.58a	0.68a

* means followed by the same letter are not significantly different by LSD at p=0.05.

This was not consistent with Experiment I results where significant decreases in both of these nutrients were found as applied K increased, and was taken as possible evidence of ionic competition

often referred to in the literature. Delta Ca and dMg values were also found to be apparently unrelated to applied K, in that no observable trends or significant differences between K rates or soils were found (Table 26).

Table 26. Influence of Applied K on Soil and Plant Mg by Soil Type Averaged Across K Sources

Soil	Pre-plant Soil Mg meq./100g	Post-harvest Soil Mg meq./100g	dMg meq./100g	Plant Mg Concentration (%)
Scobey				
K Rate:				
Check	1.78ab*	2.02a	-0.23a	0.19a
112 kg/ha	1.76ab	1.90a	-0.13a	0.15a
224 kg/ha	1.74a	1.82a	-0.07a	0.17a
448 kg/ha	1.91b	1.86a	0.05a	0.16a
Vida				
K Rate:				
Check	1.91a	2.32a	-0.41a	0.22b
112 kg/ha	2.07a	2.42a	-0.35a	0.21b
224 kg/ha	1.88a	2.40a	-0.51a	0.16a
448 kg/ha	1.97a	2.29a	-0.31a	0.17ab
Hillon				
K Rate:				
Check	1.91a	2.34b	-0.43a	0.23b
112 kg/ha	1.86a	2.28ab	-0.41a	0.19ab
224 kg/ha	1.87a	2.17a	-0.30a	0.20ab
448 kg/ha	1.91a	2.32ab	-0.40a	0.17a
Zahill				
K Rate:				
Check	2.07a	2.52a	-0.45a	0.25b
112 kg/ha	2.07a	2.54a	-0.46a	0.20ab
224 kg/ha	2.09a	2.65a	-0.55a	0.21ab
448 kg/ha	2.14a	2.52a	-0.38a	0.20a

* means within columns followed by the same letter are not significantly different by LSD at p=0.05.

Influence of Applied K on Plant Growth

Plants grown on all four soils showed a consistent response to added K for fresh harvest weight (Table 27). On every soil for every increase in added K, an increase in fresh harvest weight was found, though only the Scobey, Vida and Zahill soils produced differences which were significant. Of these differences, only those between check and high K treatments were significant on the Scobey and Vida soils. The Zahill soil responded significantly only between the check and added increments of K treatments, while with the Hillon the increase in fresh harvest weight was not significant.

Dry Matter Yield

Dry matter yield paralleled fresh weight to some extent, though overall, no consistent increase in dry matter yield was observed with increased K application (Table 27). The Scobey soil showed no significant increase between the check and high K, whereas the other three soils did. Only Hillon showed a consistent increase in dry matter with increasing K.

Percent Dry Matter

Percent dry matter appeared to be completely unrelated to applied K in that no consistent trends were observed on three of four soils. Only Hillon showed a consistent increase in percent dry matter, though

this increase was significant only between check and high K (Table 27).

Table 27. Influence of Applied K on Plant Growth - Mean Values by Soil Type - Averaged Across K Sources

Soil	Fresh Harvest Weight (g)	Dry Matter Yield (g)	Percent Dry Matter (%)
Scobey			
K Rate:			
Check	29.62a*	6.40ab	21.73ab
112 kg/ha	31.49ab	6.06a	19.27a
224 kg/ha	31.63ab	6.91ab	21.97b
448 kg/ha	34.19b	7.27b	21.56ab
Vida			
K Rate:			
Check	31.76a	6.71a	21.52a
112 kg/ha	35.31ab	6.80ab	19.66a
224 kg/ha	35.74ab	7.38b	21.06a
448 kg/ha	37.96b	7.36b	19.52a
Hillon			
K Rate:			
Check	30.26a	6.37a	21.14a
112 kg/ha	30.51a	6.63ab	21.76ab
224 kg/ha	31.09a	6.97ab	22.42ab
448 kg/ha	32.51a	7.28b	22.81b
Zahill			
K Rate:			
Check	21.87a	5.03a	23.33a
112 kg/ha	28.43b	6.31b	22.27a
224 kg/ha	29.18b	6.57b	23.03a
448 kg/ha	29.89b	6.52b	22.00a

* means followed by the same letter are not significantly different by LSD at p=0.05.

Influence of Applied K on Plant K, Ca and Mg Concentration

Plant Uptake of K

Examination of plant K concentrations (Table 24) revealed three of four soils showed no significant increase in plant K levels between the check and added K. The Scobey, Vida and Hillon soils showed no obvious trends between applied K and plant tissue K. The Zahill soil produced plants which showed significantly greater tissue K with increasing K application.

It is interesting to note that the Scobey, Hillon and Zahill soils all resulted in remarkably similar plant K concentrations, with the Vida soil producing plants with the greatest K concentration (Table 28). All four soils contain K in quantities quite different from one another, yet respond almost identically in terms of plant K at the highest rate of applied K. A large difference in native K (Scobey 1.99 ppm - Zahill 1.49 ppm) and a nearly six-fold difference in $\%CaCO_3$ (Scobey 1.00% - Zahill 5.6%) result in almost identical plant K levels at the highest K application rate. These results suggest that differences in $CaCO_3$ levels in this range have little controlling influence on plant K uptake, at least when K is applied at relatively high rates.

Plant Uptake of Ca

Examination of plant tissue Ca values over all four soils revealed consistently decreasing Ca concentration as greater rates of

K were applied, though only one difference is significant (Table 28). When these results were expressed by soil type, much of the data looked similar. Only one soil (Scobey) produced plants in which the Ca concentration decreased significantly (Table 28).

Table 28. Mean Values for Plant K, Ca, Mg Expressed as Percent of Plant Tissue.

K Source:	KCl			K_2SO_4		
	%K	%Ca	%Mg	%K	%Ca	%Mg
K Rate:						
0	3.73 a	0.72 b	0.24 b	3.67 a	0.63 a	0.21 b
112	3.53 a	0.59 a	0.18 a	3.73 a	0.61 a	0.19 ab
224	3.69 a	0.56 a	0.18 a	3.81 a	0.56 a	0.18 ab
448	3.99 a	0.56 a	0.18 a	3.86 a	0.56 a	0.17 a
$CaCO_3$ Level: (Soil)						
1 (Zahill)	3.10 a	0.64 b	0.19 ab	3.54 a	0.77 d	0.23 b
2 (Vida)	4.17 b	0.69 b	0.20 ab	4.27 b	0.65 c	0.19 a
3 (Hillon)	3.97 b	0.71 b	0.22 b	3.48 a	0.55 b	0.17 a
4 (Scobey)	3.71 b	0.38 a	0.17 a	3.78 ab	0.40 a	0.17 a

*Means followed by the same letter(s) are not significantly different by LSD at p=0.05.

Plant uptake of Mg

Plant concentrations of Mg were less than Ca levels, and exhibited what may be considered ionic competition from added K when averaged across all four soils (Table 28), particularly when K was applied as K_2SO_4.

Table 26 reveals a decrease in plant Mg between the K check and K rate 1 (112 kg/ha), after which Mg depression is evident, though inconsistent. The only statistically significant decrease in Mg levels was found on the Hillon and Zahill soils (Table 26). Plant Mg

levels, when analyzed across soils, reveal less consistent trends (Table 28).

Plant Cation Ratios

Influence of Native $CaCO_3$ on Plant Cation Ratios

Each of the cation ratios of interest, K/Ca, K/Mg and K/Ca + Mg, were strongly and negatively correlated to $\%CaCO_3$ (Appendix B). In this experiment, if the consistent decrease seen in these ratios were to continue as $CaCO_3$ content rises, a significant decrease in plant tissue K may develop, relative to Ca and Mg (Tables 29-30).

Table 29. Mean Values for Plant Tissue K/Ca + Mg Ratios - Ex. II

K Source:	KCl	K_2SO_4
K Rate:		
0	6.03a *	6.59a
112	6.77b	6.66a
224	7.17bc	7.50b
448	7.62c	7.61b
Soil/$\%CaCO_3$ Eq.:		
Scobey/1.06	9.97c	10.14c
Vida/1.88	6.50b	6.84b
Hillon/4.78	6.02b	6.49b
Zahill/5.60	5.10a	4.90a

* means followed by the same letter are not significantly different by LSD at p=0.05.

Table 30. Mean Values for Plant Tissue K/Ca and K/Mg Ratios - Ex. II

	K/Ca		K/Mg	
K Source:	KCl	K_2SO_4	KCl	K_2SO_4
K Rate:				
0	5.79a*	6.38a	16.76a	18.33a
112	6.58b	6.46a	19.98b	19.49ab
224	6.98bc	7.31b	20.14b	21.24bc
448	7.44c	4.90a	22.03b	22.47c
Soil/%$CaCO_3$ Eq.:				
Scobey/1.06	9.80c	9.96c	22.12b	22.89c
Vida/1.88	5.79b	6.31b	22.49b	20.32b
Hillon/4.78	6.30b	6.65b	18.16a	22.82c
Zahill/5.60	4.90a	4.66a	16.14a	15.49a

* means followed by the same letter are not significantly different by LSD at p=0.05.

