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Title: THE EFFECTS OF LIME AND POTASSIUM ON MINERAL UPTAKE IN FILBERTS (CORYLUS AVELLANA L. CV BARCELONA) GROWN IN POT CULTURE

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The effects of soil incorporated lime and K on the concentrations of N, P, K, Ca, Mg, Mn, Fe, Cu, B and Zn in the leaves of filbert trees (*Corylus avellana* L. cv Barcelona) were investigated. One year old filbert trees of uniform size were grown in Laurelwood clay loam (L) and Jory silt clay loam (J) in five-gallon plastic pots. The L soil was high in exchangeable K, while soil J was low in exchangeable K as determined by soil tests. Lime treatments were made to bring the initial pH of each soil up to pH 6.6 and 7.1 respectively. Potassium treatments were calculated to bring the soil test levels to intermediate and high levels.

Lime significantly increased the leaf concentration of K, Ca, Mg, Fe, Cu, and Zn and decreased that of P, Mn, and B.

Potassium treatments resulted in a significant increase in the leaf concentration of K, Mn, and a decrease in P, Mg,

and Cu, but had no effect on the concentration of Fe, B, Zn and N.

There were highly significant linear relationships between applied lime and leaf Ca and between applied K and leaf K.

Trees grown in soil L were unable to take up as much K as those grown in soil J. This indicated that the soil analysis method used to measure exchangeable K was not an appropriate one to use to predict the available K for filbert trees. Further experimentation is required to develop a test which can be used to predict the K requirement for filbert trees grown in different soils.

The Effects of Lime and Potassium on Mineral Uptake in Filberts (*Corylus avellana* L. cv Barcelona) Grown in Pot Culture

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INTRODUCTION

Oregon is the major center of filbert production in the United States. In Oregon, filbert orchards' maximum production is limited by the incidence of potassium deficiency. It is estimated from a review of commercial leaf analysis reports that potassium deficiency affects 20-25 percent of the Oregon filbert acreage to varying degrees. Responses to the application of potassium fertilizers have varied from slight or none to great, as diagnosed by leaf analysis.

Liming is a widespread agricultural practice for adjusting pH in acid soils. It has been reported that liming may decrease, increase or have no effect on K uptake by different crops. However, there is no published information as to the effects of liming on the availability of potassium and other elements for filbert trees.

This investigation was conducted to study the effects of lime and potassium, separately and in combination, on the uptake of Ca, K, Mg, P, Fe, Mn, Zn, Cu, and B as measured by leaf concentration. The effects of lime and potassium on shoot growth were also investigated.

This thesis consists of a literature review which is divided into sections on lime-plant relationships, potassium-plant relationships, calcium, potassium and magnesium interrelationships, materials and methods and a paper. The paper is written in the form of a journal article to be submitted to the Journal of the American Society for Horticultural Science, in which most of the experimental data are presented. Additional data that are not covered in the paper are included in the appendix.

LITERATURE REVIEW

Lime-Plant Relationships

Liming is an old practice in acidic soil regions. It alters the prevailing soil conditions to one more suitable for plant growth, resulting in an increase in crop yields (6, 13, 22, 28, 39, 54, 70, 86). Liming is often thought to be a practice for supplying Ca to plants. However, Al and Mn toxicity problems are generally present before Ca becomes limiting as a plant nutrient (13, 41, 48, 62, 67, 77, 78, 81).

On certain soils, calcium deficiency has been found under field conditions. Spencer and Koo (72) noted Ca deficiency symptoms in Florida grapefruit trees grown in Lakeland fine sand. This soil was reported to have one percent organic matter and a cation exchange capacity of 2.4 meq/100 g. Calcium deficiency has also been found in tobacco, corn and peanuts (41, 78).

Christenson _et al._,(17) conducted experiments to study the effects of Ca and soil pH on the yield of oats grown in Michigan soils. They found a close correlation between yields and soil pH regardless of the Ca level. Adams and Wear (3) grew cotton plants in a soil of pH 4.5. They treated the soil with $CaCO_3$ and $CaCl_2$ and found that normal plants developed only in the soil receiving $CaCO_3$. Similar results were obtained by other investigators working with different crops (13, 36, 51, 67). Thus, one can conclude that liming affects plant growth not only by supplying Ca, but also through changing the pH of the soil.

In acid soils, Al and Mn become readily available and in many cases become toxic to plants. In corn (8, 38, 61), barley (18, 29, 41, 81), millet (6), sorghum (63), potatoes (41, 82), lettuce (29), soybeans (18), alfalfa (9, 28, 67), and bush beans (40, 81), retarded growth was attributed to the toxic actions of Al and Mn. Amarasiri and Olsen (6) noted a reduction in millet root growth as a result of Al toxicity. Similar observations are reported for other crops (13, 18, 28, 41, 62, 63, 67). The exact actions of Al and Mn in plants are not fully understood.

When lime is applied to the soil, soil pH increases and the solubilities of Al and Mn decrease (5, 18, 40, 48, 67, 81). This involves the replacement of exchangeable Al by Ca with the formation of $Al(OH)_3$ and CO_2 (18, 77, 78). Liming acid soils to pH 6.5 has been reported to reduce Al availability to plants (13, 22, 41, 78). It decrease Al uptake in sorghum (63), alfalfa (28) and many other crops (3, 22, 29, 41). Similarly, liming has been reported to decrease Mn availability and reduce its uptake by plants. White (81) noted that the water-extractable Mn levels in the soil were extremely high in unlimed plots as compared to limed plots. Schmehl et al., (67) demonstrated that the increase in growth of alfalfa by liming was related to a reduction in Mn and Al uptake and not because Ca was supplied. They found that plants growing in a medium containing 400 lbs Ca/A and free of readily soluble Al and Mn yielded equally as well as those grown in a medium containing 4,000 lbs Ca/A. White et al., (82) reported that by increasing soil pH to 6.5, Mn content in potato vines decreased markedly and Mn toxicity symptoms disappeared. Working with beans, Jackson et al., (40) observed the same effect of liming on reducing Mn uptake. This was accompanied by an increase in yield.

The availability of phosphorous, a major nutrient element, is also controlled by soil reaction. Between pH values of 3.0 and 5.0, Fe and Al compounds are most responsible for P fixation; between pH values of 5.0 and 6.5, surface adsorption by clay particles has the greatest influence; and from pH 7.0 to 10.0, P fixation is attributed mostly to Ca precipitation (55). Struthers and Sieling (76) reported that active Fe and Al are the principal agents responsible for chemical fixation of P in acid soils. They added that basic Fe and Al phosphates are precipitated whenever soluble P comes into contact with these agents. Amarasiri and Olsen (6) found that liming decreased both soluble and labile P to a minimum at a pH between 6 and 7. They also noted that P was inactivated to a greater extent by freshly precipitated Fe and Al hydroxides formed by adding lime. Adams and Pearson (1) reported that the formation of insoluble Ca phosphates at high pH are reversible. Phosphorous from the insoluble Al and Fe phosphates formed at low pH, however, are still unavailable as pH increases. This effect of soil pH on P availability can be used to explain why P uptake by alfalfa was reduced as soils were limed to pH > 7, while P uptake was increased by liming from pH 4 to 6, as reported by several investigators (9, 28, 39, 48).

Soil pH also affects the availability of other nutrient elements to the plants. As pH increases, the availability of B, Zn and Fe decreases (1, 4, 9, 13, 33, 35, 78). However, as soil pH decreases, the availability of N, Mg, S and Mo decreases (13, 16, 41, 78). In addition, microorganism activities, which are important in the breakdown of organic matters and in biological N fixation, are closely related to soil pH. The optimum soil pH range for microorganisms activity has been reported to be between 6 and 8 (13, 22, 41, 78).

Potassium-Plant Relationships

Potassium is an essential macro-element for plant growth, development and reproduction. It is usually present in plants in quantities larger than any of the other essential nutrients with the exception of carbon, hydrogen, oxygen and nitrogen (15, 77). One of the reasons for the large requirement of this element is thought to be the maintenance of electrical neutrality in the plant. Potassium may balance out the negative charges of anions such as phosphate and nitrate (56, 77).

