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Title INTERRELATIONS OF MAGNESIUM, LIME, AND POTASSIUM IN BROCCOLI GROWN ON TWO WESTERN OREGON SOILS

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In order to measure the response of broccoli to applications of lime, Mg, and K, field experiments were established on a Willamette and an Olympic soil in 1959 and 1960.

The experimental design consisted of a series of factorial combinations involving rates of lime, Mg, K, and N. Responses to any one of these variables were measured at more than one level of the others allowing measurement of interaction effects. Of particular interest were the effects of lime and K on responses to Mg.

Broccoli leaves of differing maturities were sampled at different times during the growing period. Soil samples were taken prior to and after fertilization for the 1960 crop. From this information, sets of soil analyses and plant composition data were selected for use in determining relationships between yield and soil analysis data, yields and plant composition, and between plant composition and soil analysis. These relationships were developed by fitting selected models to the data using multiple regression techniques.

Yields were lower and there were fewer responses to fertilizer in 1959 than in 1960. A significant response of total yield to N was obtained on the Willamette soil. Statistically significant responses to lime, K, and Mg were not obtained, but yields were higher when these elements were applied together.

On the Olympic soil in 1959, total yield and average weights of good quality heads responded to applications of K. Responses to Mg, smaller in magnitude than those to K, were obtained where both K and the first rate of lime (L_1) had been applied. Thus, while responses to lime, Mg, and K were not generally large, yields were increased by their combined application.

In 1960, broccoli was transplanted at a later date, and total yields obtained were larger, especially on the Olympic soil. The only significant response on the Willamette soil was to N, though yields were negatively related to exchangeable Mg and Mg content of the leaf tissue. This negative response to Mg occurred at N_1 but not at N_2.

On the Olympic soil in 1960, significant positive responses of head, spear, and total yield to Mg were obtained when the first rate of lime was applied. However, the lime x Mg interaction was significant only on total yield. Maximum yields were obtained when lime, P, K, and Mg were applied in combination with the highest rate of N. Higher levels of exchangeable Mg were needed to maintain an adequate amount of Mg in the plant as the lime and K rates increased.

Application of the highest rate of lime (L_2) reduced both yield and Mg contents of the leaves. Application of Mg and K recovered only a portion of this yield reduction. The cause of this yield reduction was possibly an insufficient Mg level, or that lime applications induced a deficiency of some unidentified nutrient. A significant lime x N interaction occurred in that the yield reductions evident when the high rate of lime was applied did not occur at the high N rate. This lime x N interaction is not readily explainable.

Significant positive responses of total and head yield to K were obtained on the Olympic soil regardless of lime rate. Both head and total yields were related to exchangeable K and K contents of broccoli leaves. Responses to K were generally larger where both lime and Mg had been applied. K contents were reduced by Ca, but not by Mg.

General effects noted on the Olympic soil were the positive effects of K on head yields and Mg on spear yields. This would suggest that adequate K levels would be necessary initially to provide maximum head yields, followed by foliar application of Mg as soon as head harvests began.

The difficulties involved in obtaining relationships between yield and exchangeable Mg or Mg content of broccoli leaves were discussed. Problems involved in the determination of a "critical level" of Mg were also considered.

The results of this study suggest that simple correlations of yield with soil analysis information would be difficult. Yields were often not well correlated with any element individually unless the levels of the other elements were stipulated. This was due, in general, to interrelations between nutrient elements which alter the pattern of yield responses to any single element.

INTERRELATIONS OF MAGNESIUM, LIME, AND POTASSIUM IN BROCCOLI GROWN ON TWO WESTERN OREGON SOILS

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INTERRELATIONS OF MAGNESIUM, LIME, AND POTASSIUM IN BROCCOLI GROWN ON TWO WESTERN OREGON SOILS

INTRODUCTION

Though sprouting broccoli (*Brassica oleracea*, var italica) has been grown since Roman times, its introduction into the United States was relatively recent, occurring in the early 1920's (35, p. 170). It has gained in popularity, and has become one of the many economically important vegetable crops grown in the Willamette Valley.

Broccoli is a cool season, annual crop requiring an abundant and constant supply of both moisture and nutrients for rapid growth and heavy yield. It does best when the mean daily temperature is below 70^{o}F. (8, p. 386). Its root system is shallow and not extensive making it sensitive to low nutrient and moisture levels (35, p. 109). Any hindrance to growth can seriously affect yield and quality of the crop.

In recent years deficiency symptoms identified as those of Mg have been noted in broccoli fields in the Willamette Valley. The question has arisen as to whether broccoli would respond to Mg fertilization. Up to this time experiment station reports had not shown any response from the application of Mg in Oregon with any crop.

Little information is available in the literature regarding the mineral nutrition of broccoli or its close relatives, cauliflower and cabbage. Plant species vary significantly from each other in their nutrient requirements, and broccoli, with its rapid growth, sensitivity to nutrient status, and type of yield, seems an apt subject for investigation. Information gained from other crops would be helpful but probably not indicative of broccoli.

Studying the Mg nutrition of broccoli automatically implies the simultaneous study of Ca and K nutrition because both lime and K are known to affect Mg uptake of plants (12, 15, 41, 55). The interrelation of these elements necessitates a rather large experimental design with these variables in factorial combination.

Lime is an important factor in the nutrition of broccoli as the crop generally makes its best growth when the soil pH is 6.0-6.8. Soils are often limed to pH 6.8 - 7.0 as a control for clubroot, a soil-borne slime mold which can seriously affect brassica production (63, p. 236).

The nature of broccoli as a crop practically eliminates the use of the greenhouse for preliminary studies. Meaningful yield measurements of head and spear production are nearly impossible to obtain in the limited soil volumes used in the greenhouse. Further, broccoli plants vary greatly between individuals and many replications would be needed to detect differences of the size usually found in plant responses.

In order to effectively study the interrelations of Mg, Ca, and K in any crop the amount of each taken into the plant needs to be measured. There is much evidence to indicate that the location of these interaction effects may be in their uptake into the plant. Plant analysis information forms possibly the best basis known at this time for estimating the plant's nutritive situation. Since no information is available as to what part of the plant to sample, a study of the Mg, Ca, and K contents of leaves of varying maturity sampled at different times during the growing season was necessary.

If Mg responses were to be obtained some knowledge of a "critical level" of Mg in the plant would be useful. Also the effects of Ca and K on this critical level would need to be established.

The soils on which these experiments were located were chosen on the basis of several considerations. They are:

(1) The soils were relatively low in Mg and K, and no information regarding crop response to Mg was available on them.

(2) They are generally typical of soils on which broccoli has been grown or would be grown in the future.

(3) They were located on experimental stations where constant care could be taken regarding irrigation and pest control. These stations also had a competent labor force needed to aid in harvest and yield measurements.

OBJECTIVES

The objectives of this study are as follows:

1. To measure yield responses of broccoli to applications of Mg, lime, and K on field experiments on an Olympic and on a Willamette soil.
2. To relate, through the use of regression techniques, yield response, nutrient content, and soil analysis data.
3. To obtain information regarding the effect of interactions between lime, Mg, and K on relationships between yields and soil analysis information.
4. To determine the implications of the interaction of these nutrient elements on the nutrition and management of broccoli.
5. To evaluate some of the factors affecting the critical level of magnesium in the broccoli plant.

LITERATURE REVIEW

Broccoli, cabbage, cauliflower, and other brassicas are considered especially responsive to commercial fertilizer. Their rapid growth requires that an ample nutrient supply be available. Being high value crops that generally involve large labor costs, their growth is not often attempted without an adequate fertilizer program.

Historically, large scale commercial production of vegetable crops began on sandy coastal plain soils of the eastern United States where adequate nutrient supplies have always been a problem. Also the culture of many of these crops came to this country from Europe where fertilization had long been practiced.

These ideas are borne out in a survey of the literature on fertilization and cultural practices used in growing the brassicas. The rates of application of commercial fertilizers generally recommended are high, usually 1000 to 2000 pounds of 4-16-4 or similar material per acre (64, p. 256). Thompson and Caffrey (60, p. 12), in a U. S. D. A. Farmer's Bulletin on cauliflower and broccoli production, recommend 30 tons of barnyard manure or 1000 to 3000 pounds of commercial fertilizer per acre. A description of commercial broccoli production in Massachusetts cites additions of 2500 pounds of 0-14-14 plus 200 to 300 pounds of ammonium nitrate per acre at transplanting.

Cabbage was found to respond to K [1] and especially to P in five year trials in Virginia (52, p. 1246).

Cabbage is considered moderately responsive to lime (L) due generally to lime's effect in increasing the availability of soil P and in the control of clubroot disease. On Norfolk sandy loams in Virginia, cabbage yields were increased from 2.5 tons per acre at soil pH 4.3 to above 13 tons per acre at pH 5.8 - 6.2 (25, p. 1320). A similar pH range was recommended for cauliflower and broccoli on the basis of field observations. A further effect of lime on cauliflower and broccoli is in the prevention of "whiptail disease", a malady first identified as a molybdenum deficiency on cauliflower. Whiptail was observed on these coastal plain soils when the soil pH was below 5.3 (25, p. 1321).

Magnesium deficiencies (called "sand-drown disease") were first noted in the southeastern United States on tobacco. The name "sand-drown" originated because Mg deficiencies were commonly found on light, sandy soils following periods of excessive rainfall (42). Cabbage and other brassicas are subject to Mg deficiencies on both light and heavy soils in the coastal plain states (13, p. 1251; 14). The causes, as listed by Carolus and Brown (13, p. 1251), are: (a) a natural lack of Mg in the parent rock, (b) intensive leaching due to high

[1] Chemical symbols will be used to refer to their corresponding elements throughout this thesis.

rainfall and mild climate, (c) gradual change from organic fertilizers, and (d) the intensity of cropping practices. These authors further state that rapidly growing vegetable crops have a definite period in their growth during which their Mg requirement is quite high. This would probably be right after transplanting for cabbage since soil conditions should allow growth to begin immediately. Restricted root systems following transplanting frequently result in nutrient deficiencies; however, maximum uptake by the plant would occur when the plant is making the greatest growth. Yield increases of cabbage as high as 85 percent were noted. On vegetable crops Mg influenced such factors as earliness and uniformity of maturity, size of root and fruit, and the general quality of the marketable portion of the crop (13, p. 1253).

Dearborn (15), on two New York soils, obtained significant increases in number and weight of salable heads of cauliflower from applications of Mg. Even where symptoms of Mg deficiency were not evident, responses were noted. This last effect is opposite to that noted by Foy and Barber (20) in corn on two Indiana soils. Here Mg deficiencies were evident, but yield responses were not obtained.

Much general information relating to the general culture of broccoli, its growth habit, etc. is available and is contained in references (3, 35, 36, 43, 45, 46).

Mg - Ca - K Interrelations in Plant Growth

Generally, addition of lime, K, or Mg in a fertility study immediately requires consideration of the interrelations between these elements. Since this work deals with the use of Mg, lime, and K on broccoli, knowledge of some pertinent studies reported in the literature is important.

All types of crops have been studied, from grain and forage crops to fruit trees. Different culture systems have been employed, from field experiments to solution culture. Plant parts used have included a range from roots and leaves to stems and even bark. The combined effect of this experimental heterogenity is to make interpretation of any one experiment in relation to another quite difficult.

The response of a plant to an element is often a function of the soil concentration of the element. It is because of this that plant analysis is a useful diagnostic tool. Its use is also based on the idea that a relationship exists between plant content and yield or growth. However, if this were completely so, its use (and that of soil analysis) would be a simple matter.

But interpretation of analyses is not such a simple task, for the availability of a nutrient element for use in a plant is also affected by influences other than supply. Among the other factors in operation are the species of plant, climatic variables, the plant part sampled, and the age and/or maturity of the plant, and many others.

Foremost among these other factors capable of affecting plant composition is the ability of the presence of one nutrient element to affect the concentration of another in the plant. It is because of these interrelations that plant analysis is of great value in diagnostic work. For example, a low tissue content of an element may not only be due to a short supply of the element, but to the antagonistic action of a second element. Further, a high content of an element in tissue might be due to enhancement of its uptake by a second element.

The plant mechanisms responsible for these ion interactions are highly complex and as yet are far from being understood. Emmert (16, p. 236) cites three possible approaches toward an explanation of interaction mechanics:

(a) changes in the affinities of tissues for the nutrients, thus affecting patterns of nutrient allocation throughout the plant,

(b) changes in selective accumulation processes of the roots and the reflection of such changes throughout the plant, and

(c) a combination of (a) and (b).

Emmert considers under (a) - "internal allocation" - ion interactions that reflect changes in the proportions to which nutrients are allocated to the various integral tissues of a plant. A change in tissue content of one ion results in an accelerated or depressed mobilization of other ions in the tissue.

Under the "root uptake" concept (b), ion interactions may reflect changes in root ability to accumulate and retain ions (16, p. 237). Thus, work on ion uptake into excised barley roots is reported in the sections where it bears on the subject presented. It should be noted that there are difficulties in applying this information to interpretations involving the whole plant. Excised root tissue does not correspond in function to foliar tissue. Since leaves are often used as sample tissue, account must be taken of differences in the translocation of various ions through the plant to the leaves. As an example of this, Foy and Barber (19) concluded that low concentrations of Mg in Ohio 40B corn leaves are due primarily to an immobilization of Mg in the stems of the plant.

Another consideration which should be mentioned before surveying literature on Mg-Ca-K interrelations is the "dilution effect". Cain (10) states that ion antagonism or interaction can be partly explained by growth dilution and should not be interpreted entirely as effects on nutrient absorption by the plant. In other words decreases in leaf concentration of one ion as a result of increased nutrient supply of another are often associated with growth responses from the added nutrient.

The content of Mg in leaves has been most generally used to relate plant growth to the availability of soil Mg (1, 12, 13, 20, 27, 32, 34, 41, 42). Attempts to relate Mg responses to exchangeable Mg and some other soil Mg measurement have at times met with little success (49, 55, 63). In New Jersey (55) and Missouri (23) response to Mg is expected when the Mg saturation of the soil falls to six to ten percent. These studies were performed on New Jersey and Missouri soils exhibiting wide ranges of exchange capacities and Ca, Mg, and K contents. In the results of the New Jersey work it was also stated that the most important factor governing the uptake of Mg into alfalfa plants was the amount of available K. In a greenhouse study of seven Alabama soils, those having less than four percent Mg saturation were Mg deficient (1). Thus, an important factor in determining Mg availability is the nature and relative concentrations of complementary ions present.

It is known that the K ion, present in relatively large amounts, is capable of reducing the uptake of Ca and Mg. Instances of K induced Mg deficiency have often been reported (12, 26, 41, 49, 55, 61). To quote Broyer and Stout (9, p. 283) in a review of macronutrient uptake: "It seems that a general principle is involved wherein the K ion competes consistently with Ca and Mg when plants are absorbing these macronutrient cations. The phenomenon is general, having been demonstrated for a wide variety of plant species and a wide variety of cultural conditions". Prince, Zimmerman, and Bear found no correlation between total Mg in soils and their crop producing powers and considered the availability of soil K to be the most important factor influencing the uptake of Mg by plants (55). Nearpass and Drosdoff (49) found that leaf Mg in tung trees was not correlated with soil Mg on the basis of either milliequivalents or percentage base saturation. However leaf Mg was highly correlated with percentage K saturation. Perkins and Stelly (54) supported this in finding that the percentage Mg in both oats and crimson clover was significantly reduced by application of K in field experiments. Heavy applications of K to Valencia orange trees have been noted to reduce Mg absorption to the point of causing Mg deficiency symptoms and reducing fruit quality (41). Hovland and Dwight (26) found that Mg contents of potato and sugar beet leaves were lower on K treated plots.

The previous references cite instances of reductions of Mg content by K fertilization. These types of interaction effects are often thought of as being reciprocal; that is, Mg applications should also reduce K contents. Instances of this are cited, mainly in tree nutrition, in a review by Emmert (16, p. 233). For other crops, little evidence of Mg reducing K contents was found.

Carolus, working with potatoes in the greenhouse, concluded that

Mg contents were increased by adding K and that K absorption was increased by adding Mg (12). Adams and Henderson (1) found the availability of Mg (as measured by total uptake) to sudan grass and clover to be greater at the higher of two K levels. Mg fertilization of snap beans had little or no effect on K or Ca contents as reported by Seatz et al. (58). Tucker and Smith (61) working with red clover in the greenhouse noted a negative correlation between percent K and percent Mg. They further conclude that K exerted "control" over Mg but not vice versa (additions of K increased K content even if Mg were present).

In studying Ca-K interrelations, investigators have been concerned with solutions to at least two types of practical problems: (a) the effect of liming on soil K and K availability to plants and (b) K deficiencies on high lime soils. It is quite probable that in liming a soil two variables enter the picture with regard to K uptake, soil pH in the root region and Ca level. York, Bradfield, and Peech (65), however, found that the concentration of K in alfalfa grown on an acid soil decreased slightly (mainly due to a dilution effect) with increasing Ca saturation of the soil; however, upon addition of either four tons of gypsum or sufficient lime to maintain free $CaCO_3$ in the soil, the K content of the alfalfa increased.

The above results seem to agree with the conclusions drawn by Peech and Bradfield (53, p. 41 and 45) in a review of Ca-K literature prior to 1943. They made note of the conflicting experimental results and suggested that the explanation may lie in soil reactions. Additions of lime are said to be able to have either a repressive, an increasing, or no effect on soil K depending upon the initial Ca saturation of the soil. In an acid soil, liming will decrease the K in the soil solution, increase the Ca adsorption, and consequently give greater adsorption of K from its neutral salt (resulting in less K into the plant). In a Ca saturated soil, lime will liberate adsorbed K and increase its concentration in the soil solution (more K into the plant). Thus, adding lime to an acid soil will result in decreased absorption of K by the plants, the observed suppressive effect of lime being primarily induced by Ca-K interactions initiated in the soil.

Hester et al. (25, p. 131) suggests that liming sandy coastal plain soil reduces the amount of K lost by leaching and thereby increases the amount taken up by the crops. No percentage composition data were given here, but where leaching losses are probable it is often concluded that liming will increase the amount of K available for plant use.

The suppressive effect of lime on the uptake of K by plants has been noted by many workers. Fonder (18, p. 749) found correlation between Ca and K in alfalfa, increased Ca contents being accompanied by decreased K contents. Stanford, Kelly, and Pierre (59) and Allaway and Pierre (5, p. 943) note that corn grown on high lime soils responded to K even though a sufficient level of exchangeable K was thought to be present. They attribute the poor growth of corn largely to a failure of the plant to absorb adequate amounts of K because of an unfavorable balance of cations in the plant as well as the soil. Hunter (28, p. 72) concluded that alfalfa would make normal growth notwithstanding variations in the soil Ca:K ratio of from 1:1 to 100:1. Generally a drop in yield occurred when the Ca content of the plant exceeded two percent , when the K content fell below one percent, or when the milliequivalent cation ratio of the tops exceeded 4:1. In another experiment on the composition of alfalfa as affected by the Ca:Mg ratio, Hunter (27) noted an antagonistic effect of Ca on K and that the highest K percentages were associated with the smallest Ca:Mg ratio. Van Itallie (63, p. 177) reported that Ca had no effect on the K content of Italian rye grass.

A rather large number of workers report that the effect of lime or Ca on K uptake varies with pH, K level, or the crop used. Among these are York, Bradfield, and Peech (65) and Peech and Bradfield (53) both of whom were cited earlier. Jackson and Evans (31) in sand culture experiments note that a small increase in Ca supply tends to increase the K content in the tops of soybean seedlings and larger amounts of Ca tend to reduce it. Bender and Eisenmenger (6) found that liming an acid soil from pH 4.4 to 7.3 caused a reduction in the total amount of K taken up by wheat and oats, a slight decrease in that taken up by barley, sweet clover, and cowpeas, and an increase in K content of peanuts, tomatoes, Kentucky blue grass, timothy, and red top.

Soil reactions will undoubtedly greatly affect the concentrations and proportions of cations in the soil solution. However, the step remains whereby the cation is taken into the plant. It has often been shown that the proportions of cations found in the soil solution are not those found in the plant. Many factors can affect cation concentrations between the soil solution and plant leaf.

Recently,excised barley roots have been used to study the mechanism of ion uptake into root cells. While these roots are not whole plants, and recognizing the difficulties involved in extrapolating this type of information to crop growth in the field, consideration should be given to this type of work.

Overstreet, Jacobson, and Handley (50) in studying the effect of Ca on the absorption of K by excised barley roots found that a given concentration of Ca exerts both a depressing and stimulating effect on the absorption of K, and that the effects are related to the concentration of K in the external media. Ca repressed K uptake at both the very high and very low K concentrations. Stimulation took place at intermediate levels.

Ca was found to have the property of drastically altering the ratio of absorption on Na and K from a mixture of the two (30). Along with this, H ion has been shown to influence the absorption of monovalent cations in single salt solutions (29). The effect of Ca on absorption is likewise related to pH as well as the specific monovalent cation. The absorption of K is enhanced at low pH by Ca. This effect of Ca is considered to be essentially a blocking of interfering ions through the formation of a barrier, probably at the cell surface (29, 44). At higher pH's (above 6.5) Ca reduces K uptake. This may again be due to the action of Ca in forming a barrier to ion movement to absorption sites.

In 1901 Loew (40, p. 40) proposed that there was a specific Ca:Mg ratio in soils for proper plant growth. Though many instances of Ca-Mg interrelations have been noted since then, the idea of controlling ratio has, in general, been refuted (39, 47). Hunter (47), studying the yield and composition of alfalfa as affected by variations in the Ca:Mg ratio found no optimum ratio for yield, though the ratio treatment had significant effects on the Ca and Mg percentages in the plant. Other workers (24, 34) report similar results and note that differences in growth are associated with amounts of Ca and Mg rather than the ratio.

Reports in the literature concerning the effect of lime or Ca on the uptake of Mg often vary in the direction of the effect. Carolus (12) and Hester, et al. (25, p. 1349) working with Virginia coastal plain soils reported an increase in Mg uptake in liming. Liming these acid soils increased the amount of Mg adsorbed by the soil colloids, making it more available for plant uptake and causing less to be lost through leaching. Liming replaces Al with Ca and Mg can compete with Ca better than with Al for adsorption sites.

On the other hand, Zimmerman (67) reports that, at high levels of fertility, liming can be harmful unless adequate Mg is also applied. Foy and Barber (20) indicate that Mg deficiency symptoms in corn were not accompanied by yield decreases. Lime applications gave slight decreases in Mg uptake, but did not significantly increase the Mg deficiency symptoms. Jacoby (32) studied the influence of Ca:Mg ratios in the root medium on Mg uptake by citrus seedlings. Using a split root technique he found that decreased Mg uptake was not due to low Mg availability, but to an excess of Ca.

Van Itallie (63, p. 177) found Ca had no influence on Mg uptake by Italian rye grass; however, Mg lowered the Ca content. He also found no satisfactory relationship between the concentration of an ion in the soil and that in the plant. Jackson and Evans (31), in sand culture experiments with soybean seedlings, noted that increasing Ca supply restricted Mg accumulation in tops, but did not reduce accumulation of Mg by the roots. Moser (48) measured Ca and Mg contents of soybeans, lespedeza, and sorghum at 3 pH ranges: 3. 8 - 4. 2, 5. 0-5. 3, and 6. 0 - 6. 5. Mg percentages and total contents increased proportionately to the Ca supplied in the first two pH ranges, but no change in Mg was noted at the high pH range (6. 0 - 6. 5). York, Bradfield, and Peech (66) found differences in the effect of Ca on Mg uptake in different crops. Lime consistently reduced the Mg uptake of alfalfa, and increased the Mg uptake of corn. With sudan grass the first increment of lime added (one ton) increased the uptake of Mg, and further increments (up to 12 tons) decreased the uptake of Mg. Adams and Henderson (1), using ladino clover and sudan grass on seven Alabama soils, noted that total Mg uptake (with both crops) tended to be less at pH 6. 5 than at 5. 5 on Mg deficient soils but greater at pH 6. 5 on Mg sufficient soils.

An effect of Ca on Mg uptake has also been reported in ion uptake studies using excised barley roots. Epstein and Leggett (17) show that Ca and Mg are taken into the root over separate sites, and that there is no common carrier to account for competition in the uptake of these ions. Mg has been found to be rapidly and metabolically absorbed into similar excised roots, and a large fraction of the Mg absorption is very effectively blocked by a small amount of Ca (44). Ca is thought to act by altering the permselective properties of the cell surface region, that is, to form a barrier to Mg absorption.

Terms useful in diagnostic work involving tissue analysis are "critical level", "critical range", or "critical nutrient concentration". All of these terms generally refer to the same idea. Ulrich (62) defines the critical nutrient concentration of an element in the plant as follows:

> The critical nutrient concentration of a plant with respect to growth may be defined either in terms of the nutrient concentration that is just deficient for maximum growth or that which is just adequate for maximum growth, or as the concentration separating the zone of deficiency from the zone of adequacy.

The relation of yield responses to plant composition in Mg would be simplified and organized if a critical level of Mg could be determined.

Critical levels of Mg found for several different crops and tissues are given here, more to give an idea of the range found rather than to try to present an exact value.

Reynolds and Stark (56) state that good growth of cauliflower resulted when the Mg content of the leaves (stage of maturity not given) was 0.35 to 0.75 percent. Carolus (11) selected plants with and without deficiency symptoms based on field observations. Leaf bases with Mg deficiency symptoms averaged 0.092 percent Mg; those without symptoms had 0.165 - 0.178 percent Mg. Leaf tips with deficiency symptoms contained 0.037 percent Mg; those without symptoms had

0.076 - 0.119 percent Mg. Cabbage tops in the seedling stage showing Mg deficiency symptoms contained 0.43 percent Mg, and those without symptoms contained 0.56 - 0.57 percent Mg (51).

About 0.5 percent Mg was concluded to be the critical level for red clover (greenhouse) by Tucker and Smith (61). A composite sample of plant material from four harvests was analyzed. Interestingly enough, this value comes from the only soil of four studied that showed Mg response. This soil had the second highest exchangeable Mg level of the four, and the highest cation exchange capacity, exchangeable Ca, K, and Na (61).

Maximum Mg contents of Mg deficient ladino clover and sudan grass grown in the greenhouse were 0.27 percent and 0.29 percent respectively (1). The two crops were grown for 90 and 60 days respectively and the above ground portions of the plant were analyzed.

Under greenhouse conditions, critical levels for Mg are given as approximately 0.20 percent Mg for soybeans and approximately 0.10 percent Mg for corn(34). The plants were grown 30 days and analyses were run on total plant material (maturity not stated).

McMurtrey (42) states that when tobacco leaf contains 0.15 percent Mg, deficiency symptoms will usually be evident. When the Mg content is above 0.25 percent, leaves are usually free of symptoms. While these values are in general agreement with the others stated they relate the Mg concentrations to deficiency symptoms and not to yield.

EXPERIMENTAL METHODS

Soil Characterization

Experimental sites were chosen on two experiment stations in Clackamas County, Oregon. They were the North Willamette Branch Experiment Station near Aurora and the Red Soils Experiment Station at Oregon City.

Selection of these sites was based on several factors. First, the exchangeable Mg and K levels at the Red Soils location were low enough that responses to these elements would be expected. Exchangeable cation levels at the North Willamette location were high enough that K and Mg responses probably would not be obtained. The site was chosen, however, to obtain yield information and plant analysis data related to a soil whose K and Mg levels were considered to be on the high side of adequacy. Secondly, these soils are representative of those on which broccoli is grown. The use of experiment station land was appropriate because of the ready availability of facilities for irrigation, insect and disease control measures, and labor for the care and harvesting of the crop.

The soil at the North Willamette Branch Station is a Prairie soil, probably within the Willamette series but differing somewhat from the normal concept of Willamette in texture, drainage and shot content[1].

[1] E. G. Knox. Personal communication (Memo on North Willamette Station)

It contains more sand and less silt, and has slightly more shot than is typical for Willamette. It is developed from water-deposited silts and has a weakly developed fragipan. The soil is relatively uniform over the experimental area and is well drained. The plow-layer has a silt loam or loam texture, and the B horizon has a clay texture.

The soil at the Red Soils Experiment Station is a Reddish Brown Latosol developed from residuum from basalt and is mapped as an Olympic soil (38). It is well drained and has a silt loam surface texture and a clay loam B horizon texture.

The following soil test results were obtained by analysis of samples obtained through random sampling of each replication (0-6'' depth) prior to the application of fertilizer in the spring of 1959.

Clay minerals identified by X-ray diffraction methods in the 0-8 inch depth of the Willamette soil include a montmorillionite-vermiculite interlayer material and illite. These two materials appear to be present in equal amounts. [1]

The Olympic soil (0-7 inch depth) has been reported to contain vermiculite and chlorite, with a possibility of the presence of small amounts of kaolin and illite (21, p. 32-33). This vermiculite was thought to possibly be interlayered with some other material.

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[1] Information supplied by Mac Etter, Soils Department, Oregon State University.

		pH	P(ppm)	Exchangeable Bases[1] m. e. /100 g. K	Ca	Mg	CEC[2] m. e./100g
Willamette Soil							
Rep	I	5.5	61.3	0.67	7.8	1.20	16.8
	II	5.7	52.3	0.63	7.1	1.35	17.8
	III	5.5	49.3	0.67	7.4	1.70	17.4
	IV	5.7	53.3	0.67	6.8	1.35	16.7
Olympic Soil							
Rep	I	5.6	6.5	0.38	4.7	0.80	15.6
	II	5.4	9.8	0.48	4.8	0.90	16.3
	III	5.5	6.5	0.54	6.1	1.00	17.2
	IV	5.3	5.3	0.49	4.9	1.00	16.5

[1] Analyses performed by the Oregon State University Soil Testing Laboratory.