The relationship between K/Ca, K/Mg and K/Ca + Mg ratios and %$CaCO_3$ eq. represent some of the most consistent and significant data found in either experiment (Tables 29,30). Although the differences in tissue concentration for individual elements was not always large enough to be statistically significant, ratio comparisons illustrate the combined effects of increases in K with simultaneous decreases in Ca and/or Mg to provide more consistent results.

As mentioned previously, large differences between all soils make it necessary to break K application rates down between soils to understand how the soils differ from one another. Tables 31-32 present mean values of cation ratios for both soils and plant tissue between soils.

Influence of Applied K on Plant Cation Ratios

Increasing the rate of applied K produced expected changes in plant tissue cation ratios (Tables 31-32). Increasing K consistently increased all K ratios, though not always significantly. Surprisingly, rate of applied K was less correlated with plant K ratios than was $\%CaCO_3$ eq. This is the opposite of what was found in Experiment I, and perhaps is the result of a much greater range of $CaCO_3$ present in the soils of Experiment II.

Examination of K/Ca + Mg ratios in pre-plant soils reveals a consistent increase in K/Ca + Mg with every increment of added K (Table 31). The difference in native Ca level of each soil is obvious by the magnitude of differences in soil K/Ca + Mg values, but less so when examining plant tissue K/Ca + Mg. For instance, plant tissue ratios between the Vida and Hillon soils appear fairly close to one another despite a difference in %CaCO of 2.5 times (1.88% vs. 4.74%, respectively). A five-fold increase in $\%CaCO_3$ eq. in the Zahill soil results in a K/Ca + Mg ratio of almost half that of the Scobey. Potassium, being a nutrient required in relatively large amounts by most crops, could possibly become deficient in crops where K/Ca + Mg values are below a certain threshold value.

Plant K/Ca and K/Mg ratios behaved in a manner identical to that observed for K/Ca + Mg. Increasing additions of K resulted in consistent and usually significant increases in K/Ca and K/Mg

(Tables 32 and 33). Differences in soils were quite obvious when both ratios were examined, probably due to reasons discussed above. Differences in K/Mg due to applied K were found to be of much greater magnitude than were those for K/Ca. This may provide additional evidence of the greater influence of K on Mg, compared to Ca. It is interesting to note that for all three cation ratios, where soils exhibited highly significant changes from applied K, little significance in differences in plant tissue ratios was observed. Conversely, where soil cation ratios showed little change from applied K, differences in corresponding plant tissue ratios were often highly significant (Tables 31-33). This may provide some support for the idea that the percentage of an element in a plant does not necessarily indicate the availability of that nutrient in the soil as estimated by chemical extraction methods.

Table 31. Mean K/Ca + Mg Values for Soils and Plant Tissue - Exp. II.

Soil	Pre-plant Soil K/Ca + Mg	Post-harvest Soil K/Ca + Mg	Plant Tissue K/Ca + Mg
Scobey			
K Rate:			
Check	0.15a*	0.08a	6.21a
112 kg/ha	0.19b	0.09b	6.69a
224 kg/ha	0.22c	0.10c	7.22a
448 kg/ha	0.31d	0.12d	7.25a
Vida			
K Rate:			
Check	0.08a	0.05a	4.60a
112 kg/ha	0.09ab	0.05ab	4.71ab
224 kg/ha	0.12b	0.06bc	5.28ab
448 kg/ha	0.16c	0.06c	5.52b
Hillon			
K Rate:			
Check	0.02a	0.01a	4.10a
112 kg/ha	0.03b	0.01b	4.45ab
224 kg/ha	0.04c	0.02bc	4.81bc
448 kg/ha	0.07d	0.02c	5.01c
Zahill			
K Rate:			
Check	0.02a	0.01a	3.03a
112 kg/ha	0.03a	0.01a	3.62b
224 kg/ha	0.03a	0.01a	3.76cb
448 kg/ha	0.04a	0.01a	4.25c

* means followed by the same letter are not significantly different by LSD at p=0.05.

Table 32. Mean K/Ca Values for Soils and Plant Tissue - Exp. II.

Soil	Pre-plant Soil K/Ca	Post-harvest Soil K/Ca	Plant Tissue K/Ca
Scobey			
K Rate:			
Check	0.22a*	0.11a	8.96a
112 kg/ha	0.27b	0.13b	9.46a
224 kg/ha	0.31b	0.15c	10.46a
448 kg/ha	0.44c	0.17d	10.65a
Vida			
K Rate:			
Check	0.09a	0.06a	5.94a
112 kg/ha	0.11ab	0.07ab	6.11ab
224 kg/ha	0.14b	0.07bc	6.80ab
448 kg/ha	0.19c	0.08c	7.05b
Hillon			
K Rate:			
Check	0.03a	0.01a	5.46a
112 kg/ha	0.04b	0.02a	5.82ab
224 kg/ha	0.04b	0.02a	6.38b
448 kg/ha	0.08c	0.02b	6.54b
Zahill			
K Rate:			
Check	0.02a	0.01a	3.99a
112 kg/ha	0.04a	0.01a	4.70b
224 kg/ha	0.03a	0.01a	4.94bc
448 kg/ha	0.04a	0.02a	5.51c

* means followed by the same letter are not significantly different by LSD at p=0.05.

Table 33. Mean K/Mg Values for Soils and Plant Tissue - Exp. II.

Soil	Pre-plant Soil K/Mg	Post-harvest Soil K/Mg	Plant Tissue K/Mg
Scobey			
K Rate:			
Check	0.57a	0.28a	20.35a
112 kg/ha	0.70b	0.34b	23.05a
224 kg/ha	0.84c	0.38c	23.53a
448 kg/ha	1.05d	0.43d	22.95a
Vida			
K Rate:			
Check	0.52a	0.27a	20.57a
112 kg/ha	0.61ab	0.30ab	20.90a
224 kg/ha	0.79b	0.34bc	23.70ab
448 kg/ha	1.03c	0.39c	25.60b
Hillon			
K Rate:			
Check	0.35a	0.19a	16.61a
112 kg/ha	0.44b	0.22b	18.99b
224 kg/ha	0.52c	0.24b	19.70bc
448 kg/ha	0.86d	0.31c	21.68c
Zahill			
K Rate:			
Check	0.23a	0.16a	12.65a
112 kg/ha	0.39b	0.16a	16.01bc
224 kg/ha	0.42b	0.19ab	15.84b
448 kg/ha	0.51b	0.23b	18.77c

* means followed by the same letter are not significantly different by LSD at p=0.05.

Variation Due to Source of Applied K

In Experiment I, almost every parameter of interest, soil K, plant growth, and plant tissue cation ratios exhibited apparent

differences due to K source. However, as stated previously, each K source was set up as a complete factorial design, each independent of the other on separate greenhouse benches. If any observed variation was due to K source differences, it was not possible in the experiment to systematically compare sources and arrive at any conclusive discoveries. Uncontrolled differences in greenhouse growing conditions were likely responsible for differences in results.

In Experiment II however, both K sources were present in one complete factorial design, and as such, constituted a major treatment factor. It is thus possible to analyze the variation between sources of K and attempt to account for it.

Variation between K source was absent for the most part from Experiment II, which suggests K source variation in Experiment I was quite possibly due to variation in greenhouse conditions. Table 34 lists experimental parameters of interest, and whether any of these were significantly different due to K source.

Thus, essentially the only differences between K source which were significant at the 95% confidence level were those of fresh plant weight, and corresponding dry matter. Tables 35-39 summarize these differences.

Table 34. K Source Variation - Experiment II
Averaged Across K Rates and Soils

Parameter	Difference in K Source (p=0.05.)
Soil K (Pre-plant soil)	n.s.
Soil Ca "	n.s.
Soil Mg "	n.s.
Soil K (Post harvest soil)	n.s.
Soil Ca "	n.s.
Soil Mg "	n.s.
Fresh harvest weight	.05
Dry Matter yield	.05
Percent dry matter	n.s.
Plant tissue K	n.s.
Plant tissue Ca	n.s.
Plant tissue Mg	n.s.
Plant tissue K/Ca	n.s.
Plant tissue K/Mg	n.s.
Plant tissue K/Ca + Mg	n.s.

Table 35. Harvest Parameters Affected by K Source - Exp. II
Averaged Across K Rates and Soils

K Source	Fresh Harvest Weight(g)	Dry Matter(g)
KCl	32.59b*	6.88b
K_2SO_4	30.09a	6.44a

* Means followed by the same letter are not significantly different by LSD at p=0.05.

Table 36. Comparison of Extractable soil K and Plant K Concentration by K Source and Soil - Exp. II. Averaged Across K Rates

Soil	Pre-plant Soil K (meq./100g)	Post-harvest Soil K (meq./100g)	dK	Plant K Concentration
Scobey				
KCl	1.43a*	0.70a	0.72a	3.71a
K_2SO_4	1.44a	0.67a	0.77a	3.78a
Vida				
KCl	1.41a	0.78a	0.63a	4.17a
K_2SO_4	1.39a	0.79a	0.60a	4.27a
Hillon				
KCl	1.07a	0.55a	0.52b	3.97b
K_2SO_4	1.00a	0.58a	0.41a	3.48a
Zahill				
KCl	0.84a	0.48a	0.36a	3.10a
K_2SO_4	0.80a	0.52a	0.28a	3.54b

* means followed by the same letter are not significantly different by LSD at p=0.05.