Potassium is known to be associated with plant metabolism. Cummings (21) measured K content of different parts of the peach tree and found a close relationship between K content and the metabolic activity of the plant parts. Other investigators reported similar findings in several crops (42, 46, 77, 78). Potassium was postulated to activate one of the first reactions in photosynthesis, in which part of the light energy is captured in a reaction between adenosine diphosphate and an inorganic phosphate to form adenosine triphosphate (13). Culturing Ankistrodesmus in K-free media depressed photosynthesis. Upon the addition of K to the medium, the photosynthetic rate returned to nearly normal within one-half hour.

Potassium is an important element in the biosynthesis of carbohydrates such as sugars and starches (13, 42, 46, 77, 78). The fact that root crops have a higher requirement for K and that the shortage of this element would affect tuber and root enlargement more than leaf development supports this view (25).

Potassium plays an important role in protein synthesis. In sugar cane, Tisdal and Nelson (78) reported that plants deficient in K accumulated non-protein nitrogen in their leaves. They also reported that K-deficient barley plants accumulated free amino acids in their leaves. As the deficiency becomes more severe, these amino acids decrease with an increase in the concentration of amides. Application of K to these plants resulted in the opposite effects. Other investigators noted the importance of K in the coupling of certain amino acids to form peptides, suggesting that K is essential in protein synthesis (80).

There are contradicting reports in the literature on the effects of K on plant growth and crop yield in different crops. In filberts, K did not affect shoot growth (59). Yield was unaffected by potassium in prunes (44) and peaches (75). In apple (8), tomato (12), corn (73) and pecans (30), however, K was reported to have increased the crop yields. Potassium has been reported to increase the growth of many crops (23, 24, 31, 47). Stanford et al., (73) related the poor growth of corn on high-lime Iowa soils as being due to the failure of plants to take up adequate amounts of K from the soil. On the other hand, K was reported to reduce growth in sweet orange seedlings (50). This may well represent the differences among plants in their requirements for K and their reaction to different K levels in the soil.

Response from potassium is frequently associated with improved quality of many crops. In apple, K treatments resulted in production of larger fruits with higher total acidity (8, 27). In papaya K increased fruit weight and soluble solids (7). In prunes K applications resulted in a higher titrable acid content in fruits (44). In filbert and pecan, K was found to increase the percentage of large size nuts. The weight of nuts and shells was increased, while the percentage of blank nuts was reduced (30, 50). Stembridge _et al._, (75) conducted an experiment to study the effect of K on peach. They reported that the skin and flesh color of fresh fruits was associated with foliar concentration of K. As the concentration of K increased, a more desirable fruit color developed. Reeves and Cummings (65) reported that K application increased firmness, color and keeping quality in peach fruits. Lilleland _et al._, (47) found that fruits developed on K-deficient peach trees failed to make adequate growth in the latter part of their growth cycle. They also observed an increase in the bearing area in peach trees as a result of K treatments. Cummings and Wilcox (20) extensively reviewed the effects of K on fruit and vegetable quality. They showed that K played an important role in controlling fruit color, fruit size, fruit acidity, crop maturation, fruit juiciness and plant resistance to many diseases. Again, it should be kept in mind that not only do plants differ in their K requirements and uptake, but they also vary in their ability to accumulate K in their tissue for luxury consumption (10, 13, 43, 77, 78).

Calcium, Potassium and Magnesium Interrelationships

Calcium, potassium and magnesium ions are known to affect each other in terms of their availability and uptake by plants. Christenson *et al*., (17) reported that extractable soil Mg level increased with an application of 550 ppm Ca, but decreased sharply when high Ca rates were used. Hossnr and Doll (37) noted a decrease in soil Ca and Mg as a result of K treatments. York (85) observed that large amounts of K were fixed in nonexchangeable forms upon the addition of $CaCO_3$ to acid Mardin silt loam. Other workers have written extensively on this phenomena (2, 8, 10, 11, 14, 22, 38, 52, 53, 58, 61, 78).

The uptake of Ca, K and Mg by plants varies greatly from species to species and according to the ratios of these cations in the soil. Liming decreased K uptake in wheat and oat (11), while increasing its uptake in alfalfa (10, 22) barley and sorghum (11, 18). With liming, Mg uptake was found to decrease in alfalfa (28, 53), oat (17), millet (6) and increase in potatoes (37). It did not affect Mg uptake in peach (36) and citrus (51).

Potassium was reported to reduce Ca uptake in corn (73), alfalfa (53, 86), Sudangrass (86), bromegrass (45) and papaya (7). Different responses to K application are found in various apple varieties (8, 27).

Potassium applications reduced Mg uptake in corn (73), alfalfa (53, 86), Sudangrass (86), bromegrass (45), cranberry (23), papaya (7), citrus (34, 50, 52), apple (8, 14, 27), peach (19, 21, 75) and filbert (59, 60). Magnesium depressed K uptake in barley (26) and peach (19), and the uptake of Ca in peach (19).

Woodruff (84) reported that the ratio of molar concentrations of a monovalent cation, to the square root of the molar concentration of a divalent cation is the important criterion by which soil solutions should be judged. Bear and Toth (10) asserted that as soon as the Ca:K ratio in alfalfa reached 4:1, yields were reduced. Potassium deficiency symptoms, however, did not appear until the Ca:K ratio reached 8:1. Working with pot cultures, Hunter _et al._, (38) observed that increasing the Ca:K ratio from 1:1 to 32:1 resulted in a leaf K reduction from 3.30 to 1.12, while increasing leaf Ca from 0.77 to 1.92 percent. Adams and Henderson (2) noted that plants had higher Mg content at deficient K levels than at adequate K levels. They added that the effect of K on Mg content was generally greater on Mg sufficient soils than in Mg deficient soils. Cummings (19) also reported that K was more competitive with Mg than Mg with K. This can be explained by the hypothesis that a selective uptake mechanism in the roots favors the uptake of K much more than Mg, and that both K and Mg are taken up by a single carrier (57). Elgabaly

(26) noted that maximum shoot growth in many plants occurred at a Ca:Mg ratio of 7:3.

While plants differ in their requirements and abilities to take up different cations as shown above, the best growing medium must contain these cations in adequate amounts and in a reasonable ratio (26, 64).

MATERIALS AND METHODS

Two soils, selected on the basis of their exchangeable K content as determined by soil tests at the Oregon State University Soil Analysis Laboratory (66), were used in the experiments. Laurelwood soil (L) which was high in exchangeable K and Jory silt clay loam soil (J) which was low in exchangeable K.

Seventy-two one year old filbert trees of uniform size were planted individually in five gallon plastic pots in each soil and set outdoors in holes with gravel drains. For each soil, treatments were replicated into eight blocks, each consisting of nine treatments. Treatments within a block were randomized. Trees were planted in soil L in May, 1972 and in soil J in July, 1972. Because of the late planting date, dormancy was delayed in the trees grown in soil J and they were killed by an early December, 1972 freeze. Trees were replanted in soil J during January, 1973 which resulted in an age difference between the trees in soil L and those in soil J.

Treatments consisted of 0, 3200 and 6400 ppm of finely ground agricultural limestome ($CaCO_3$) per pot in combination with 0, 150 and 300 ppm K as K_2SO_4. The lime levels used were determined from the SMP soil buffer test (69) for lime requirement to bring the pH of the soils from their initial pH of 5.9 to 6.6 and 7.1 respectively. Potassium levels were chosen to represent control, intermediate and high treatments calculated to bring the soil test levels to optimum and high.

Lime was thoroughly mixed with L and J soils prior to planting in May and July, 1972. Potassium treatments were applied to both soils by syringe in January, 1973.

After planting, the trees were irrigated every other day from June to September. Two hundred and twenty ppm of urea per pot was applied twice to satisfy tree requirements for N.

Leaf samples from the middle of the current season's terminal shoots were collected on August 18, 1973. They were washed, dried at 80°C for 48 hours and ground in a Wiley mill to pass a 40-mesh screen. Total nitrogen was determined with a Technicon Auto Analyzer using the Kjeldahl procedure (79). The elements P, K, Ca, Mg, Fe, Mn, Zn, Cu, Al, and B were analyzed with a Jarrell-Ash 3/4 meter direct reading emission spectrometer (15).

Total shoot growth was measured on individual trees at the end of the growing season. Summer suckers were excluded.