[2] CEC cation exchange capacity.

Experimental Design and Statistical Analysis

The experimental design consisted of treatments selected to give a series of factorial combinations. These factorials allow the measurement of interaction effects and, through the effect of additional replication, also increase precision in the estimation of the main effects of the individual elements. The following factorials are included within the design:

(a) a 2 x 2 x 2 lime x Mg x K factorial with levels of L_0 and L_1, Mg_0 and Mg_2, and K_0 and K_2 (treatments 1 through 8) all at N_1.

(b) a 2 x 2 x 2 lime x Mg x N factorial with levels of L_1 and L_2, Mg_0 and Mg_2, and N_1 and N_2 (treatments 4, 8, and 14 through 19) all at K_2.

(c) a 3 x 3 K x Mg factorial with levels of K_0, K_1, and K_2, and Mg_0, Mg_1, and Mg_2 (treatments 2, 4, 6, and 8 through 13) all at L_1N_1.

(d) a 3 x 2 lime x Mg factorial with levels of L_0, L_1, and L_2, and Mg_0 and Mg_2 (treatments 3, 4, 6, 8, 14 and 15) all at K_2N_1.

P and S levels were held constant in these factorials at the P_2 and S_1 levels respectively. This design was replicated four times.

Table 1 gives the treatment numbers, treatment level combinations, and rates of fertilizer application. Treatments making up N x P and N x S factorials were also included in the experimental design in order to give information as to the phosphorus and sulfur responses that would be obtained. Six added treatments were needed to measure these effects. These bring the total number of treatments in the whole design up to 25. The extra treatments are not included in Table 1. Since this thesis is primarily concerned with the effects of lime, Mg, and K on broccoli growth, yield and plant analysis data obtained from the P and S treatments are tabulated in Appendix Tables 1-7, 13.

Yield data from the entire experiment (25 treatments and 4

Table 1. Treatment Combinations, Treatment Levels and Source of Fertilizer Elements. Willamette and Olympic Soils. 1959-1960.

No.	Treatment Combination						No.	Treatment Combination					
	Lime	K	Mg	N	P	S		Lime	K	Mg	N	P	S
(1)	0	0	0	1	2	1	(10)	1	2	1	1	2	1
(2)	1	0	0	1	2	1	(11)	1	1	1	1	2	1
(3)	0	2	0	1	2	1	(12)	1	0	1	1	2	1
(4)	1	2	0	1	2	1	(13)	1	1	0	1	2	1
(5)	0	0	2	1	2	1	(14)	2	2	0	1	2	1
(6)	1	0	2	1	2	1	(15)	2	2	2	1	2	1
(7)	0	2	2	1	2	1	(16)	1	2	0	2	2	1
(8)	1	2	2	1	2	1	(17)	1	2	2	2	2	1
(9)	1	1	2	1	2	1	(18)	2	2	0	2	2	1
							(19)	2	2	2	2	2	1

Treatment Levels

Willamette Soil		Olympic Soil		Source
L_0	= no lime added (8.6 m.e. bases originally)	L_0	= 3 m.e. lime added to raise level of bases to that of Willamette soil	$Ca(OH)_2$
L_1	= 95% base saturation	L_1	= 95% base saturation	
L_2	= 120% base saturation	L_2	= 120% base saturation	
K_1	= 100 lbs. K_2O/A	K_1	= 120 lbs. K_2O/A	K Cl
K_2	= 200 lbs. K_2O/A	K_2	= 200 lbs. K_2O/A	
Mg_1	= 40 lbs. Mg/A	Mg_1	= 40 lbs. Mg/A	$MgSO_4 \cdot 7\,H_2O$
Mg_2	= 120 lbs. Mg/A	Mg_2	= 120 lbs. Mg/A	
N_1	= 150 lbs. N/A	N_1	= 150 lbs. N/A	NH_4NO_3
N_2	= 300 lbs. N/A	N_2	= 300 lbs. N/A	

Willamette soil plots received 120 lbs. P_2O_5 per acre.
Olympic soil plots received 180 lbs. P_2O_5 per acre.
P as concentrated superphosphate was banded at transplanting.
All plots received blanket applications of boron. (4 lbs. B/A at planting plus folier spray) and molybdenum (1 lb. Mo/A)
All materials except P were broadcast and worked in prior to planting.

replications) was analyzed using analysis of variance[1]. A model of the analysis of variance is given below:

Source of Variation	Degrees of Freedom
Total	99
Replication	3
Treatment	24
Error	72

As mentioned earlier, within the first 19 treatments are a series of factorials. A separate analysis of variance was performed on the treatments of each of these factorials. The significance of the various main and interaction effects was determined using the appropriate effect mean square and the error mean square determined for the experiment as a whole. The models for these analyses of variance can be seen in Tables 3 and 8.

Rates of Fertilizer Application and Source of Fertilizer Elements

Table 1 gives information as to rates of application and source of fertilizer elements. Fertilizer applications were made prior to both the 1959 and 1960 crops. These applications were the same in both years with the exception of the rate of lime application and the timing of the N application. These differences will be covered in later paragraphs.

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[1] Statistical analyses courtesy of the Agricultural Experiment Station Statistical Service, Oregon State University.

All fertilizer treatments except P were broadcast and worked into the surface 3-5 inches of soil two and one-half to three months prior to planting the crop. P was banded at planting time.

Hydrated lime, containing less than 1/4 percent $Mg(OH)_2$ as an impurity, was used as a lime source to reduce Mg contamination of the lime treatments. The lime levels used in the experimental design were based on percentage base saturation, and rates of application were calculated so that 95 percent base saturation might be reached at the L_1 level and 120 percent base saturation might be reached at the L_2 level. No lime was added to the Willamette soil at the L_0 rate; however, on the Olympic soil, approximately 3 milliequivalents of Ca were added to bring the base saturation up to a level similar to that of the Willamette soil. The soil analysis values given in Tables 17 and 18 will indicate the actual levels of exchangeable Ca obtained by the hydrated lime applications. The milliequivalents of Ca added per 100 grams of soil are given below:

	Amounts added in m. e. /100 g. of soil		
Lime Level	1959	1960	Total
Willamette Soil			
L_0	0	0	0
L_1	5.4	2.7	7.9
L_2	8.1	4.0	12.1
Olympic Soil			
L_0	3	0	3
L_1	6.8	2.2	9.0
L_2	10.1	2.2	12.3

In 1959 all the N fertilizer necessary to establish both N levels was added to the plots prior to planting. However, in 1960, all plots received the N_1 rate (150 pounds of N per acre) before planting; then the N_2 level was established, three weeks before the first harvest, by sidedressing the additional 150 pounds of N necessary.

Since sulfur was contained in the Mg fertilizer (epsom salts - $MgSO_4 \cdot 7\,H_2O$), the amount of S added varied with the Mg level. To balance this variation sufficient S (as gypsum) was applied to the Mg_0 and Mg_1 treatments to make the total S application equivalent to that needed at the Mg_2 level.

Cultural and Harvest Methods

The treatments were established on plots 13 x 40 feet at the North Willamette location and 13 x 35 feet at the Red Soils location. Each plot contained four rows of broccoli, the two center rows being harvested for yield records and the two outer rows being used as border rows.

Broccoli of the Eastern Waltham variety was transplanted at the North Willamette location on July 6, 1959 and July 14, 1960, and for the Red Soils location on July 8, 1959 and July 15, 1960. The planting date in 1960 was set back this period of time in order to reduce the amount of "bolting" of heads. Evidence obtained in 1959 and previous years indicated the planting date was of critical importance with regard to bolting. High temperatures are conducive to bolting, and a later planting date, in effect, replaces one or two weeks of growth in a period of high mean daily temperatures with a similar period of growth in the late fall.

Rows were spaced 39 inches apart and the individual plants were set 18 inches apart in the rows. Irrigation, cultivation, and weed and insect control were carried out by the personnel of the experiment stations. Sprinkler irrigation was used to maintain the soil in a moist condition or to maintain at least 50 percent usable moisture in the surface foot.

In 1959 harvest of the plots began September 2nd and continued for nine consecutive weekly harvests. In 1960, harvests began September 14 and continued at weekly intervals for six weeks. All broccoli cut was trimmed to a six-inch length and excess foilage was removed. Heads and spears were counted and graded and the weight of each class of yield was taken.

In 1959 heads were divided into two grades:

(a) Good heads - compact heads, with good conformation and color. Marketable without being trimmed into spears.

(b) Cull heads - those showing poor color, poor conformation, or excessive looseness. Unmarketable unless cut into spears.

Spears were not graded.

In 1960, both heads and spears were classified as follows:

(a) Number 1 broccoli - compact curds with good conformation and color. Number 1 heads were marketable without being trimmed into spears.

(b) Number 2 broccoli - those with poor conformation, poor color, or looseness. This grade of head would have to be trimmed to spears to be marketable.

(c) Cull broccoli - those with excessive looseness, with dead areas in the curd, or those overmature for causes other than late harvest. This class was unmarketable.

These grades were set up to obtain information concerning the effect of fertility levels on quality of product. It was also intended that they would roughly correspond to the type of grading imposed by the packer.

Several different yield categories are used throughout this work. The most important of these are defined below:

(a) Total Yield - total weight of heads and spears harvested including all harvests and grades unless qualified otherwise.

(b) Yield of heads or yield of spears - total weight of heads or spears from all harvests, possibly qualified by grade.

(c) Group I Yield - (Used in 1960 results only) total yield of heads and spears for the first three harvests.

(d) Average weight per head or spear - total weight of heads or spears divided by the number of heads or spears harvested.

(e) Number of spears per plant - total number of spears harvested divided by the number of plants in the particular plot.

Yield data presented in the body of this thesis is in summary form. A more complete tabulation of yield observations is given in

Appendix Tables 1 through 9.

Regression Analysis

One of the objectives of this study was to relate yield responses to the exchangeable Ca, Mg, and K in the soil and to the content of these cations in the plant tissue. Further, the plant content of Ca, Mg, and K should be a function of the levels of these cations in the soil. These relationships can be identified using multiple regression techniques.

Data used in developing these equations included three yield categories: (1) total yield of heads and spears for six harvests, (2) total yield of heads for six harvests, and (3) Group I yield, that is, the total yield of heads and spears from the first three harvests. Soil analysis values used were from the July 1960 sampling. Plant composition data used were from the first and second sampling, 1960, oldest mature leaves. All these data were from individual plots within the experiment. All treatments used (numbers 1-15) were at a single N level (N_1).

Few, if any, assumptions could be made regarding the shape of the curve that would best fit the data. Empirically, these relations are seldom observed to be linear; thus, it would appear reasonable to use a polynomial approximation of the unknown function. In order to possibly obtain a curvilinear relationship, while keeping the number of regression coefficients to be estimated at a minimum, some of the equations involved logarithmic or reciprocal transformations.

Briefly, the regression technique used was a step-wise procedure. Variables in the basic polynomial equation to be fitted were entered one at a time in order of their simple correlation coefficients. Thus at each step the model was different, i. e., one more term was included. A complete new set of coefficients was estimated for each step which was different, in general, from the estimators of the previous reduced model. Also, at each step in the procedure other statistics such as effect constants, standard errors of Y, standard errors of the b's, and correlation coefficients were calculated. In this way, an estimate of the fit of the data to each stepwise equation was obtained.

Segments of the results of the regression analysis will be used in the discussion of yield results and relation of plant composition to soil analysis.

The models used in the regression procedure were chosen on the basis of relationships noted in preliminary examination of the data. They are given in the table that follows.

	Regression Equations
(a) Total, head, and Group I yields	$= b_0 + b_1 \log Ca_{ex} + b_2 \log K_{ex} + b_3 \log Mg_{ex} + b_4 \log Ca_{ex} \times \log Mg_{ex}$.
(b) Total, head, and Group I yields	$= b_0 + b_1\ Ca_{ex}/Mg_{ex}$
(c) Total, head, and Group I yields	$= b_0 + b_1\ Mg_{1st} + b_2\ Ca_{1st} + b_3\ K_{1st} + b_4\ Ca_{1st} \times Mg_{1st}$
(d) Total, head, and Group I yields	$= b_0 + b_1\ Mg_{2nd} + b_2\ Ca_{2nd} + b_3\ K_{2nd} + b_4\ Ca_{2nd} \times Mg_{2nd}$
(e) Mg_{1st} Mg_{2nd}	$= b_0 + b_1 \log Mg_{ex} + b_2 \log Ca_{ex} + b_3 \log Ca_{ex} \times \log Mg_{ex} + b_4 \log K_{ex}$
(f) Mg_{1st} Mg_{2nd}	$= b_0 + b_1 \dfrac{1}{Ca_{ex}/Mg_{ex}} + b_2\ K_{ex}$
(g) K_{1st} K_{2nd}	$= b_0 + \log K_{ex} + b_2 \log Ca_{ex} + b_3 \log Ca_{ex} \times \log K_{ex}$
(h) Ca_{1st} Ca_{2nd}	$= b_0 + b_1\ Ca_{ex} + b_2\ K_{ex}$

Where: Total yield = total yield of heads and spears in tons per acre, all harvests.

Head yield = total yield of heads in tons per acre, all harvests.

Group I yield = total yield of heads and spears in tons per acre, first three harvests.

Mg_{ex}, Ca_{ex}, K_{ex} = m. e. of exchangeable Mg, Ca, or K per 100 grams of soil.

Mg_{1st}, Ca_{1st} or K_{1st} = plant content of Mg, Ca or K in m. e. per 100 grams of dry matter. Oldest mature leaves, 1st sampling.

Mg_{2nd}, Ca_{2nd}, or K_{2nd} = plant content of Mg, Ca, or K in m. e. per 100 grams of dry matter. Oldest mature leaves, 2nd sampling.

b_0 = constant in regression.

b_1, b_2, etc. = regression coefficients describing the changes in yield or plant composition with changes in the appropriate variable.

Soil Sampling and Analysis

Soil samples were taken from individual plots on both the Willamette and Olympic soils in April 1960 prior to the addition of fertilizer for the 1960 crop, and in July 1960 after fertilizer addition and just prior to planting of the crop. These samples were taken from between the record rows of each plot and were analyzed for pH and exchangeable Ca, Mg, and K using the methods of the Oregon State University Soil Testing Laboratory (2).

Plant Sampling and Analysis

The plant content of a nutrient is known to change over a period of time and vary according to the plant part sampled (62). In order to follow these variations as they affect the content of Ca, Mg, and K in broccoli, the plants on each plot on the Willamette and Olympic soils were sampled at three different times during the 1959 and 1960 growing seasons. Leaves of different stages of maturity were taken at each sampling. These data were used to evaluate the time of sampling and type of leaf to be sampled to give the best relationship to the growth of broccoli.

The sampling procedure consisted generally of taking a single leaf (not including petiole) of the appropriate type from 10 to 15 plants in the record rows of each plot. The leaf samples were dried at 65° C. and ground in an Osterizer blender. One gram samples were digested with nitric and perchloric acids and Ca and Mg determined by versenate titration (33, p. 32, 35-37). K was determined flame photometrically with a Beckman Model DU spectrophotometer.

Both the 1959 and 1960 crops were sampled. Dates of sampling and the leaves taken in each sampling are given in the following list:

Sampling and Date	Type of leaf
	1959 - Willamette and Olympic Soils
1st Sampling August 27,	(a) recently matured leaf (b) oldest mature leaf
2nd Sampling September 16,	(a) recently matured leaf (b) middle leaf (3rd or 4th leaf up from base of plant) (c) oldest mature leaf
3rd Sampling October 9,	(a) recently matured leaf.

Sampling and Date	Type of leaf
	1960 - Willamette and Olympic Soils
1st Sampling August 29,	(a) recently matured leaf. (b) oldest mature leaf.
2nd Sampling September 23,	(a) recently matured leaf from plant with head harvested (b) recently matured leaf from plant with head not yet harvested (c) oldest mature leaf
3rd Sampling October 13,	(a) recently matured leaf.

The first sampling was within seven to 14 days of the start of harvest. In 1959 the second sampling was just after the third harvest; in 1960 this sampling was between the second and third harvests in order to obtain leaves from plants with and without heads. The second sampling leaves were taken at a time within the period of peak harvests. The third sampling was taken after the sixth harvest in 1959 and after the fifth harvest in 1960. These dates correspond generally to the end of productive harvests. Only recently matured leaves could be obtained at this time because the older leaves had abscissed and most other leaf bearing portions of the plant had been removed.

RESULTS AND DISCUSSION

The yield effects obtained have been evaluated in two ways. First, treatment means have been compared and standard statistical analyses run. These comparisons were on the basis of treatment levels. Soil test and plant analysis data were not included. Secondly, data from individual plots (yield, soil test, and plant analysis) were entered into a multiple regression analysis. Specific equations were chosen to be fitted to the data. Generally, more than one nutrient element variable was incorporated in these equations so that yields might be related to more than one element at a time. This was done in order to obtain better relationships by attempting to account for the interaction between the effects of each of the nutrients on yield.

The results of these two types of evaluation are thus presented in separate sections. Further, the use of treatment means in one case and of individual plot data in the other results in some relationships being significant in one analysis and not in the other.

Effect of Treatments on Yield

Yields obtained in 1959 were smaller at both locations than those of 1960. Further, the 1960 yields were taken in six harvests while nine were required in 1959. These lower yields were, in general, due to a pronounced bolting of heads which took place in 1959. "Bolting" is the premature formation and rapid maturation of a head of poor quality.

In 1959 approximately 20-30 percent of the heads at the North Willamette location and 40-60 percent of the heads at the Red Soils location bolted. Since they would be unmarketable, these heads were removed prior to the regular harvests to allow the plants to begin producing side shoots (spears). This reduced the head and total yields to an unknown extent. The removal of heads caused spear production to begin earlier and continue longer than on non-bolted plants. In this way, losses in head yield were probably partially compensated.

Bolting is generally attributed to an excessively early transplanting date. Since broccoli is generally transplanted from the seed bed in the first part of July, an earlier date would subject the plants to higher temperatures and moisture stresses for a longer portion of the growing period than would normally occur.

In 1959 broccoli was transplanted at the earliest recommended date to try for maximum yields. If bolting did not occur, then higher yields would result and harvests would be completed before the fall rains. In 1960, transplanting was done a week later and resulted in nearly normal growth with very little bolting.

Since yields in 1959 were affected by this unknown quantity and the 1960 yields more closely approximated those obtained by growers, the 1959 yields were given less consideration in this work than those of 1960.

Willamette Soil - North Willamette Location - 1959

Large yield responses were not expected on this soil as it was fairly high in bases; the levels of both exchangeable Mg and K were on the borderline regarding the need for supplemental fertilizer application. Responses to Mg have not been observed at similar Mg levels in previous fertility work done in the Willamette Valley. However, less than 10 percent of the exchange capacity was saturated with Mg, which is the Mg saturation considered by Prince _et al_ (55) to be optimum for crop growth. Preliminary soil analyses for this location have been presented earlier on p. 24.

In 1959 nine harvests were taken and the yields segregated into several classes: total yield, yield of heads of good or poor quality (cull heads), yield of spears, and several others. Descriptions of these yield classes are included in the section on experimental methods. An analysis of variance (Tables 2 and 3) was performed on total yield results for the various factorials included in the experiment. Least significant differences are generally given to indicate the magnitude of response necessary for significance.

A significant response of total yield to N was obtained on the

Willamette soil (Tables 3 and 4). Yield data (tons per acre) extracted from the lime x Mg x N factorial are given below to illustrate the response.

at Mg_0:

	L_1	L_2
N_1	4)5.26	14)4.99
N_2	16)5.20	18)5.61

at Mg_2:

	L_1	L_2
N_1	8)5.44	15)5.14
N_2	17)5.67	19)5.43

Besides showing the significant yield increases due to the application of the high rate of N, these data indicate some probability of a lime x N interaction. Averaging across Mg levels, N increased yield 0.09 tons per acre at L_1 and 0.45 tons per acre at L_2. The addition of the highest rate of lime generally decreased yields except at Mg_0N_2 where a yield increase occurred.

The application of lime, K, or Mg did not produce responses large enough to be significant on this soil. However, the application of the first rate of lime (L_0 to L_1) increased total yield where K or K and Mg had been applied (compare treatments 3, 5, 7, averaging 5.05 tons per acre _vs._ 4, 6, 8 averaging 5.31 tons per acre - Table 4).

Meaningful differences in response patterns were not evident in comparing "total yields of the first six harvests" with "total yield of nine harvests". The variability of the six harvest data was somewhat greater than for the nine harvest information, and significant responses were not evident.

Table 2. Summary of Basic Analysis of Variance for Total Yield of Nine Harvests and Total Yield of the First Six Harvests. Willamette and Olympic Soils. 1959.

Source of Variation	Degrees of Freedom	9 Harvests		6 Harvests	
		Mean Square	F	Mean Square	F
Willamette Soil					
Replication	3	2.2952	18.05**	1.9308	12.93**
Treatment	24	0.3502	2.76**	0.2525	1.69*
Error	72	0.1269	---	0.1493	---
Olympic Soil					
Replication	3	0.2618	0.78	0.5980	1.95
Treatment	24	2.2430	6.71**	1.2510	4.08**
Error	72	0.3341	---	0.3067	---

* Effect significant at the 5% probability level

** Effect significant at the 1% probability level

Table 3. Summary of Analysis of Variance of Total Yield Data. Sum of 9 Harvests. Willamette and Olympic Soils. 1959.

Source of Variation	Degrees of Freedom	Willamette Soil	Olympic Soil
Error Mean Square	72	0.1269	0.3341
		F values	
L x K x Mg	1	0.46	0.031
L	1	2.52	1.11
K	1	0.84	2.85
Mg	1	0.057	0.10
L x K	1	0.038	0.61
L x Mg	1	0.23	0.001
K x Mg	1	1.93	0.86
L x N x Mg	1	1.52	0.38
L	1	0.63	2.89
Mg	1	1.51	0.36
N	1	4.60*	0.30
L x Mg	1	1.82	1.85
L x N	1	2.26	2.12
N x Mg	1	0.006	0.019
K x Mg	4	0.77	0.41
K	2	2.19	2.54
Mg	2	0.14	0.066
L x Mg	2	0.025	0.14
L	2	1.43	0.99
Mg	1	1.65	0.52

* Effect significant at the 5% probability level.
F value required for significance at the 5% level:
with 1 and 72 d.f. = 3.99
2 and 72 d.f. = 3.14
4 and 72 d.f. = 2.50

Table 4. Two-way Table of Total Yield of Broccoli in Tons per Acre. Sum of Nine Harvests and Sum of First Six Harvests. Means of Four Replications. Willamette Soil. 1959.

	N_1			N_2	
	L_0	L_1	L_2	L_1	L_2
Mg_0K_0	(1)5.18* 3.87#	(2)5.21 3.75			
Mg_0K_1		(13)5.00 3.94			
Mg_0K_2	(3)5.01 3.56	(4)5.26 3.87	(14)4.99 3.74	(16)5.20 3.71	(18)5.61 4.09
Mg_1K_0		(12)5.20* 4.04#			
Mg_1K_1		(11)5.22 3.80			
Mg_1K_2		(10)5.24 3.85			
Mg_2K_0	(5)4.89* 3.59#	(6)5.21 3.96			
Mg_2K_1		(9) 4.82 3.52			
Mg_2K_2	(7)5.24 3.85	(8)5.44 3.92	(15)5.14 3.92	(17)5.67 4.18	(19)5.43 4.04

* Total yield for 9 harvests.

\# Total yield for first 6 harvests.

Least Significant Differences (5% level)	9 Harvests	6 Harvests
Comparing 2 treatment means	0.50 T/A	0.55 T/A
Comparing averages of 2 treatment means	0.36 T/A	0.39 T/A
Comparing averages of 3 treatment means	0.29 T/A	0.31 T/A

In summary, on the Willamette soil in 1959, increasing the N rate from 150 to 300 pounds per acre produced significant responses in total yield. This N response was larger at the high rate of lime, L_2, than at L_1. A lack of response to K and Mg was to be expected in view of the rather high levels of exchangeable K and Mg present in the soil. However, yields were generally largest where both K and Mg had been applied at the first rate of added lime.

Olympic Soil - Red Soils Location - 1959

Total yields of nine harvests for 1959 are given in Table 6 with an analysis of variance for the experiment as a whole being given in Table 2. Analyses of variance for the factorials within the experiment are given in Table 3.

The levels of exchangeable K and Mg in the Olympic soil prior to the experiment were lower than in the Willamette soil (p. 24 of "Experimental Methods" section). Initially, the exchangeable K and Mg levels were approximately 0.45 and 0.90 milliequivalents per 100 grams respectively. On the basis of these analyses, responses to K and possibly Mg would be expected.

An increase in total yield (nine harvests) from K occurred at L_1 and at all Mg levels (treatments 2, 12, 6 averaging 4.10 tons per acre _vs._ 4, 10, 8 averaging 4.61 tons per acre - Table 6). These data are shown below:

	Mg_0	Mg_1	Mg_2
K_0	2) 4.12	12) 4.20	6) 3.97
K_2	4) 4.40	10) 4.74	8) 4.70

all at L_1

The F value for K was not significant when all K effects were analyzed but, an LSD of 0.41 tons per acre for comparing three treatment means indicates the probability that this response should be considered.

Additions of Mg increased total yield at $L_0K_2N_1$, $L_1K_2N_1$, and $L_1N_2K_2$ (treatments 3, 4, 16 - averaging 4.40 tons per acre vs. 7, 8, 17 - averaging 4.76 tons per acre - Table 6). Thus, on the Olympic soil as on the Willamette, the highest yields at the N_1 rate of nitrogen occurred where both K and Mg were applied together.

Average weights of good quality heads, though quite variable, were increased by K as were total yields (Table 7). Average head weight data (grams), extracted from Table 7, show this:

at Mg_0:

	L_0	L_1
K_0	139	157
K_2	175	184

at Mg_2:

	L_0	L_1
K_0	135	148
K_2	171	163

The combined result of these effects was that, at the 150 pound N rate, when lime, K, and Mg were applied together, a considerable increase in yield resulted. This increase was larger than it would have been if each of these elements had been applied separately.

Table 5. Two-way Table of Average Weights of Good Quality Heads[1] (Grams per Head). Means of Four Replications. Willamette Soil. 1959.

	N_1			N_2	
	L_0	L_1	L_2	L_1	L_2
Mg_0K_0	(1) 244	(2) 216			
Mg_0K_1		(13) 226			
Mg_0K_2	(3) 229	(4) 240	(10) 253	(16) 245	(18) 245
Mg_1K_0		(12) 230			
Mg_1K_1		(11) 239			
Mg_1K_2		(10) 242			
Mg_2K_0	(5) 221	(6) 234			
Mg_2K_1		(9) 215			
Mg_2K_2	(7) 235	(8) 224	(15) 242	(17) 254	(19) 244

[1] Yield categories defined in "Experimental Methods" section.

Table 6. Two-way Table of Total Yield of Broccoli in Tons per Acre. Sum of Nine Harvests and Sum of First Six Harvests. Means of Four Replications. Olympic Soil. 1959.

	N_1			N_2	
	L_0	L_1	L_2	L_1	L_2
Mg_0K_0	(1)4.04* 2.77#	(2)4.12 2.83			
Mg_0K_1		(13)4.29 2.75			
Mg_0K_2	(3)4.07 2.53	(4)4.40 2.84	(14)4.50 2.97	(16)4.71 3.13	(18)4.47 2.98
Mg_1K_0		(12)4.20* 2.53#			
Mg_1K_1		(11)4.07 2.73			
Mg_1K_2		(10)4.74 3.31			
Mg_2K_0	(5)3.94* 2.71#	(6)3.97 2.68			
Mg_2K_1		(9)4.38 3.23			
Mg_2K_2	(7)4.28 2.78	(8)4.70 3.10	(15)4.50 3.04	(17)5.21 3.33	(19)4.16 2.27

* Total yield for 9 harvests.

\# Total yield for first 6 harvests.

Least Significant Differences (5% level)	9 Harvests	6 Harvests
Comparing 2 treatment means	0.82 T/A	0.78 T/A
Comparing averages of 2 treatment means	0.53 T/A	0.55 T/A
Comparing averages of 3 treatment means	0.47 T/A	0.45 T/A

Table 7. Two-way Table of Average Weights of Good Quality Heads[1] (Grams per Head). Means of Four Replications. Olympic Soil. 1959.

	N_1			N_2	
	L_0	L_1	L_2	L_1	L_2
Mg_0K_0	(1) 139	(2) 157			
Mg_0K_1		(13) 142			
Mg_0K_2	(3) 175	(4) 184	(14) 140	(16) 160	(18) 177
Mg_1K_0		(12) 129			
Mg_1K_1		(11) 154			
Mg_1K_2		(10) 176			
Mg_2K_0	(5) 135	(6) 148			
Mg_2K_1		(9) 170			
Mg_2K_2	(7) 171	(8) 163	(15) 182	(17) 191	(19) 148

[1] Yield categories defined in "Experimental Methods" section.

Willamette Soil - 1960

Levels of exchangeable K and Mg were fairly high at this location prior to the 1960 fertilization (approximately 0.5 - 0.6 milliequivalents exchangeable K and 1.0 - 1.2 milliequivalents exchangeable Mg per 100 grams).

Visual observations during the growing season showed no readily apparent differences between treatments and growth was excellent overall. Notes taken showed that Mg deficiency symptoms were scattered on the low Mg plots; though in no case did the number of plants showing these symptoms exceed 10 percent.