Table 37. Comparison of Plant Growth Parameters by K Source and Soil - Exp. II. Averaged Across K Rates

Soil	Fresh Harvest Weight (g)	Dry Matter Yield (g)	Percent Dry Matter (%)
Scobey			
KCl	31.83a*	6.77a	21.39a
K_2SO_4	31.63a	6.55a	20.87a
Vida			
KCl	36.69a	7.25a	20.11a
K_2SO_4	33.69a	6.87a	20.77a
Hillon			
KCl	30.14a	7.03a	21.95a
K_2SO_4	32.05a	6.60a	22.11a
Zahill			
KCl	29.80b	6.48a	21.90a
K_2SO_4	24.88a	5.74a	23.41a

* means followed by the same letter are not significantly different by LSD at p=0.05.

Table 38. Comparison of Soil and Plant K/Mg Ratios by K Source and Soil - Exp. II. Averaged Across K Rates

Soil	Pre-plant Soil	Post-harvest Soil	Plant K/Mg Ratios
	- K/Mg Ratios -		
Scobey			
KCl	0.31a*	0.36a	22.12a
K_2SO_4	0.32a	0.36a	22.82a
Vida			
KCl	0.81a	0.32a	22.49a
K_2SO_4	0.66a	0.33a	22.89a
Hillon			
KCl	0.57b	0.24a	18.16a
K_2SO_4	0.51a	0.24a	20.32b
Zahill			
KCl	0.39a	0.17a	16.14a
K_2SO_4	0.39a	0.20a	15.49a

* means followed by the same letter are not significantly different by LSD at p=0.05.

Table 39. Comparison of Soil and Plant K/Ca Ratios by K Source and Soil - Exp. II. Averaged Across K Rates.

Soil	- K/Ca Ratios - Pre-plant Soil	Post-harvest Soil	Plant Tissue K/Ca
Scobey			
KCl	0.31a*	0.14a	9.80a
K_2SO_4	0.32a	0.14a	9.96a
Vida			
KCl	0.14a	0.07a	6.30a
K_2SO_4	0.13a	0.07a	6.65a
Hillon			
KCl	0.05a	0.02a	5.79a
K_2SO_4	0.04a	0.02a	6.31a
Zahill			
KCl	0.03a	0.01a	4.90a
K_2SO_4	0.03a	0.01a	4.66a

* means followed by the same letter are not significantly different by LSD at p=0.05.

Increased plant yield with KCl over K_2SO_4 may suggest a response to applied chloride. Plant tissue was not analyzed for Cl, thus no data were obtained to support this idea.

Examination of pre-plant and post-harvest soils (Table 35) revealed no significant differences in extractable K between either K source. Two soils, Hillon and Zahill, produced plants with significantly different plant K concentrations in response to differences in source of K, although in one case the greatest K resulted from KCl while in the other it resulted from K_2SO_4.

Fresh harvest weight on the Zahill soil was greater with KCl compared to K_2SO_4 (Table 37). Overall, the only variables which exhibited consistent results on all soils were pre-plant soil K levels and dry matter yield, both of which were higher with KCl though none of these differences were significant (Tables 34, 35).

SUMMARY AND CONCLUSIONS

Two separate greenhouse experiments, using barley as an indicator crop, were designed to examine whether $CaCO_3$ influences the availability and uptake of K. The first experiment utilized a slightly acidic soil, to which different levels of reagent-grade $CaCO_3$ were added. The second experiment utilized four regionally occurring soils from north-central Montana, each of which contained distinctly different amounts of $CaCO_3$. Soils for both experiments were from the Ap or 0-6" layer.

In both experiments, three separate factors (K source, K rate, $CaCO_3$ level) were examined to determine whether each had any influence on nutrient availability (K, Ca, Mg) or on each other (interaction). Soil samples before planting and after harvest were analyzed to examine changes in concentrations of the three main elements in question. In addition, plant tissue was analyzed to determine differences in plant uptake of each of the three elements.

Percent $CaCO_3$ Equivalent

The amount of added $CaCO_3$ in the first experiment produced few significant differences and no trends in extractable soil K. This was true for pre-plant, post-harvest and dK values. This contrasts with results of the second experiment and is considered due to the narrow

range (2.28-2.93%) of $CaCO_3$ equivalent present in treatments in experiment I.

The level of $CaCO_3$ in the first experiment caused no differences in extractable K across all treatments. A significant difference in extractable Mg was found between the check and all other treatments.

Differences in extractable K corresponded to $CaCO_3$ level in Experiment II, with K decreasing across soils with increasing %CaCO eq. However, a small R^2 between pre-plant K and %CaCO eq. (R^2=.30) suggests that only a small amount of the observed variation in extractable K was due to %$CaCO_3$ eq., and that much more variation comes from other soil differences.

In both experiments, pre-plant soil Ca levels increased significantly as $CaCO_3$ increased. A very high correlation (R=.98) was found between pre-plant soil Ca and %$CaCO_3$ eq. in Experiment II, though a significant correlation was not found between the two in Experiment I. This may be due to the problem created by adding calcareous sand to the soils in Experiment I and causing the $CaCO_3$ levels to become re-ordered and above the desired level of interest (0-1% $CaCO_3$).

Level of $CaCO_3$ produced different results between the two experiments. While no significant differences in extractable K or Mg levels were observed over $CaCO_3$ treatments (only one between check and other treatments for Mg), extractable Ca levels increased with increasing $CaCO_3$. In Experiment I however, no significant correlations were found between post-harvest extractable K, Ca or Mg,

and %$CaCO_3$ eq. This contrasts sharply with results in Experiment II where, as %$CaCO_3$ increased, extractable K levels were significantly reduced, and Ca and Mg both increased greatly. Levels of all three elements in Experiment II showed highly significant ($p=0.001$) correlations to %$CaCO_3$ eq.

Some highly significant differences in fresh and dry matter yield were observed across $CaCO_3$ treatments in experiment I, but these differences were not present as trends related to the lime treatments. No significant correlation values were associated with fresh weight, dry weight or percent dry weight and %$CaCO_3$ eq. in either experiment.

The distinct lack of influence of $CaCO_3$ level on plant concentration of Ca in both experiments may provide support for the idea that plants can take up nutrients in much different quantities than those which exist in the soil. Across the relatively narrow $CaCO_3$ range in Experiment I, the only differences in plant Ca concentration were found between the check $CaCO_3$ level and the rest of the treatments. In Experiment II, plants grown on Scobey (with the lowest %$CaCO_3$) were lower in Ca concentration than those grown on the three remaining soils, including two soils which contain 4 and 5 times as much $CaCO_3$.

No differences in K concentration across $CaCO_3$ treatments were observed in Experiment I. Similar results are evident in Experiment II. Where differences were found, they did not follow any order of increasing or decreasing %$CaCO_3$, and are thought due to other differences in the soils used in Experiment II.

Rate of Applied K

The effect of K rate in pre-plant soils was the same in both experiments: increasing levels of extractable K were found with increasing K application. In a few instances significant differences, or trends, were found with extractable Ca or Mg.

In both experiments, soils demonstrated the well-known effects of ionic competition between K-Ca and K-Mg. As K was increased, both extractable Ca and Mg were decreased. While this was true of Mg in Experiment II, the opposite effect was observed with Ca where increased levels of applied K produced increased levels of extractable Ca on post-harvest soils (over the checks). This may be due to much higher extractable K in all soils of Experiment II, compared to Experiment I, so that adding more K may have released exchangeable Ca, even when measured at the end of the plant growth period.

Differences in response to K rate are thought due to native K levels present in the soils. The four soils of Experiment II all showed 3 to 4 times more extractable K than the soil of Experiment I, which may account for the lack of a response to increased K application in Experiment II.

Increased K rate showed a greater depression of plant Ca concentration in Experiment I than in Experiment II, where the much higher levels of native Ca may have helped prevent any ionic competition between K and Ca.

Greater depression of Mg concentration in response to increased K rate was seen in Experiment I than in Experiment II. The only significant difference in plant Mg concentration in Experiment II was between the K check and the three levels of added K. Again, differences in native level of extractable Mg between the soil used in Experiment I and those used in Experiment II may account for the different nature of response in the two experiments.

Source of K

Soils from Experiment II showed no differences in concentration for K, Ca or Mg in reponse to source of applied K. Potassium chloride, in both experiments, produced greater fresh and dry matter yield compared to K_2SO_4. This may have occurred at least in part to a chloride response. Increasing the rate of applied K from both sources increased fresh weight, while increases in dry weight were significant only from KCl.

Some marked differences in plant K concentration were found between the experiments. Plant concentration of K in both experiments was the same with both sources of applied K.

Plant concentration of Mg was significantly higher with K_2SO_4 compared to KCl in Experiment I. No K source differences for Mg were evident in Experiment II.

Results of these experiments suggest that $CaCO_3$ in these soils, and in these quantities, has limited direct influence on availability and plant uptake of K, Ca, or Mg when these elements are present in

quantities which can minimize the effects of ionic competition between them. Results of other studies which suggest detrimental effects of $CaCO_3$ on crop yields are apparently not a direct result of $CaCO_3$ influences on plant K nutrition. Other studies would need to be conducted to determine relative importance of other soil physical or chemical factors such as lower water holding capacity, low organic matter (erosion), phosphorus and micro-nutrient tie-up and how these influence crop growth and yield, to determine specific $CaCO_3$ effects.