The data were subjected to analysis of variance for a 3 x 3 factorial experimental design, and by regression analysis to obtain the relationships of applied lime and K to Ca and K concentration in the leaves (74).

Soil samples were taken from the pots at the end of the experiment and analyzed for pH, K, Ca, Mg, and Cation Exchange Capacity (CEC) by the Oregon State University Soil Testing Laboratory.

THE EFFECTS OF LIME AND POTASSIUM ON THE UPTAKE OF CA, K AND MG BY FILBERT TREES GROWN IN POT CULTURE

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Abstract. The effects of soil incorporated lime and K on the uptake of Ca, K and Mg by filbert trees (*Corylus avellana* L. cv Barcelona) grown in two soils were investigated in outdoor pot culture experiments. Liming significantly increased leaf Ca, K and Mg, while applied potassium decreased leaf Ca and Mg and increased leaf K significantly. Trees grown in a soil of low exchangeable K, as determined by ammonium acetate extraction, were able to take up much more K than those grown in a soil of higher exchangeable K. These results indicate that a soil analysis method used to measure exchangeable K cannot be used to predict the available K for filbert trees. Further experimentation is required to develop a test which can be used to predict the K requirement for filbert trees grown in different soils.

Potassium deficiency is a common nutritional disorder in Oregon filbert orchards, estimated from commercial leaf analysis reports to affect 20-25 percent of the Oregon filbert acreage in varying degrees (32). Leaf analysis has been used successfully in diagnosing the disorder as well

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as showing various responses to the application of K fertilizer. Painter, et al., (59) reported that K application to filberts significantly increased leaf K but only after five years. In another experiment they reported a response to applied K the year following treatment (60). They gave no reason for this variation in filbert tree response to K fertilization.

Liming is becoming a widespread practice in the acid soils of western Oregon. Reported effects of liming on K availability within the pH range 4-7 are conflicting. Liming has been shown to increase K availability for some crops (22, 34, 76) while decreasing it for others (11, 30). Liming an acid soil of a pH 4-7 has been shown to increase adsorption of K in the soil, thus reducing leaching losses and increasing potential reserve supplies of K in acid soils.

Few reports have been published on the effects of liming on leaf K of perennial horticultural crops. In citrus, liming was found to decrease leaf K content (71), while in another report lime increased leaf K content in apple (58).

This experiment was conducted to determine the effects of lime and K, separately and in combination, on the concentrations of K, Ca and Mg found in filbert leaves.

Materials and Methods

Two soils, selected on the basis of their exchangeable K content as determined by soil tests at the Oregon State University Soil Analysis Laboratory (66), were used in the experiments. Laurelwood soil (L) which was high in exchangeable K and Jory silt clay loam soil (J) which was low in exchangeable K.

Seventy-two one year old filbert trees of uniform size were planted individually in five gallon plastic pots in each soil and set outdoors in holes with gravel drains. For each soil, treatments were replicated into eight blocks, each consisting of nine treatments. Treatments within a block were randomized. Trees were planted in soil L in May, 1972 and in soil J in July, 1972. Because of the late planting date, dormancy was delayed in the trees grown in soil J and they were killed by an early December, 1972 freeze. Trees were replanted in soil J during January, 1973 which resulted in an age difference between the trees in soil L and those in soil J.

Treatments consisted of 0, 3200 and 6400 ppm of finely ground agricultural limestone ($CaCO_3$) per pot in combination with 0, 150 and 300 ppm K as K_2SO_4. The lime levels used were determined from the SMP soil buffer test (69) for lime requirement to bring the pH of the soils from their initial pH of 5.9 to 6.6 and 7.1 respectively. Potassium levels were chosen to represent control, intermediate and high treatments calculated to bring the soil test levels to optimum and high.

Lime was thoroughly mixed with L and J soils prior to planting in May and July, 1972. Potassium treatments were applied to both soils by syringe in January, 1973.

After planting, the trees were irrigated every other day from June to September. Two hundred and twenty ppm of urea per pot was applied twice to satisfy tree requirements for N.

Leaf samples from the middle of the current season's terminal shoots were collected on August 18, 1973. They were washed, dried at 80°C for 48 hours, and ground in a Wiley mill to pass a 40-mesh screen. Total nitrogen was determined with a Technicon Auto Analyzer using the Kjeldahl procedure (79). The elements P, K, Ca, Mg, Fe, Mn, Zn, Cu, Al, and B were analyzed with a Jarrel-Ash 3/4 meter direct reading emission spectrometer (15).

The data were subjected to analysis of variance for a 3 x 3 factorial experimental design, and by regression analysis to obtain the relationships of applied lime and K to Ca and K concentration in the leaves (74).

Soil samples were taken from the pots, at the end of the experiment, and analyzed for pH, K, Ca, Mg, and Cation Exchange Capacity (CEC) by the Oregon State University Soil Testing Laboratory.

Results and Discussion

Application of K significantly increased leaf K of filbert trees grown in the two soils (Tables 1 and 2). Similar results for other crops have been reported by other investigators (8, 27, 30, 75). Applied K significantly reduced leaf Mg concentration (Tables 1 and 2). This result can be attributed to the ion competition for uptake mechanism as described by Moore (57).

Leaf Ca was significantly increased in both soils by liming (Tables 1 and 2). Similar responses have been reported for citrus (51, 48), apple (68) and peach (36). Applied K reduced filbert leaf Ca, but not significantly. Potassium has been reported to reduce leaf Ca content of apple (27) and pecan (30).

There was no lime by K interaction effects on filbert leaf content of Ca, K or Mg in either of the two soils.

Significant linear relationships between applied lime and leaf Ca and between applied K and leaf K were found (Table 3). Lime increased K uptake, while applied K had no significant effect on Ca uptake in either soil.

Liming raised soil pH from 5.9 (Table 4) to approximately 6.7 and 7.2 in both soils (Tables 5 and 6), which was very close to the values predicted by the SMP soil buffer test method (69). Liming has been reported by many investigators to result in greater root development in many crops (26, 49, 63). In this experiment liming significantly increased leaf K of filbert trees grown in both soils (Tables 1 and 2). This could be attributed to an improvement in soil conditions leading to development of a better root system and an increased absorbing surface.

The first lime increment increased leaf Mg content, while the second tended to reduce it. The possible reasons that could explain why this happened are: when lime was added at the first level, Ca could have competed with Mg for the exchange sites. This would result in Mg movement into the soil solution. At the second level of lime, soil pH was raised above 7.0 (Tables 5 and 6) which could have resulted in formation of $MgCO_3$ and thus magnesium was precipitated. Also, Ca may have affected the K and Mg ion carrier in the ion uptake mechanism that favored the uptake of K on Mg as described by Moore (57).

Trees grown in soil J, with lower levels of exchangeable K, showed a greater increase in shoot growth than those grown in soil L with a higher level of exchangeable K. Potassium leaf concentrations in soil J trees were higher than those of soil L trees (Tables 1 and 2). It was concluded that using the ammonium acetate method (66) to measure available K for filbert trees was inappropriate. This was supported by the fact that soil L contained more exchangeable K than soil J at the end of the experiment (Tables 5 and 6), yet leaves from trees grown in soil J contained more K. Additional investigations should be conducted in order to find a better method for measuring available K for filbert trees. Since no calibration curves have been established for filbert trees grown in Oregon, such investigations can include both the extraction method and the calibration curve determination. This information will enable K recommendations to be made with greater accuracy.

Table 1. Effects of varying levels of lime and K on the concentration of K, Ca and Mg in the leaves of filbert trees grown in Laurelwood soil.

Treatment*	% Dry Weight		
	K	Ca	Mg
K_0	.38	1.50	.27
K_1	.42	1.49	.26
K_2	.49	1.47	.26
Ca_0	.36	1.30	.27
Ca_1	.45	1.52	.28
Ca_2	.48	1.65	.25
LSD 5% K Ca	.05	.11	.02

* $K_{0,1,2}$ = 0.0, 150, 300 ppm K.

$Ca_{0,1,2}$ = 0.0, 3200, 6400 ppm $CaCO_3$.

Table 2. Effects of varying levels of lime and K on the concentration of K, Ca and Mg in the leaves of filbert trees grown in Jory soil.