Tables 9, 10, 11, and 12 show results of the various yield measurements taken in 1960 on the Willamette soil. Analyses of variance performed on three yield categories (head yield, spear yield, and total yield) for the 1960 crop are given in Table 8. Results of these analyses indicated that significant responses to lime, Mg, or K were not found. However, some of the yield increases from K and Mg were fairly large and approached significance.

Yield of spears and total yield (heads plus spears) were increased by the application of the high rate of N. The increase in spear yield was statistically significant. Total and spear yield data (tons per acre) extracted from Table 9 are given below.

Table 8. Summary of Analysis of Variance for Head, Spear, and Total Yields. Willamette and Olympic Soils. 1960.

Source of Variation	Degree of Freedom	Willamette Soil			Olympic Soil		
		Heads	Spears	Total	Heads	Spears	Total
Error mean square	72	0.0701	0.2579	0.4285	0.0768	0.2453	0.3772
		F values for each yield class					
Treatment	24	0.61	1.13	0.76	2.58**	4.76**	6.74**
Replication	3	0.84	0.31	0.28	2.61	1.14	1.47
L x Mg x N	1	1.38	0.25	0.76	0.87	0.22	0.00
L	1	0.00	1.71	1.05	1.08	0.12	0.56
Mg	1	1.38	0.22	0.69	5.87**	1.96	4.93*
N	1	0.01	4.24*	2.66	0.98	11.57**	10.17**
L x Mg	1	0.03	1.71	0.93	0.48	1.37	1.58
L x N	1	1.26	1.79	0.33	0.04	7.07**	4.84*
Mg x N	1	0.35	2.10	1.82	0.42	0.21	0.11
L x K x Mg	1	0.48	0.32	0.02	0.02	0.41	0.24
L	1	0.23	1.47	1.26	2.19	1.54	2.79
K	1	0.01	0.10	0.04	7.31**	3.95*	7.96**
Mg	1	0.03	3.43	2.29	0.21	2.08	0.91
L x Mg	1	0.01	0.21	0.17	3.00	2.99	4.74**
L x K	1	0.94	0.12	0.01	0.04	0.17	0.18
K x Mg	1	0.00	0.43	0.27	0.04	0.92	0.75
L x Mg	2	0.45	0.31	0.18	1.25	0.64	0.75
L	2	1.65	1.82	1.39	2.06	5.57**	6.43**
Mg	1	0.21	1.45	0.56	0.19	2.19	1.81
K x Mg	4	0.29	0.60	0.39	1.04	0.25	0.56
K	2	1.27	2.22	1.64	3.90*	0.70	1.68
Mg	2	0.10	0.19	0.11	0.42	3.77*	3.00

F value needed for significance	1 and 72 d. f.	2 and 72 d. f.	4 and 72 d. f.
* 5%	3.99	3.14	2.50
** 1%	7.03	4.93	3.61

Table 9. Two-Way Table of Total Yield of Broccoli (Heads plus Spears) in Tons per Acre. Sum of Six Harvests. Means of Four Replications. Willamette Soil. 1960.

	N_1			N_2	
	L_0	L_1	L_2	L_1	L_2
Mg_0K_0	(1)2.25 3.04 5.29	(2)2.13# 3.35* 5.48#*			
Mg_0K_1		(13)2.17 2.55 4.72			
Mg_0K_2	(3)2.10 3.04 5.14	(4)2.29 3.00 5.29	(14)2.27 2.67 4.94	(16)2.24 2.78 5.02	(18)2.23 3.11 5.34
Mg_1K_0		(12)2.01# 3.01* 5.02#*			
Mg_1K_1		(11)2.19 2.75 4.94			
Mg_1K_2		(10)2.25 3.21 5.46			
Mg_2K_0	(5)2.16 2.61 4.77	(6)2.19# 2.87* 5.06#*			
Mg_2K_1		(9)2.12 2.76 4.88			
Mg_2K_2	(7)2.14 2.64 4.78	(8)2.20 2.97 5.17	(15)2.45 2.35 4.80	(17)2.50 3.45 5.95	(19)2.30 3.13 5.43

Tons of heads per acre.
* Tons of spears per acre.
#* Tons of heads plus spears per acre (Total yield)

Least Significant Difference (5% level) Total Yield	
Comparing 2 treatment means	0.92 T/A
Comparing average of 2 treatment means	0.65 T/A
Comparing averages of 3 treatment means	0.53 T/A

Table 10. Two-way Table of Yield of Heads (Tons per Acre) and Average Weights of Good Quality Heads (Grams per Head). Means of Four Replications. Willamette Soil. 1960.

	N_1			N_2	
	L_0	L_1	L_2	L_1	L_2
Mg_0K_0	(1)2. 25 182	(2)2. 13* 179*#			
Mg_0K_1		(13)2. 17 183			
Mg_0K_2	(3)2. 10 182	(4)2. 29 194	(14)2. 27 184	(16)2. 24 177	(18)2. 23 183
Mg_1K_0		(12)2. 01* 177*#			
Mg_1K_1		(11)2. 19 176			
Mg_1K_2		(10)2. 25 193			
Mg_2K_0	(5)2. 16 175	(6)2. 19* 168#			
Mg_2K_1		(9)2. 12 176			
Mg_2K_2	(7)2. 14 174	(8)2. 20 176	(15)2. 45 181	(17)2. 50 192	(19)2. 30 167

* Tons of heads per acre.

\# Average head weight in grams per head.

Least Significant Differences (5% level)	Head Yield	Ave. Head Wt.
Comparing 2 treatment means	0. 37 T/A	20. 8 gms.
Comparing averages of 2 treatment means	0. 26 T/A	14. 7 gms.
Comparing averages of 3 treatment means	0. 22 T/A	12. 0 gms.

Table 11. Two-way Table of Distribution of Spear Yield and Total Spear Yield (Tons per Acre). Means of Four Replications. Willamette Soil. 1960.

	N_1			N_2	
	L_0	L_1	L_2	L_1	L_2
Mg_0K_0	(1) 0.19 1.98 0.87 3.04	(2) 0.22[1] 2.25[2] 0.88[3] 3.34[4]			
Mg_0K_1		(13) 0.21 1.67 0.67 2.55			
Mg_0K_2	(3) 0.06 2.20 0.78 3.03	(4) 0.16 2.07 0.76 3.00	(14) 0.05 1.75 0.88 2.67	(16) 0.18 1.79 0.81 2.78	(18) 0.21 2.23 0.67 3.11
Mg_1K_0		(12) 0.13[1] 1.96[2] 0.91[3] 3.00[4]			
Mg_1K_1		(11) 0.30 1.70 0.76 2.75			
Mg_1K_2		(10) 0.13 2.30 0.78 3.21			
Mg_2K_0	(5) 0.15 1.91 0.54 2.61	(6) 0.15[1] 1.63[2] 1.09[3] 2.87[4]			
Mg_2K_1		(9) 0.11 1.74 0.91 2.76			
Mg_2K_2	(7) 0.09 1.80 0.74 2.63	(8) 0.06 1.81 1.10 2.97	(15) 0.10 1.46 0.79 2.35	(17) 0.16 2.19 1.10 3.45	(19) 0.07 1.77 1.30 3.13

[1] Tons spears/A cuts 1 and 2

[2] Tons spears/A cuts 3 and 4

[3] Tons spears/A cuts 5 and 6

[4] Tons spears/A Total

Table 12. Two-way Table of Average Weight per Spear (Grams) and Number of Spears per Plant. Means oi Four Replications. Willamette Soil. 1960.

	N_1			N_2	
	L_0	L_1	L_2	L_1	L_2
Mg_0K_0	(1) 6.9 36	(2) 7.1# 38*			
Mg_0K_1		(13) 5.7 37			
Mg_0K_2	(3) 6.8 37	(4) 6.5 38	(14) 6.2 36	(16) 6.1 38	(18) 6.4 40
Mg_1K_0		(12) 6.7 37			
Mg_1K_1		(11) 6.1 37			
Mg_1K_2		(10) 7.8 35			
Mg_2K_0	(5) 6.0 35	(6) 6.4 37			
Mg_2K_1		(9) 6.2 37			
Mg_2K_2	(7) 6.3 35	(8) 6.9 36	(15) 5.6 36	(17) 7.5 38	(19) 7.2 36

Number of spears per plant.

* Average weight per spear (g.)

at Mg_0:

	L_1	L_2
N_1	4) 3.00* 5.29#	14) 2.67 4.94
N_2	16) 2.78 5.02	18) 3.11 5.34

at Mg_2:

	L_1	L_2
N_1	8) 2.97* 5.17#	15) 2.35 4.80
N_2	17) 3.45 5.95	19) 3.13 5.43

* Spear yields # Total yields

As mentioned in the "Experimental Methods" section, in 1960 the high N rate was established by side-dressing an additional 150 pounds of N per acre approximately two weeks before the first harvest. The effect of this further addition of N was to increase yields in later harvests when spears were being taken. This effect is shown in Table 11, the "Distribution of Spear Yields", and is supported in Table 12, the "Number of Spears per Plant". Head yields do not show a response to N, quite probably because of the split application. Possibly the N_1 rate was sufficient for head yields, but after head removal (and consequent removal of N) added N was needed for spear production.

Applications of Mg (at N_1) generally reduced total and spear yields on this soil, though not to a large enough extent to be significant. Total yield data shown below illustrate these yield reductions.

at K_0:

	L_0	L_1
Mg_0	1) 5.29	2) 5.48
Mg_2	5) 4.77	6) 5.06

at K_2:

	L_0	L_1
Mg_0	3) 5.14	4) 5.29
Mg_2	7) 4.78	8) 5.17

Averaging across lime and K rates the average total yield at Mg_0

(treatments 1-4) was 5.30 tons per acre and the average total yield at Mg_2 (treatments 5-8) was 4.95 tons per acre. A relatively large F value for the Mg effect in the L x K x Mg factorial was obtained (Table 8). These yield reductions amounted to between 0.2 and 0.4 tons. While head yields did not seem to be affected, this negative response to Mg was apparent in average weights of good heads (Table 10) and in spears harvested in the third and fourth cuttings (Table 11).

An interesting point to note is the change in pattern of Mg responses that occurred when the high rate of N was applied. These changed effects were seemingly a reflection of increased spear yields resulting from the extra N applied. At N_1, Mg additions reduced yields; at N_2, Mg increased yields. The maximum benefit of the increased N supply was obtained mainly at the high level of Mg. Evidence for this may be seen in Tables 9 and 11. Spear yields showed a greater response to N at Mg_2 than occurred at Mg_0. Spear yield data (tons per acre) illustrating this are shown below:

at Mg_0:	L_1	L_2
N_1	4) 3.00	14) 2.67
N_2	16) 2.78	18) 3.11

at Mg_2:	L_1	L_2
N_1	8) 2.97	15) 2.35
N_2	17) 3.45	19) 3.13

The positive response to N, averaged across lime rates, at Mg_0 was 0.11 tons per acre, while at Mg_2 the average response to N was 0.63 tons per acre. While none of these differences were significant, a comparatively large F value for the Mg x N interaction term was found in the analyses of variance for spear yields (Table 8, L x Mg x N factorial).

Neither head, spear, nor total yield responded positively to applications of K in 1960 on this soil.

Application of the first increment of lime (L_0 to L_2) increased spear and total yields, though not significantly. Total yield data extracted from Table 9 show this response.

at Mg_0:

	K_0	K_2
L_0	1) 5.29	3) 5.14
L_1	2) 5.48	4) 5.29

at Mg_2:

	K_0	K_2
L_0	5) 4.77	7) 4.78
L_1	6) 5.06	8) 5.17

Further additions of lime, L_1 to L_2 (at N_1), decreased spear and total yields. Again, as was the case with response to Mg, head yields were unaffected.

Olympic Soil - 1960

The initial exchangeable K and Mg levels of plots on this soil in 1960 were lower than those of the Willamette soil. Exchangeable K and Mg levels on the K_0 and Mg_0 plots in April 1960 were approximately 0.35 and 0.75 milliequivalents per 100 grams respectively.

Growth was quite varied over the plot area, responses to K and Mg being evident. Up to 25 percent of the plants on the low K plots showed K deficiency symptoms. Low Mg plots, at the low lime rate, showed 5-10 percent of the plants deficient in Mg; where lime was applied, approximately 40 percent of the plants were deficient. On low Mg plots where both high lime and high K rates had been used, 50-60 percent of the plants showed Mg deficiency symptoms.

Total, head, and spear yields for this soil are given in Table 13, and the analyses of variance for this data are shown in Table 8.

Responses to Mg, Lime and N - Applications of Mg resulted in significant increases in total yield (compare Mg_0 treatments 2, 4, 14, 16, 18 averaging 5.09 tons per acre with their Mg_2 counterparts 6, 8, 15, 17, and 19 averaging 5.60 tons per acre). This response was large compared with the LSD for averages of 5 treatment means.

Mg interacted with lime in that a response to Mg was obtained only where lime had been applied. This is evidenced by a significant L x Mg interaction effect in the L x K x Mg factorial (Table 8), and is shown in the following total yield data extracted from Table 13 for the N_1 level.

at K_0:

	L_0	L_1
Mg_0	1) 5.46	2) 4.61
Mg_2	5) 4.90	6) 5.21

at K_2:

	L_0	L_1
Mg_0	3) 5.87	4) 5.05
Mg_2	7) 5.90	8) 5.81

Table 13. Two-way Table of Total Yield of Broccoli (Heads plus Spears) in Tons per Acre. Sum of Six Harvests. Means of Four Replications. Olympic Soil. 1960.

	N_1			N_2	
	L_0	L_1	L_2	L_1	L_2
Mg_0K_0	(1)2.13 3.33 5.46	(2)1.84# 2.77* 4.61*#			
Mg_0K_1		(13)2.15 2.88 5.03			
Mg_0K_2	(3)2.40 3.47 5.87	(4)2.06 2.99 5.05	(14)1.92 2.75 4.67	(16)1.99 3.28 5.27	(18)2.06 3.81 5.87
Mg_1K_0		(12)1.88# 3.16* 5.04*#			
Mg_1K_1		(11)2.12 3.50 5.62			
Mg_1K_2		(10)2.21 3.31 5.52			
Mg_2K_0	(5)1.90 3.00 4.90	(6)1.94# 3.27* 5.21*#			
Mg_2K_1		(9)2.21 3.30 5.51			
Mg_2K_2	(7)2.20 3.70 5.90	(8)2.21 3.60 5.81	(15)2.12 2.79 4.91	(17)2.45 3.57 6.02	(19)2.20 3.85 6.05

Tons per acre of heads.

* Tons per acre of spears.

#* Tons per acre of heads plus spears (Total Yield)

Least Significant Differences (5% level)	Total Yield
Comparing 2 treatment means	0.87 T/A
Comparing averages of 2 treatment means	0.60 T/A
Comparing averages of 3 treatment means	0.50 T/A
Comparing averages of 5 treatment means	0.31 T/A

Table 14. Two-way Table of Yield of Heads (Tons per Acre) and Average Weights of Good Quality Heads (Grams per Head) Means of Four Replications. Olympic Soil. 1960.

	N_1			N_2	
	L_0	L_1	L_2	L_1	L_2
Mg_0K_0	(1)2. 13 181	(2)1. 84* 158#			
Mg_0K_1		(13)2. 15 182			
Mg_0K_2	(3)2. 40 191	(4)2. 06 173	(14)1. 92 162	(16)1. 99 173	(18)2. 06 185
Mg_1K_0		(12)1. 88* 170#			
Mg_1K_1		(11)2. 12 172			
Mg_1K_2		(10)2. 21 182			
Mg_2K_0	(5)1. 90 173	(6)1. 94* 174#			
Mg_2K_1		(9)2. 21 175			
Mg_2K_2	(7)2. 20 203	(8)2. 21 182	(15)2. 12 193	(17)2. 45 208	(19)2. 20 176

* Tons of heads per acre.

\# Average head weight in grams per head.

Least Significant Differences (5% level)	Head Yield	Ave. Hd. Wt.
Comparing 2 treatment means	0. 38 T/A	26. 8 gms.
Comparing averages of 2 treatment means	0. 28 T/A	19. 0 gms.
Comparing averages of 3 treatment means	0. 23 T/A	15. 5 gms.

Table 15. Two-way Table of Distribution of Spear Yield and Total Spear Yield (Tons per Acre). Means of Four Replications. Olympic Soil. 1960.

	N_1			N_2	
	L_0	L_1	L_2	L_1	L_2
Mg_0K_0	(1)0.51 1.90 0.92 3.33	(2)0.32[1] 1.59[2] 0.86[3] 2.77[4]			
Mg_0K_1		(13)0.22 1.59 1.07 2.88			
Mg_0K_2	(3)0.12 1.96 1.38 3.47	(4)0.20 1.68 1.11 2.99	(14)0.15 1.42 1.18 2.75	(16)0.11 1.68 1.48 3.28	(18)0.06 1.93 1.82 3.81
Mg_1K_0		(12)0.23[1] 1.57[2] 1.35[3] 3.16[4]			
Mg_1K_1		(11)0.24 2.09 1.17 3.50			
Mg_1K_2		(10)0.22 1.91 1.19 3.31			
Mg_2K_0	(5)0.61 1.80 0.59 3.00	(6)0.58[1] 1.76[2] 0.93[3] 3.27[4]			
Mg_2K_1		(9)0.23 2.12 0.94 3.30			
Mg_2K_2	(7)0.30 1.86 1.54 3.70	(8)0.17 1.96 1.48 3.60	(15)0.11 1.29 1.38 2.79	(17)0.08 2.11 1.38 3.57	(19)0.15 2.70 0.99 3.85

[1] Tons spears/A cuts 1 and 2

[2] Tons spears/A cuts 3 and 4

[3] Tons spears/A cuts 5 and 6

[4] Tons spears/A Total

Table 16. Two-way Table of Average Weight per Spear (Grams) and Number of Spears per Plant. Means of Four Replications. Olympic Soil. 1960.

	N_1			N_2	
	L_0	L_1	L_2	L_1	L_2
Mg_0K_0	(1) 6.5 38	(2) 5.9# 34*			
Mg_0K_1		(13) 6.1 37			
Mg_0K_2	(3) 7.5 38	(4) 6.4 36	(14) 5.9 37	(16) 7.0 38	(18) 7.8 40
Mg_1K_0		(12) 6.6# 37*			
Mg_1K_1		(11) 6.7 39			
Mg_1K_2		(10) 7.2 37			
Mg_2K_0	(5) 6.2 33	(6) 6.8# 36*			
Mg_2K_1		(9) 6.9 38			
Mg_2K_2	(7) 7.2 40	(8) 7.0 41	(15) 5.3 41	(17) 7.2 39	(19) 6.5 40

Number of spears per plant.

* Average weight per spear in grams.

Least Significant Differences (5% level)	Ave. Spear Wt.
Comparing 2 treatment means	4.6 gms. per spear
Comparing averages of 2 treatment means	3.3 gms. per spear
Comparing averages of 3 treatment means	2.7 gms. per spear

At the L_0 level no response to Mg was evident but at the L_1 rate a marked response was obtained. These responses generally corresponded with the incidence of Mg deficiency symptoms, the symptoms being more severe where lime had been applied. Mg responses occurred at both the 150 and 300 pound rates of N.

Yield of heads, shown in Tables 13 and 14, showed a significant response to Mg in the treatments of the L x Mg x N factorial (treatments 4, 14, 16, 18 averaging 2.01 tons per acre vs. 8, 15, 17, 19 averaging 2.25 tons per acre). The main portion of this response took place at N_2 and where lime had been applied (L_1 and L_2); at L_0, small negative responses to Mg occurred. These results were similar to those of total yield.

Average weights of good heads, shown in Table 14, followed a similar pattern and responded to Mg at the L_2 N_1 and L_1 N_2 levels. At L_2 N_1, average head weight was 162 grams on treatment 14 and 193 grams on treatment 15; at L_1 N_2, average head weight was 173 grams on treatment 16 and 208 grams on treatment 17. These responses were significant using the LSD for comparison of two treatment means.

The response to the high rate of N is evident when the treatments receiving lime and K are compared. This response was larger at the L_2 lime rate as the following total yield data, extracted from Table 13, illustrate:

at L_1:

	N_1	N_2
Mg_0	4) 5.05	16) 5.27
Mg_2	8) 5.81	17) 6.02

at L_2:

	N_1	N_2
Mg_0	14) 4.67	18) 5.87
Mg_2	15) 4.91	19) 6.05

The average total yield difference between N_1 and N_2 at L_1 was 0.22 tons per acre and at L_2 was 1.17 tons per acre.

At the 150 pound N rate (N_1) there was a decrease in total yield going from L_1 to L_2. This decrease in yield did not occur at the 300 pound N rate (N_2). The yield reductions brought about by the high lime rate were apparently eliminated by adding the extra 150 pounds of N later in the season. L x N effects shown in total yield were primarily brought about by increased spear yields rather than larger head yields (see Tables 13 and 15). This probably occurred because the N applications establishing the N_2 rate were split. 150 pounds of N were applied in July prior to planting and the remaining 150 pounds were supplied two weeks before the first harvest of the 1960 crop year. Head formation had started at this time, and most of the effect of the additional N probably took place during spear growth. The L x N interaction term was significant for both spear and total yield (Table 8).

One of the objectives of this experiment was to evaluate the response of broccoli at varying levels of lime. Literature cited (27, 32, 67) indicated that responses to Mg could often be expected when soils had been limed. The incidence of Mg deficiency symptoms on this soil seemed to bear this out. Greater percentages of plants were deficient on limed plots. Also total yield responded to Mg when the first increment of lime had been applied. Mg responses were not obtained at the L_0 level.

The following table shows the total yields and percentages of plants showing Mg deficiency symptoms for the L x Mg x N factorial treatments. The deficiency symptoms were estimated visually and are an average figure for the four replications.

	N_1		N_2	
	L_1	L_2	L_1	L_2
Mg_0	4)5.05 - 45%	14)4.67 - 52%	16)5.27 - 51%	18)5.87 - 47%
Mg_2	8)5.81 - 4%	15)4.91 - 7%	17)6.02 - 0%	19)6.05 - 5%

Approximately 50 percent of the plants on the Mg_0 treatments showed Mg deficiency symptoms; less than 7 percent showed these symptoms at the Mg_2 level - regardless of yield. Comparing treatments 8 and 15 (L_1 vs. L_2, all at $N_1K_2Mg_2$) shows a large decrease in yield and practically no change in the percentage of deficient plants. Treatment 18 had a total yield of 5.87 tons per acre, one of the largest yields within the experiment, yet 47 percent of its plants showed deficiency symptoms. This seems to confirm the observation of Foy and Barber (20) that plants may show Mg deficiency symptoms and yet not have the yield affected. Further, treatments 14 and 15 ($L_2K_2Mg_0$ and $L_2K_2Mg_2$), while showing a slight response to Mg, had similar low yields. Yet these treatments had 52 and 7 percent deficient plants respectively.

Low yields on these treatments were due to the application of the high rate of lime at the low rate of N, but it seems not necessarily due to lime's effect on Mg uptake into the plant. In short, at L_2, application of Mg decreased the percentages of deficient plants but did not greatly increase yields.

At the high rate of N the response pattern changed; application of Mg (treatments 16 and 18 vs. 17 and 19) reduced the percentage of deficient plants and increased total yields.

Response to K - A significant positive response of head, spear, and total yield to K was noted in the L x K x Mg factorial. This response was seemingly unaffected by lime rate though it became larger as the Mg application increased. Total yield data (tons per acre), extracted from Table 13, are given below to illustrate this response.

at Mg_0:

	L_0	L_1
K_0	1) 5.46	2) 4.61
K_2	3) 5.87	4) 5.05

at Mg_2:

	L_0	L_1
K_0	5) 4.90	6) 5.21
K_2	7) 5.90	8) 5.81

Average weights of good quality heads were also increased by K applications where lime or Mg had been applied (Table 14). The response was significant at L_0 Mg_2 (treatment 5 vs. 7) when compared with the LSD measuring differences between two treatment means.

Effect of Treatment on Soil Analysis Results

Tables 17 and 18 give the results of the analysis of soil samples taken from the Willamette and Olympic soils in April and July 1960. The data in these tables are averages of four replications. Complete results by replication for the July 1960 sampling of both soils are given in the data used for the regression analysis, Appendix Tables 8 and 9.

Since the July sampling represented the pH and exchangeable cation levels of the soil after fertilization for the 1960 crop, these data were chosen as most suitable for relation with yield and plant composition data (see sections on "Relationships between Yield and Soil Analysis" and "Relationships between Plant Composition and Soil Analysis").

The April 1960 analyses indicated the pH and exchangeable cation levels of the plots prior to 1960 fertilizer applications. A comparison of the April and July sampling shows the effects of these fertilizer applications on these soil test values.

The approximate range of exchangeable Mg levels established on the Willamette soil was 1.0 to 1.2 milliequivalents at Mg_0 to 1.7 to 1.9 at Mg_2. The Mg_0 levels are in the area of borderline adequacy; not high, but not low enough that responses to Mg application would be expected with certainty.

Table 17. Effect of Applications of Lime, Mg, and K on pH and Exchangeable Cation Levels. April and July Samplings[1], 1960. Means of Four Replications. Willamette Soil.

Treatments[2]	pH and Exchangeable Cations in m. e. /100 g.							
	April 1960				July 1960			
LKMgN	pH	Ca	K	Mg	pH	Ca	K	Mg
(1) 0 0 0 1	5.7	7.6	0.50	1.17	5.9	7.6	0.57	1.23
(2) 1 0 0 1	6.6	12.3	0.57	1.17	6.7	13.3	0.56	1.17
(3) 0 2 0 1	5.7	7.9	0.76	1.18	6.0	7.9	0.84	1.27
(4) 1 2 0 1	6.7	13.1	0.75	1.19	6.6	11.4	0.93	1.12
(5) 0 0 2 1	5.7	8.3	0.51	1.61	5.8	6.1	0.58	1.95
(6) 1 0 2 1	6.7	13.5	0.57	1.51	6.7	11.4	0.58	1.70
(7) 0 2 2 1	5.7	7.5	0.73	1.52	5.8	5.8	0.93	1.83
(8) 1 2 2 1	6.6	11.8	0.74	1.46	6.6	11.0	0.87	1.71
(9) 1 1 2 1	6.8	12.8	0.71	1.48	6.5	11.5	0.75	1.70
(10) 1 2 1 1	6.7	12.3	0.73	1.28	6.6	10.6	0.91	1.30
(11) 1 1 1 1	6.8	12.6	0.62	1.43	6.6	11.6	0.72	1.27
(12) 1 0 1 1	6.7	15.4	0.60	1.40	6.6	12.1	0.59	1.29
(13) 1 1 0 1	6.7	13.5	0.73	1.13	6.6	12.2	0.78	1.07
(14) 2 2 0 1	7.0	15.9	0.76	1.19	6.8	13.7	0.85	1.16
(15) 2 2 2 1	6.9	12.5	0.81	1.29	6.8	13.6	1.00	1.60
(16) 1 2 0 2	6.6	12.2	0.80	1.14	6.5	10.9	0.83	1.15
(17) 1 2 2 2	6.4	10.2	0.70	1.35	6.5	10.3	0.82	1.64
(18) 2 2 0 2	6.7	13.6	0.73	1.11	6.7	12.6	0.81	1.12
(19) 2 2 2 2	6.9	13.6	0.78	1.37	6.8	12.6	0.86	1.68

1 April sampling was prior to fertilization for the 1960 crop year. The July sampling was taken after fertilizer application.

2 P and S treatments constant at P_2 and S_1 levels, respectively.

Table 18. Effect of Application of Lime, Mg, and K on pH and Exchangeable Cation Levels. April and July Samplings[1], 1960. Means of Four Replications. Olympic Soil.

Treatments[2]	pH and Exchangeable Cations in m. e. / 100 g.							
	April 1960				July 1960			
LKMgN	pH	Ca	K	Mg	pH	Ca	K	Mg
(1) 0 0 0 1	6.1	7.2	0.34	0.71	6.0	6.9	0.33	0.81
(2) 1 0 0 1	6.8	12.9	0.36	0.74	6.9	16.5	0.39	0.95
(3) 0 2 0 1	6.0	7.1	0.61	0.79	6.0	7.3	0.97	0.92
(4) 1 2 0 1	6.7	11.9	0.59	0.75	6.8	15.6	1.01	1.03
(5) 0 0 2 1	6.0	6.4	0.37	1.12	6.1	5.9	0.49	1.70
(6) 1 0 2 1	6.7	11.0	0.39	1.07	6.8	11.3	0.58	1.62
(7) 0 2 2 1	6.0	7.0	0.69	1.14	5.9	6.1	0.99	1.68
(8) 1 2 2 1	6.6	11.6	0.52	1.05	6.8	12.6	0.82	1.63
(9) 1 1 2 1	6.6	11.9	0.53	1.05	6.9	14.4	0.69	1.75
(10) 1 2 1 1	6.7	12.0	0.65	0.90	6.9	14.6	1.02	1.33
(11) 1 1 1 1	6.7	12.0	0.65	0.91	6.9	15.2	0.79	1.31
(12) 1 0 1 1	6.6	11.9	0.54	0.89	7.0	15.9	0.60	1.39
(13) 1 1 0 1	6.7	12.7	0.48	0.78	6.9	14.4	0.61	1.02
(14) 2 2 0 1	6.9	16.8	0.59	0.87	7.0	17.9	0.94	1.12
(15) 2 2 2 1	6.9	15.7	0.69	1.17	7.0	16.4	1.05	1.81
(16) 1 2 0 2	6.6	11.7	0.57	0.82	6.8	14.7	0.90	1.00
(17) 1 2 2 2	6.6	11.5	0.75	1.09	6.7	12.2	1.04	1.92
(18) 2 2 0 2	7.0	16.1	0.72	0.88	7.0	18.2	0.98	1.06
(19) 2 2 2 2	6.8	13.6	0.57	1.06	6.9	15.9	0.92	1.59

[1] July 1960 sampling was after fertilizer had been applied for the 1960 crop year.