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APPENDICES

APPENDIX A - ANALYSIS OF VARIANCE TABLES

Table 40. Analysis of Variance - Experiment I Potassium

Significance of p-values for treatment means for K source indicated

Source of Variation	Pre Plant Soil K	Post Harvest Soil K	Delta K (dK)	Plant Tissue K (%)
K Source: KCl				
K Rate	0.01	0.01	0.01	0.01
% $CaCO_3$ Eq.	NS	NS	NS	NS
K x % $CaCO_3$ Eq.	NS	NS	NS	NS
K Source: K_2SO_4				
K Rate	0.01	0.01	0.01	0.01
% $CaCO_3$ Eq.	NS	NS	NS	NS
K x % $CaCO_3$ Eq.	NS	NS	NS	NS

Table 41. Analysis of Variance - Experiment I Calcium

Source of Variation	Pre Plant Soil Ca	Post Harvest Soil Ca	Delta Ca (dCa)	Plant Tissue Ca (%)
K Source: KCl				
K Rate	NS	NS	NS	0.01
% $CaCO_3$ Eq.	0.01	0.01	NS	0.02
K x % $CaCO_3$ Eq.	NS	NS	NS	NS
K Source: K_2SO_4				
K Rate	NS	NS	NS	NS
% $CaCO_3$ Eq.	0.01	0.01	NS	NS
K x % $CaCO_3$ Eq.	NS	NS	NS	NS

Table 42. Analysis of Variance - Experiment I Magnesium

Significance of p-values for treatment means for K source indicated

Source of Variation	Pre Plant Soil Mg	Post Harvest Soil Mg	Delta Mg (dMg)	Plant Tissue Mg (%)
K Source: KCl				
K Rate	NS	0.01	NS	0.01
% $CaCO_3$ Eq.	0.01	0.01	NS	NS
K x % $CaCO_3$ Eq.	NS	NS	NS	NS
K Source: K_2SO_4				
K Rate	NS	NS	NS	0.01
% $CaCO_3$ Eq.	0.01	0.01	NS	NS
K x % $CaCO_3$ Eq.	NS	NS	NS	NS

Table 43. Analysis of Variance - Experiment I Treatment Effects

Plant stand, fresh weight, dry matter and % dry matter

Source of Variation	Plants per Pot	Fresh Harvest Weight	Dry Matter Yield	% Dry Matter Yield
K Source: KCl				
K Rate	0.01	0.01	0.01	0.01
% $CaCO_3$ Eq.	NS	0.01	0.01	NS
K x % $CaCO_3$ Eq.	NS	NS	NS	NS
K Source: K_2SO_4				
K Rate	NS	NS	NS	NS
% $CaCO_3$ Eq.	NS	NS	0.02	NS
K x % $CaCO_3$ Eq.	NS	NS	NS	NS

Table 44. Analysis of Variance - Experiment I Treatment Effects

Plant Tissue K/Ca Ratios

Source of Variation	Pre Plant Soil K/Ca	Post Harvest Soil K/Ca	Plant Tissue K/Ca
K Source: KCl			
K Rate	0.01	0.01	0.01
% $CaCO_3$ Eq.	0.01	0.01	0.03
K x % $CaCO_3$ Eq.	NS	NS	NS
K Source: K_2SO_4			
K Rate	0.01	0.01	0.01
% $CaCO_3$ Eq.	0.01	0.01	NS
K x % $CaCO_3$ Eq.	NS	NS	NS

Table 45. Analysis of Variance - Experiment I Treatment Effects

Plant Tissue K/Mg Ratios

Source of Variation	Pre Plant Soil K/Mg	Post Harvest Soil K/Mg	Plant Tissue K/Mg
	K Source: KCl		
K Rate	0.01	0.01	0.01
% $CaCO_3$ Eq.	NS	0.01	NS
K x % $CaCO_3$ Eq.	NS	NS	NS
	K Source: K_2SO_4		
K Rate	0.01	0.01	0.01
% $CaCO_3$ Eq.	0.01	NS	NS
K x % $CaCO_3$ Eq.	NS	NS	NS

Table 46. Analysis of Variance - Experiment I Treatment Effects

Plant Tissue K/(Ca+Mg) Ratios

Source of Variation	Pre Plant Soil K/(Ca+Mg)	Post Harvest Soil K/(Ca+Mg)	Plant Tissue K/(Ca+Mg)
K Source: KCl			
K Rate	0.01	0.01	0.01
% $CaCO_3$ Eq.	0.01	0.01	0.05
K x % $CaCO_3$ Eq.	NS	NS	NS
K Source: K_2SO_4			
K Rate	0.01	0.01	0.01
% $CaCO_3$ Eq.	0.01	0.01	NS
K x % $CaCO_3$ Eq.	NS	NS	NS

Table 47. Analysis of Variance - Experiment II Potassium

Significance of p-values for treatment means for K source indicated

Source of Variation	Pre Plant Soil K	Post Harvest Soil K	Delta K (dK)	Plant Tissue K (%)
K Source	NS	NS	NS	NS
K Rate	0.01	0.01	0.01	NS
Source x Rate	NS	NS	NS	NS
Soil	0.01	0.01	0.01	0.01
Source x Soil	NS	NS	NS	NS
Rate x Soil	0.01	NS	0.03	NS
Source x Rate x Soil	0.01	NS	NS	NS

Table 48. Analysis of Variance - Experiment II Calcium

Source of Variation	Pre Plant Soil Ca	Post Harvest Soil Ca	Delta Ca (dCa)	Plant Tissue Ca (%)
K Source	NS	NS	NS	NS
K Rate	NS	NS	NS	0.02
Source x Rate	NS	NS	NS	NS
Soil	NS	0.01	0.01	0.01
Source x Soil	NS	0.04	NS	0.01
Rate x Soil	NS	NS	NS	NS
Source x Rate x Soil	NS	NS	NS	NS

Table 49. Analysis of Variance - Experiment II Magnesium

Source of Variation	Pre Plant Soil K	Post Harvest Soil K	Delta K (dK)	Plant Tissue K (%)
K Source	NS	NS	NS	NS
K Rate	NS	NS	NS	0.01
Source x Rate	NS	NS	NS	NS
Soil	0.01	0.01	0.01	0.01
Source x Soil	0.03	NS	NS	0.01
Rate x Soil	NS	NS	NS	NS
Source x Rate x Soil	NS	NS	NS	NS

Table 50. Analysis of Variance - Experiment II Plant Growth

Source of Variation	Fresh Harvest Weight	Dry Matter Yield	% Dry Matter
K Source	0.01	0.01	NS
K Rate	0.01	0.01	NS
Source x Rate	NS	NS	NS
Soil	0.01	0.01	0.01
Source x Soil	NS	NS	NS
Rate x Soil	NS	NS	NS
Source x Rate x Soil	NS	NS	NS

Table 51. Analysis of Variance - Experiment II Plant K/Ca

Source of Variation	Pre Plant Soil K/Ca	Post Harvest Soil K/Ca	Plant Tissue K/Ca
K Source	NS	NS	NS
K Rate	0.01	0.01	0.01
Source x Rate	NS	NS	NS
Soil	0.01	0.01	0.01
Source x Soil	NS	NS	NS
Rate x Soil	0.01	0.01	0.01
Source x Rate x Soil	NS	NS	NS

Table 52. Analysis of Variance - Experiment II Plant K/Mg

Source of Variation	Pre Plant Soil K/Mg	Post Harvest Soil K/Mg	Plant Tissue K/Mg
K Source	NS	NS	NS
K Rate	0.01	0.01	0.01
Source x Rate	NS	NS	NS
Soil	0.01	0.01	0.01
Source x Soil	NS	NS	NS
Rate x Soil	NS	NS	NS
Source x Rate x Soil	NS	NS	NS

Table 53. Analysis of Variance - Experiment II Plant K/(Ca+Mg)

Source of Variation	Pre Plant Soil K/(Ca+Mg)	Post Harvest Soil K/(Ca+Mg)	Plant Tissue K/(Ca+Mg)
K Source	NS	NS	NS
K Rate	0.01	0.01	0.01
Source x Rate	NS	NS	NS
Soil	0.01	0.01	0.01
Source x Soil	NS	NS	NS
Rate x Soil	0.01	0.01	NS
Source x Rate x Soil	0.01	NS	NS

APPENDIX B - CORRELATION MATRICES

Table 54. Correlation Matrix Showing R Values for Experiment I Variables

K Source: KCl

Variable	No.	1	2	3	4	5	6	7	8	9	10	11	12	13
K Source	1													
K Rate	2													
%$CaCO_3$ Eq.	3													
Soil0	4													
pH	5													
EC	6			-0.43		-0.97								
CEC	7					0.98	-0.98							
Pre-plant soil K	8		0.94											
Pre-plant soil Ca	9					0.93	-0.86	0.88						
Pre-plant soil Mg	10			-0.53		-0.79	0.86	-0.85		-0.57				
Post-harvest soil K	11		0.89						0.82					
Post-harvest soil Ca	12					0.79	-0.67	0.71		0.90	-0.42			
Post-harvest soil Mg	13		-0.35			-0.76	0.78	-0.78		-0.61	0.76			
Delta K (dK)	14		0.84						0.95			0.63		
Delta Ca (dCa)	15			0.44		-0.38				-0.51			0.83	
Delta Mg (dMg)	16									0.40				-0.54
Plant tissue %K	17		0.60							0.53	-0.35	0.62		
Plant tissue %Ca	18		-0.61							-0.56		-0.64		
Plant tissue %Mg	19		-0.70							-0.67		-0.68		