Treatment*	% Dry Weight		
	K	Ca	Mg
K_0	.43	1.48	.26
K_1	.71	1.48	.21
K_2	.99	1.39	.19
Ca_0	.60	1.30	.22
Ca_1	.70	1.49	.24
Ca_2	.81	1.56	.21
LSD 5% K Ca	.07	.08	.02

* $K_{0,1,2}$ = 0.0, 150, 300 ppm K.

$Ca_{0,1,2}$ = 0.0, 3200, 6400 ppm $CaCO_3$.

Table 3. Relationships between lime and K treatments on percentage leaf Ca and K content of filberts grown in Laurelwood and Jory soils.

Independent Var. X	Dependent Var. Y	d.f.	R^2	Equation *	Soil
Applied lime-gms	% leaf Ca	1°	.98	$Y = 1.312 - .0082X$	L
Applied K-gms	% leaf K	7°	.90	$Y = .3153 + .0027X_1 + .02023X_2$	L
Applied lime-gms	% leaf Ca	1°	.92	$Y = 1.3199 - .0064X$	J
Applied K-gms	% leaf K	7°	.97	$Y = .3263 + .0048X_1 + .1007X_2$	J

* X_1 = applied lime and X_2 = applied K.

Table 4. Chemical analysis of Laurelwood and Jory soils at the beginning of the experiment.

Soil Type	pH	SMP* pH	K (ppm)	Ca (meq/100 g)	Mg (meq/100 g)	CEC** (meq/100 g)	PBS ***
L	5.9	5.7	250	3.4	0.52	13.9	33%
J	5.9	5.7	88	5.5	0.78	14.2	46%

* SMP soil test-buffer pH (69).

** Cation exchange capacity.

*** Percentage base saturation.

Table 5. Chemical analysis of Laurelwood soil at the end of the experiment.

Treatments* (K, Ca)	pH	K (ppm)	Ca (meq/100 g)	Mg (meq/100 g)	CED** (meq/100 g)	PBS ***
0, 0	5.9	152	4.2	1.9	15	43
1, 0	5.9	292	4.2	2.0	14	50
2, 0	5.9	404	3.5	1.6	15	41
0, 1	6.8	146	9.3	1.8	16	73
1, 1	6.6	180	6.8	1.5	15	59
2, 1	6.7	364	8.3	1.8	16	71
0, 2	7.2	140	12.2	1.8	15	99
1, 2	7.3	298	11.2	1.5	17	80
2, 2	7.0	340	9.7	1.5	17	72

* See Table 1.

** Cation exchange capacity.

*** Percentage base saturation.

Table 6. Chemical analysis of Jory soil at the end of the experiment.

Treatments* (K, Ca)	pH	K (ppm)	Ca (meq/100 g)	Mg (meq/100 g)	CED** (meq/100 g)	PBS ***
0, 0	6.0	72	5.1	2.0	16	61
1, 0	6.0	198	5.8	1.8	15	53
2, 0	5.9	336	5.1	1.8	15	54
0, 1	6.7	88	10.4	2.0	17	74
1, 1	6.7	174	8.8	1.8	13	83
2, 1	6.7	256	9.1	1.8	16	72
0, 2	7.2	72	12.9	1.3	15	94
1, 2	7.2	186	13.5	1.6	17	90
2, 2	7.2	256	12.2	1.5	18	82

* See Table 1.

** Cation exchange capacity.

*** Percentage base saturation.

BIBLIOGRAPHY

1. Adams, F. and R. Pearson. 1967. Crop response to lime in southern United States and Puerto Rico. In: Soil Acidity and Liming, ed. by R. Pearson and F. Adams. Madison, Wisconsin.

2. Adams, F. and J. B. Henderson. 1962. Magnesium availability as affected by deficient and adequate levels of potassium and lime. Soil Sci. Soc. Amer. Proc. 26:65-68.

3. Adams, F. and J. I. Wear. 1957. Manganese toxicity and soil acidity in relation to crinkle leaf of cotton. Soil Sci. Soc. Amer. Proc. 21:305-308.

4. Agboola, A. and R. B. Corey. 1973. The relationships between soil pH, organic matter, available phosphorous, exchangeable potassium, calcium, magnesium, and nine elements in the maize tissue. Soil Sci. 115:367-375.

5. Alban, L. A. and C. J. Lin. 1958. Effect of lime additions on pH and base saturation of five Western Oregon soils. Soil Sci. 86:271-275.

6. Amarasiri, S. L. and S. Olsen. 1973. Liming as related to solubility of P and plant growth in an acid tropical soil. Soil Sci. Soc. Amer. Proc. 37:716-721.

7. Awada, M. and C. Long. 1971. The selection of the potassium index in papaya tissue analysis. J. Amer. Soc. Hort. Sci. 96:74-77.

8. Barden, J. A. and A. H. Thompson. 1962. Effects of heavy annual applications of potassium on red delicious apple trees. Proc. Amer. Hort. Sci. 81:18-25.

9. Bartlett, R. J. and C. J. Picarelli. 1973. Availability of boron and phosphorous as affected by liming an acid potato soil. Soil Sci. 116:77-83.

10. Bear, F. E. and S. J. Toth. 1948. Influence of calcium on availability of other soil cations. Soil Sci. 65:69-75.

11. Bender, W. H. and W. S. Eisenmenger. 1941. Intake of certain elements by calciphilic and calciphobic plants grown on soils differing in pH. Soil Sci. 52:297-307.

12. Benson, D. W. and S. J. Toth. 1963. Availability of Ca and K adsorbed on clay minerals and soils. Soil Sci. 95:196-203.

13. Black, C. A. 1968. Soil-Plant Relationships. John Wiley and Sons, Inc. New York.

14. Boynton, D. and A. B. Burrell. 1944. Potassium-induced magnesium deficiency in the McIntosh apple trees. Soil Sci. 58:441-454.

15. Chaplin, M. H. and A. Dixon. 1973. A method for analysis of plant tissue by direct reading spark emission spectroscopy. Applied Spectroscopy 28:5-8.

16. Chernove, V. A. 1964. The nature of soil acidity. Soil Sci. Soc. Amer. Madison, Wisconsin.

17. Christenson, D. R., R. P. White and E. C. Doll. 1973. Yields and magnesium uptake by plants as affected by soil pH and calcium levels. Agronomy J. 65:205-206.

18. Coleman, N. T., E. J. Kamprath and S. B. Weed. 1958. Liming Advances in Agronomy 10:475-522.

19. Cummings, G. A. 1965. Plant and soil effects of K and Mg fertilization of Elberta peach trees. Proc. Amer. Soc. Hort. Sci. 86:141-147.

20. Cummings, G. A. and G. E. Wilcox. 1968. Effect of potassium on quality factors - fruits and vegetables. In: The Role of Potassium in Agriculture, ed. by V. Kilmer, S. Younts and N. Brady. Madison, Wisconsin.

21. Cummings, G. A. 1973. The distribution of elements in "Elberta" peach trees tissues and the influence of potassium and magnesium fertilization. J. Amer. Soc. Hort. Sci. 98:474-477.

22. Dunn, L. E. 1943. Effect of lime on availability of nutrients in certain western Washington soils. Soil Sci. 56:297-316.

23. Eaton, G. W. 1971. Effects of NPK fertilizers on the growth and composition of vines in a young cranberry bog. J. Amer. Soc. Hort. Sci. 96:426-429.

24. Eck, P. F., F. J. Campbell and A. F. Spelman. 1962. Effect of nitrogen and potassium fertilizator treatments on soil concentrations and on production, quality and mineral composition of carnation. Proc. Amer. Soc. Hort. Sci. 80:565-570.

25. Eckstein, O. 1939. Effect of potash manuring on the production of organic matter. Plant Phys. 14:113-128.

26. Elgabaly, M. M. 1955. Specific effects of absorbed ions on plant growth. I. Effect of different combinations of calcium, magnesium and sodium on barley seedlings. Soil Sci. 80:235-248.

27. Forsyth, F. R. and D. W. Webster. 1971. Volatiles from "McIntosh" apple fruits as affected by phosphorous and potassium nutrition. J. Amer. Soc. Hort. Sci. 96:259-263.