[2] P and S treatments constant at P_2S_1 levels, respectively.

The approximate range of exchangeable Mg levels on the Olympic soil was 0.8 to 0.9 milliequivalents at Mg_0 and 1.6 to 1.7 milliequivalents at Mg_2. These levels are somewhat lower than those found in the Willamette soil and Mg responses would probably be expected.

Exchangeable K levels were lower on the Olympic soil than on the Willamette. Again, regarding K levels at both locations, responses would be expected on the Olympic soil, but probably not on the Willamette soil.

The anticipated levels of base saturation, 95 percent at L_1 and 120 percent at L_2, were not achieved on the Willamette soil as measured by analyses of the July sampling. Base saturations ranged from 65 to 70 percent at L_1 and up to 75 percent at L_2. These low base saturations may possibly be explained by comparing the exchangeable Ca levels on this soil between April and July (Table 17). In this intervening period 2.5 and 4.0 milliequivalents of Ca were applied to the L_1 and L_2 plots respectively (see p. 29). This application of Ca does not show up in the July soil test results.

On the Olympic soil the desired levels were more closely approximated, the range found in the soil test results being 75 to 85 percent base saturation at L_1 and 100 to 110 percent base saturation at L_2.

Effect of Treatment on Plant Composition

Information regarding the number of plant samplings, dates of sampling, and types of leaves taken on both the Willamette and Olympic soils in 1959 and 1960 is described in "Experimental Methods - Plant Sampling and Analysis". These data were taken in order to evaluate the best sampling date and plant part to use in obtaining relations between yield and plant composition or plant composition and soil analysis information.

Table 19 shows data from the first and second samplings, oldest mature leaves, Willamette soil. Table 20 shows data from the same samplings from the Olympic soil. Plant contents in these tables are given in terms of percentage of Ca, Mg, or K. The plant contents, as entered into the regression analysis, are in terms of milliequivalents of Ca, Mg, or K per 100 grams of dry matter. These data are included in Appendix Tables 8 and 9.

The choice of the best plant sampling date and leaf maturity to be used in the regression analysis was based on the relative differences between the Mg contents of the tissue over the range of Mg applications for the various sampling dates and leaf maturities. The first and second sampling dates were chosen because of their proximity to the periods of greatest yield (harvests 1 through 4). Also, at times later than this many of the older leaves had abscissed and portions of the plant had been removed by harvesting.

The oldest mature leaves were used because their Mg contents and the differences in Mg content caused by fertilizer application were larger than in the recently matured leaves. Figure 1 illustrates these differences for both old and recently matured leaves of the first sampling from the Olympic soil. The data shown were taken from samples at the L_0 and L_1 lime rates. At higher lime levels the amount of Mg taken up was smaller and thus the differences in Mg contents between Mg levels was somewhat smaller. Mg contents of old mature leaf tissue from the second sampling followed the same pattern.

Further discussion of the changes in the Ca, Mg, or K composition will be discussed in the section on "Relationships between Plant Composition and Soil Analysis".

Relationship Between Yield and Soil and Plant Analyses

To aid in the interpretation of the 1960 yield results already presented, the relationships between yield and soil and plant analysis data were determined using multiple regression analysis. Further, relationships were obtained between plant composition and soil analyses to determine the effect of exchangeable cation levels (a measure of soil supply of a nutrient) on the content of these nutrients in the plant.

Table 19. Two-way Table of Chemical Composition of Broccoli Leaf Tissue in Percentage of Dry Matter. Oldest Mature Leaves, First and Second Samplings, 1960. Willamette Soil. Means of Four Replications.

	L_0			L_1			L_2		
	%Ca	%Mg	%K	%Ca	%Mg	%K	%Ca	%Mg	%K
Mg_0K_0	(1)5.87* 5.88#	0.41 0.22	2.27 2.11	(2)6.28* 6.21#	0.33 0.22	2.11 2.19			
Mg_0K_1				(13)5.73 6.21	0.29 0.22	2.61 2.53			
Mg_0K_2	(3)5.49 5.80	0.39 0.25	3.03 2.94	(4)5.46 6.18	0.30 0.23	3.12 2.79	(14)5.99 6.17	0.29 0.22	2.76 2.77
Mg_1K_0				(12)6.02* 6.39#	0.35 0.26	2.23 2.12			
Mg_1K_1				(11)5.65 6.45	0.34 0.31	2.37 2.48			
Mg_1K_2				(10)5.82 5.66	0.35 0.22	2.90 2.82			
Mg_2K_0	(5)5.38 5.34	0.52 0.42	2.38 2.20	(6)5.59* 6.18#	0.45 0.34	2.36 2.15			
Mg_2K_1				(9)5.93 5.95	0.43 0.32	2.70 2.56			
Mg_2K_2	(7)4.90 6.01	0.54 0.41	3.26 3.07	(8)6.08 6.18	0.39 0.35	2.92 3.09	(15)5.83 6.33	0.38 0.31	2.90 2.84

* First sampling.

\# Second sampling.

Table 20. Two-way Table of Chemical Composition of Broccoli Leaf Tissue in Percentage of Dry Matter. Oldest Mature Leaves, First and Second Samplings, 1960. Olympic Soil. Means of Four Replications.

	L_0			L_1			L_2		
	%Ca	%Mg	%K	%Ca	%Mg	%K	%Ca	%Mg	%K
Mg_0K_0	(1)5.96* 5.59#	0.23 0.23	1.09 1.18	(2)6.12* 6.09#	0.17 0.19	1.13 1.11			
Mg_0K_1				(13)5.71 5.80	0.18 0.16	2.44 2.21			
Mg_0K_2	(3)5.51 5.45	0.19 0.19	2.90 2.22	(4)5.46 5.61	0.18 0.14	2.60 2.52	(14)5.60 5.25	0.14 0.11	3.17 2.52
Mg_1K_0				(12)6.17* 6.05#	0.22 0.18	2.34 2.08			
Mg_1K_1				(11)5.93 6.13	0.22 0.26	2.60 1.95			
Mg_1K_2				(10)5.50 5.30	0.24 0.14	2.95 2.43			
Mg_2K_0	(5)5.10 5.64	0.50 0.47	1.13 1.11	(6)6.16* 6.45#	0.35 0.27	1.40 1.14			
Mg_2K_1				(9)5.22 5.90	0.33 0.25	2.13 1.70			
Mg_2K_2	(7)4.93 5.58	0.40 0.37	3.22 2.45	(8)5.64 6.29	0.29 0.23	2.70 2.06	(15)5.20 5.98	0.21 0.22	3.34 2.59

* First sampling.

\# Second sampling.

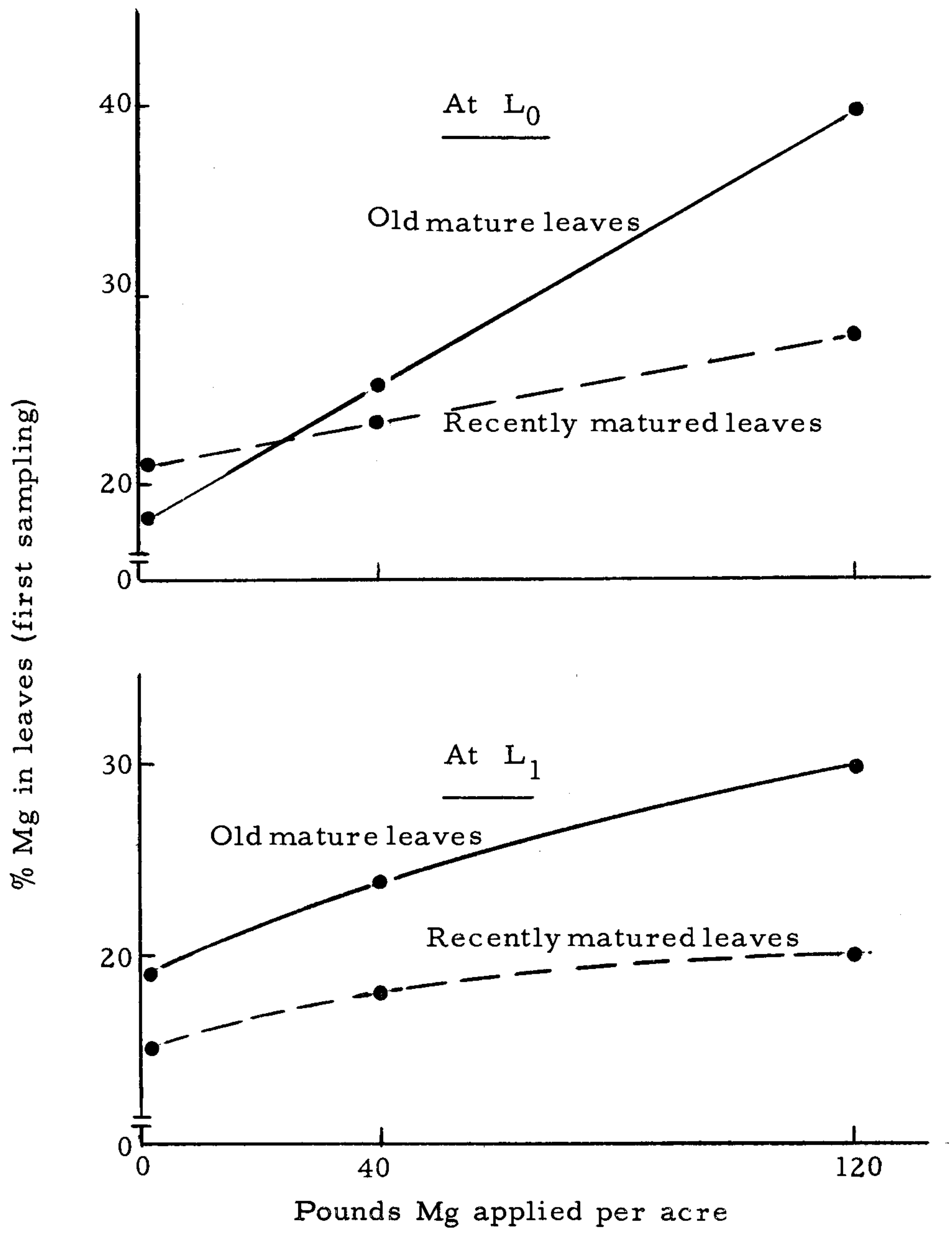

Figure 1. Comparison of changes in % Mg in old mature leaves and recently matured leaves as related to Mg applications. Data at two lime rates. Olympic soil. 1960. Means of four replications.

A general description of the regression procedure, including the models which were fitted to the data, is given in the "Experimental Methods" section. The data used included each replication from the first fifteen treatments, or those comprising the lime x K x Mg , K x Mg, and lime x Mg factorials. Thus, the total number of observations in the analyses equaled 60.

Yield results chosen for inclusion in the regression analyses were (1) total yield of heads plus spears, (2) total yield of heads and (3) yield of heads plus spears for the first three harvests, hereafter called "Group I Yield". Leaf analyses from the first and second samplings 1960, oldest mature leaves, were used as an index of plant composition. The plant composition data were entered into the regression analyses in units of milliequivalents of Ca, K or Mg per 100 grams of dry matter. The coefficients in the resulting equations are in the same units. Conversions were made to more conventional percentages in the discussion. Soil analysis data used was from the July 1960 sampling. The reasons for these choices were covered in the sections on the "Effect of Treatments on Soil Analyses", and "Effect of Treatments on Plant Composition." General information as to dates and methods of sampling was given in the "Experimental Methods" section.

As mentioned earlier in the section on "Experimental Methods -

Regression Analysis", the procedure used was a stepwise one and the variables of the model were entered one at a time. At each step the model was different, that is, one more term was included. At each step a new set of coefficients was estimated. Also new correlation coefficients and standard error of the mean were calculated. From the several steps obtained in the fitting of each model to the data, the one with the lowest standard error of the mean was chosen as the best fitting equation. Thus, in some cases, the equation selected as best fitting the data would have one or more fewer variables than the full model. Nothing would be gained by including extra variables if they only contributed to error.

In the subsequent discussions, the equation of the regression line will be given in the figure showing the relationship. The signifi- of the regression coefficients will be shown by asterisks. The significance of the coefficients was determined by a "t" test; that is, $t = \frac{b_i}{s_b}$ with n degrees of freedom, depending on the number of parameters in the model and the number of observations used. The significance of a coefficient will be noted as follows:

* Significant at the 5% level

** Significant at the 2.5% level

*** Significant at the 1% level

Generally, when a regression equation was solved in order to present a particular relationship graphically, neither the regression lines nor the levels of other independent variables were extrapolated outside the range of the observed data. For example in Figure 5, the regression equation was solved to illustrate the relationship between percentage Mg and exchangeable Mg at two levels of exchangeable Ca, 6 and 14 milliequivalents. These values were chosen to approximate the levels of exchangeable Ca in the soil at the L_0 level and the L_1 or L_2 levels, that is, where no lime was applied and where lime had been applied.

All the models listed in the Experimental Methods section were used and sets of coefficients determined for each dependent variable of yield or plant composition. From these combinations only those involving useful information were used. The remaining relationships, by their absence, should indicate results not requiring comment.

Willamette Soil

Yield and Exchangeable Cations - The general lack of significant yield responses on the Willamette soil in 1960 was borne out in a similar lack of significant relationships between yield and soil analysis information. Total yield of heads plus spears was not significantly related to either exchangeable Ca, Mg, or K. Only the regression coefficient for Mg was large enough in comparison with its standard error to approach significance. This negative relationship of total yield to exchangeable Mg is shown in Figure 2. It should be noted that Mg is the only variable in the regression equation. The addition of variables for Ca, K, and Ca x Mg in later steps of the complete model only increased the standard error of the mean. Therefore they were omitted and the first step used.

A positive relationship, approaching significance, was obtained between head yield and exchangeable K. Exchangeable Ca or Mg were not related to head yield, and the addition of further variables to the equation only increased error. Thus, as has been mentioned earlier in the discussion of yield results, the effect of K seems greatest on head growth, with the effect of Mg being more apparent in later harvests.

Group I yields were not related to exchangeable Ca, K or Mg. Yields were not related to the ratio of exchangeable Ca to Mg as would be expected in view of the general lack of relation between yield and exchangeable Ca or Mg individually.

Yield and Plant Composition - Total yield (heads plus spears) was not found to be significantly related to percentage Ca, Mg, K, or Ca x Mg in the leaf tissue of the first sampling, oldest mature leaves.[1]

[1] Hereafter called Ca, Mg, or K first or second sampling for brevity.

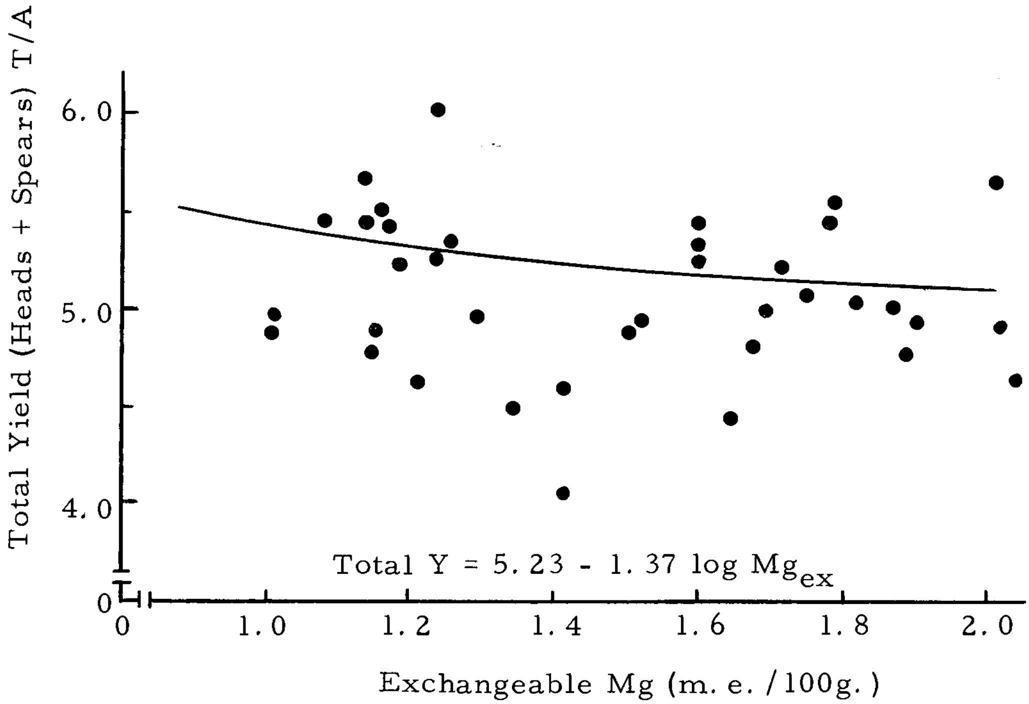

Figure 2. Relationship between total yield (heads + spears) and exchangeable Mg, July 1960 sampling. Willamette Soil. 1960. Observed data points from treatments 1-8, 14, 15.

In general, the magnitudes of the regression coefficients were similar to those of their standard errors. However, the relation between total yield and percentage Mg, though poor, was negative; that is, total yield decreased with increasing Mg content of the leaves. This agrees with the negative relationship found between total yield and exchangeable Mg (Figure 2).

Total yield was significantly related to the Ca x Mg interaction term (percentage Ca x percentage Mg) second sampling. This is a term used in the model to describe changes in the relation between yield and percentage Mg caused by changing Ca contents. The relationship is shown in Figure 3. Total yield decreased as the percentage Mg increased; the larger the Ca content of the leaves, the sharper the decrease became. This curve also shows that total yields decreased as percentage Ca increased. The inverse relationship between the percentage of Ca and Mg prevailed in all the plant analysis data obtained (see Tables 19 and 20).

A significant positive relationship was found between head yield and percentage K, first sampling, and is shown in Figure 4. A positive relationship between head yield and percentage Ca approached significance. Head yields (Table 9) responded to K when lime had been applied (L_1) and responded positively to lime at the high K rate (K_2). Since the model used was linear, it was not possible to show a

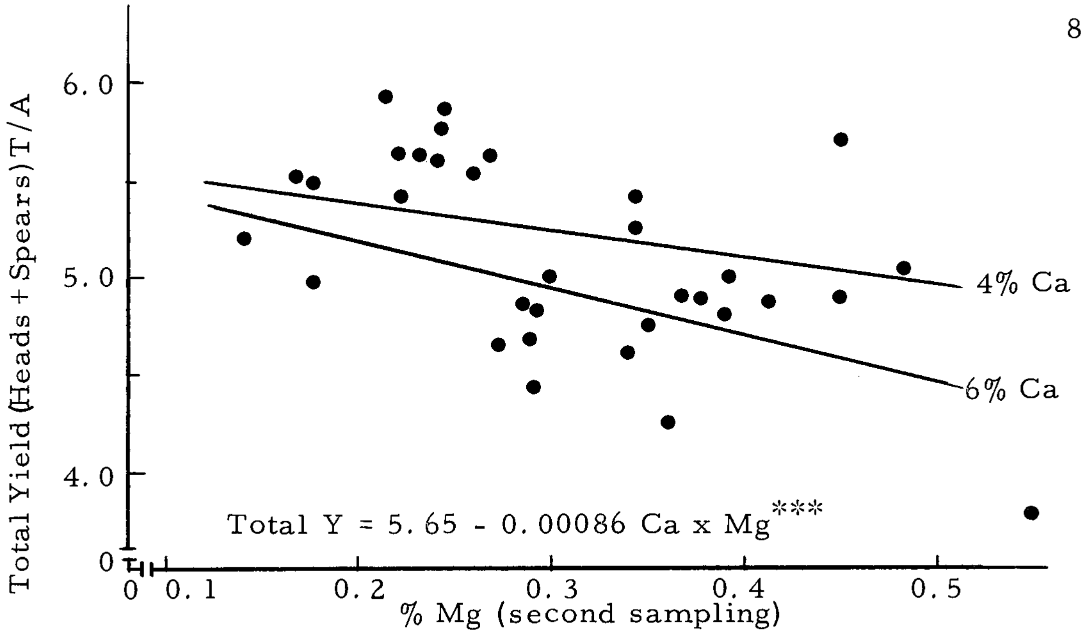

Figure 3. Relationship between total yield (heads + spears) and % Mg (second sampling). Willamette soil. 1960. Observed data points from treatments 1-8, 14, 15 where % K was above 1.5%.

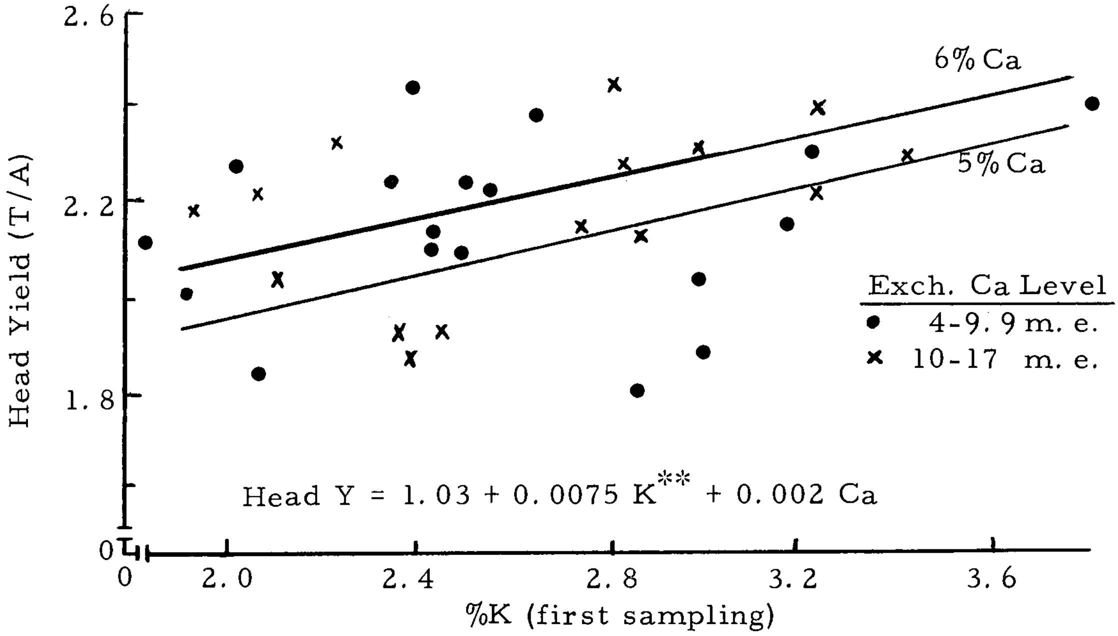

Figure 4. Relationship between head yield and % K (first sampling). Willamette soil. 1960. Observed data points from treatments 1-8.

maximum in the regression line. Nor do observed data points plotted in Figure 4 give a clear idea of a percentage K where head yield ceased to increase.

Head yield was positively, but not significantly, related to percentage K in the second sampling leaves. It was, however, negatively related to percentage Mg. As was shown earlier (Figure 3) total yields were also negatively related to Mg contents in the second sampling. The effect of Mg on yields apparently occurred after the beginning of harvests as shown by spear yield data in Table 9 and by significant relationships of yield to Mg contents in the second sampling. This effect of Mg on yields was also related to N level, as Mg increased yields on this soil at the 300 pound N rate (Table 9).

In general, the correlations between yield and exchangeable cations or plant composition on the Willamette soil were poorer than those on the Olympic soil. The correlation coefficients, R^2, did not exceed 0. 15. This probably was partially due to the rather high initial fertility of the site and lack of significant yield responses. Larger yield responses to nutrient elements will generally take place only when nutrient levels are low to the point of deficiency. At these levels, the effect of one element on another may be critical, while at higher levels of supply these effects may not be so evident.

Plant Composition and Soil Analyses - The relationships discussed in the following section reflect the effect of levels of exchangeable cations on the percentages of Ca, K, or Mg in the oldest mature leaves of the first and second samplings.

The correlation of plant contents with exchangeable cation levels was in general, consistently better than correlations of yield with either plant composition or soil analysis data. Correlation coefficients (R^2) ranged from 0. 3 to 0. 7.

Figure 5 shows the relationship found between percentage Mg, first sampling and exchangeable Mg on the Willamette soil. The relationship was positive and significant at the one percent level. Percentage Mg in the first sampling leaves was also related to exchangeable Ca at the same significance level. Mg contents of the leaves increased with increasing amounts of exchangeable Mg and were reduced as the exchangeable Ca level increased. Increasing the exchangeable Ca level from 6 to 14 milliequivalents decreased the predicted percentage Mg value by approximately 0. 10 percent Mg. This was a decrease of about 1/3 from the Mg contents at the low Ca level.

Figure 6 shows the relationship between percentage Mg in the second sampling leaves and exchangeable Mg. The regression equation shows that the effect of exchangeable Ca on predicted Mg contents varied. Exchangeable Ca level had little or no effect on predicted Mg

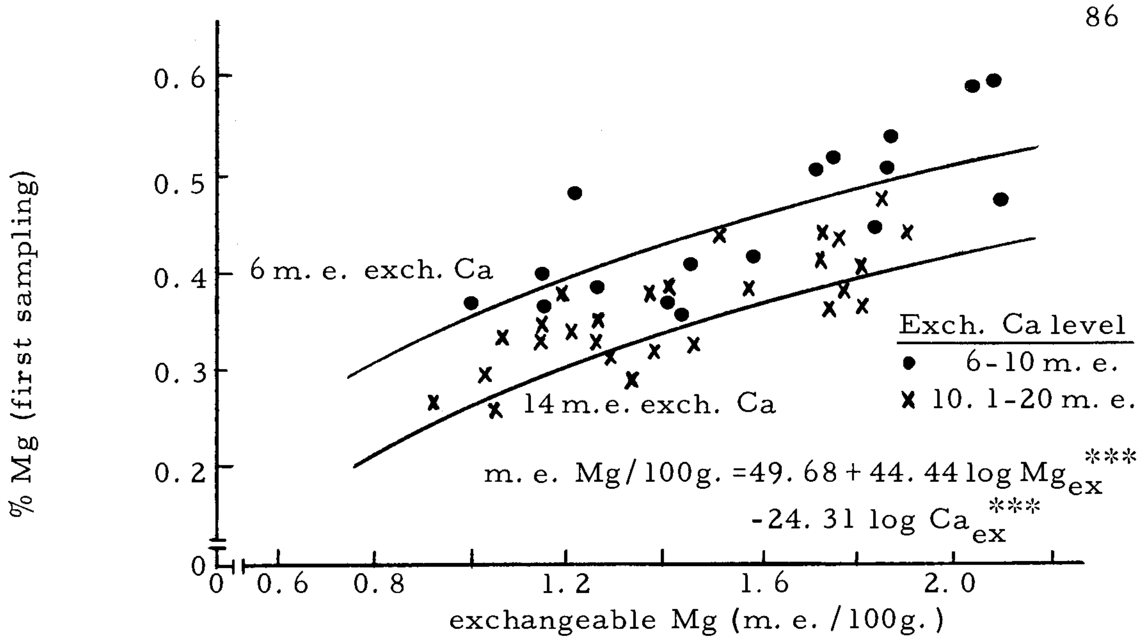

Figure 5. Relationship between % Mg (first sampling) and exchangeable Mg, July 1960 sampling. Willamette Soil. 1960. Observed data points from treatments 1-15.

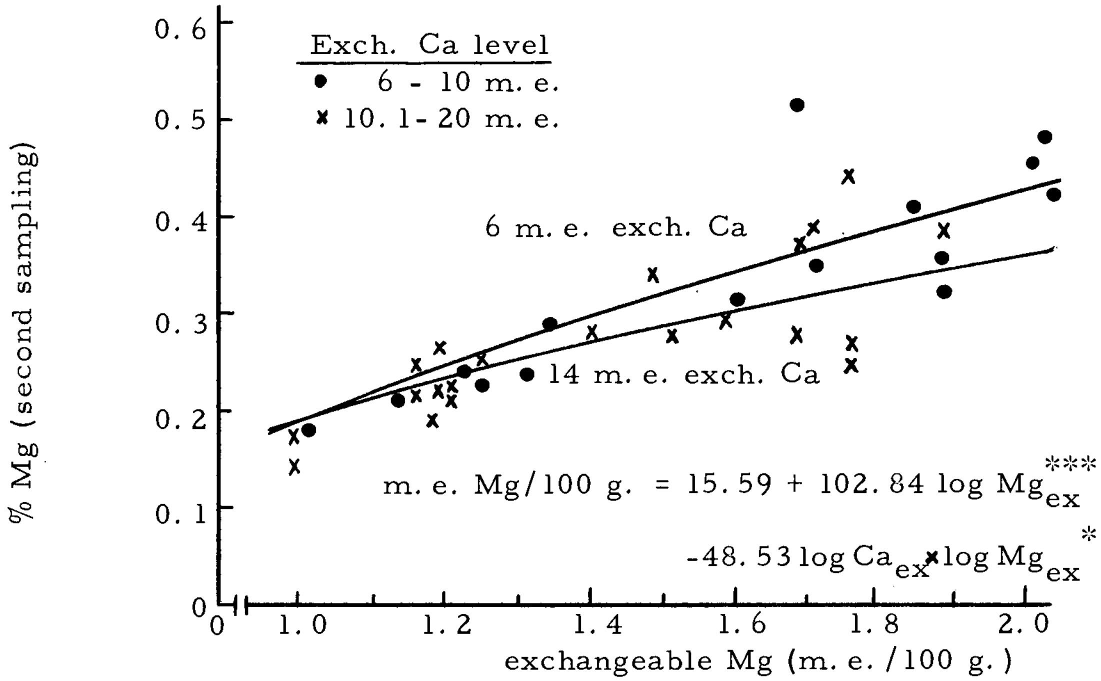

Figure 6. Relationship between % Mg (second sampling) and exchangeable Mg, July 1960 sampling. Willamette Soil. 1960. Observed data points from treatments 1-8, 14, 15.

contents at low levels of exchangeable Mg; at higher exchangeable Mg contents, predicted Mg contents were reduced to a greater extent. At the low exchangeable Ca level, the increase in Mg contents over the range of Mg applications was greater than that at the high Ca level. This effect of Ca was significant as shown by the Ca x Mg interaction term of the regression equation. Observed data points from treatments 1-15 were plotted to show the degree of fit of the points to the regression line. Though these points are coded for exchangeable Ca level, it would be difficult to foresee the results obtained in the regression equation by merely looking at the observed data.