R >= .34 Significant at p=0.05
R >= .44 Significant at p=0.01
R >= .55 Significant at p=0.001

Table 55. Correlation Matrix Showing R Values for Experiment I Variables

K Source: K_2SO_4

Variable	No.	1	2	3	4	5	6	7	8	9	10	11	12	13
K Source	1													
K Rate	2													
$\%CaCO_3$ Eq.	3													
Soil@	4													
pH	5													
EC	6			-0.43		-0.97								
CEC	7					0.98	-0.98							
Pre-plant soil K	8		0.80											
Pre-plant soil Ca	9					0.87	-0.82	0.84						
Pre-plant soil Mg	10					-0.70	0.72	-0.72		-0.36				
Post-harvest soil K	11		0.85						0.64					
Post-harvest soil Ca	12					0.86	-0.75	0.80		0.80	-0.60			
Post-harvest soil Mg	13					-0.88	0.88	-0.87		-0.79	0.56		-0.60	
Delta K (dK)	14		0.55						0.91					
Delta Ca (dCa)	15			0.35						0.41				
Delta Mg (dMg)	16										0.36	0.51	0.37	-0.54
Plant tissue %K	17			0.44										
Plant tissue %Ca	18			-0.44										
Plant tissue %Mg	19			-0.41										

R >= .34 Significant at p=0.05
R >= .44 Significant at p=0.01
R >= .55 Significant at p=0.001

Table 56. Correlation Matrix Showing R Values for Experiment I Variables

K Source: KCl

Variable	No.	1	2	3	4	5	6	7	8	9	10	11	12	13
K Source	1													
K Rate	2													
%$CaCO_3$ Eq.	3													
Soil#	4													
pH	5			-0.43		-0.97								
EC	6					0.98	-0.98							
CEC	7		0.94											
Pre-plant soil K	8					0.93	-0.86	0.88						
Pre-plant soil Ca	9			-0.53		-0.79	0.86	-0.85		-0.57				
Pre-plant soil Mg	10					-0.49					-0.36			
# plants/pot	11					-0.47				-0.38				
Fresh Harvest Wt.	12													
Dry Harvest Wt.	13				0.83				0.71					
% Dry Matter	14					0.51	-0.54	0.55		0.51	-0.52			
Total Plant K	15		0.36			0.41	-0.45	0.45		0.40	-0.46			
Total Plant Ca	16		0.86			-0.38	0.36	-0.36	0.93	-0.50				
Total Plant Mg	17		0.69			-0.47	0.41	-0.44	0.72	-0.61				
Pre-Harvest soil K/Ca+Mg	18		0.71						0.65					
Post-Harvest soil K/Ca+Mg	19													
% K/Ca+Mg Plant Tissue	20													

R >= .34 Significant at p=0.05
R >= .44 Significant at p=0.01
R >= .55 Significant at p=0.001

Table 57. Correlation Matrix Showing R Values for Experiment I Variables

K Source: K_2SO_4

Variable	No.	1	2	3	4	5	6	7	8	9	10	11	12	13
K Source	1													
K Rate	2													
%$CaCO_3$ Eq.	3													
Soil#	4													
pH	5													
EC	6			-0.43		-0.97								
CEC	7					0.98	-0.98							
Pre-plant soil K	8		0.80											
Pre-plant soil Ca	9					0.87	-0.82	0.84						
Pre-plant soil Mg	10					-0.70	0.72	-0.72		-0.36				
# plants/pot	11													
Fresh Harvest Wt.	12													
Dry Harvest Wt.	13													
% Dry Matter	14													
Total Plant K	15		0.41				-0.35	0.36						
Total Plant Ca	16					0.60	-0.60	0.62		0.48	-0.46			
Total Plant Mg	17					0.52	-0.51	0.53		0.39	-0.39			
Pre-Harvest soil K/Ca+Mg	18		0.76						0.90					
Post-Harvest soil K/Ca+Mg	19		0.62			-0.42	0.35	-0.37	0.40	-0.43				
% K/Ca+Mg Plant Tissue	20		0.72							0.45	0.72			

R >= .34 Significant at p=0.05
R >= .44 Significant at p=0.01
R >= .55 Significant at p=0.001

Table 58. Correlation Matrix Showing R Values for Experiment I Variables

K Source: KCl

Variable	No.	1	2	3	4	5	6	7	8	9	10	11	12	13
K Source	1													
K Rate	2													
%$CaCO_3$ Eq.	3													
Soil@	4													
pH	5													
EC	6			-0.43		-0.97								
CEC	7					0.98	-0.98							
Pre-plant soil K	8		0.94											
Pre-plant soil Ca	9					0.93	-0.86	0.88						
Pre-plant soil Mg	10			-0.53		-0.79	0.86	-0.85		-0.57				
Plant Tissue K/Ca	11		0.68						0.62	-0.37				
Plant Tissue K/Mg	12		0.77						0.71					

R >= .34 Significant at p=0.05
R >= .44 Significant at p=0.01
R >= .55 Significant at p=0.001

Table 59. Correlation Matrix Showing R Values for Experiment I Variables

K Source: K_2SO_4

Variable	No.	1	2	3	4	5	6	7	8	9	10	11	12	13
K Source	1													
K Rate	2													
$\%CaCO_3$ Eq.	3													
Soil%	4													
pH	5													
EC	6			-0.43		-0.97								
CEC	7					0.98	-0.98							
Pre-plant soil K	8		0.80											
Pre-plant soil Ca	9					0.87	-0.82	0.84						
Pre-plant soil Mg	10					-0.70	0.72	-0.72		-0.36				
Plant Tissue K/Ca	11		0.57						0.37					
Plant Tissue K/Mg	12		0.57						0.35					

R >= .34 Significant at p=0.05
R >= .44 Significant at p=0.01
R >= .55 Significant at p=0.001

Table 60. Correlation Matrix Showing R Values for Experiment I Variables

K Source: KCl

Variable	No.	1	2	3	4	5	6	7	8	9	10	11	12	13
K Source	1													
K Rate	2													
%$CaCO_3$ Eq.	3													
Soil@	4													
pH	5													
EC	6			-0.43		-0.97								
CEC	7					0.98	-0.98							
Pre-plant soil K	8		0.80											
Pre-plant soil Ca	9					0.87	-0.82	0.84						
Pre-plant soil Mg	10					-0.70	0.72	-0.72		-0.36				
Post-harvest soil K	11		0.85						0.64					
Post-harvest soil Ca	12					0.86	-0.75	0.80		0.80	-0.60			
Post-harvest soil Mg	13					-0.88	0.88	-0.87		-0.79	0.56		-0.60	
Plant tissue %K	14		0.44											
Plant tissue %Ca	15		-0.44											
Plant tissue %Mg	16		-0.41											

R >= .34 Significant at p=0.05
R >= .44 Significant at p=0.01
R >= .55 Significant at p=0.001

Table 61. Correlation Matrix Showing R Values for Experiment I Variables

K Source: K_2SO_4

Variable	No.	1	2	3	4	5	6	7	8	9	10	11	12	13
K Source	1													
K Rate	2													
$\%CaCO_3$ Eq.	3													
Soil%	4													
pH	5													
EC	6			-0.43		-0.97								
CEC	7					0.98	-0.98							
Pre-plant soil K	8		0.80											
Pre-plant soil Ca	9					0.87	-0.82	0.84						
Pre-plant soil Mg	10					-0.70	0.72	-0.72		-0.36				
Post-harvest soil K	11		0.85						0.64					
Post-harvest soil Ca	12					0.86	-0.75	0.80		0.80	-0.60			
Post-harvest soil Mg	13					-0.88	0.88	-0.87		-0.79	0.56		-0.60	
Plant tissue %K	14		0.44											
Plant tissue %Ca	15		-0.44											
Plant tissue %Mg	16		-0.41											

R >= .34 Significant at p=0.05
R >= .44 Significant at p=0.01
R >= .55 Significant at p=0.001

Table 62. Correlation Matrix Showing R Values for Experiment II Variables

K Source: KCl

Variable	No.	1	2	3	4	5	6	7	8	9	10	11	12	13
K Source	1													
K Rate	2													
Soil @	3													
% $CaCO_3$ Eq.	4													
pH	5				0.84									
EC	6				-0.58									
CEC	7				0.59	0.91								
Pre-plant soil K	8				-0.55	-0.42	0.36							
Pre-plant soil Ca	9		0.74		0.98	0.90	-0.48	0.67	-0.51					
Pre-plant soil Mg	10				0.64	0.52		0.47		0.64				
Post-harvest soil K	11				-0.72	-0.46	0.63		0.90	-0.65	-0.38			
Post-harvest soil Ca	12				0.99	0.88	-0.52	0.65	-0.52	0.97	0.62	-0.68		
Post-harvest soil Mg	13		0.58		0.64	0.78		0.83	-0.38	0.66	0.63		0.71	
Delta K (dK)	14				-0.42	-0.37			0.97	-0.41		0.79	-0.40	-0.38
Delta Ca (dCa)	15		0.77		-0.64	-0.45	0.45			-0.51		0.52	-0.67	-0.59
Delta Mg (dMg)	16						-0.60		-0.70		-0.36		-0.43	-0.80
Plant tissue %K	17				-0.39		0.41		0.37			0.45	-0.36	
Plant tissue %Ca	18				0.49	0.75		0.73	-0.51	0.58		-0.40	0.52	0.52
Plant tissue %Mg	19		-0.47		0.36	0.43			-0.59	0.41		-0.52	0.36	0.84