28. Foy, C. D. 1964. Toxic factors in acid soils of the Southeastern United States as related to the response of alfalfa to lime. Washington, D. C. (U.S. Dept. of Agr., Agricultural Research Service. Production Research Report no. 80).

29. Gilbert, B. and F. Pember. 1931. Further evidence concerning the toxic action of aluminum in connection with plant growth. Soil Sci. 31:267-273.

30. Gossard, A. C. and H. E. Hammer. 1962. Some effects of potassium fertilization and sod culture on pecan tree performance and nutrition. Proc. Amer. Soc. Hort. Sci. 81:184-193.

31. Gouin, F. R. and C. B. Link. 1966. The effects of various levels of nitrogen, phosphorous, and potassium on the growth and chemical composition of Taxus cv "Hatfield". Proc. Amer. Soc. Hort. Sci. 89:702-705.

32. Grower Diagnostic Service. Leaf analysis report records. Plant Analysis Laboratory. Department of Horticulture, Oregon State University, Corvallis, Oregon.

33. Harada, T. and M. Tamai. 1968. Some factors affecting behavior of boron in soil. Soil Sci. and Plant Nutrition 14:215-224.

34. Harding, R. B. 1954. Exchangeable cations in soils of California orange orchards in relation to yield and size of fruit and leaf composition. Soil Sci. 77:119-127.

35. Hatcher, J. T., C. A. Bower and M. Clark. 1967. Absorption of boron by soils as influenced by hydroxy aluminum and surface area. Soil Sci. 104:422-426.

36. Hauis, A. Leon. 1962. Effects of old peach soil treatments on young peach trees in the greenhouse. Proc. Amer. Soc. Hort. Sci. 81:147-152.

37. Hossnr, L. R. and E. Doll. 1970. Magnesium fertilization of potatoes as related to liming and potassium. Soil Sci. Soc. Amer. Proc. 34:772-774.

38. Hunter, S. H., S. J. Toth and F. E. Bear. 1943. Calcium-potassium ratios for alfalfa. Soil Sci. 55:61-72.

39. Jackson, T. L., H. H. Rampton and McDermid. 1964. The effect of lime and phosphorous on the yield and phosphorous content of legumes on Western Oregon. Corvallis (Oregon Agricultural Experiment Station. Technical Bulletin no. 83).

40. Jackson, T. L., D. T. Westerman and D. G. Moore. 1966. The effect of chloride and lime on the Mn uptake by bush beans and sweet corn. Soil Sci. Soc. Amer. Proc. 30:70-73.

41. Jackson, W. A. 1967. Physiological effects of soil acidity and liming. In: Soil Acidity and Liming, ed. by R. W. Pearson and F. Adams. Madison, Wisconsin.

42. Jackson, W. A. and R. J. Volk. 1968. Roll of potassium in photosynthesis and respiration. In: The role of potassium in agriculture, ed. by V. Kilmer, S. Younts and N. Brady. Madison, Wisconsin.

43. Koo, R. C. 1968. Potassium nutrition of tree crops. In: The Role of Potassium in Agriculture, ed. by V. Kilmer, S. Younts and N. Brady. Madison, Wisconsin.

44. Kwong, S. S. 1973. Nitrogen and potassium fertilization effects on yield, fruit quality and leaf composition of "Stanley" prunes. Proc. Amer. Soc. Hort. Sci. 98:72-74.

45. Laughlin, W. M., P. F. Martin and G. R. Smith. 1973. Potassium rate and source influences on yield and composition of bromegrass forage. Agronomy J. 65:85-87.

46. Liebhardt, W. C. 1968. Effect of potassium on carbohydrate metabolism and translocation. In: The Roll of Potassium in Agriculture, ed. by V. Kilmer, S. Younts and N. Brady. Madison, Wisconsin.

47. Lilleland, O., K. Uriu, T. Murooka and J. Pearson. 1962. The relationship of potassium in the peach leaf to fruit growth and size at harvest. Proc. Amer. Soc. Hort. Sci. 81:162-167.

48. Lucas, R. E. and J. F. Davis. 1961. Relationships between pH values of organic soils and availability of 12 plant nutrients. Soil Sci. 92:177-182.

49. Lyle, E. S. and F. Adams. 1971. Effect of available soil calcium on taproot elongation of loblolly pine (Pinus taeda L.) seedlings. Soil Sci. Soc. Amer. Proc. 35:800-805.

50. Martin, J. P., J. O. Ervin and R. A. Shepherd. 1961. Influence of exchangeable Na and K at different base-saturation levels on growth and composition of citrus plants. Soil Sci. 91:273-279.

51. Martin, J. P. and A. L. Page. 1969. Influence of exchangeable Ca and Mg and percentage base saturation on growth of citrus plants. Soil Sci. 107:39-46.

52. McColluch, R. C., F. T. Binghanr and D. G. Aldrich. 1957. Relation of soil potassium and magnesium to magnesium nutrition of citrus. Soil Sci. Soc. Amer. Proc. 21:85-88.

53. McLean, E. O. and M. D. Carbonell. 1972. Calcium, magnesium, and potassium saturation ratios in two soils and their effects upon yields and nutrient contents of German millet and alfalfa. Soil Sci. Soc. Amer. Proc. 36:927-930.

54. Mehlich, A. 1942. Base saturation and pH in relation to liming and nutrient conservation of soil. Soil Sci. Soc. Amer. Proc. 7:353-361.

55. Midgley, A. R. 1940. Phosphate fixation in soils - A critical review. Soil Sci. Soc. Amer. Proc. 5:24-30.

56. Mengel, K. 1971. Plant ionic status. In: The Plant Root and Its Environment, ed. by E. Carson. University Press of Virginia, Charlottesville.

57. Moore, D. P. 1964. Absorption of nutrient ions by plants. Proceedings, Fifteenth Annual Fertilizer Conference of the Pacific Northwest, Salem, Oregon.

58. Mortland, M. M. 1961. The dynamic character of potassium release and fixation. Soil Sci. 91:11-13.

59. Painter, J. H. and H. E. Hammer. 1962. Effects of differential applications of nitrogen, potassium, magnesium, boron, and phosphorus on their concentration in leaves of filbert trees. Proc. Amer. Soc. Hort. Sci. 80:315-326.

60. _______________. 1963. Effect of differential levels of applied K and B on Barcelona filbert trees in Oregon. Proc. Amer. Soc. Hort. Sci. 82:225-230.

61. Peech, M. and R. Bradfield. 1943. The effect of lime and magnesia on the soil potassium and on the absorption of potassium by plants. Soil Sci. 55:37-48.

62. Piper, C. S. 1931. Availability of manganese in the soil. J. Agricultural Science 21:762-769.

63. Ragland, J. L. and N. T. Coleman. 1959. The effects of soil solution and Ca on root growth. Soil Sci. Soc. Amer. Proc. 23:355-357.

64. Rassmussen, G. K. and P. F. Smith. 1960. Growth of pineapple orange seedlings in sand cultures with various levels of K, Ca, and Mg. Proc. Soil and Crop Sci. Soc. Florida 20:183-190.

65. Reeves, J. and G. Cummings. 1970. The influence of some nutritional and management factors upon certain physical attributes of peach quality. J. Amer. Soc. Hort. Sci. 95:338-341.

66. Roberts, S., R. V. Vodraska, M. D. Kauffman, and E. H. Gardner. 1971. Methods of soil analysis used in the Soil Testing Laboratory at Oregon State University. Agricultural Experiment Station, OSU, Corvallis.

67. Schmehl, W. R., M. Peech and R. Bradfield. 1950. Causes of poor growth of plants on acid soils and beneficial effects of liming. II. Evaluation of factors responsible for acid-soil injury. Soil Sci. 70: 393-410.

68. Shear, C. B. and M. Faust. 1971. Nutritional factors influencing the mineral content of apple leaves. J. Amer. Soc. Hort. Sci. 96:234-240.

69. Shoemaker, H. E., E. McLean and P. Pratt. 1961. Buffer methods for determining lime requirement of soils with appreciable amounts of extractable aluminum. Soil Sci. Soc. Amer. Proc. 25:274-277.

70. Sistrunk, J. W. and R. W. Campbell. 1966. Calcium content differences in various apple cultivars as affected by rootstock. Proc. Amer. Soc. Hort. Sci. 88: 38-40.