The reduction of Mg contents of second sampling leaves brought about by increasing the exchangeable Ca level from 6 to 14 milliequivalents was smaller than that of the first sampling leaves. This was possibly because the Mg contents, second sampling, were smaller than those of the first sampling. The removal of heads between the first and second samplings had probably reduced the reserve of Mg remaining in the plant. Thus, the negative effect of Ca on the Mg contents was smaller. It should be noted, however, that competitive effects took place not only at high Mg levels and that this is not merely a reduction of luxury consumption of Mg. Further, when Mg contents are low, even small reductions may be detrimental to the growth or yield of the plant.

The percentage Mg in both the first and second sampling leaves was related to the ratio of exchangeable Ca to Mg as shown in Figure 7. A reciprocal transformation was used in the model for this equation (see "Experimental Methods - Regression Analysis") in order to obtain a better fit of the regression line to the observed data. In order that the ratio of Ca to M could be expressed in whole numbers, the percentages Mg in Figure 7 were plotted against the ratio $\frac{Ca_{ex}}{Mg_{ex}}$. This in no way affected the shape of the curve, but did eliminate the awkward reciprocal term and allowed the ratio to represent the number of times exchangeable Ca was greater than exchangeable Mg. This relationship was significant at the one percent level for both leaf samplings. The correlation coefficients (R^2) were approximately 0.67 and 0.43 for the first and second samplings respectively. These R^2 values were no larger than those for the direct relation of Mg content to exchangeable Mg or Ca. Thus, the ratio would probably not be a better measure of the effects of exchangeable Mg and Ca than these variables considered separately.

The plant composition data for broccoli leaves (Tables 19 and 20) and Figures 5, 6, and 7 show that Mg contents were reduced as the exchangeable Ca level increased. This information generally agrees with the results of other workers (27, 21, 32). This effect was noted on some crops but not on others by York, Bradfield and Peech (66). Broccoli, being a crop rather sensitive to low Mg levels, would probably be expected to be sensitive to any reduction in Mg content or uptake.

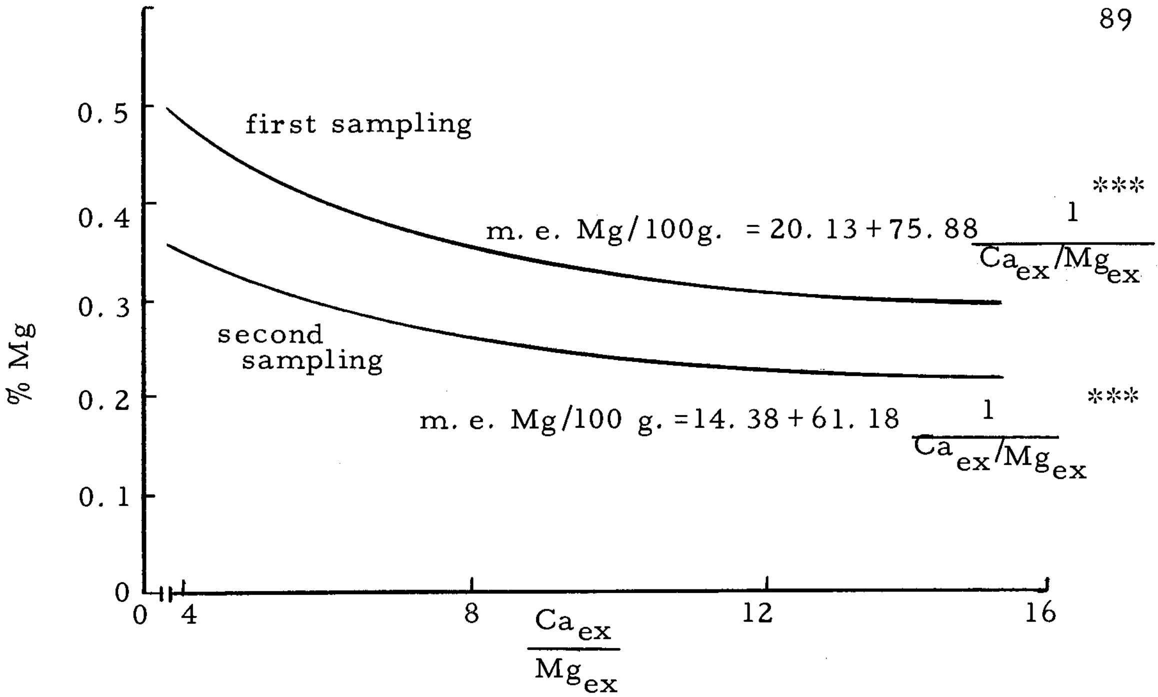

Figure 7. Relationship between % Mg (first and second samplings) and $\frac{Ca_{ex}}{Mg_{ex}}$, July 1960 sampling. Willamette Soil. 1960.

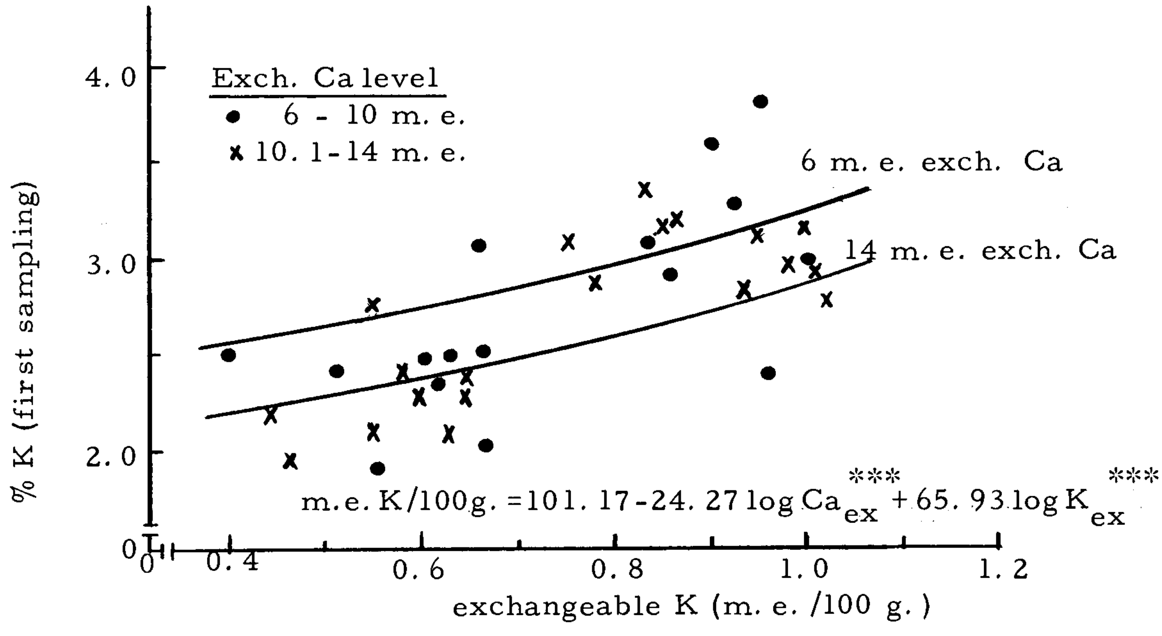

Figure 8. Relationship between % K (first sampling) and exchangeable K, July 1960 sampling. Willamette Soil. 1960. Observed data points from treatments 1-8, 14, 15.

Percentage K in the first and second samplings was positively related to exchangeable K and negatively related to exchangeable Ca. The results for the first sampling leaves are shown in Figure 8. The K coefficients were significant at the one percent level for both samplings and the relationship was similar. However, the reduction of K contents by exchangeable Ca was less evident in the second sampling leaves than in the first and the Ca coefficient was significant only for the first sampling leaves. The reduction of percentage K in the plant by increased levels of Ca (or liming) has been reported by many workers (18, p. 749; 27; 28, p. 72; 59).

Percentage Ca in both the first and second samplings was positively related to exchangeable Ca. These coefficients were significant for both samplings. While Ca contents were negatively related to exchangeable K in both samplings, the coefficient for K approached significance only in the first sampling relationship.

Though a measurement was not included among the regression models used, percentage Ca was not consistently affected by Mg level in either sampling (see Table 19).

Olympic Soil

Yield and Exchangeable Cations - Due to the lower initial fertility level of the Olympic soil, the yield responses found and the number of significant relationships between yield and soil analysis and plant composition was greater than for the Willamette soil. Though there was a greater variation among replications in terms of both yields (Table 8, F value for replication) and soil test values, the correlations found in the regression analyses were fully as good, if not better, than those for the Willamette soil.

On the Olympic soil, total yield (heads plus spears) was positively related to exchangeable K and negatively related to exchangeable Ca. Coefficients for both variables were significant at the one percent level. These relationships are shown in Figure 9 and in general agreement with the total yield responses shown in Table 13. Predicted yield responded to increased levels of exchangeable K regardless of exchangeable Ca level, but total yield was reduced by approximately one ton per acre at the high Ca level.

A significant relationship of total yield to exchangeable Mg or to the interaction between exchangeable Ca and Mg was not found. However, total yield results (Table 13) indicate that fairly large responses to Mg were obtained where the first rate of lime (L_1) had been applied, but not at L_0 or L_2. Since treatments including all lime, K and Mg levels (treatments 1-15) had been used for the regression analyses, it was thought that selecting data from only the pertinent treatments might serve to eliminate some of the variation. Thus, yield and exchangeable

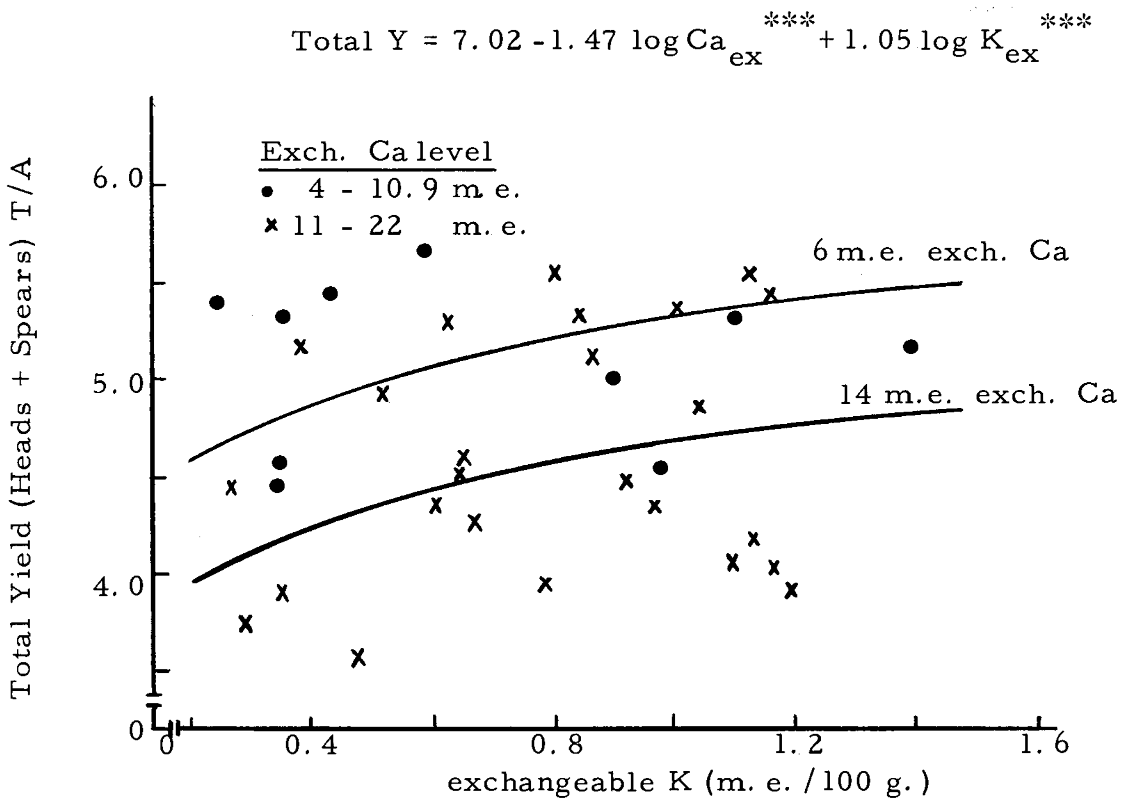

Figure 9. Relationship between total yield (heads + spears) and exchangeable K, July 1960 sampling. Olympic Soil. 1960. Observed data points from treatments 1-4, 13, 14.

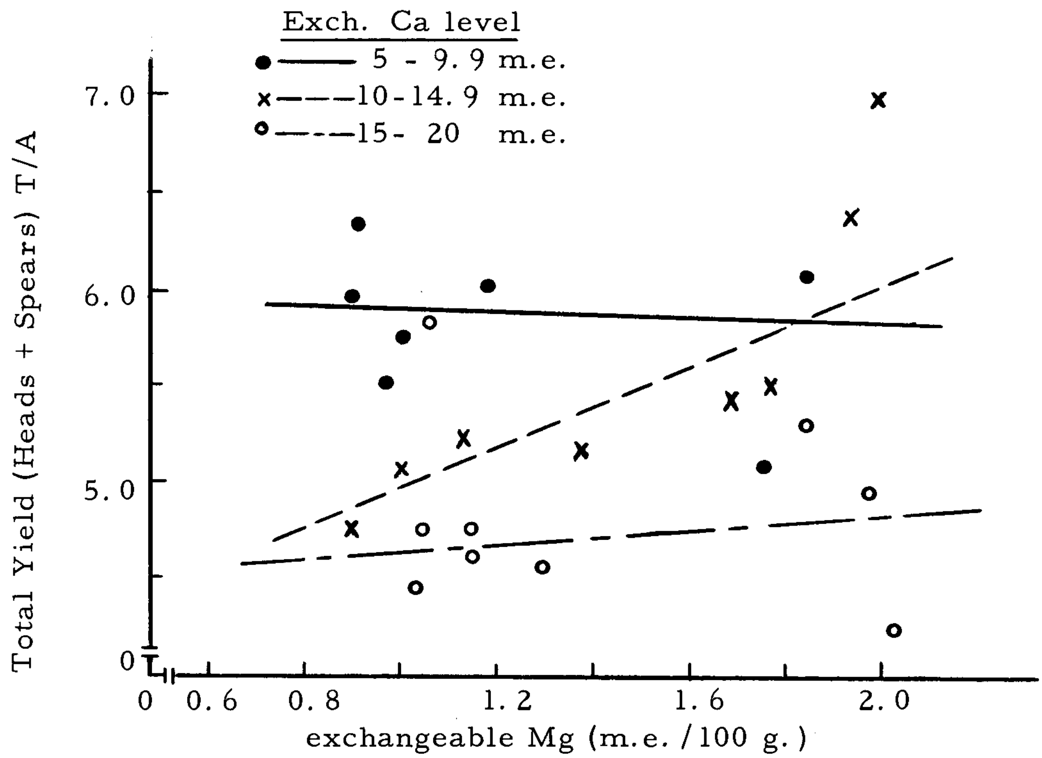

Figure 10. Relationship between total yield (heads + spears) and exchangeable Mg (July 1960 sampling) at varying levels of exchangeable Ca. Olympic Soil. 1960. Observed data points from treatments 3, 4, 7, 8, 14, 15.

Mg data from treatments 3, 4, 7, 8, 14, and 15 (all lime and Mg rates at the K_2 level) were plotted in Figure 10. These data were further segregated into three ranges of exchangeable Ca values. While the data were quite variable, it can be seen that a response to Mg was not obtained within the low range of exchangeable Ca values (5.0-9.9 milliequivalents exchangeable Ca). In the middle range (10-14.9 milliequivalents) total yield was lowest at low exchangeable Mg values and increased with increasing soil Mg. Yield reductions caused by Ca at low exchangeable Mg levels were apparently eliminated by additional Mg. However, at the highest exchangeable Ca range, total yields were reduced and the addition of 120 pounds of Mg per acre did not increase them.

The above type of complex response pattern shown in Figure 10 cannot be handled with the relatively simple models used in these regression analyses. Thus, the equation cannot fit the data perfectly and the resulting sets of coefficients are a compromise. More complicated models involving quadratic or higher order terms and requiring many more coefficients might be used; but these, of necessity, would require many more experimental observations.

Total yields were related to the ratio of exchangeable Ca to Mg. As the ratio increased, yields were significantly reduced. However, the correlation of yield to the ratio was somewhat poorer than for the relation of yield to exchangeable Ca or Mg considered individually (for the ratio, R^2=0.13; for Ca and Mg separately R^2=0.16). Thus, as on the Willamette soil, the ratio offered no improvement over consideration of the separate effects of Ca and Mg.

Head yields were significantly related to exchangeable K and Ca levels in a manner similar to total yields with one exception; a significant negative relationship was found between head yield and exchangeable Mg. Figure 11 shows the positive response of predicted head yield to exchangeable K and the effects of exchangeable Ca and Mg levels. Data from Tables 8 and 13 indicate that head yields responded significantly to K in treatments of the L x K x Mg and K x Mg factorials (treatments 1-13) and that the response was of a similar magnitude at both L_0 and L_1. Note that exchangeable Ca or Mg did not alter the K response but did lower the predicted yield levels (Figure 11).

Figure 12 shows the relationship of head yield to exchangeable Mg. Predicted head yields were reduced at low Ca levels as exchangeable Mg increased. At the higher exchangeable Ca level head yield showed no response to Mg level. Yield data in Table 13 generally indicate the same pattern; head yield was decreased by Mg applications at L_0 and showed only a slight positive response at L_1 and L_2. Since head yields responded positively to K at all lime and Mg rates, it was thought that the effect of Mg might be an indirect one of reducing K uptake. However, plant composition data for both the first and second

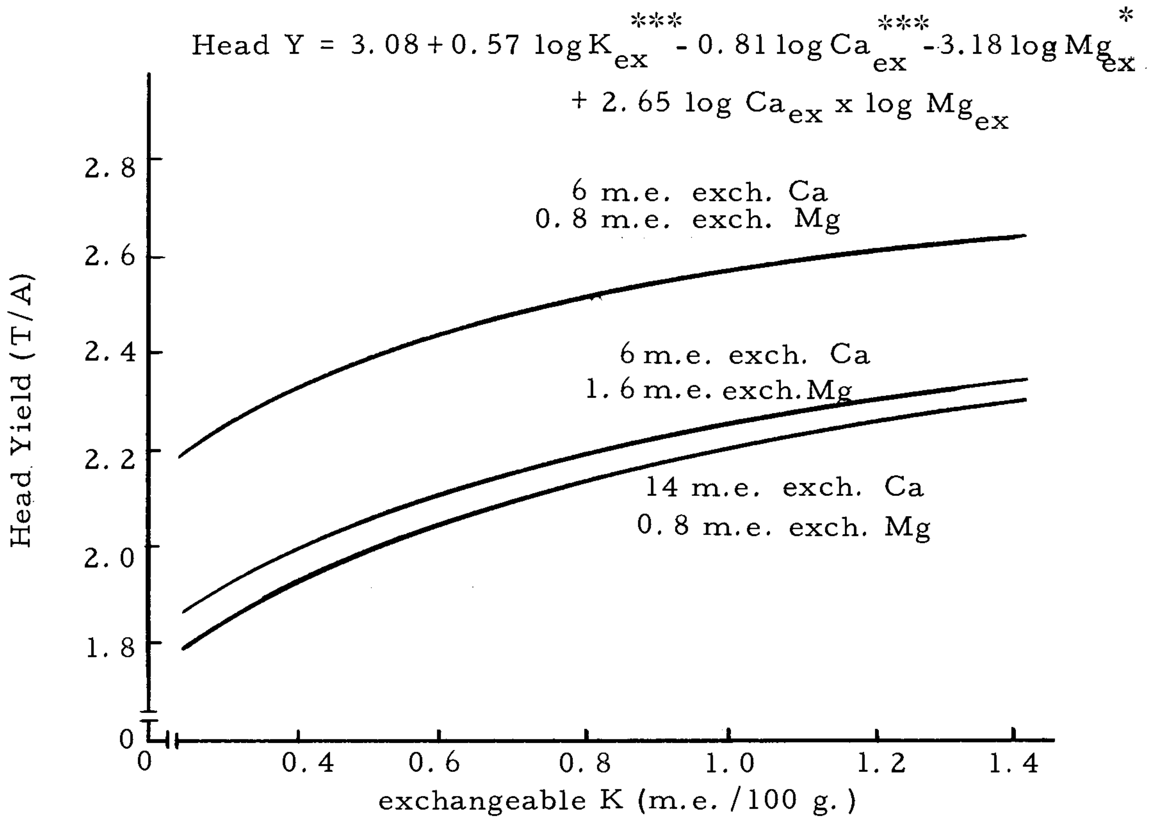

Figure 11. Relationship between head yield and exchangeable K (July 1960 sampling) at varying levels of exchangeable Ca and Mg. Olympic Soil. 1960.

$$\text{Head } Y = 3.08 + 0.57 \overset{***}{\log K_{ex}} - 0.81 \overset{***}{\log Ca_{ex}} - 3.18 \log Mg_{ex}^{\;*} + 2.65 \log Ca_{ex} \times \log Mg_{ex}$$

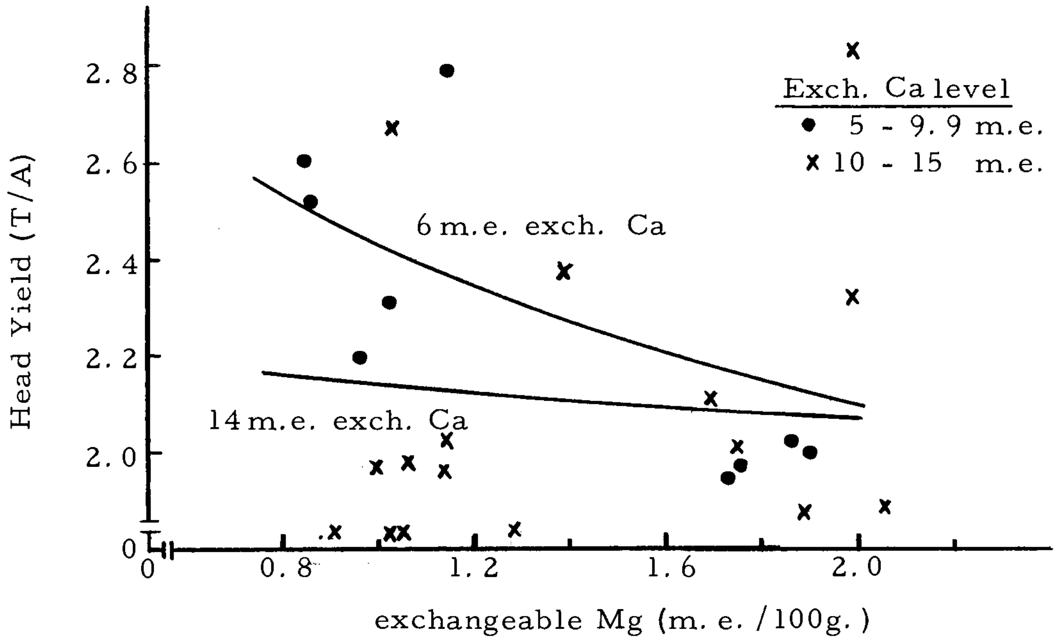

Figure 12. Relationship between head yield and exchangeable Mg, July 1960 sampling. Exchangeable K constant at 1 m. e. /100g. in equation. Olympic Soil. 1960. Observed data points from treatments 3, 4, 7, 8, 14, 15.

samplings (Table 20) show that the K contents were not reduced by Mg additions.

Group I yields (total yield of the first three harvests) were significantly negatively related to both exchangeable K and Ca. This negative relation to K was interesting in that head and total yields were positively related to exchangeable K. Group I yield data for the Olympic soil are shown in Table 21. Also included are the percentages of the total yield harvested in the first three cuttings. These data indicate that the application of K (or the increase in exchangeable K level) reduces this percentage. Even though total yields were increased by K additions, if only the first three harvests were considered, the response would generally be negative. Since the yield values here were based on harvests of all plots at one time at weekly intervals, it seems as if K applications had the effect of delaying maturity. The largest portion of the yield of the K_2 treatments was removed later in the season as may be seen in Table 15, the "Distribution of Spear Yield". As the K level increased, there was an increase in the weight of spears cut in the fifth and sixth harvests. This is in contrast to the often reported result that K deficiency delays maturity (7, p. 317).

A likely explanation for this is that K deficient plants on this soil mature earlier, then decrease in production. Plants having a

Table 21. Two-way Table of Group I Yield (Total Yield of First Three Harvests) in Tons per Acre and Percentage of Total Yield Harvested in First Three Harvests. Means of Four Replications. Olympic Soil. 1960.

	N_1			N_2	
	L_0	L_1	L_2	L_1	L_2
Mg_0K_0	(1)3.72* 68%#	(2)2.99 65%			
Mg_0K_1		(13)3.14 62%			
Mg_0K_2	(3)3.22 55%	(4)2.81 55%	(14)2.58 55%	(16)2.43 46%	(18)2.52 43%
Mg_1K_0		(12)2.64 52%			
Mg_1K_1		(11)2.91 52%			
Mg_1K_2		(10)3.12 57%			
Mg_2K_0	(5)3.58 73%	(6)3.36 64%			
Mg_2K_1		(9)3.19 58%			
Mg_2K_2	(7)3.11 53%	(8)3.15 54%	(15)2.33 48%	(17)3.37 56%	(19)2.51 42%

* Group I Yield - Total yield of first three harvests.

\# Percentage of total yield harvested in first three harvests.

sufficient amount of K available did not form heads and spears so quickly, but continued to produce for a longer period of time.

Yield and Plant Composition - Total yield was positively related to percentage K in the first sampling leaves. The combination of this variable and the Ca x Mg interaction term formed the equation best fitting the data. Figure 13 shows the plot of this relationship. Though total yields increased as the percentages of Mg and Ca increased, these effects were not significant.

While the regression analysis did not indicate a significant relationship between total yield and percentage Mg when 15 treatments were included (60 observations at all rates of lime and K), an attempt was made to find such a relationship. Treatment observations were selected where the plant composition data indicated a K content of 2.5 percent or better. This was done to eliminate some of the variability caused by allowing the K contents to vary (and thus to limit the variability of yield in response to K). Figure 14 shows a plot of this data segregated by exchangeable Ca level. Mg responses were obtained only where lime had been applied (Table 13) and, while the data points are somewhat scattered, the curves plotted show this. Application of lime (raising the exchangeable Ca level to above 10 milliequivalents) reduced yields at low Mg contents. As the Mg contents increase, total yields also increase to a yield level equal to that of the low lime

Total Y=4. 10 +0. 013 K*** + 0. 000055 Ca x Mg

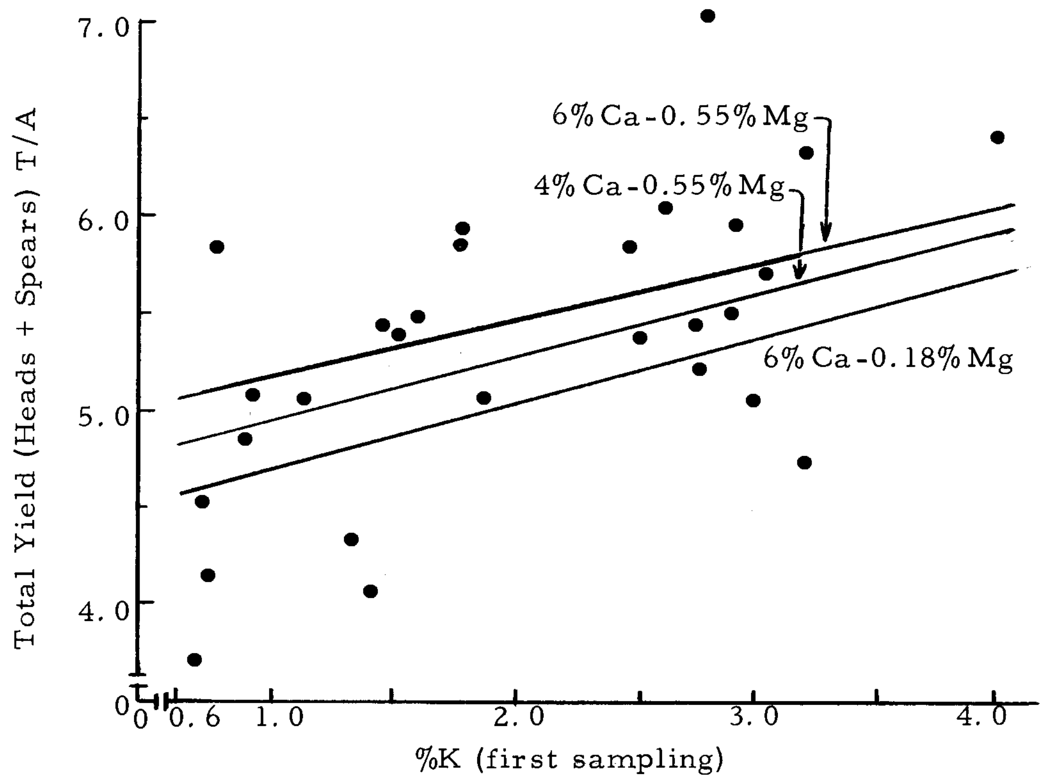

Figure 13. Relationship between total yield (heads + spears) and %K (first sampling). Olympic Soil. 1960. Observed data points from treatments 1-8.