R >= .49 Significant at p=0.05
R >= .62 Significant at p=0.01
R >= .74 Significant at p=0.001

Table 63. Correlation Matrix Showing R Values for Experiment II Variables

K Source: K_2SO_4

Variable	No.	1	2	3	4	5	6	7	8	9	10	11	12	13
K Source	1													
K Rate	2													
Soil #	3													
%$CaCO_3$ Eq.	4													
pH	5				0.84									
EC	6				-0.58									
CEC	7				0.59	0.91								
Pre-plant soil K	8		0.72		-0.66	-0.53	0.42	-0.36						
Pre-plant soil Ca	9				0.98	0.91	-0.46	0.69	-0.65					
Pre-plant soil Mg	10				0.35	0.63	0.38	0.79		0.44				
Post-harvest soil K	11		0.58		-0.62		0.68		0.87	-0.56				
Post-harvest soil Ca	12				0.98	0.88	-0.52	0.63	-0.62	0.98	0.35	-0.54		
Post-harvest soil Mg	13				0.72	0.90		0.90	-0.52	0.78	0.74		0.76	
Delta K (dK)	14		0.72		-0.62	-0.59		-0.47	0.97	-0.63		0.73	-0.60	-0.64
Delta Ca (dCa)	15				-0.64	-0.45	0.58			-0.59			-0.72	-0.41
Delta Mg (dMg)	16				-0.76	-0.81		-0.69	0.61	-0.78			0.82	-0.87
Plant tissue %K	17				-0.59		0.81		0.49	-0.51		0.65	-0.52	
Plant tissue %Ca	18				0.66	0.82		0.88	-0.56	0.70	0.81		0.62	0.85
Plant tissue %Mg	19		-0.40		0.51	0.46		0.50	-0.66	0.48	0.60	-0.50	0.42	0.60

R >= .49 Significant at p=0.05
R >= .62 Significant at p=0.01
R >= .74 Significant at p=0.001

Table 64. Correlation Matrix Showing R Values for Experiment II Variables

K Source: KCl

Variable	No.	1	2	3	4	5	6	7	8	9	10	11	12	13
K Source	1													
K Rate	2													
Soil #	3													
%$CaCO_3$ Eq.	4													
pH	5				0.84									
EC	6				-0.58									
CEC	7				0.59	0.91								
Pre-plant soil K	8		0.74		-0.55	-0.42	0.36							
Pre-plant soil Ca	9				0.98	0.90	-0.48	0.67	-0.51					
Pre-plant soil Mg	10				0.64	0.52		0.47		0.64				
Fresh Harvest Wt.	11		0.57				0.52		0.70					
Dry Harvest Wt.	12		0.67						0.69					
% Dry Matter	13				0.43		-0.64		-0.39	0.36				
Total Plant K	14		0.49		-0.35		0.43		0.60					
Total Plant Ca	15				0.39	0.71		0.72		0.52				
Total Plant Mg	16					0.41				0.36				
Pre-Harvest soil K/Ca+Mg	17				-0.86	-0.90		-0.75	0.73	-0.89	-0.47			
Post-Harvest soil K/Ca+Mg	18				-0.91	-0.91		-0.73	0.66	-0.93	-0.49			
% K/Ca+Mg Plant Tissue	19		0.41		-0.77	-0.89		-0.82	0.73	-0.79	-0.44			

R >= .49 Significant at p=0.05
R >= .62 Significant at p=0.01
R >= .74 Significant at p=0.001

Table 65. Correlation Matrix Showing R Values for Experiment II Variables

K Source: K_2SO_4

Variable	No.	1	2	3	4	5	6	7	8	9	10	11	12	13
K Source	1													
K Rate	2													
Soil #	3													
%$CaCO_3$ Eq.	4													
pH	5				0.84									
EC	6				-0.58									
CEC	7				0.59	0.91								
Pre-plant soil K	8		0.72		-0.66	-0.53	0.42	-0.36						
Pre-plant soil Ca	9				0.98	0.91	-0.46	0.69	-0.65					
Pre-plant soil Mg	10				0.35	0.63	0.38	0.79		0.44				
Fresh Harvest Wt.	11				-0.73	-0.44	0.60		0.70	-0.63				
Dry Harvest Wt.	12				-0.44				0.49	-0.41				
% Dry Matter	13				0.59	0.44	-0.40			0.53				
Total Plant K	14				-0.64		0.77		0.68	-0.54				
Total Plant Ca	15				0.51	0.83	0.36	0.96		0.61	0.83			
Total Plant Mg	16					0.46		0.62	-0.39		0.72			
Pre-Harvest soil K/Ca+Mg	17				-0.83	-0.90		-0.77	0.78	-0.88	-0.49			
Post-Harvest soil K/Ca+Mg	18				-0.92	-0.93		-0.74	0.74	-0.96	-0.44			
% K/Ca+Mg Plant Tissue	19				-0.84	-0.88		0.71	0.71	-0.87	-0.67			

R >= .49 Significant at p=0.05
R >= .62 Significant at p=0.01
R >= .74 Significant at p=0.001

Table 66. Correlation Matrix Showing R Values for Experiment II Variables

K Source: KCl

Variable	No.	1	2	3	4	5	6	7	8	9	10	11	12	13
K Source	1													
K Rate	2													
Soil %	3													
%$CaCO_3$ Eq.	4													
pH	5				0.84									
EC	6				-0.58									
CEC	7				0.59	0.91								
Pre-plant soil K	8		0.74		-0.55	-0.42	0.36							
Pre-plant soil Ca	9				0.98	0.90	-0.48	0.67	-0.51					
Pre-plant soil Mg	10				0.64	0.52		0.47		0.64				
Plant Tissue K/Ca	11		0.35		-0.76	-0.92		-0.87	0.67	-0.79	-0.42			
Plant Tissue K/Mg	12		0.61		-0.70	-0.55	0.44	-0.39	0.88	-0.65	-0.42			

R >= .34 Significant at p=0.05
R >= .44 Significant at p=0.01
R >= .55 Significant at p=0.001

Table 67. Correlation Matrix Showing R Values for Experiment II Variables

K Source: K_2SO_4

Variable	No.	1	2	3	4	5	6	7	8	9	10	11	12	13
K Source	1													
K Rate	2													
Soil #	3													
%$CaCO_3$ Eq.	4													
pH	5				0.84									
EC	6				-0.58									
CEC	7				0.59	0.91								
Pre-plant soil K	8		0.72		-0.66	-0.53	-0.36							
Pre-plant soil Ca	9				0.98	0.91	-0.46	-0.65						
Pre-plant soil Mg	10				0.35	0.63	0.38		0.44					
Plant Tissue K/Ca	11				-0.83	-0.92								
Plant Tissue K/Mg	12													

R >= .49 Significant at p=0.05
R >= .62 Significant at p=0.01
R >= .74 Significant at p=0.001

APPENDIX C - ANALTYICAL PROCEDURES

Table 68. Selected Chemical and Physical Analysis Results

	- Soil Series -				
Analysis	Bozeman	Zahill	Vida	Hillon	Scobey
Texture	SiCl	SiCl	SiCl	SiCl	SiCl
pH	5.7	8.2	7.7	8.1	6.5
E.C.	0.090	0.084	0.155	0.078	0.095
% O.M.	4.48	2.19	2.95	2.11	2.27
CEC(meq/100g)	22.6	20.6	20.5	12.2	18.1
P (ppm)	16.3	10.9	23.2	16.3	18.6
K (ppm)	0.90	1.49	3.25	1.98	2.99
Ca (ppm)	11.22	23.01	14.66	21.58	5.92
Mg (ppm)	7.02	1.85	1.77	1.54	1.53
%$CaCO_3$ Eq.	1.10	5.60	1.88	4.78	1.06

TOTAL POTASSIUM, CALCIUM, MAGNESIUM, AND SODIUM IN PLANTS

REFERENCE: Atomic Absorption determination of ashed material. Dry Ash - H.D. Chapman and P.F. Pratt, Methods of Analysis of Soils, Plants, and Waters, University of California, 1961.

EQUIPMENT: 303 Perkin-Elmer Atomic Absorption Spectrophotometer, Test tubes, and Dilutrol 11 Automatic dilutor.

REAGENTS:

1. Strontium Solution - 1% - Dissolve 60.4 g of $SrCl_2 \cdot 6H_2O$ in d.d. water, in a 2 liter V.F. and bring to volume c d.d. water.

2. Strontium Solution - 10% - Dissolve 30.2 g of $SrCl_2$ in d.d. water, in a 100 ml V.F. and bring to volume c d.d. water.