71. Spencer, W. F. 1960. Effects of heavy applications of phosphate and lime on nutrient uptake, growth, freeze injury and root distribution of grapefruit trees. Soil Sci. 89:311-318.

72. Spencer, W. F. and R. C. Koo. 1962. Calcium deficiency in field-grown citrus trees. Proc. Amer. Soc. Hort. Sci. 81:202-208.

73. Stanford, G., J. B. Kelly, and W. H. Pierre. 1941. Cation balance in corn grown on high lime soils in relation to potassium deficiency. Soil Sci. Soc. Amer. Proc. 6:335-341.

74. Steel, R. G. and J. H. Torrie. 1960. Principles and Procedures of Statistics. McGraw-Hill Book Company, New York.

75. Stembridge, G. E., C. E. Gambrell, H. J. Sefick and L. O. Blaricom. 1962. The effect of high rates of nitrogen and potassium on the yield, quality, and foliar mineral composition of dixigem peaches in the South Carolina sandhills. Proc. Amer. Soc. Hort. Sci. 81:153-161.

76. Struthers, P. H. and D. H. Sieling. 1950. Effect of organic anion on phosphate precipitation by iron and aluminum as influenced by pH. Soil Sci. 69:205-213.

77. Thompson, L. M. and F. R. Troeh. 1973. Soils and Soil Fertility. McGraw-Hill Book Company. New York.

78. Tisdale, S. L. and W. L. Nelson. 1971. Soil Fertility and Fertilizers. The MacMillan Company, London.

79. Warner, M. H. and J. B. Jones. 1967. Determination of total nitrogen in plant tissue using a technicon Kjeldahl nitrogen apparatus. Symp. Automation Anal. Chem. 1:145-148.

80. Webster, G. C. and J. E. Varner. 1955. Aspartate and asparagine synthesis in plant systems. J. Biol. Chem. 215:21-99.

81. White, R. P. 1970. Effects of lime upon soil and plant manganese levels in an acid soil. Soil Sci. Soc. Amer. Proc. 34:625-629.

82. White, R. P., E. C. Doll, and J. R. Melton. 1970. Growth and manganese uptake by potatoes as related to liming and acidity of fertilizer bands. Soil Sci. Soc. Amer. Proc. 34:268-271.

83. Westermann, D. T., T. L. Jackson, and D. P. Moor. 1971. Effect of potassium salts on extractable soil manganese. Soil Sci. Soc. Amer. Proc. 35:43-46.

84. Woodruff, C. M. 1955. The energies of replacement of calcium by potassium in soil. Soil Sci. Soc. Amer. Proc. 19:167-171.

85. York, E. T., R. Bradfield and M. Peech. 1953. Calcium-potassium interactions in soils and plants. I. Lime-induced potassium fixation in Mardin silt loam. Soil Sci. 76:379-387.

86. _______________. 1954. Influence of lime and potassium on yield and cation composition of plants. Soil Sci. 77:53-63.

APPENDIX

This appendix contains additional data obtained from the previous experiment. Even though these data do not pertain directly to the data presented in the paper, they provide some information about the effect of liming and K treatments on the filbert leaf content of other nutrient elements.

Applied lime reduced leaf P, Mn and B in soils L and J (Tables 1, 2, 3 and 4). This reduction can be attributed to the decrease in the availability of these elements as the soil pH is increased. Phosphorus might have been converted to a less soluble Ca-phosphate compound. Manganese might have become immobile in the roots as Ca was increased, resulting in Mn translocation depression (41).

On the other hand, lime increased the concentration of Cu, Fe, Zn and Al in filbert leaves (Tables 1, 2, 3 and 4). Even though leaf Cu content was increased significantly by liming, this had no biological effects on the plants since a difference of less than one ppm results in a significant difference statistically. One would expect liming to decrease the uptake of Fe, Zn and Al because their solubility decreases with the increase in pH. However, since Fe determined in this analysis was total Fe, drawing a definite conclusion becomes difficult.

Jackson (41) reported that some of the beneficial effects of liming are commonly ascribed to immobilization of Al in the Soil, thereby preventing Al toxicity from developing. To explain the increase in Al uptake in filbert trees as limed, three possibilities should be considered. First, interference by some other elements in the emission spectrometer may have resulted in reading higher Al values. On the other hand, because the trees used in this experiment were planted in pots, some physiological changes might have occurred that enabled the plants to extract more Al in the presence of high levels of Ca. Finally, it could simply be the nature of filbert trees to accumulate Al as they are limed. Further research would be necessary to determine the reasons for such results.

Potassium application reduced the concentration of P and Cu and increased Mn in leaf tissue (Tables 1, 2, 3 and 4). Other investigators reported similar effects of K on leaf Mn in prunes (44) and filbert trees (59). Painter and Hammer (59) related this to a possible K replacement of Mn ion adsorbed on the soil particles, thus making Mn readily available for absorption. Westermann, et al., (83) explained the increase in the level of extractable Mn when salts such as K Br and K Cl were used by postulating that the anion would function in an oxidation-reduction reaction.

Shoot growth, measured at the end of the growing season, was subjected to analysis of variance. There was no significant difference at the five percent level in either soil (Table 5). Liming tended, however, to increase shoot growth, but K did not affect it. Trees grown in J soil were more vigorous than those grown in L.

Table 1. Effects of varying levels of lime and K on the concentration of N, P, K, Ca and Mg in the leaves of filberts grown in Laurelwood soil.

Treatments* (K, Ca)	Nutrient Concentrations % Dry Weight				
	N	P	K	Ca	Mg
0, 0	2.21	.21	.31	1.28	.26
1, 0	2.05	.18	.35	1.32	.28
2, 0	2.01	.16	.44	1.29	.27
0, 1	2.01	.19	.41	1.63	.31
1, 1	2.19	.18	.41	1.41	.26
2, 1	2.19	.19	.51	1.52	.27
0, 2	2.12	.21	.42	1.61	.25
1, 2	2.14	.18	.51	1.74	.25
2, 2	2.08	.20	.52	1.60	.24
LSD .05	0.15	.02	.05	.11	.02

* $K_{0,1,2}$ = 0.0, 150, 300 ppm K.

$Ca_{0,1,2}$ = 0.0, 3200, 6400 ppm $CaCO_3$.

Table 2. Effects of varying levels of lime and K on the concentration of Mn, Fe, Cu, B, Zn and Al in the leaves of filberts grown in Laurelwood soil.

Treatments* (K, Ca)	Nutrient Concentrations ppm Dry Weight					
	Mn	Fe	Cu	B	Zn	Al
0, 0	1071	452	4	30	12	642
1, 0	1220	490	4	27	10	702
2, 0	1328	446	3	27	9	621
0, 1	336	689	5	27	16	867
1, 1	329	667	4	26	12	869
2, 1	302	716	5	28	18	925
0, 2	261	728	5	29	15	911
1, 2	230	811	5	29	15	980
2, 2	233	756	5	27	15	942
$LSD_{.05}$	138	71	.8	5	4	90

* $K_{0,1,2}$ = 0.0, 150, 300 ppm K.

$Ca_{0,1,2}$ = 0.0, 3200, 6200 ppm $CaCO_3$.

Table 3. Effects of varying levels of lime and K on the concentration of N, P, K, Ca, and Mg in the leaves of filberts grown in Jory soil.

Treatments* (K, Ca)	Nutrient Concentrations % Dry Weight				
	N	P	K	Ca	Mg
0, 0	2.09	.11	.40	1.29	.25
1, 0	2.23	.10	.54	1.34	.21
2, 0	2.12	.09	.87	1.27	.20
0, 1	1.93	.11	.43	1.54	.29
1, 1	2.07	.10	.72	1.53	.22
2, 1	2.02	.09	1.00	1.41	.20
0, 2	2.12	.09	.46	1.60	.25
1, 2	2.11	.08	.85	1.56	.20
2, 2	2.07	.08	1.11	1.50	.18
LSD .05	.12	.014	.07	.08	.02

* $K_{0,1,2}$ = 0.0, 150, 300 ppm K.

$Ca_{0,1,2}$ = 0.0, 3200, 6400 $CaCO_3$.

Table 4. Effects of varying levels of lime and K on the concentration of Mn, Fe, Cu, B, Zn and Al in the leaves of filberts grown in Jory soil.