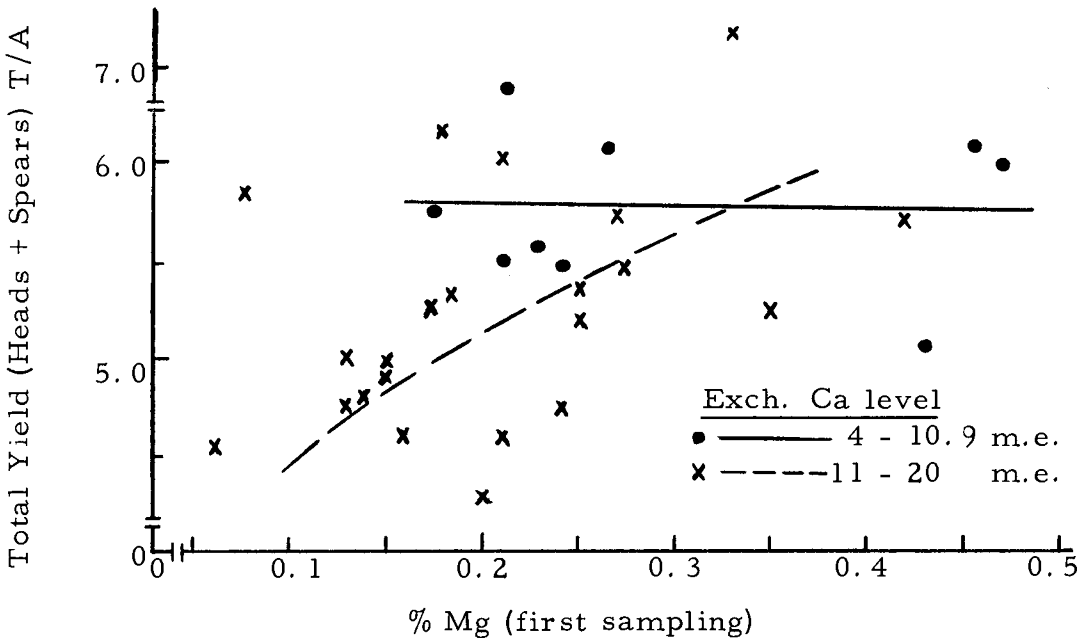

Figure 14. Relationship between total yield (heads + spears) and %Mg (first sampling). Olympic Soil. 1960. Observed data points from observations with 2.5% K or larger, treatments 1-15.

treatments. At the low exchangeable Ca level, total yields were approximately the same at all Mg contents. This information would seem to indicate that yield reductions brought about by the application of lime were at least partially due to reductions in Mg uptake into the plant.

Total yield was not significantly related to Mg, K, or Ca contents of the second sampling leaves. The fit of the equation to the data was extremely poor, the correlation coefficient, R^2, being 0.019.

Figure 15 shows a significant relationship of head yield to percentage K in leaves of the first sampling. Head yields were not related to either Mg or Ca contents and the inclusion of any further variables to the equation only contributed to error.

Head yields were significantly related to percentage Mg and the Ca x Mg interaction term for the second sampling. However, the fit of the equation to the data in this case was extremely poor, the correlation coefficient being 0.06.

Group I yields were positively (though non-significantly) related to percentage Mg in the first sampling leaves. For the second sampling leaves, significant negative relationships between Group I yields and both K and Ca contents were obtained.

Plant Composition and Soil Analysis - Percentage Mg in old mature leaves of both the first and second samplings was positively related to exchangeable Mg, and negatively related to exchangeable Ca

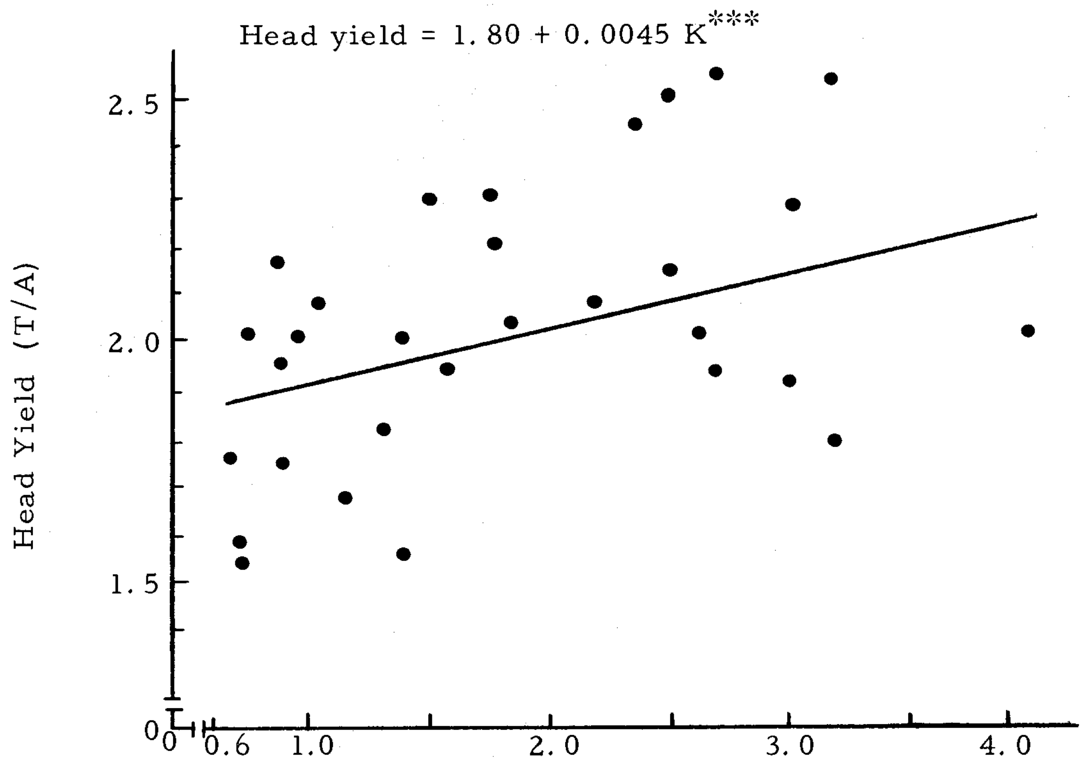

Figure 15. Relationship between head yield and % K (first sampling). Olympic Soil. 1960. Observed data points from treatments 1-8.

and K. These relationships are shown for the first sampling leaves in Figures 16, 17, and 18. The relationships for second sampling leaves varied only slightly in the magnitudes of the plant contents and not at all in shape of the curves.

Increasing the level of exchangeable Ca from 6 to 14 milliequivalents reduced the predicted Mg content of the first sampling leaves by 0.05 to 0.10 percent Mg. If exchangeable K was increased from 0.4 to 1.4 milliequivalents, predicted Mg contents were reduced by a like amount. The importance of these reductions in Mg content can be seen when it is recalled that above an exchangeable Ca level of approximately 11 milliequivalents, maximum total yields were obtained only when the Mg content (first sampling) was above 0.25 percent (see Figure 14). Further consideration will be given to these relationships in the "General Discussion" section.

Percentage Mg in both the first and second sampling was decreased by increasing the ratio of exchangeable Ca to Mg. Considering the relationships noted above, this is quite likely a result of the effect of exchangeable Ca. Percentage Mg was as well correlated with exchangeable Mg and Ca when considered separately as it was with the ratio of Ca to Mg.

The effect of exchangeable K and Ca on the predicted percentage K in leaves of the first sampling is shown in Figure 19. Predicted K

$$\text{m.e. Mg/100g.} = 31.33 + 83.95 \log Mg_{ex}^{*} - 16.99 \log Ca_{ex}^{**}$$
$$- 37.80 \log Ca_{ex} \times \log Mg_{ex} - 19.45 \log K^{***}$$

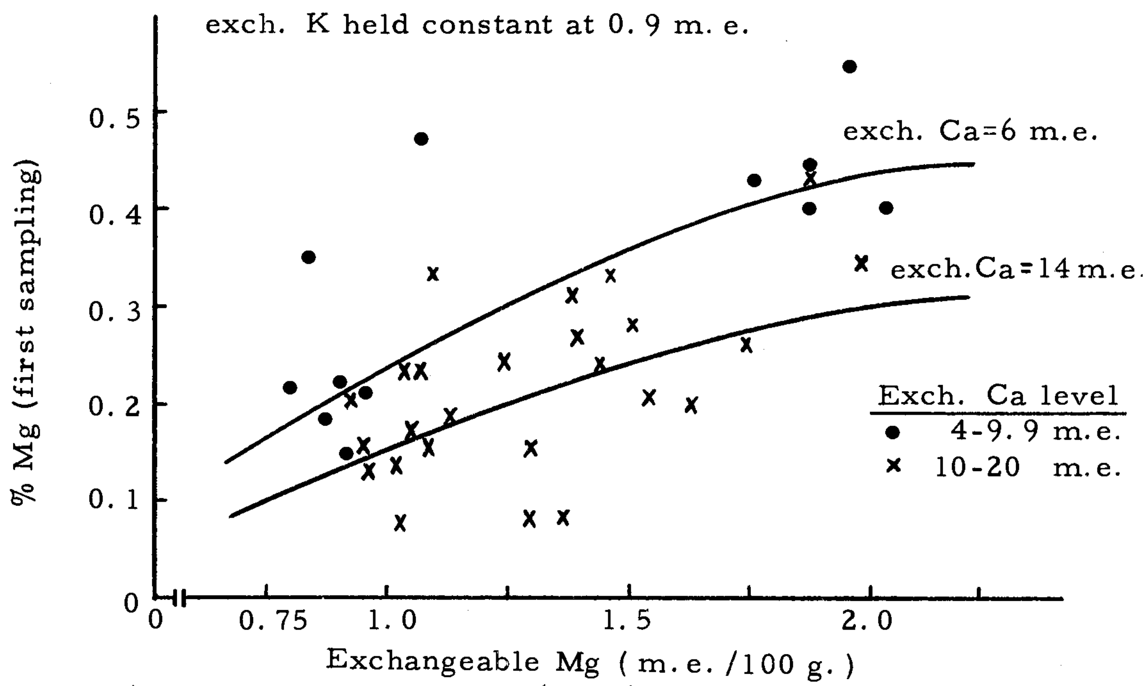

Figure 16. Relationship between % Mg (first sampling) and exchangeable Mg, July 1960 sampling. Olympic Soil. 1960. Observed data points from treatments 1-8, 10, 12, 14, 15, where exchangeable K level was between 0. 3 and 1. 10.

$$\text{m.e. Mg/100g.} = 31.33 + 83.95 \log Mg_{ex}^{*} - 16.99 \log Ca_{ex}^{**}$$
$$- 37.80 \log Ca_{ex} \times \log Mg_{ex} - 19.45 \log K^{***}$$

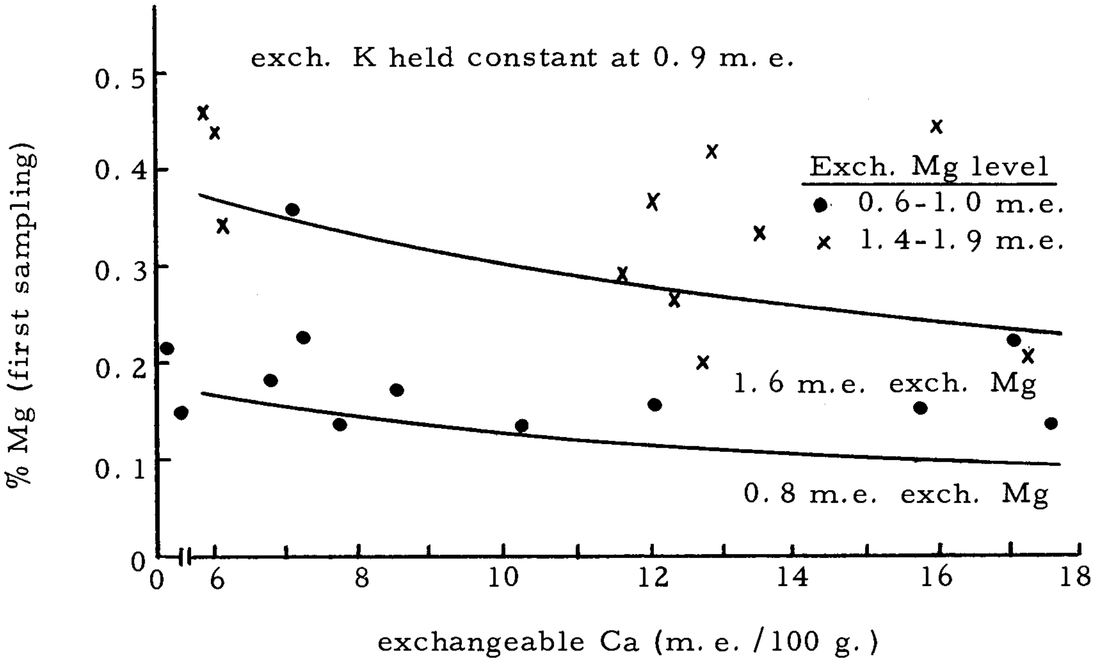

Figure 17. Relationship between % Mg (first sampling) and exchangeable Ca, July 1960 sampling. Olympic Soil. 1960. Observed data points from treatments 1-8 where exchangeable K was between 0. 3 and 1. 10 m. e.

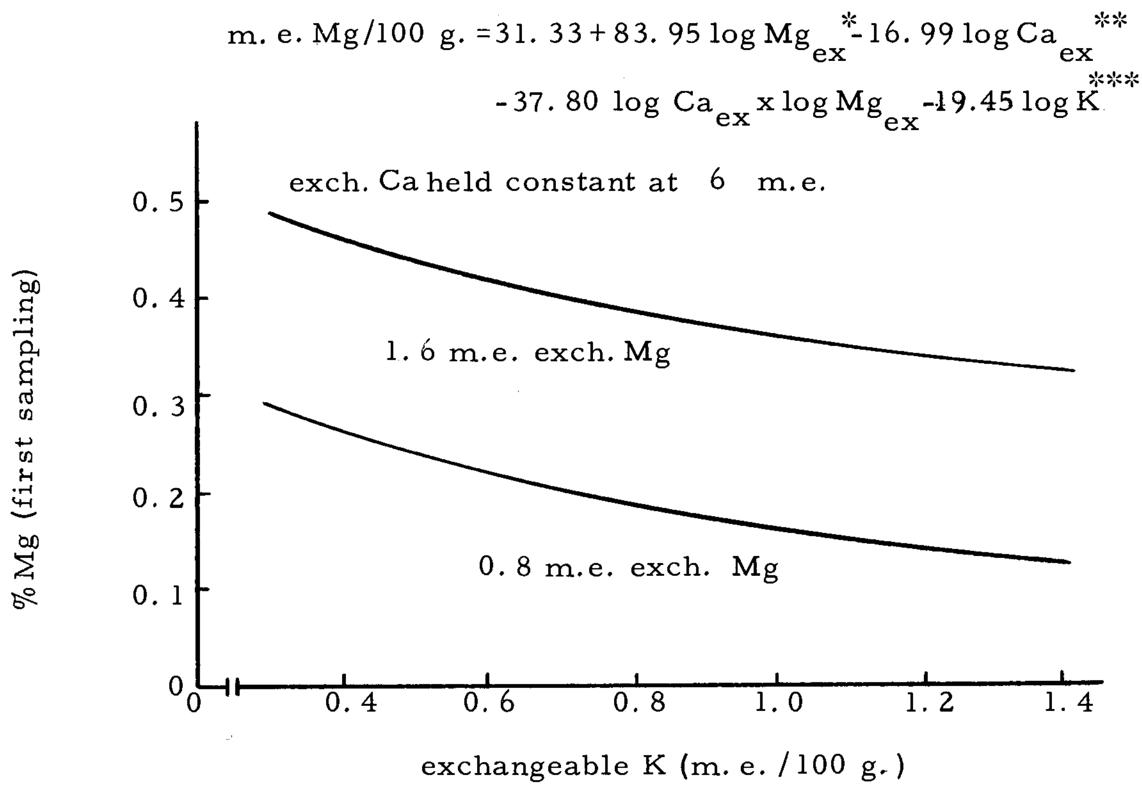

Figure 18. Relationship between % Mg (first sampling) and exchangeable K, July 1960 sampling. Olympic Soil. 1960. Variable for exchangeable Ca in regression equation held constant at 6 m. e.

contents were increased as exchangeable K increased. The effect of exchangeable Ca level on this relationship is also shown by Figure 19. Below approximately 1 milliequivalent of exchangeable K, an increase in exchangeable Ca decreased the predicted K contents. The coefficient for the interaction term describing this effect was significant at the one percent level. This same relationship was found for second sampling leaves, and the correlation coefficients R^2, were large in both cases, 0.36 and 0.55 respectively.

This effect of Ca on K contents was similar to that noted by Peech and Bradfield (53, p. 41, 45). These workers stated that K contents should be reduced when an acid soil is limed, and that with a Ca saturated soil, K contents would be increased. Another explanation may be that, as an acid soil is limed, exchangeable Al^{+++} is replaced by Ca^{++}. K^+ can compete more easily with Ca^{++} than with Al^{+++} for exchange sites on the soil colloid. Thus, more K^+ will be adsorbed in association with Ca^{++} than with Al^{+++}, and more K^+ would be in solution at low pH's than at high pH's.

Percentage Ca in both first and second samplings was positively related to exchangeable Ca and negatively related to exchangeable K. The relationship of Ca content to exchangeable Ca was significant in the second sampling, but not in the first. The negative relationship to exchangeable K was significant for both samplings. This information (for the first sampling) is illustrated in Figure 20. Increasing exchangeable Ca from 6 to 18 milliequivalents increased the predicted Ca contents approximately 0.4 percent. When the exchangeable K level was increased from 0.6 to 1.0 milliequivalents, the predicted Ca content decreased approximately 0.3 percent. In the second sampling leaves, Ca contents were increased more sharply by Ca additions while the size of the reductions caused by exchangeable K remained approximately the same.

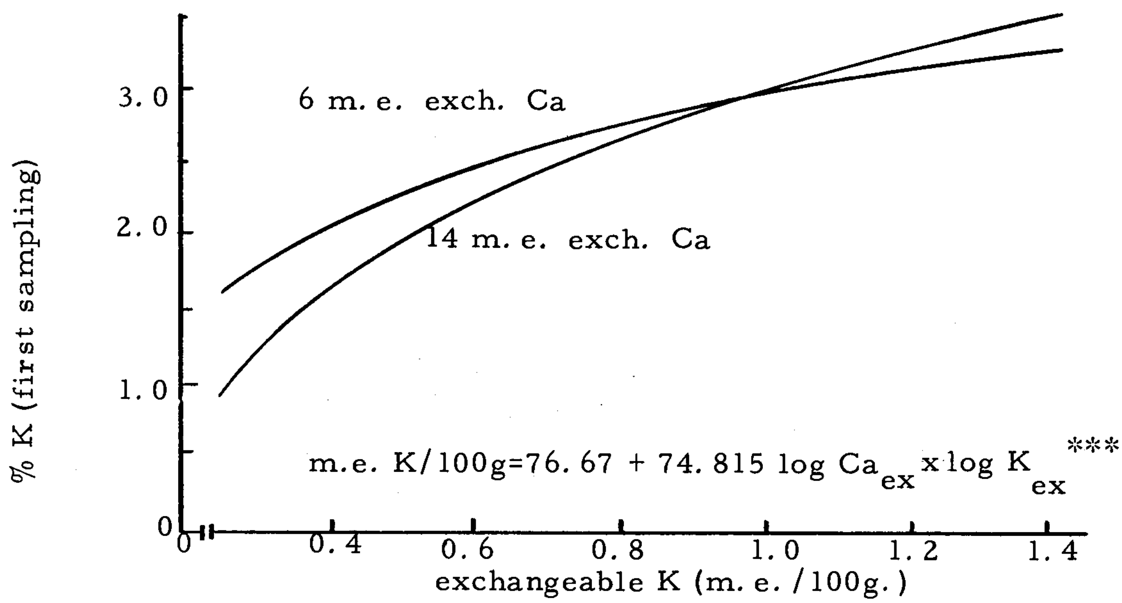

Figure 19. Relationship between %K (first sampling) and exchangeable K, July 1960 sampling. Olympic Soil. 1960.

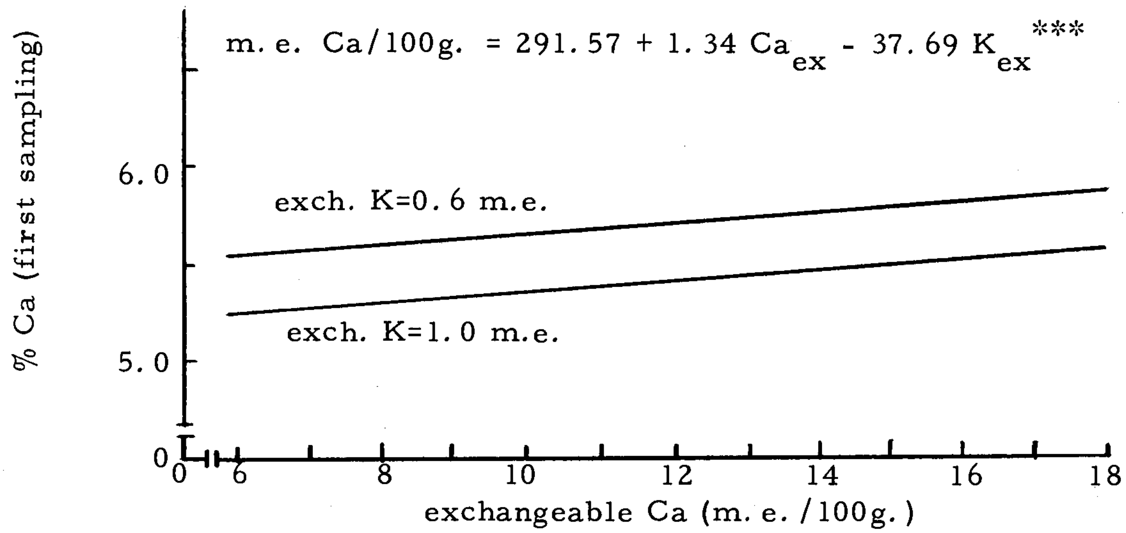

Figure 20. Relationship between %Ca (first sampling) and exchangeable Ca, July 1960 sampling. Olympic Soil. 1960

GENERAL DISCUSSION

In the preceding sections results and some discussion of the various parts of this study have been presented. In this section a more general discussion will be given some of the responses or effects found.

Willamette Soil

Besides a significant response of spear yield to N, one other response on the Willamette soil was large enough to warrant discussion.

This was a negative response of spear and total yield to Mg (Table 9, treatments 1, 2, 3, 4, averaging 5.30 tons per acre vs. 5, 6, 7, 8, averaging 4.95 tons per acre). These yield reductions were related to both exchangeable Mg and percentage Mg in the leaves of the second sampling (Figures 2 and 3). From the data available the cause of these yield reductions is not evident. Plant composition data (Table 19) indicate that Mg contents of the leaves were not overly high. K contents were also entirely adequate and not reduced by additions of Mg. The negative Mg response was possibly related in some way to the rate of N application as at the high rate of N, a large positive response of spear and total yields to Mg occurred (treatment 16 vs. 17).

Olympic Soil

Effect of Mg on Reductions of Yield by Lime Applications

Total, head, and spear yields were reduced by lime applications where Mg had not been applied (Table 13, treatments 1 and 3 vs. 2 and 4). On treatments where 120 pounds of Mg had been applied, application of the first rate of lime (L_1) did not reduce yields, but adding the high rate (L_2) did decrease yields. Thus, Mg applications recovered yield losses due to the first rate of lime.

Figure 10 shows the relationship between total yield and exchangeable Mg at different levels of exchangeable Ca. High total yields required higher exchangeable Mg levels when lime had raised the exchangeable Ca level to between 10 and 15 milliequivalents. These higher levels of exchangeable Mg were required to maintain the Mg content of the plant at an adequate level. This was brought about by a reduction in Mg uptake as the exchangeable Ca level increased (Figures 16 and 17).

Total yields were reduced when the Mg content of the first sampling leaves fell below approximately 0.25 percent Mg. The graph of percentage Mg versus exchangeable Ca (Figure 17) indicates that predicted Mg contents would approach 0.25 percent when no Mg had been applied (0.8 milliequivalents of exchangeable Mg) only at the lowest exchangeable Ca levels.

A similar plot of percentage Mg versus exchangeable Mg (Figure 16) shows that to obtain a predicted Mg content of 0.25 percent, the exchangeable Mg level must have been above 1 milliequivalent when no lime had been applied (6 milliequivalents of exchangeable Ca). The exchangeable Mg level would have to be above approximately 1.75 milliequivalents to obtain this Mg content when lime had been applied (14 milliequivalents exchangeable Ca).

The data mentioned above were supported by visual observations of the incidence of Mg deficiency symptoms. Up to 50 percent of the plants on the low Mg plots exhibited Mg deficiency symptoms. The percentage of plants showing these symptoms was increased by adding lime. When Mg had been applied, less than 7 to 10 percent of the plants were Mg deficient.

When the lime rate was increased from L_1 to L_2 total yields were further reduced (Table 13). The application of Mg did not recover this yield loss as it had done at the lower lime rate. This may have been due to either or both of two reasons. First, insufficient Mg may have been applied to overcome the competitive effect of the higher Ca level. Mg contents were slightly below 0.25 percent, the "critical level" mentioned above, at the high lime rate, even when Mg had been applied (treatment 15, Table 20). However, these Mg contents were generally only slightly lower than those at the L_1 lime rate (treatment 14).

A second possible cause for the reduction in yield is that lime additions (from L_1 to L_2) induced a deficiency of some other nutrient element. The response of total yield to increasing exchangeable Mg at the L_2 lime rate (15-22 milliequivalents of exchangeable Ca) was very small (Figure 10). There is no other way to support this idea and it is only mentioned as one possible explanation for the data.

Lime x N Interaction

A significant lime x N interaction effect was obtained in the total and spear yield from the L x Mg x N factorial. Total yield data selected from Table 13 to illustrate this are given below.

	N_1		N_2	
all at K_2:	L_1	L_2	L_1	L_2
Mg_0	4)5.05	14)4.67	16)5.27	18)5.87
Mg_2	8)5.81	15)4.91	17)5.02	19)6.05

Total yields were significantly decreased by lime applications at the N_1 level (treatments 4 and 8 *vs.* 14 and 15). These yield reductions were accounted for mainly by reductions in spear yield and did not take place at the N_2 level. Another way of looking at this would be to say that the L x N interaction comes about mainly from a small N response at L_1 (treatments 4 and 8 *vs.* 16 and 17), and a very large N response at L_2 (treatments 14 and 15 vs. 18 and 19).

One of the explanations proposed for the yield reductions at N_1 caused by application of the highest rate of lime (L_1 to L_2) was that Mg uptake into the plant was reduced. If this same explanation were to apply at the N_2 level, then one reason for the increase in yield caused by lime at the Mg_0 level (treatment 16 vs. 17) would be that, at the N_2 rate, application of the high rate of lime increased the amount of available Mg. This idea would be supported by the smaller Mg response at L_2 N_2 (treatment 18 vs. 19).

If the lime x N interaction were to be explained simply as a direct effect of N application increasing spear yields, then the N response would not be so much larger at the L_2 lime rate than at L_1. The possibility exists that some other nutrient element is affecting yields at these levels of fertilization. Thus, it would seem from the data at hand, that no completely satisfactory explanation is available.

Effect of Lime on Uptake of Mg

The data obtained in this study were not meant to provide an explanation for competition effects between Ca, Mg, and K. Information was obtained, however, that described the effect of application of these elements on their contents in broccoli leaves.

On both the Willamette and Olympic soils Mg contents of the leaves of both samplings were reduced by increasing exchangeable Ca. Figures 5 and 6 show this relationship in the leaves of the first and second samplings respectively for the Willamette soil. In the first sampling (Figure 5), increasing the exchangeable Ca level from 6 to 14 milliequivalents reduced the predicted Mg contents by approximately 0.10 percent Mg at all exchangeable Mg levels. In the second sampling leaves, Figure 6, the regression equation predicts a slightly different relationship. Here, the interaction between exchangeable Ca and Mg was significant, that is, exchangeable Ca reduced predicted Mg contents more at high Mg levels (about 1.2 milliequivalents) than at low Mg levels. It should be noted in Figures 5 and 6 that second sampling Mg contents were lower than those of the first sampling. The interaction mentioned above may occur because the competitive effect of Ca would quite likely be smaller when Mg contents were low. It seems unlikely that even a high level of exchangeable Ca would completely eliminate uptake of Mg. If Mg contents were low, an increase in exchangeable Ca might easily reduce them to deficient amounts. It is also noteworthy that, where 120 pounds of Mg had been applied, applications of lime seldom reduced Mg contents below percentages found where neither lime nor Mg had been applied.