3. Stock Solutions:

   a. Calcium-1000 ppm: Weigh 2.4972 g of pure dry (1 hour in oven at 105°C) $CaCO_3$ into a liter V.F.. Add sufficient 1 N HCl to dissolve, then bring to volume with d.d. water.

   b. Magnesium-1000 ppm: Weigh 1.0000 g of purified magnesium metal turnings (dried at 105°C) into a liter V.F., add sufficient 1 N HCl to dissolve, then bring to volume with d.d. water.

   c. Potassium-1000 ppm: Weigh 1.9066 g of pure dry (1 hour in oven at 105°C) KCl into a liter V.F., add d.d. water to dissolve, then bring to volume with d.d. water.

   d. Sodium-1000 ppm: Weigh 2.542 g of pure dry (1 hour in oven at 105°C) NaCl into a liter V.F., add d.d. water to dissolve, then bring to volume with d.d. water.

4. Standard Element Solutions:

   a. 100 ppm Calcium: Pipet 10 ml of 1000 ppm Ca solution into a V.F., then bring to volume with d.d. water.

   b. 100 ppm Magnesium: Pipet 10 ml of 1000 ppm Mg stock solution into a 100 ml V.F., then bring to volume with d.d. water.

   c. 150 ppm Potassium: Pipet 15 ml of 1000 ppm K stock solution into a 100 ml V.F., then bring to volume with d.d. water.

d. 100 ppm Sodium: Pipet 10 ml of 1000 ppm Na stock solution into a 100 ml V.F., then bring to volume with d.d. water.

CURVE PREPARATION: Using pipets and 6-100 ml V.F. numbered 1 through 6, pipet 2 mls of each standard element solution (100 ppm for Ca, Mg, Na, and 150 ppm for K) into flask #2. Pipet 4 mls of each standard element solution into flask #3. Pipet 6 mls of each standard element solution into flask #4. Pipet 8 mls of each standard element solution into flask #5. Pipet 10 mls of each standard element solution into flask #6. Add 5 mls of 10% Sr to each flask and bring to volume with d.d. water. These volumetrics then contain 0, 2, 4, 6, 8, & 10 ppm of the elements Ca, Mg, Na, and 0, 3, 6, 9, 12 & 15 ppm of K. Use these to set the Atomic Absorption Spectrophotometer.

PROCEDURE FOR ANALYZING PLANT SAMPLES:

1. Transfer 5 ml of the original plant solution into a filter tube.

2. Add 5 mls of 1.0% $SrCl_2.6H_2O$ and mix.

3. Analyze on 303 A.A.S., if a dilution is necessary for an on scale absorbance value dilute with 0.5% $SrCl_2.6H_2O$ using the Monostat Dilutrol.

CALCULATIONS: The % Ca, Mg, Na, and K in the samples equals;

$$\frac{(\text{ppm in solution}) \cdot 100\text{ml} - 10 \text{ mls} - \text{additional dilution factor} - 10^{6} - (\text{ppm}) - 102(\%)}{\text{Sample Wt.} \quad 5}$$

OR

(ppm in solution)-.02-additional dilution = % in plants

DRY ASH TECHNIQUE FOR PLANT TISSUE

REFERENCE: Atomic Absorption determination of ashed material. Dry Ash - H.D. Chapman and P.F. Pratt, Methods of Analysis of Soils, Plants, and Waters, University of California, 1961.

EQUIPMENT: 303 Perkin-Elmer Atomic Absorption Spectrophotometer, Test tubes, and Dilutrol 11 Automatic dilutor.

Initial Sample Preparation:

1. Plant samples taken from specific parts of plant should be rinsed with distilled H_2O to remove dust particles.
2. Place the samples in brown paper bags and put them into the forced-draft oven to dry at 70°C for 24 hours.
3. After drying, grind the samples in a wiley mill to pass a 20-mesh screen.
4. Store the ground sample in a plastic vial.

To put the sample into solutions:

1. Using a 3 or 4 place mettler balance, weigh 2 g of plant tissue into a Coors #1 crucible.
2. Ash the samples in a muffle furnace at 500 to 550°C for 2 hours.
3. To each sample, add 1.5 ml of conc HCl and 2.5 ml of distilled-deionized H_2O, then evaporate to near dryness on the hot plate. Samples must not spatter (when adding HCl).
4. Add 1 ml of 2.5 N HCl and 5 ml of distilled-deionized H_2O.*
5. Quantitatively transfer each solution to 100 ml V.F's, then bring to volume with distilled-dionized H_2O and mix thoroughly. Samples are now ready for analysis of Fe, Zn, Mn, and Cu.

* Prepare 2.5 N HCl by placing 500 ml of distilled-deionized water into a liter V.F. Add 204 ml of conc HCl and dilute to volume with distilled-deionized H_2O.

AVAILABLE CALCIUM, MAGNESIUM, POTASSIUM, AND SODIUM IN SOILS

REFERENCE: "Atomic Absorption determination of extract", Bower, C.A., Reitemeier, R.F., and Fireman, M., 1952. "Exchangeable Cation Analysis of Saline and Alkali Soils", Soil Science 73:251-261, illus.

EQUIPMENT: Sample shaking racks, shaker set at 180 o.p.m., sample filtering racks, filter paper, balance, and Spectrophotometer (303 Perkin-Elmer AAS).

REAGENTS:

1. 1 N Ammonium Acetate (NH_4OAc) Extracting Solution (pH 7) - Weigh 1541.6 g of Ammonium Acetate into a 20 liter bottle and bring to volume with d.d. water.

2. Strontium Solution - 0.5% - Dissolve 30.2 g of $SrCl_2 \cdot 6H_2O$ in NH_4OAc in a 2 liter V.F. and bring to volume 1 N NH_4OAc.

3. Strontium Solution - 1.0% - Dissolve 60.4 g of $SrCl_2 \cdot 6H_2O$ in NH_4OAc in a 2 liter V.F. and bring to volume 1 N NH_4OAc.

4. Strontium Solution - 10% - Dissolve 30.2 g of $SrCl_2$ . . in 1 N NH_4OAc in a 100 ml V.F. and bring to volume 1 N NH_4OAc.

5. Stock Solutions:
   a. Calcium-1000 ppm Weigh 2.4972 g of pure dry (1 hour in oven at 105° C) $CaCO_3$ into a liter V.F.. Add sufficient 1 N HCl to dissolve, then bring to volume with d.d. water.

   b. Magnesium-1000 ppm: Weigh 1.0000 g of purified magnesium metal turnings (dried at 105° C) into a liter V.F., add sufficient 1 N HCl to dissolve, then bring to volume with d.d. water.

   c. Potassium-1000 ppm: Weigh 1.9066 g of pure dry (1 hour in oven at 105° C) KCl into a liter V.F., add d.d. water to dissolve, then bring to volume with d.d. water.

   d. Sodium-1000 ppm: Weigh 2.542 g of pure dry (1 hour in oven at 105° C) NaCl into a liter V.F., add d.d. water to dissolve, then bring to volume with d.d. water.

6. Standard Element Solutions:

   a. 100 ppm Calcium: Pipet 10 ml of 1000 ppm Ca solution into a 100 ml V.F., then bring to volume with 1 N NH_4OAc extracting solution.

b. 100 ppm Magnesium: Pipet 10 ml of 1000 ppm Mg stock solution into a 100 ml V.F., then bring to volume with 1 N NH_4OAc extracting solution.

c. 150 ppm Potassium: Pipet 15 ml of 1000 ppm K stock into a 100 ml V.F., then bring to volume with 1 N NH_4OAc extracting solution.

d. 100 ppm Sodium: Pipet 10 ml of 1000 ppm Na stock solution into a 100 ml V.F., then bring to volume with 1 N NH_4OAc extracting solution.

CURVE PREPARATION:

Using pipets, 6-100 ml V.F. flasks, and the standard solutions of each element, number Volumetrics 1-6. Pipet 2 mls of each standard element solution (100 ppm for Ca, Mg, Na, and 150 ppm for K) into flask #2. Pipet 4 mls of each standard element solution into flask #3. Pipet 6 mls of each standard element solution into flask #4. Pipet 8 mls of each standard element solution into flask #5. Pipet 10 mls of each standard element solution into flask #6. Add 5 mls of 10% Sr to each flask and bring to volume with 1 N NH_4OAc. These volumetrics then contain 0, 2, 4, 6, & 10 ppm of the elements Ca, Mg, Na, and 0.3, 6, 9, 12 & 15 ppm of K. Use these to set the Atomic Absorption Spectrophotometer.

PROCEDURE FOR ANALYZING SOILS SAMPLES:

1. Weigh 2.5 g of soil into each beaker in the shaker racks.
2. Add 50 ml of 1 N NH_4OAc to each sample.
3. Shake the soil on the mechanical shaker for 30 minutes at 180 O.p.m.
4. Filter the extract into filter tubes calibrated for 5 mls (using Whatman #40 filter papers).
5. Aspirate the filtrate down to the 5 ml mark.
6. Add 5 ml of 1.0% strontium solution.
7. Analyze the filtrates for Ca, Mg, K, and Na directly on the model 303 Perkins-Elmer Atomic Absorption Spectrophotometer, setting the machine with the curves prepared.