Treatments* (K, Ca)	Nutrient Concentrations ppm Dry Weight					
	Mn	Fe	Cu	B	Zn	Al
0, 0	874	429	3	59	13	594
1, 0	1352	413	2	61	13	577
2, 0	1443	466	2	55	14	643
0, 1	246	529	3	61	20	617
1, 1	394	533	2	58	14	650
2, 1	386	557	3	56	17	695
0, 2	188	499	3	54	16	636
1, 2	218	524	3	42	13	644
2, 2	227	531	2	46	13	657
LSD .05	136	60	.8	5	3	85

* $K_{0,1,2}$ = 0.0, 150, 300 ppm K.

$Ca_{0,1,2}$ = 0.0, 3200, 6400 ppm $CaCO_3$.

Table 5. Effects of varying levels of lime and K on shoot growth of filberts grown in Laurelwood and Jory soils.

Treatments* (K, Ca)	Soil Type L	Soil Type J
0, 0	24.97	59.54
1, 0	18.38	62.28
2, 0	25.28	68.78
0, 1	18.59	57.00
1, 1	23.92	62.00
2, 1	23.03	42.37
0, 2	20.09	49.50
1, 2	24.78	64.83
2, 2	22.16	69.56

* $K_{0,1,2}$ = 0.0, 150, 300 ppm K.

$Ca_{0,1,2}$ = 0.0, 3200, 6300 ppm $CaCO_3$.

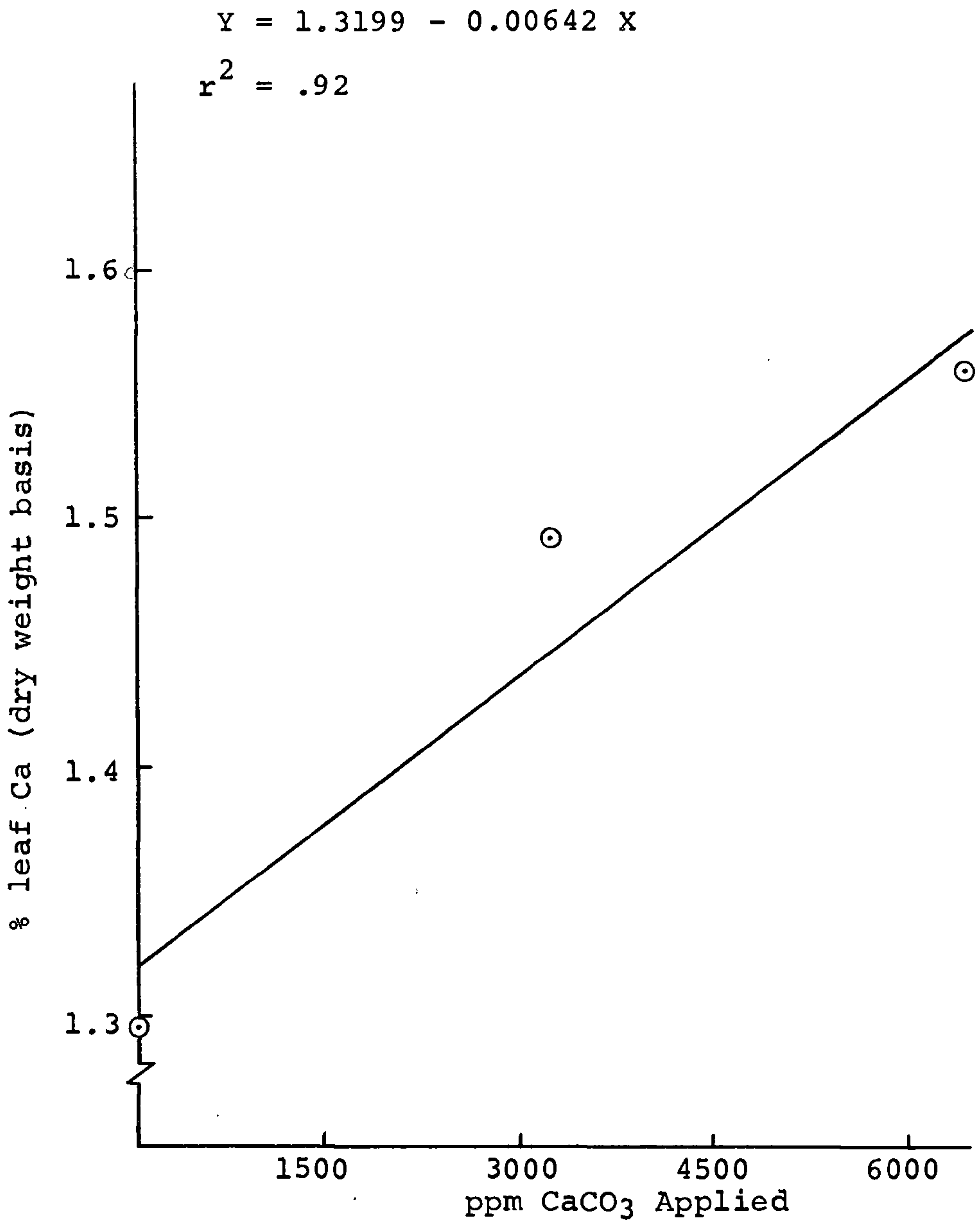

Figure 1. The effects of applied $CaCO_3$ on percentage leaf Ca from filbert trees grown in Laurelwood soil.

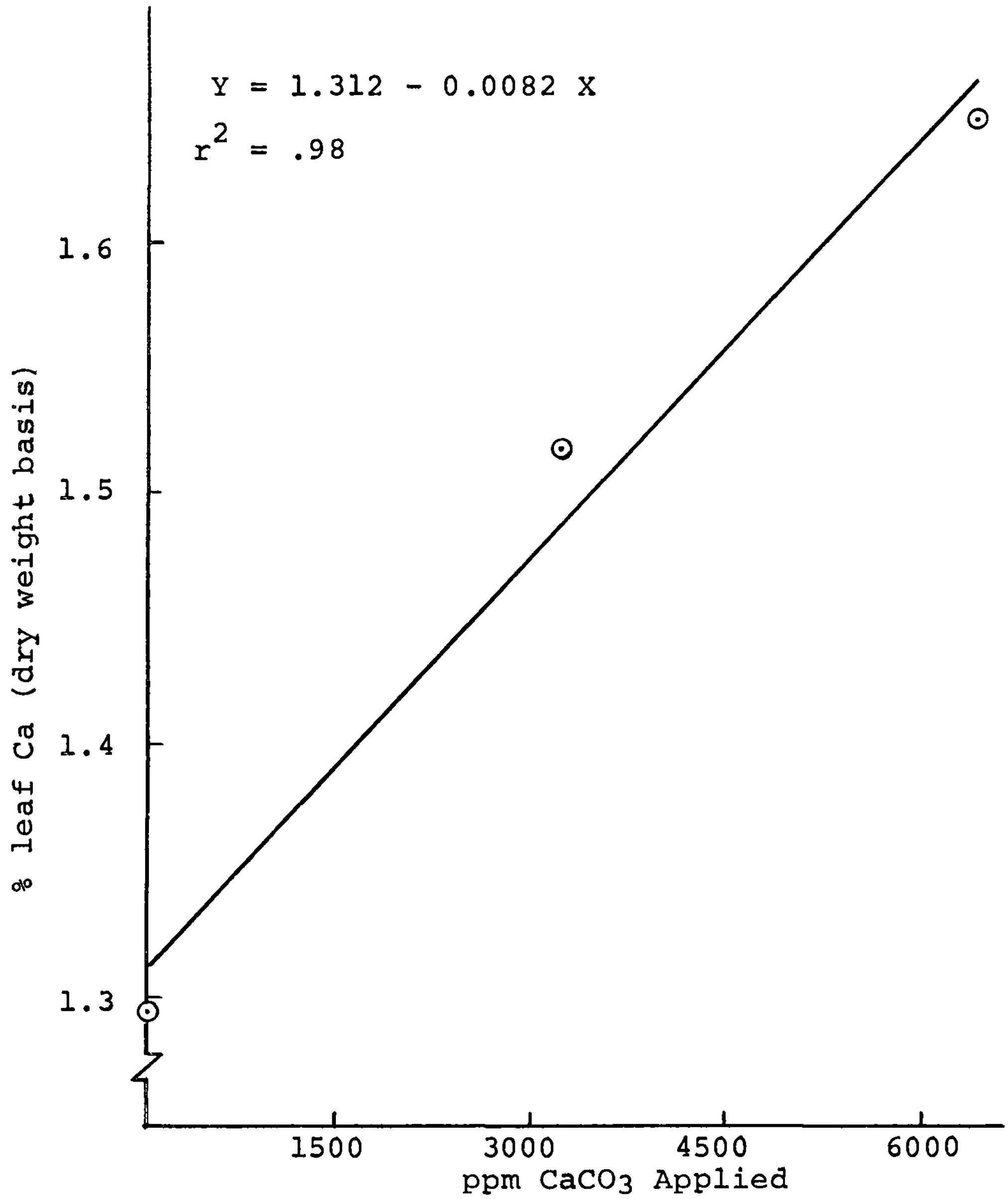

Figure 2. The effects of applied $CaCO_3$ on percentage leaf Ca from filbert trees grown in Jory soil.