Figure 16 shows the relationship of percentage Mg, first sampling, to exchangeable Mg for the Olympic soil. A pattern generally similar to that for the first sampling on Willamette soil occurred. However, there was some tendency for an interaction effect in that the reductions in Mg content caused by increasing exchangeable Ca levels were slightly smaller at lower exchangeable Mg levels.

The antagonistic effect of Ca may be at least partially brought about in two ways: first, by the effect of Ca on Mg uptake into the plant, and secondly, by the influence of liming on the concentration of Mg in the soil solution.

In the first case, Mg absorption into cells of excised barley roots was found to be blocked by small amounts of Ca (70). Ca was thought to act by altering the "permselective" properties of the cell membrane and blocking the entrance of Mg to absorption sites. It should be mentioned that this work was not done to explain results obtained with whole plants under field conditions. Its inclusion here is, in effect, "taking it out of context". However, it is interesting in that it suggests a mechanism within the plant that could possibly be a partial explanation of some of the results obtained.

The second approach to the problem would explain the effect of Ca on Mg (or K) uptake on the basis of soil reactions. Peech and Bradfield (53, p. 41 and 45) and others (1, 65) have considered this point. As an acid soil is limed exchangeable Al^{+++} is replaced by Ca^{++}. Mg^{++} and K^{+} can compete more easily with Ca^{++} than with

Al^{+++} for absorption sites on the clay colloid. Therefore more Mg^{++} and K^{+} would be absorbed in association with Ca^{++} than with Al^{+++}. Less Mg^{++} and K^{+} would be in the soil solution at high pH's than at low pH's, and there would be less Mg^{++} or K^{+} taken into the plant. Other factors, besides the two mentioned above could alter the relationship between Ca and Mg in the plant. Several workers have found differences in the effect of Ca on Mg content between species of plants (22, 62). Adams and Henderson (1) noted that the effect of pH on total Mg uptake varied with the amount of Mg in the soil. Jackson and Evans (31) in sand culture experiments with soybean seedlings noted that increasing Ca supply restricted Mg accumulation in the tops, but did not reduce accumulation into the roots.

Effect of Lime on Uptake of K

Liming, or increasing the exchangeable Ca level, also affected the K contents of broccoli leaves. Figures 8 and 19 show these effects for the Willamette and Olympic soils. On the Willamette soil (Figure 8) increasing the exchangeable Ca level significantly decreased K contents in much the same manner as it did Mg contents. However, on the Olympic soil (Figure 19), the exchangeable Ca x K interaction was highly significant. Predicted K contents were reduced by Ca at low exchangeable K levels. As the amount of exchangeable K in the soil increased, the negative effect of Ca was diminished until, at exchangeable K levels above 1 milliequivalent, K contents were increased as soil Ca increased.

The general reduction of K contents by Ca has been reported often (9, p. 283), but no reference was found to relationship similar to that found on the Olympic soil (Figure 19). To a large extent the shape of the curves in this figure are due to the fact that the only term in the equation was the interaction term. This equation, however, was the one which best fit the data. By its nature, an equation containing only an interaction term will show this reversal of response. The plant composition data in Table 20 gives some clue as to the reason for the significant interaction term, and thus the shape of the curves. Little or no significant effect of lime on K contents can be seen at the K_0 rate (K contents in treatments 1 and 4 vs. 2 and 6). This does not generally agree with the regression equation. At the K_2 level K contents are generally decreased going from L_0 to L_1 (treatments 3 and 7 vs. 4 and 8) and increased going from L_1 to L_2 (treatments 4 and 18 vs. 14 and 15). The increase in K content going from L_1 to L_2 was quite large and probably had a large influence in the computation of the regression equation. This agrees to a fair extent with the effects predicted by the equation.

The model used to develop this relationship was the following:

$$\text{m. e. K/100g.} = b_0 + b_1 \log K_{ex} + b_2 \log Ca_{ex} + b_3 \log Ca_{ex} \times \log K_{ex}.$$

In the equation containing all three variables a plot of the equation is very similar to Figure 19, though no coefficient was significant. Interpretation of the results in this case became difficult and probably the best conclusion is that the model chosen was insufficiently flexible to properly fit the data.

Factors Affecting the Critical Level of Mg in Broccoli Leaves

As defined by Ulrich (62), the "critical level" is the nutrient concentration that is just deficient for maximum growth or that which is just adequate for maximum growth, or the concentration separating the zone of deficiency from the zone of adequacy.

In order to simplify the discussion of a possible critical level for Mg, only data from the Olympic soil and leaf analysis data from first sampling leaves will be used. Responses to Mg were obtained on the Olympic soil and first sampling leaf data has been included in relationships referred to in earlier sections.

Large responses of total yield to Mg application were obtained on the Olympic soil where the first rate of lime had been applied (compare treatments 2, 13, 4 vs. 6, 9, 8 in Table 13). This response was significant when compared to the LSD for comparing averages of three treatments means. Though this response was large and statistically significant, total yield was not significantly related to percentage Mg in either the first or second sampling leaves. The reason for this was apparently the effect of K and lime applications on yield and Mg contents. The following table showing data from treatments 1-8, the lime x K x Mg factorial, was extracted from Tables 13 and 23 and shows total yield and Mg contents in the first sampling leaves.

	L_0			L_1		
	Tot. Y.	%Mg	%K	Tot. Y.	%Mg	%K
Mg_0K_0	1) 5.46	0.23	1.09	2) 4.61	0.17	1.13
Mg_0K_2	3) 5.87	0.19	2.90	4) 5.05	0.18	2.60
Mg_2K_0	5) 4.90	0.50	1.13	6) 5.21	0.35	1.40
Mg_2K_2	7) 5.90	0.40	3.22	8) 5.81	0.29	2.70

Comparing treatments at K_0 (1, 2, 5, and 6) vs. treatment (3, 4, 7, and 8) shows that application of K increased total yields and at the same time decreased Mg contents. Also note that the two lowest yields shown, treatments 2 and 5, had Mg contents of 0.17 and 0.50 percent Mg respectively. However, K contents were low on both treatments and low yields were probably due to K deficiency. Where Mg had been applied, application of lime either increased or had little effect on total yield, but Mg contents were reduced (treatments 5 and 7 vs. 6 and 8).

The closest approach that the data of this experiment would allow toward establishment of a critical level of Mg is shown in Figure 14. Data for this figure were selected so that only those observations with

K contents above 2.5 percent were used. This selection partially removed the effects of K. The graph showing this data indicates that yields tend to increase with increasing Mg contents up to a Mg percentage of approximately 0.25 to 0.30 percent. However, the scatter of observed yield points at about 0.20 to 0.25 percent Mg should be noted. Yields varied from 4.5 to 6.5 tons per acre at this Mg content. For a Mg content of 0.20, yields at the 4 - 10.9 milliequivalent exchangeable Ca level were higher generally than at the higher exchangeable Ca level.

Thus, it seems evident that if a critical level of Mg were to be established, the levels of exchangeable K and Ca would have to be stipulated.

It does appear from Figure 14 that total yields were generally reduced below 0.25 percent Mg, but certainly not in every case. Possibly a wide critical range could be established here, but certainly no critical level. Further difficulties would certainly be added to the determination of a critical level of Mg by the necessity of specifying a particular plant part to be sampled, its maturity, and the date of sampling.

<u>Implications of Nutrient Interrelations on the Management of Broccoli</u>

Generally, maximum yields were obtained on treatments that had received applications of lime, P, K, Mg and the 300 pound rate of N. As indicated in Table 1, P, S, Mg, and B were also applied. This applied to both the Willamette and Olympic soils.

An outstanding feature of the responses noted on both soils was the effect of lime application on the Mg content of broccoli leaves. On the Willamette soil the initial exchangeable Mg level was approximately 1.2 milliequivalents, and Mg contents were not reduced enough to limit yield. On the Olympic soil, where exchangeable Mg was approximately 0.8 milliequivalents initially, application of the first rate of lime reduced yields except where Mg had been applied. This lime application raised the percentage base saturation of the soil to 90 percent and pH to 6.8. Application of Mg raised both Mg content in the plant and yields. The above base saturation level is probably not unusually high for soils used in broccoli production. Where no lime had been applied, responses to Mg were not obtained.

Application of the high rate of lime (L_2) produced further reductions in yield and Mg uptake. Yield losses were not recovered by Mg fertilization. Mg contents were increased to approximately 0.2 percent Mg. While no critical level of Mg could be established from this data, total yields were generally reduced on the Olympic soil at Mg contents below this figure.

Perhaps, the high rate of Mg (120 pounds per acre) was insufficient to supply enough Mg at this high lime rate. It is a further possibility that the high rate of lime induced a deficiency of some other element.

The problem of reductions in yield brought about by lime applications on the Olympic soil was complicated by a pronounced lime x N interaction; that is, when an extra 150 pounds of N were added halfway between planting and the first harvest, application of the high rate of lime did not reduce yields. Thus, if the negative yield responses to lime were due to reduced Mg uptake, and apparently this was a partial cause, then the pattern of lime-Mg responses was altered by increasing the N application.

Results on the Olympic soil indicated that responses to Mg and K varied according to the yield category considered. Head yields, except at high N, were not greatly affected by Mg applications, but were strongly affected by K. In fact, this effect of K was a rather general occurrence. Average weights of good heads were increased by K in both years, especially on the Olympic soil. If broccoli were grown at a N level comparable to N_1 (150 pounds of N per acre) on this soil, and if the grower harvested only heads, then reductions in yield by lime or yield responses to Mg would not be so evident as if he were to harvest both heads and spears over a larger period of time. If the crop were grown with 300 pounds of N added in a split application, head and total yields would be increased, and a Mg response would probably be obtained. The above information seems to suggest that an adequate K level would be essential in the early stages of growth of this crop and that foliar applications of Mg would be beneficial after harvest of heads.

Responses to K occurred on the Olympic soil whether lime had been applied or not. Lime applications reduced K uptake but not to the extent that Mg uptake was reduced.

Implications of Interactions on Relationships between Yield and Exchangeable Cations

If, from the preceding discussions, any one statement can be made concerning the results obtained, it would probably be similar to this: the response of broccoli to any single element will be conditioned by the levels of one or more nutrients . Examples of this are the effect of lime and N on Mg responses and the effect of N on reductions of yield by lime on the Olympic soil.

These effects illustrate the difficulties that arise in attempting to relate yields or yield responses to a single nutrient element without taking into consideration the levels of one or more other elements. Further, with a crop such as broccoli where more than one part of the plant is harvested (heads and spears), response patterns can shift depending upon which type of yield is being considered. Thus, it would seem that attempts to draw simple relationships between yield and,

e. g., exchangeable Mg would be highly difficult.

In this work, attempts were made to obtain relationships between yields (total or head) and exchangeable cations or plant composition on treatments at several levels of lime, Mg, and K. Regression equations including more than one variable were used. That these were at least partially successful can be seen from the fact that yields were generally related to more than one variable at a time and that, on occasion, significant interactions were measured. In nearly all cases, the inclusion of more than one variable improved correlations. In an outstanding case, head yields on the Olympic soil in 1960 were significantly related to exchangeable Ca, K, and Mg, and the interaction term between exchangeable Ca and Mg approached significance. As successive models, each containing an additional variable were used, correlations improved. As suggested earlier, not all attempts were this successful. At times adding further variables to the model only increased error. Since the choice of the proper model was based only on preliminary observation of the data and not on any theoretical basis, this seems to indicate that the choice was not always the proper one or that the model chosen was not flexible enough to fit the response pattern involved. But, nonetheless, the use of these models does recognize the fact that the response to an element can vary with the levels of other nutrient elements.

From the above discussion, and from the fact that only one crop and one soil were considered, a small indication of the difficulties involved in obtaining meaningful correlations between yields and soil test values can be seen.

SUMMARY

In order to measure the response of broccoli to applications of lime, K, and Mg, field experiments were established on a Willamette soil (North Willamette Branch Experiment Station) and on an Olympic Soil (Red Soils Experiment Station) in 1959 and 1960.

The experimental design consisted of treatments selected to give a series of factorial combinations involving rates of lime, Mg, K, and N. This was done so that the response to any one of these variables could be measured at more than one level of the others and to allow the measurement of interaction effects. Of particular interest were the effects of lime and K on responses to Mg.

Yields of heads and spears and total yields were taken. Head and spear yields were further segregated on the basis of conformation and color to determine what effect, if any, fertilizer treatment had on quality.

Samples of broccoli leaves of differing maturities were taken at three different times during the growing period. Soil samples were taken prior to and after fertilization for the 1960 crop. From this information sets of soil analysis and plant composition data were selected for use in determining relationships between yields and soil analysis data, yields and plant composition, and between plant composition

and soil analysis. These relationships were developed by fitting selected models to the data using multiple regression techniques.

In 1959, yields were lower than in 1960, especially on the Olympic soil. This was due to a rather pronounced bolting of heads due to an early planting date. Yield responses in 1959 on both soils were small and few in number. A significant response of total yield to N was obtained on the Willamette soil and, while significant responses from lime, K, and Mg were not obtained, yields were higher when these elements were applied together.

On the Olympic soil in 1959 total yield and average weights of good quality heads responded to applications of K. These responses were expected due to the initial low exchangeable K status of this soil. Responses to Mg, slightly smaller in magnitude than the responses to K, were obtained where both K and the first rate of lime (L_1) had been applied. Total yields were slightly increased by application of the first rate of lime. Thus, while the responses to lime, Mg, and K were not generally large, yields were increased by their combined application.

In 1960, broccoli was transplanted at a later date, and total yields obtained were larger, especially on the Olympic soil. The only significant response on the Willamette soil was to N, though yields were negatively related to exchangeable Mg and Mg content of the leaf tissue. This negative response to Mg approached significance at N_1 but did not occur at the high rate of N.

On the Olympic soil in 1960, positive responses of head, spear, and total yield to Mg were obtained, but only when the first rate of lime had been applied (90 percent base saturation). This lime x Mg interaction of total yield was statistically significant. Higher levels of exchangeable Mg were needed to maintain an adequate amount of Mg in the plant as the lime rate (or percentage base saturation) increased. The Mg content of the leaf tissue was negatively related to exchangeable Ca and K levels in the soil.

Application of the highest lime rate (L_2), or a level approaching 100 percent base saturation, reduced both yields and Mg contents of the leaves. At this high exchangeable Ca level, application of 120 pounds of Mg per acre (Mg_2) increased yields only slightly. Mg contents of the leaf tissue were further decreased, but to values only slightly below those at the lower lime rate (90 percent base saturation). The cause of this yield reduction by the high lime rate may be that insufficient Mg had been applied to maintain an adequate level of Mg in the plant, or that lime additions induced the deficiency of some other (and unidentified) nutrient.

These yield reductions caused by lime applications were related to N fertilization. Spear and total yields responded significantly to the last portion of a split N application. (150 pounds of N were applied at planting, and an additional 150 pounds of N were added approximately three weeks prior to the first harvest). A significant lime x N interaction occurred in that the yield reductions evident when the high rate of lime was applied (L_1 to L_2) did not occur at the high N rate. Yield reductions due to lime were primarily evident in spear yield and N increased spear yields. If, however, yield reductions due to high lime were related to its effect on Mg availability, then N must have altered this pattern in some way. An altogether satisfactory explanation of the lime x N interaction was not found.

Significant positive responses of total and head yield to K were obtained on the Olympic soil. These responses occurred both where lime had and had not been applied. Head yields were increased to a greater extent by K than were spear yields. Both head and total yields were significantly related to exchangeable K and K content of broccoli leaves. Responses to K were generally larger where both lime and Mg had been applied. Percentage K in the leaves was reduced by Ca, but not by Mg.

Rather general effects observed on the Olympic soil were the positive effects of K on head yield and Mg on spear yields. This would seem to suggest that adequate K levels would be necessary initially to provide maximum head yields, followed by foliar applications of Mg as soon as head harvest began. The largest total yields for the Olympic soil in 1960 were obtained where lime, Mg, K, and the 300 pound rate of N had been applied. Yields were often not particularly well correlated with any element individually unless the levels of the other elements were stipulated.

The difficulties involved in obtaining relationships between yield and exchangeable Mg or the Mg content of broccoli leaves were discussed. Total and spear yield did not respond to Mg except at the higher levels of exchangeable Ca. Total and head yields were also increased by applications of K. Therefore, before a meaningful relationship between yield and exchangeable Mg could be developed, the levels of exchangeable Ca and K would have to be known.

The difficulties involved in determining a "critical level" for Mg for this data were also considered. High yields were generally associated with Mg contents of 0. 25 percent in the oldest mature leaves, first sampling.

The results of this study suggest that simple correlations of yield with soil test values would be difficult. A better approach would involve correlations with more than one element at one time. This is due, in general, to the interactions between nutrient elements which alter the pattern of yield responses to any single element.

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APPENDIX

Appendix Table 1. Yields of Broccoli of Various Yield Categories.[2] 1959. Willamette Soil. Data Tabulated by Replication and Totals of 4 Replications.

Treatments[1] LKMg NPS	Rep.	Wt. of Good Heads (g. /plot)	Total Yield T/A[2] Heads plus Spears Harvests 1-6	Total Yield T/A[2] Heads plus Spears Harvests 1-9
(1) 0 0 0 1 2 1	1	1910	4.31	5.49
	2	2840	3.12	4.23
	3	1920	4.21	5.84
	4	3510	3.82	5.16
	Total	10180	15.46	20.72
(2) 1 0 0 1 2 1	1	3280	3.34	5.07
	2	4290	3.69	5.09
	3	2830	4.10	5.38
	4	2790	3.88	5.31
	Total	13190	15.01	20.85
(3) 0 2 0 1 2 1	1	3570	4.01	5.16
	2	2510	2.80	4.59
	3	3740	4.35	5.89
	4	3040	3.08	4.38
	Total	12860	14.24	20.02
(4) 1 2 0 1 2 1	1	2320	3.98	5.49
	2	1410	3.39	4.64
	3	4200	4.23	5.62
	4	3690	3.87	5.27
	Total	11620	15.47	21.02
(5) 0 0 2 1 2 1	1	1820	3.68	4.99
	2	2180	3.01	4.18
	3	4770	3.97	5.14
	4	3650	3.70	5.25
	Total	12420	14.36	19.56
(6) 1 0 2 1 2 1	1	2540	3.56	4.78
	2	2610	3.80	5.21
	3	5960	4.69	5.82
	4	5890	3.78	5.02
	Total	17000	15.83	20.83
(7) 0 2 2 1 2 1	1	3930	4.07	5.30
	2	3540	3.73	5.10
	3	3890	3.90	5.49
	4	2980	3.71	5.05
	Total	14340	15.41	20.94
(8) 1 2 2 1 2 1	1	2870	4.33	5.69
	2	2280	3.75	5.37
	3	5700	3.67	5.29
	4	2710	3.93	5.40
	Total	13560	15.68	21.75
(9) 1 1 2 1 2 1	1	2120	2.92	4.35
	2	2440	3.61	4.58
	3	5110	4.23	5.45
	4	3450	3.33	4.91
	Total	13120	14.09	19.29
(10) 1 2 1 1 2 1	1	2110	3.83	5.31
	2	2780	3.78	5.29
	3	4970	4.04	5.33
	4	4900	3.75	5.04
	Total	14760	15.40	20.97
(11) 1 1 1 1 2 1	1	1470	3.26	4.95
	2	2140	3.07	4.51
	3	4555	4.31	5.67
	4	3940	4.55	5.73
	Total	12105	15.19	20.86
(12) 1 0 1 1 2 1	1	3060	3.96	5.15
	2	4090	4.19	5.16
	3	2940	4.16	5.71
	4	4390	3.86	4.76
	Total	14480	16.17	20.78
(13) 1 1 0 1 2 1	1	2420	4.21	4.98
	2	3500	2.67	3.73
	3	5380	4.79	5.77
	4	6290	4.09	5.50
	Total	17590	15.76	19.98
(14) 2 2 0 1 2 1	1	1560	3.23	4.31
	2	3440	3.58	5.19
	3	5430	4.49	5.62
	4	3920	3.67	4.83
	Total	14350	14.97	19.95
(15) 2 2 2 1 2 1	1	3570	3.74	4.74
	2	3130	3.50	4.75
	3	2670	4.10	5.35
	4	3540	4.35	5.71
	Total	12910	15.69	20.55
(16) 1 2 0 2 2 1	1	2220	3.91	5.28
	2	4180	3.23	4.69
	3	6380	3.81	5.58
	4	4450	3.88	5.26
	Total	17230	14.83	20.81
(17) 1 2 2 2 2 1	1	4820	3.96	5.58
	2	4720	3.85	5.24
	3	4590	4.40	5.94
	4	5120	4.49	5.90
	Total	19250	16.70	22.66
(18) 2 2 0 2 2 1	1	7310	4.11	5.67
	2	4080	3.32	5.33
	3	4970	4.48	5.37
	4	3870	4.43	6.07
	Total	20230	16.34	22.44
(19) 2 2 2 2 2 1	1	3500	4.53	5.59
	2	1880	3.59	5.01
	3	3120	3.66	5.53
	4	5800	4.39	5.59
	Total	14300	16.17	21.72
(20) 1 2 0 1 2 0	1	1750	3.26	4.38
	2	4080	3.50	4.63
	3	3170	3.03	4.55
	4	3380	3.61	4.67
	Total	12380	13.40	18.23
(21) 1 2 0 2 2 0	1	4040	3.15	4.59
	2	2630	2.81	4.03
	3	4420	3.33	4.90
	4	4030	3.32	4.30
	Total	15120	12.61	17.82
(22) 1 2 2 1 0 1	1	2680	4.23	5.24
	2	1980	3.58	4.56
	3	3050	3.70	5.14
	4	3670	3.22	4.37
	Total	11380	14.73	19.31
(23) 1 2 2 2 0 1	1	1260	3.24	4.62
	2	2420	3.13	4.44
	3	5660	4.62	6.04
	4	3330	3.26	4.65
	Total	12690	14.25	19.75
(24) 1 2 2 1 1 1	1	1700	4.36	5.53
	2	3290	3.88	5.21
	3	4580	4.57	5.92
	4	2690	3.84	5.41
	Total	12260	16.65	22.07
(25) 1 2 2 2 1 1	1	2920	3.78	5.05
	2	4280	3.86	5.09
	3	4110	4.58	5.94
	4	3030	4.06	5.46
	Total	14340	16.28	21.54

[1] See Table 1 for treatment level combinations and rates of fertilizer application.

[2] Yield categories are defined in "Experimental Methods" section.

Appendix Table 2. Yields of Broccoli of Various Yield Categories.[2] 1959. Olympic Soil. Data Tabulated by Replication and Totals of 4 Replications.

Treatments[1] LKMg NPS	Rep.	Wt. of Good Heads (g./plot)	Total Yield T/A[2] Heads plus Spears Harvests 1-6	Total Yield T/A[2] Heads plus Spears Harvests 1-9
(1) 0 0 0 1 2 1	1	1380	2.44	3.40
	2	680	2.48	3.90
	3	1560	3.09	3.99
	4	1180	3.05	4.86
	Total	4800	11.06	16.15
(2) 1 0 0 1 2 1	1	620	2.01	3.49
	2	590	2.92	4.00
	3	3570	3.59	4.92
	4	1650	2.80	4.05
	Total	6430	11.32	16.46
(3) 0 2 0 1 2 1	1	2300	3.09	4.31
	2	1420	2.45	3.90
	3	1260	2.58	4.19
	4	2180	2.00	3.88
	Total	7160	10.12	16.28
(4) 1 2 0 1 2 1	1	1760	2.35	3.78
	2	920	3.16	4.45
	3	3450	3.14	4.53
	4	3550	2.72	4.84
	Total	9680	11.37	17.60
(5) 0 0 2 1 2 1	1	680	2.41	3.75
	2	1420	2.85	3.57
	3	2560	2.77	4.31
	4	2770	2.82	4.12
	Total	7430	10.85	15.75
(6) 1 0 2 1 2 1	1	1730	2.41	4.10
	2	1550	2.16	3.40
	3	1620	3.41	4.49
	4	2540	2.72	3.89
	Total	7440	10.70	15.88
(7) 0 2 2 1 2 1	1	2010	3.31	4.71
	2	1800	2.75	4.47
	3	3190	2.34	3.86
	4	1750	2.72	4.07
	Total	8750	11.12	17.11
(8) 1 2 2 1 2 1	1	1670	2.53	4.13
	2	1550	2.67	4.04
	3	1260	3.96	5.64
	4	4200	3.24	4.98
	Total	8680	12.40	18.79
(9) 1 1 2 1 2 1	1	2050	3.38	4.78
	2	1750	2.79	4.16
	3	2300	3.16	4.30
	4	1860	3.59	4.29
	Total	7960	12.92	17.53
(10) 1 2 1 1 2 1	1	1910	4.31	5.50
	2	2550	2.77	4.30
	3	3050	4.18	5.68
	4	2450	1.97	3.46
	Total	9960	13.23	18.94
(11) 1 1 1 1 2 1	1	1040	2.31	3.39
	2	2270	2.91	4.21
	3	1770	2.99	4.50
	4	2510	2.71	4.17
	Total	7590	10.92	16.27
(12) 1 0 1 1 2 1	1	580	3.26	4.37
	2	1860	2.57	4.52
	3	1370	1.66	3.31
	4	1890	2.61	4.60
	Total	5700	10.10	16.80
(13) 1 1 0 1 2 1	1	1040	3.93	5.22
	2	2000	2.11	4.02
	3	1640	2.82	4.36
	4	3060	2.14	3.56
	Total	7740	11.00	17.16
(14) 2 2 0 1 2 1	1	1820	3.18	4.74
	2	860	2.53	4.26
	3	2240	3.24	4.67
	4	2900	2.91	4.34
	Total	7820	11.86	18.01
(15) 2 2 2 1 2 1	1	2510	3.34	4.73
	2	2130	3.72	4.96
	3	2310	2.81	4.59
	4	1810	2.29	3.72
	Total	8760	12.16	18.00
(16) 1 2 0 2 2 1	1	1420	3.90	5.39
	2	2110	3.12	4.61
	3	970	2.70	4.53
	4	1650	2.80	4.30
	Total	6150	12.52	18.83
(17) 1 2 2 2 2 1	1	2610	4.13	6.03
	2	1950	3.34	5.34
	3	2630	3.04	5.02
	4	2960	2.82	4.45
	Total	10150	13.33	20.84
(18) 2 2 0 2 2 1	1	2080	3.91	4.95
	2	2260	2.77	4.44
	3	1680	2.47	3.92
	4	2150	2.76	4.56
	Total	8170	11.91	17.87
(19) 2 2 2 2 2 1	1	1970	2.56	4.83
	2	1690	2.39	3.76
	3	1730	2.10	3.49
	4	1750	2.01	4.54
	Total	7140	9.06	16.62
(20) 1 2 0 1 2 0	1	1530	3.10	4.53
	2	2720	3.30	5.05
	3	2300	2.49	4.33
	4	1460	2.94	4.19
	Total	8010	11.83	18.10
(21) 1 2 0 2 2 0	1	2150	3.72	5.50
	2	2180	2.53	4.24
	3	2170	2.62	4.45
	4	3020	2.27	4.19
	Total	9520	11.14	18.38
(22) 1 2 2 1 0 1	1	380	0.60	1.21
	2	1830	2.47	3.91
	3	1370	1.20	1.91
	4	1250	1.15	2.34
	Total	4830	5.42	9.37
(23) 1 2 2 2 0 1	1	1390	0.73	1.48
	2	940	0.87	1.67
	3	940	1.18	1.73
	4	1530	0.79	1.54
	Total	4800	3.57	6.42
(24) 1 2 2 1 1 1	1	1770	4.08	5.67
	2	2810	3.39	4.79
	3	2660	2.84	4.59
	4	2670	3.03	4.57
	Total	9910	13.34	19.62
(25) 1 2 2 2 1 1	1	670	2.14	3.40
	2	4050	3.33	4.61
	3	1490	1.91	3.44
	4	2040	2.80	3.64
	Total	8250	10.18	15.09

[1] See Table 1 for treatment level combinations and rates of fertilizer application.

[2] Yield categories are defined in "Experimental Methods" section.

Appendix Table 3. Average Head Weights of Good and Cull Heads and Average Spear Weights for Harvests 4-6 and 7-9. Willamette and Olympic Soils. 1959. Means of 4 Replications.