CALCULATIONS:

$$(\text{ppm in solution}) \times \frac{50}{2.5} \times \frac{10}{5} = \text{ppm in soil}$$

(ppm in soil) - (Equivalent weight x 10) = meq/100 grams

Convert slipchart reading to ppm or meq/100 grams directly from the chart.

$$\text{Na } \frac{\text{meq}}{100\text{g}} = \frac{(2.5 \times \frac{50}{5}) \text{ (from curve)} \times \text{(dilution factor)}}{230}$$

$$\text{Ca } \frac{\text{meq}}{100\text{g}} = \frac{(2.5 \times \frac{50}{5}) \text{ (ppm soln)} \text{ (dilution factor)}}{200}$$

$$\text{Mg } \frac{\text{meq}}{100\text{g}} = \frac{(2.5 \times \frac{50}{5}) \text{ (ppm soln)} \text{ (dilution factor)}}{121.6}$$

$$\text{K ppm in soil} = (2.5 \times \frac{50}{5}) \text{ (ppm soln)} \text{ (dilution factor)}$$

MECHANICAL ANALYSIS - BOUYOUCOS METHOD

REFERENCE: Bouyoucos, C.J., "Directions for making Mechanical Analyses of Soils by the Hydrometer Method", Soil Science, Vol. 42, No. 3, September 1936.

1. Weigh 50 grams of a fine textured (100 gms of coarse textured) soil and place in a special baffled cup. Fill the cup 1/2 full with distilled water and add 10 ml of 1 N sodium hexametaphosphate.

   To disperse the soil and to avoid subsequent flocculation, a dispersing agent is used. Sodium from $(NaPO_3)_6$ (100 g of sodium hexametaphosphate add water to 1 liter mark) replaces exchangeable calcium. Precipitation of the calcium as the phosphate prevents its reabsorption and flocculating action. The net negative charge on clay particles increases due to absorption of sodium and causes the particles to repel each other and disperse.

2. Place cup on stirrer and stir until soil aggregates are broken down. (10 minutes).

   Most soils in their natural condition tend to be aggregated. These aggregates are broken down by chemical (sodium hexametaphosphate) and physical (stirrer) dispersion techniques to enable the sand, silt and clay particles to be separated and free in the suspension.

3. Transfer to a special cylinder and fill to the 1100 ml mark if using 25 gms. 1130 ml mark if using 50 grams, or 1205 if using 100 grms. of soil with distilled water while the hydrometer is in suspension.

4. With hydrometer removed stopper the cylinder and invert several times to suspend all the sand evenly throughout the solution. Using time 0 seconds as the moment you stop shaking the solution. Do the following in order.

   0 seconds - note time that you topped inverting the solution.
   20 seconds - carefully insert the hydrometer.
   35 seconds - familiarize yourself with hydrometer scale markings.
   40 seconds - read hydrometer and record.

5. Remove the hydrometer from the suspension. Record the Temperature reading on the data sheet.

6. Take a reading at the end of two hours and record. Insert hydrometer just before the two-hour reading is made. Take temp after reading is taken.

7. Calculate the percent sand in the sample.

For each degree above 67°F, add 0.2 to the reading to get the corrected hydrometer reading. For each degree less than 67°, subtract 0.2 from the reading.

The hydrometer is calibrated so that the corrected reading gives the grams of soil material in suspension. The sand settles to the bottom of the cylinder within 40 seconds, therefore, the 40 second hydrometer reading actually gives the amount of silt and clay in suspension. The weight of sand in the sample is obtained by subtracting the corrected hydrometer reading from the total weight of the sample. The percentage sand is calculated by dividing the weight of the sand by the weight of the sample and multiplying by 100.

8. Calculate the percent clay in the sample.

At the end of two hours, the silt in addition to the sand has settled out of suspension. The corrected hydrometer reading divided by grams of sample multiplied by 100 hours represents the grams of clay in the sample.

9. Calculate the percent of silt in the sample.

Find the percent silt by difference. Subtract the sum of the percentage of sand and clay from 100 to get the percent silt.

10. Or avoid all of this and use the Mechanical Analysis card for the Hp-97.

11. Determine the class name or texture of the soil from the textural triangle in figure 1.

Manual Calculation

$$\% \text{ Sand} = \frac{50-(1\text{st corrected reading}) \times 100}{\text{grams of sample}}$$

$$\% \text{ Clay} = \frac{2\text{nd corrected reading} \times 100}{\text{grams of sample}}$$

$$\% \text{ Silt} = 100\%-(\% \text{ sand} + \% \text{ Clay})$$

AKALINE-EARTH CARBONATES BY GRAVIMETRIC LOSS OF CARBON DIOXIDE

Reference: Carbonate, by Allison, L.E. and C.D. Moodie. 1965. In Methods of Soil Analysis - Part 2. Chemical and Microbiological Properties.1965. ASA monograph no. 9. Black, C.A. and R.C. Dinauer (eds.) American Society of Agronomy, Inc. Madison, WI.

Reagent

A. Hydrochloric acid, 3 N

Procedure

Pipet 10 ml. of reagent A into a 50-ml. Erlenmeyer flask, stopper with a cork, and weigh. Transfer a 1-10-gm. sample of soil containing 0.1 to 0.3 gm. of calcium carbonate to the flask, a little at a time, so as to prevent excessive frothing. After effervescence as largely subsided, replace the stopper LOOSELY and swirl the flask. Let stand with occasional swirling until the weight of the flask and contents does not change more than 2 or 3 mg. during a 30-min. period. The reaction is usually complete within 2 hours. Prior to weighing, displace any accumulated carbon dioxide gas in the flask with air. This is important and may be done by swirling with the stopper removed for 10 to 20 sec.

Calculations

Weight of CO_2 lost=(initial wt. of flask+acid+soil) - (final wt. of flask+acid+soil).

$CaCO_3$ equivalent in percent=(wt. of CO_2 lost X 227.4)/wt. of soil sample.

Remarks

The accuracy of this method depends to a large extent upon the sensitivity of the balance used for weighing. Using a torsion-type balance capable of detecting weight differences of 2 to 3 mg., the relative error is about $\pm$ 10 percent.

SOIL pH AND CONDUCTIVITY

Reference: U.S.D.A. Handbook No. 60 .. "Diagnosis and Improvement of Saline and Alkali Soils" - pg. 88.

Equipment: Beakers, Orbital shaker, pH meter, Conductivity bridge with matching conductivity cell, a balance, and an auto-pipet for dispensing water.

Reagents: Distilled water, 0.01 N KCl (0.7456 g KCl/L) pH 4, pH 10 and pH 7 buffer solution.

Procedure for 2:1 pH and conductivity:

1. Weigh 20 g soil into beaker and add 40 ml distilled water.
2. Shake for 3 minutes to suspend soil and allow 30 minutes to settle. After 20 minutes:
   a) Turn on conductivity bridge to warm up while setting pH meter.
   b) Place the electrode into a pH 7 buffer. Allow stabilization of reading then adjust to pH 7 with calibration knob. Remove pH 7 buffer and thoroughly rinse electrodes with distilled water.
   c) Place electrode into a pH 10 buffer, allow stabilization of reading, then adjust to pH 10 with temperature knob. After temperature knob is adjusted to display pH 10, set % slope know to room temperature. Calibration is adequate if % slope is greater than 95%. Rinse electrode with distilled water. Check pH 7 buffer, if it reads correctly the pH meter is ready.
   d) Rinse the conductivity cell with 0.01 N KCl solution, then take up enough of this solution to just cover the electrodes. Conductivity should read 1.41 mmhos/cm.
3. You are now ready to read the Soil Samples.
4. Place the pH electrode into the sediment of the sample.
5. While waiting for the pH meter to equilibrate, read the soil conductivity.
6. Record values.
7. Convert conductivity bridge readings to mmhos in a saturated paste by use of the following equation: $Y = 3X + 0.7$, where Y is the conductivity of the saturated paste and X is the meter reading.

Below a conductivity of 0.7, Y = 4X. You may prepare a conversion chart of the above to simplify matters.

Comments:

1. If you are running a S.A.R. take the pH of the saturated paste before you extract water from it. Run the conductivity on the extracted water.

ORGANIC MATTER

Sims, James R., and Haby, Vincent A. 1970 Simplified Colormetric Determination of Soil Organic Matter, V. 112, No. 2, pp 137-141, Soil Science.

A. EQUIPMENT: Oxidation racks containing 180 ml Electrolytic beakers, filter tube racks, Whatman #1 filter paper, balance, and colorimeter, with 1.3 cm light path.

B. REAGENTS:

1. 1 N Potassium Dichromate ($K_2Cr_2O_7$) - Weigh 98.08 g of potassium dichromate into a 2 liter volumetric flask, dissolve in about 1000 ml of distilled water and bring to volume.

2. Concentrated Sulfuric Acid (H_2SO_4).

C. PROCEDURE:

1. Weigh 1g of soil into each oxidation flask.
2. Add 10 ml of 1 N potassium dichromate and swirl.
3. Add 10 ml of conc. sulfuric acid, swirl, and allow to react 20 min.
4. Add water to bring the volume to 100 ml, using automatic dispenser, and allow to cool 20 min.
5. Filter into filtration tubes through Whatman #1 paper.
6. Analyze on the "Spectronic 20" colorimeter, with a flow-thru curvette, at 600 mu.

D. COMMENTS:

1. *Sims and Haby original paper procedure was modified, by them, to use 10 ml of sulfuric acid, because the filter paper was oxidized by 20 ml or 7.2 N H_2SO_4.

   $r = -.9755 \qquad y = 8.016 - .0948X$

2. If the % OM in the sample is >7.0, use 1/2 g of soil; if less than 1.5%, use 2 g of soil. The correlation follows Beer's law between 1.5 and 7.0% OM.

3. Check organic matter curve using "knowns", (Walkley and Black Titration standards.)

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