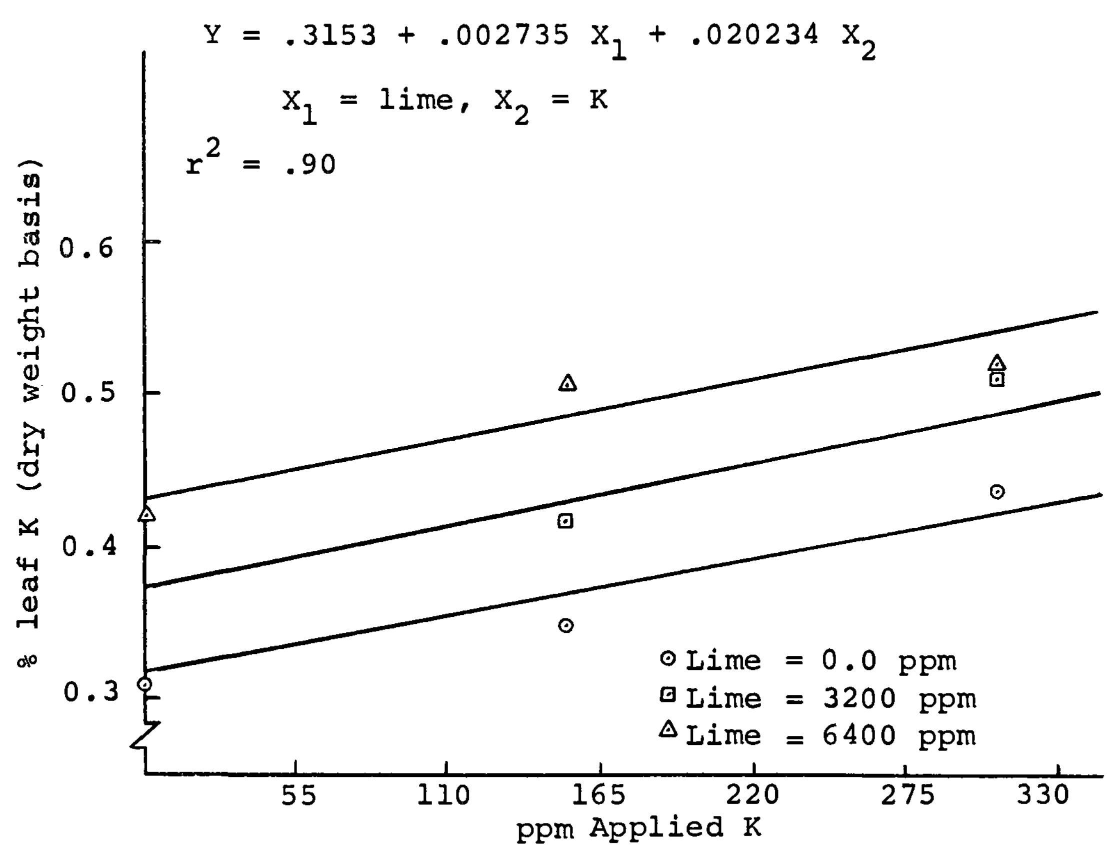

Figure 3. The effects of applied K on percentage leaf K from filbert trees grown in three levels of applied lime in Laurelwood soil.

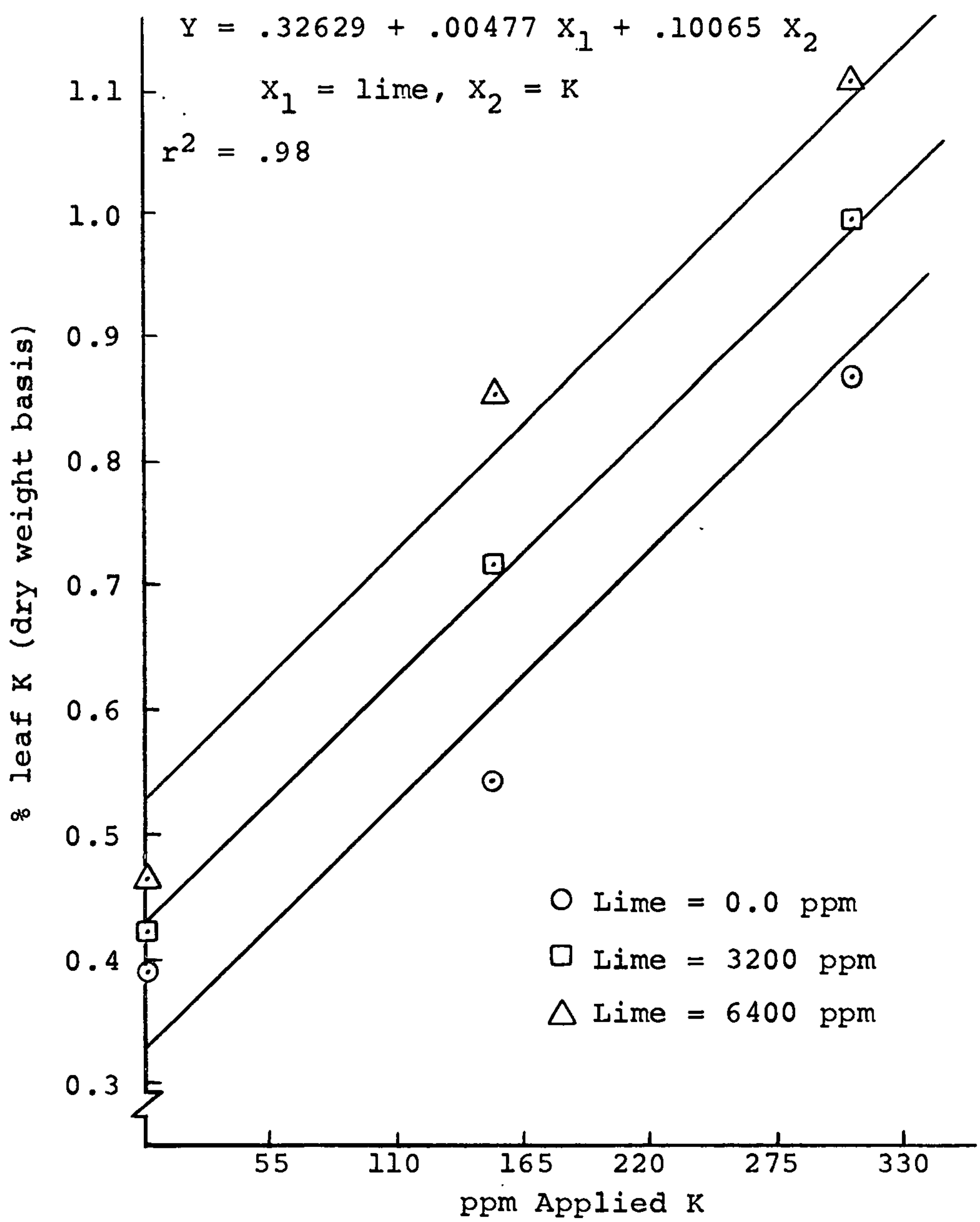

Figure 4. The effects of applied K on percentage leaf K from filbert trees grown in three levels of applied lime in Jory soil.