Treatments	Willamette Soil				Olympic Soil			
	Av. Head Wts. (g.)		Av. Spear Wts. (g.)		Av. Head Wts. (g.)		Av. Spear Wts. (g.)	
LKMg NPS	Good	Cull	Harvests 4-6	Harvests 7-9	Good	Cull	Harvests 4-6	Harvests 7-9
(1) 0 0 0 1 2 1	234	244	51	39	139	164	51	41
(2) 1 0 0 1 2 1	216	232	53	45	157	154	52	36
(3) 0 2 0 1 2 1	229	248	54	45	175	201	61	40
(4) 1 2 0 1 2 1	240	258	53	39	184	189	61	39
(5) 0 0 2 1 2 1	221	224	55	45	135	124	58	40
(6) 1 0 2 1 2 1	234	252	53	36	148	150	54	36
(7) 0 2 2 1 2 1	235	258	53	36	171	163	68	37
(8) 1 2 2 1 2 1	224	231	59	49	163	182	58	38
(9) 1 1 2 1 2 1	215	244	51	38	170	140	58	36
(10) 1 2 1 1 2 1	242	225	49	49	176	224	61	45
(11) 1 1 1 1 2 1	239	230	54	38	154	174	61	38
(12) 1 0 1 1 2 1	230	242	49	35	129	155	68	41
(13) 1 1 0 1 2 1	226	229	51	39	142	153	59	46
(14) 2 2 0 1 2 1	253	255	54	45	140	185	64	44
(15) 2 2 2 1 2 1	242	266	54	37	182	171	65	39
(16) 1 2 0 2 2 1	245	247	50	40	160	204	65	41
(17) 1 2 2 2 2 1	254	253	62	37	191	165	68	48
(18) 2 2 0 2 2 1	245	246	53	61	177	153	67	40
(19) 2 2 2 2 2 1	244	249	57	51	148	161	60	51
(20) 1 2 0 1 2 0	236	273	51	43	175	211	63	38
(21) 1 2 0 2 2 0	245	244	53	48	183	164	66	47
(22) 1 2 2 1 0 1	263	260	51	39	86	117	63	38
(23) 1 2 2 2 0 1	242	244	52	41	174	171	48	36
(24) 1 2 2 1 1 1	249	282	53	39	181	206	64	38
(25) 1 2 2 2 1 1	247	262	53	39	179	155	63	46

Appendix Table 4. Yields of Broccoli of All Yield Categories.[2] 1960. Willamette Soil. Data Tabulated by Replication.

Treatments[1] LKMg NPS	Rep.	Plants /plot	Number 1 Heads No.	Number 1 Heads g. /plot	Number 2 Heads No.	Number 2 Heads g. /plot	Heads Total Wt. (T/A)	Number 1 Spears No.	Number 1 Spears g. /plot	Number 2 Spears No.	Number 2 Spears g. /plot	Spears Total Wt. (T/A)
(1) 0 0 0 1 2 1	1	44.	33	6120	10	1750	2. 11	267	9560	11	350	2. 65
	2	44	34	5745	13	2570	2. 23	313	11290	2	70	3. 04
	3	43	39	7470	7	1360	2. 42	344	12540	17	515	3. 58
	4	41	31	5590	10	2160	2. 23	257	9610	9	410	2. 88
(2) 1 0 0 1 2 1	1	44	27	4640	18	3480	2. 18	316	12020	22	590	3. 38
	2	45	30	5285	15	2715	2. 10	282	12460	12	510	3. 40
	3	40	37	6520	3	370	2. 03	272	10760	7	390	3. 29
	4	46	31	5870	13	2710	2. 20	385	12560	8	350	3. 31
(3) 0 2 0 1 2 1	1	43	24	4100	16	3650	2. 12	279	10330	4	90	2. 86
	2	41	33	6330	8	1870	2. 36	284	11940	8	290	3. 52
	3	45	32	6050	9	2080	2. 13	326	11750	4	150	3. 12
	4	42	35	6130	2	280	1. 80	279	9385	1	40	2. 64
(4) 1 2 0 1 2 1	1	41	31	6300	8	1500	2. 24	279	10250	4	130	2. 98
	2	43	35	6970	9	1690	2. 37	299	12225	8	310	3. 44
	3	39	25	4590	13	2870	2. 26	207	8260	11	320	2. 59
	4	43	26	4810	19	3530	2. 29	297	10190	17	650	2. 97
(5) 0 0 2 1 2 1	1	41	37	6490	6	1390	2. 26	223	8250	8	210	2. 43
	2	45	34	6080	10	1800	2. 07	269	10780	1	40	2. 83
	3	43	28	4740	14	3330	2. 21	248	7770	21	720	2. 33
	4	44	33	5830	10	2010	2. 10	300	10060	14	510	2. 83
(6) 1 0 2 1 2 1	1	44	30	5300	10	1880	1. 92	319	10800	14	360	2. 99
	2	45	27	4250	16	2850	1. 86	225	9955	28	710	2. 79
	3	47	36	5970	9	1660	2. 31	273	10560	16	540	2. 78
	4	39	36	6110	1	260	1. 92	297	9670	0	0	2. 92
(7) 0 2 2 1 2 1	1	42	33	5820	11	2300	2. 28	263	8910	3	70	2. 52
	2	43	34	6395	11	2290	2. 38	251	9740	0	0	2. 67
	3	39	38	6045	1	130	1. 87	179	5725	0	0	1. 73
	4	41	30	5170	10	1900	2. 03	347	12300	6	290	3. 62
(8) 1 2 2 1 2 1	1	39	20	3270	19	3800	2. 14	316	10770	3	70	3. 28
	2	44	35	6310	10	1550	2. 11	320	12510	8	220	3. 41
	3	37	33	5970	8	1620	2. 42	227	7685	1	25	2. 46
	4	41	38	6610	6	1070	2. 21	253	9260	6	225	2. 73
(9) 1 1 2 1 2 1	1	42	30	5810	10	2350	2. 29	239	9490	8	370	2. 77
	2	44	27	5280	14	3660	2. 40	266	10415	1	30	2. 80
	3	42	32	4720	7	1130	1. 64	195	7337	1	40	2. 07
	4	45	31	5360	13	2780	2. 13	380	12850	2	90	3. 39
(10) 1 2 1 1 2 1	1	45	25	5320	15	3530	2. 32	345	12060	0	0	3. 16
	2	44	33	5850	9	1710	2. 03	287	10990	16	530	3. 09
	3	45	32	6030	17	3580	2. 52	359	12200	2	60	3. 21
	4	45	30	5960	10	2190	2. 13	373	12390	13	450	3. 36
(11) 1 1 1 1 2 1	1	43	32	5740	9	1890	2. 09	254	10370	3	100	2. 87
	2	46	25	4250	17	3440	1. 97	198	8380	10	410	2. 25
	3	42	33	5710	15	3440	2. 54	375	13440	4	140	3. 81
	4	48	31	5600	16	3120	2. 14	271	8105	10	360	2. 08
(12) 1 0 1 1 2 1	1	41	28	4850	11	1640	1. 86	326	12080	2	80	3. 50
	2	38	23	3610	19	4290	2. 45	259	9445	0	0	2. 93
	3	46	35	6230	3	350	1. 69	284	9705	17	570	2. 63
	4	45	31	5990	9	1740	2. 03	263	10310	22	970	2. 96
(13) 1 1 0 1 2 1	1	41	32	6120	8	1690	2. 25	276	10110	5	320	3. 00
	2	42	30	5040	11	2010	1. 98	161	7055	1	30	1. 99
	3	43	27	5410	12	2540	2. 18	316	10560	8	270	2. 97
	4	44	31	5390	14	3020	2. 25	220	8015	12	400	2. 25

Continued on next page

Appendix Table 4 (continued)

Treatments[1] LKMg NPS	Rep.	Plants /plot	Number 1 Heads		Number 2 Heads		Heads Total Wt. (T/A)	Number 1 Spears		Number 2 Spears		Spears Total Wt. (T/A)
			No.	g. /plot	No.	g. /plot		No.	g. /plot	No.	g. /plot	
(14) 2 2 0 1 2 1	1	38	33	6700	8	1510	2.55	177	7015	14	580	2.35
	2	43	27	4600	18	3570	2.24	340	11680	1	70	3.22
	3	41	31	6130	11	2300	2.42	278	9790	7	290	2.90
	4	41	35	5760	4	750	1.87	216	7360	3	100	2.22
(15) 2 2 2 1 2 1	1	40	32	5890	10	1890	2.29	213	7610	0	0	2.24
	2	41	29	5590	17	4630	2.94	238	8950	4	120	2.62
	3	40	33	5430	8	1760	2.12	268	9370	0	0	2.76
	4	35	38	6950	2	310	2.45	150	5210	3	80	1.78
(16) 1 2 0 2 2 1	1	40	34	5250	9	2320	2.23	237	8120	8	350	2.50
	2	46	31	5610	9	1500	1.82	209	9510	14	580	2.58
	3	41	39	6400	5	800	2.07	200	7420	1	45	2.14
	4	45	32	6755	15	4110	2.85	401	14540	9	355	3.90
(17) 1 2 2 2 2 1	1	42	40	7530	8	1800	2.62	343	12430	0	0	3.49
	2	42	27	5610	12	2610	2.31	331	14060	1	120	3.98
	3	46	37	7150	14	4195	2.91	374	13420	14	280	3.51
	4	40	31	5685	9	1560	2.14	233	8845	14	720	2.82
(18) 2 2 0 2 2 1	1	47	40	6550	11	1920	2.12	234	8600	13	550	2.29
	2	43	28	5210	12	2590	2.14	307	14280	3	70	3.94
	3	41	30	6010	10	2110	2.34	357	13480	2	50	3.89
	4	40	29	5460	14	2380	2.31	199	7480	9	400	2.32
(19) 2 2 2 2 2 1	1	42	30	6110	14	3330	2.65	366	13230	10	420	3.83
	2	43	32	5270	12	2530	2.14	280	10765	0	0	2.95
	3	41	47	6190	8	1170	2.12	277	9070	6	160	2.65
	4	48	35	6545	11	2750	2.28	329	12445	2	80	3.07
(20) 1 2 0 1 2 0	1	40	34	6970	7	1420	2.47	239	8770	13	480	2.73
	2	40	22	3745	18	3380	2.10	257	10050	1	50	2.98
	3	45	32	6540	9	1940	2.22	288	9210	30	1350	2.77
	4	43	29	5510	14	2430	2.18	330	11490	6	280	3.23
(21) 1 2 0 2 2 0	1	39	28	4740	11	2200	2.10	238	8880	0	0	2.68
	2	39	25	4270	16	3160	2.25	223	7810	27	810	2.62
	3	43	30	5950	14	2775	2.39	274	9410	2	80	2.60
	4	41	29	5180	15	3310	2.44	190	7085	20	810	2.27
(22) 1 2 2 1 0 1	1	43	37	7340	5	1240	2.35	330	11260	3	100	3.11
	2	39	36	5960	3	630	1.99	149	5810	7	290	1.84
	3	40	37	6470	8	1280	2.29	255	9600	7	290	2.92
	4	41	36	6320	7	1560	2.26	306	11870	9	330	3.52
(23) 1 2 2 2 0 1	1	42	28	5415	10	2070	2.10	272	8890	7	210	2.55
	2	41	31	6110	11	2325	2.42	286	11360	8	230	3.33
	3	43	37	7230	7	1520	2.40	279	11370	0	0	3.12
	4	44	36	6210	7	1200	1.98	212	10525	6	250	2.89
(24) 1 2 2 1 1 1	1	42	29	5720	13	4080	2.75	363	13250	3	90	3.79
	2	40	25	4330	16	2860	2.12	259	9870	7	250	2.99
	3	43	28	5550	10	2010	2.07	239	7740	2	60	2.14
	4	39	25	4610	5	1460	1.83	299	11000	6	450	3.46
(25) 1 2 2 2 1 1	1	42	35	6985	8	1540	2.39	261	10310	0	0	2.89
	2	43	32	6370	14	2830	2.52	192	8100	28	1110	2.52
	3	42	31	5425	13	2850	2.32	198	8330	16	680	2.53
	4	44	24	4230	18	3650	2.11	185	6600	19	540	1.91

1 See Table 1 for rates of fertilizer application

2 Yield categories defined in "Experimental Methods" section.

Appendix Table 5. Yields of Broccoli of Various Yield Categories.[2] 1960. Olympic Soil. Data are Tabulated by Replication.

Treatments[1] LKMg NPS	Rep.	Plants /plot	Number 1 Heads No.	Number 1 Heads g. /plot	Number 2 Heads No.	Number 2 Heads g. /plot	Heads Total Wt. (T/A)	Number 1 Spears No.	Number 1 Spears g. /plot	Number 2 Spears No.	Number 2 Spears g. /plot	Spears Total Wt. (T/A)
(1) 0 0 0 1 2 1	1	33	21	4225	11	1850	2.17	183	7675	10	305	2.92
	2	36	29	4480	13	1700	2.02	238	9885	32	700	3.83
	3	32	18	3875	15	2370	2.30	223	8270	17	685	3.63
	4	35	22	3680	15	2300	2.01	246	8340	9	210	2.92
(2) 1 0 0 1 2 1	1	30	13	1805	17	2120	1.54	160	4535	2	50	2.59
	2	33	23	3640	10	1850	1.96	194	7085	30	810	2.92
	3	34	23	4145	13	2500	2.30	219	8185	10	315	3.08
	4	34	26	3805	5	700	1.56	200	6785	14	335	2.49
(3) 0 2 0 1 2 1	1	31	17	3900	13	2720	2.52	220	8700	5	125	3.37
	2	34	26	4715	12	2775	2.60	275	10340	4	105	3.73
	3	30	21	3680	13	2140	2.29	213	3250	0	0	3.46
	4	34	25	4720	8	1620	2.20	257	9265	6	205	3.31
(4) 1 2 0 1 2 1	1	33	20	3420	10	1630	1.80	221	7385	6	120	2.94
	2	33	20	3490	12	1875	1.92	221	8410	6	225	3.13
	3	35	23	4045	9	1360	1.82	200	7070	10	350	2.61
	4	32	21	3585	17	3720	2.69	207	7665	30	1040	3.27
(5) 0 0 2 1 2 1	1	33	18	2970	12	1560	1.58	194	6340	23	800	2.97
	2	34	17	2610	15	2480	1.76	149	3770	55	1305	1.94
	3	29	15	2760	13	2660	2.20	208	7540	24	870	3.72
	4	35	21	4050	12	1990	2.04	256	9185	17	480	3.39
(6) 1 0 2 1 2 1	1	30	19	3195	10	1755	1.95	208	7865	20	640	3.54
	2	35	24	4120	5	860	1.68	256	8570	25	1020	3.38
	3	30	18	2925	11	2275	2.04	179	6775	16	504	3.00
	4	35	30	5610	4	550	2.07	235	8270	32	885	3.17
(7) 0 2 2 1 2 1	1	33	20	3780	10	1915	2.03	265	10075	15	440	4.04
	2	35	25	5440	12	2885	2.80	227	8727	16	515	3.21
	3	29	15	2695	14	2280	2.02	216	10685	0	0	4.40
	4	36	18	3950	11	1990	1.94	256	9185	5	130	3.16
(8) 1 2 2 1 2 1	1	30	25	5350	7	1860	2.83	245	10020	6	295	4.22
	2	33	18	3250	13	2135	1.92	220	9090	0	0	3.29
	3	32	28	4305	6	970	1.94	200	8730	14	430	3.55
	4	32	23	4240	8	1610	2.15	227	8975	2	50	3.35
(9) 1 1 2 1 2 1	1	34	19	2935	16	3330	2.17	208	8250	8	350	3.05
	2	33	22	4495	14	3025	2.69	286	10240	8	225	3.96
	3	34	21	3300	11	1820	1.77	195	7210	12	355	2.64
	4	34	21	3755	14	2570	2.19	243	9375	8	200	3.54
(10) 1 2 1 1 2 1	1	34	22	4185	10	1920	2.12	218	8610	13	340	3.20
	2	35	22	4465	13	2695	2.41	273	9440	10	390	3.36
	3	33	21	3620	13	2500	2.19	267	10430	1	25	3.89
	4	35	16	2860	19	3420	2.11	224	8170	2	60	2.81
(11) 1 1 1 1 2 1	1	33	19	2700	15	3005	2.04	179	7035	7	500	2.95
	2	37	27	4745	8	1620	2.03	275	10565	5	305	3.57
	3	28	18	3255	8	1685	2.08	206	8445	8	355	4.10
	4	33	20	3740	12	2845	2.35	222	8455	29	960	3.40
(12) 1 0 1 1 2 1	1	30	19	2560	14	1705	1.68	171	5610	28	660	2.72
	2	32	27	5235	8	1710	2.56	229	8565	20	625	3.60
	3	32	15	2645	8	1240	1.43	190	8070	0	0	3.09
	4	31	21	3490	10	1380	1.85	234	8360	0	0	3.22
(13) 1 1 0 1 2 1	1	34	25	4235	10	2105	2.20	250	9195	16	475	3.48
	2	34	20	3905	13	2610	2.26	189	6320	16	550	2.49
	3	30	19	3790	10	1970	2.26	179	7040	6	125	3.01
	4	31	14	2285	15	2615	1.86	168	6385	8	200	2.54

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Appendix Table 5 (continued).

Treatments[1] LKMg NPS	Rep.	Plants /plot	Number 1 Heads No.	Number 1 Heads g. /plot	Number 2 Heads No.	Number 2 Heads g. /plot	Heads Total Wt. (T/A)	Number 1 Spears No.	Number 1 Spears g. /plot	Number 2 Spears No.	Number 2 Spears g. /plot	Spears Total Wt. (T/A)
(14) 2 2 0 1 2 1	1	33	18	3340	15	2440	2.06	183	7155	2	80	2.69
	2	36	24	3615	11	1985	1.83	212	8390	6	215	2.92
	3	36	24	3780	11	1740	1.81	207	7740	8	190	2.75
	4	32	21	3345	12	2025	1.98	200	6685	5	175	2.62
(15) 2 2 2 1 2 1	1	34	21	4655	11	2125	2.35	156	6350	32	950	2.62
	2	37	29	5575	12	1930	2.39	218	8000	7	210	2.74
	3	29	11	1910	17	2720	1.88	126	5515	1	40	2.34
	4	31	13	2115	18	2795	1.87	199	8960	4	80	3.45
(16) 1 2 0 2 2 1	1	32	23	3855	10	1670	2.04	198	7680	10	300	3.12
	2	32	26	4820	4	700	2.03	238	9050	5	140	3.44
	3	29	21	3255	7	1365	1.88	188	7575	4	160	3.20
	4	34	15	2805	17	3010	2.02	271	9400	2	60	3.34
(17) 1 2 2 2 2 1	1	34	24	4895	10	2055	2.42	235	8390	24	895	3.28
	2	35	22	4755	14	3190	2.68	256	8920	5	170	3.09
	3	35	17	3990	17	3780	2.62	289	12125	13	480	4.43
	4	32	23	4280	8	1390	2.09	201	8740	14	475	3.46
(18) 2 2 0 2 2 1	1	34	26	4860	6	1055	2.05	242	9825	1	30	3.58
	2	38	26	4745	11	1965	2.08	328	12045	3	110	3.92
	3	32	16	3410	14	2640	2.23	265	10810	0	0	4.06
	4	30	18	2935	10	1800	1.86	208	8910	7	210	3.70
(19) 2 2 2 2 2 1	1	32	17	3180	11	1995	1.91	250	10310	2	90	4.04
	2	34	24	4670	11	2545	2.50	234	9475	19	585	3.67
	3	29	20	3170	7	1470	1.89	167	7020	0	0	2.89
	4	30	25	4125	5	880	1.97	164	5860	5	190	2.42
(20) 1 2 0 1 2 0	1	35	25	4665	9	1940	2.22	253	9525	9	305	3.47
	2	34	16	2870	15	3045	2.05	192	6000	4	125	2.30
	3	30	24	4065	12	2250	2.48	183	7315	3	75	2.94
	4	36	27	5130	9	1760	2.26	194	7790	3	150	2.64
(21) 1 2 0 2 2 0	1	33	15	2605	15	2770	1.92	189	6685	4	100	2.72
	2	32	22	4060	10	1630	2.10	197	7940	12	485	3.12
	3	32	23	4455	6	1130	2.06	231	8685	1	20	3.25
	4	33	19	3105	13	2380	1.96	227	8835	0	0	3.29
(22) 1 2 2 1 0 1	1	33	22	2955	13	1830	1.71	115	3580	24	440	1.56
	2	32	25	4145	6	1395	2.04	258	9055	0	0	3.38
	3	34	19	2475	14	2070	1.58	120	4565	0	0	1.60
	4	35	27	2650	7	755	1.15	110	2730	0	0	0.96
(23) 1 2 2 2 0 1	1	32	18	2420	14	1680	1.51	106	3130	0	0	1.15
	2	35	21	2870	12	2060	1.66	194	5360	3	100	1.88
	3	35	28	3890	10	1350	1.76	90	3828	3	80	1.35
	4	35	14	1420	5	570	0.67	70	2750	0	0	0.96
(24) 1 2 2 1 1 1	1	35	21	3895	11	2130	2.03	262	10635	12	360	3.96
	2	34	24	4810	7	1350	2.14	192	8460	5	155	3.05
	3	28	19	3090	8	1010	1.73	113	4945	0	0	2.14
	4	32	24	4545	7	1110	2.08	206	7695	8	385	3.00
(25) 1 2 2 2 1 1	1	33	23	4025	12	1770	2.07	210	8815	9	255	3.35
	2	34	18	3550	16	2840	2.22	255	9515	27	825	3.81
	3	30	17	2770	11	1830	1.81	171	7605	1	30	3.08
	4	35	20	3900	14	2500	2.15	226	8895	2	90	3.12

1 See Table 1 for rates of fertilizer application.

2 Yield categories are defined in "Experimental Methods" section.

Appendix Table 6. Yield of Broccoli of All Yield Categories.[3] 1960. Willamette Soil. Tabulated by Group[2] and by Season Totals. Totals of 4 Replications.

Treatments[1] LKMg NPS	Group[2]	Wt. of No. 1 Heads (g.)	Average Wt. No. 1 Heads (g.)	Wt. of No. 2 Heads (g.)	Total[4] Wt. Heads (T/A)	Wt. of No. 1 Spears (g.)	Average Wt. No. 1 Spears (g. /spears)	Wt. of No. 2 Spears (g.)	Total[4] Wt. of Spears (T/A)
(1) 0 0 0 1 2 1	1	18985		5050	6.57	1970		845	0.77
	2	5940		2790	2.41	28310		500	7.91
	3	0		0	0	12720		0	3.48
	Total	24925	182	7840	8.98	43000	36	1345	12.16
(2) 1 0 0 1 2 1	1	13485		5455	5.13	1580		1560	0.86
	2	8830		3820	3.37	33100		280	8.98
	3	0		0	0	13120		0	3.53
	Total	22315	179	9275	8.50	47800	38	1840	13.37
(3) 0 2 0 1 2 1	1	14650		6000	5.69	280		570	0.24
	2	7960		1880	2.72	31860		0	8.80
	3	0		0	0	11265		0	3.10
	Total	22610	182	7880	8.41	43405	37	570	12.13
(4) 1 2 0 1 2 1	1	16800		7330	6.86	1580		690	0.65
	2	5870		2260	2.30	28700		720	8.30
	3	0		0	0	10645		0	3.04
	Total	22670	194	9590	9.16	40925	38	1410	11.98
(5) 0 0 2 1 2 1	1	14490		5270	5.37	1570		700	0.62
	2	8650		3260	3.28	27320		780	7.64
	3	0		0	0	7970		0	2.17
	Total	23140	175	8530	8.64	36860	35	1480	10.42
(6) 1 0 2 1 2 1	1	10390		7800	4.76	1320		1030	0.61
	2	11240		3410	4.01	23630		580	6.53
	3	0		0	0	16035		0	4.36
	Total	21630	168	11210	8.77	40985	37	1610	11.49
(7) 0 2 2 1 2 1	1	10730		4800	4.39	1000		360	0.38
	2	12700		1820	4.16	25470		0	7.21
	3	0		0	0	10205		0	2.94
	Total	23430	174	6620	8.56	36675	35	360	10.54
(8) 1 2 2 1 2 1	1	12020		5480	5.10	290		540	0.24
	2	10140		2560	3.76	24960		0	7.23
	3	0		0	0	14975		0	4.41
	Total	22160	176	8040	8.87	40225	36	540	11.88
(9) 1 1 2 1 2 1	1	13400		6550	5.40	1150		530	0.46
	2	7770		3370	3.06	25747		0	6.95
	3	0		0	0	13195		0	3.62
	Total	21170	176	9920	8.46	40092	37	530	11.03
(10) 1 2 1 1 2 1	1	13810		6560	5.38	1100		850	0.51
	2	9350		4450	3.62	34700		190	9.20
	3	0		0	0	11840		0	3.11
	Total	23160	193	11010	9.00	47640	35	1040	12.82
(11) 1 1 1 1 2 1	1	16190		9380	6.73	3590		830	1.18
	2	5110		2410	2.02	25225		180	6.78
	3	0		0	0	11480		0	3.04
	Total	21300	176	11790	8.74	40295	37	1010	11.01
(12) 1 0 1 1 2 1	1	11490		3990	4.32	1140		790	0.51
	2	9190		4030	3.71	27390		830	7.86
	3	0		0	0	13010		0	3.65
	Total	20680	177	8020	8.03	41540	37	1620	12.01
(13) 1 1 0 1 2 1	1	14550		5830	5.65	2060		1020	0.85
	2	7410		3430	3.01	24040		0	6.67
	3	0		0	0	9640		0	2.69
	Total	21960	183	9260	8.66	35740	37	1020	10.21
(14) 2 2 0 1 2 1	1	10620		3450	4.08	580		120	0.20
	2	12570		4680	5.00	23350		920	6.99
	3	0		0	0	12185		0	3.50
	Total	23190	184	8130	9.08	36115	36	1040	10.70
(15) 2 2 2 1 2 1	1	10370		5040	4.55	1250		120	0.40
	2	13490		3550	5.25	19500		80	5.85
	3	0		0	0	10390		0	3.15
	Total	23860	181	8590	9.80	31140	36	200	9.40

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Appendix Table 6 (continued)

Treatments[1] LKMg NPS	Group[2]	Wt. of No. 1 Heads (g.)	Average Wt. No. 1 Heads (g.)	Wt. of No. 2 Heads (g.)	Total[4] Wt. Heads (T/A)	Wt. of No. 1 Spears (g.)	Average Wt. No. 1 Spears (g. /spears)	Wt. of No. 2 Spears (g.)	Total[4] Wt. of Spears (T/A)
(16) 1 2 0 2 2 1	1	15975		3970	5.44	1800		880	0.72
	2	8040		4760	3.53	25910		450	7.16
	3	0		0	0	11830		0	3.25
	Total	24015	177	8730	8.97	39590	38	1330	11.13
(17) 1 2 2 2 2 1	1	16295		5865	6.15	1340		920	0.64
	2	9680		4300	3.82	31540		200	8.76
	3	0		0	0	15875		0	4.40
	Total	25975	192	10165	9.97	48755	38	1120	13.80
(18) 2 2 0 2 2 1	1	17420		6120	6.48	2080		1070	0.85
	2	5810		2880	2.43	32210		0	8.92
	3	0		0	0	9550		0	2.67
	Total	23230	183	9000	8.91	43840	40	1070	12.44
(19) 2 2 2 2 2 1	1	12065		4480	4.47	280		660	0.26
	2	12050		5300	4.72	26110		0	7.07
	3	0		0	0	19120		0	5.18
	Total	24115	167	9780	9.19	45510	36	660	12.51
(20) 1 2 0 1 2 0	1	13145		7110	5.69	1180		310	0.41
	2	9620		2060	3.29	28400		1850	8.50
	3	0		0	0	9940		0	2.78
	Total	22765	195	9170	8.97	39520	35	2160	11.70
(21) 1 2 0 2 2 0	1	14560		8685	6.78	1480		1700	0.94
	2	5580		2760	2.40	23570		0	6.88
	3	0		0	0	8135		0	2.35
	Total	20140	180	11445	9.18	33185	36	1700	10.18
(22) 1 2 2 1 0 1	1	16060		3650	5.70	1080		860	0.56
	2	10030		1060	3.20	26970		150	7.81
	3	0		0	0	10490		0	3.02
	Total	26090	179	4710	8.89	38540	37	1010	11.40
(23) 1 2 2 2 0 1	1	16665		4835	5.96	2180		620	0.76
	2	8300		2280	2.95	27350		70	7.63
	3	0		0	0	12615		0	3.50
	Total	24965	189	7115	8.91	42145	40	690	11.89
(24) 1 2 2 1 1 1	1	14890		5700	5.90	730		650	0.40
	2	5320		4710	2.88	31900		200	9.34
	3	0		0	0	9230		0	2.64
	Total	20210	189	10410	8.78	41860	36	850	12.37
(25) 1 2 2 2 1 1	1	12820		8250	5.80	1260		1680	0.80
	2	10190		2620	3.56	22560		650	6.42
	3	0		0	0	10640		0	2.93
	Total	23010	189	10870	9.35	34460	40	2330	10.16

1 See Table 1 for rates of fertilizer application.

2 Group 1 includes harvests 1 and 2; group 2, harvests 3 and 4; and group 3, harvests 5 and 6.

3 Yield categories defined in "Experimental Methods" section.

4 Cull head or spears not tabulated but are included in Total Weights of Heads or Spears.

Appendix Table 7. Yield of Broccoli of All Yield Categories.[3] 1960. Olympic Soil. Tabulated by Group[2] and by Season Totals. Totals of 4 Replications.

Treatments[1] LKMg NPS	Group[2]	Wt. of No. 1 Heads (g.)	Average Wt. No. 1 Heads (g. /head)	Wt. of No. 2 Heads (g.)	Total[4] Wt. Heads (T/A)	Wt. of No. 1 Spears (g.)	Average Wt. No. 1 Spears (g./spears)	Wt. of No. 2 Spears (g.)	Total[4] Wt. of Spears (T/A)
(1) 0 0 0 1 2 1	1	12620		6390	6.62	3605		1900	2.05
	2	3640		1830	1.90	19960		0	7.58
	3	0		0	0	10605		0	3.67
	Total	16260	181	8220	8.51	34170	38	1900	13.30
(2) 1 0 0 1 2 1	1	10015		4400	5.18	1715		1510	1.28
	2	3380		2770	2.19	15145		2445	6.36
	3	0		0	0	9730		0	3.44
	Total	13395	158	7170	7.37	26950	34	1510	11.08
(3) 0 2 0 1 2 1	1	11985		6700	6.76	970		345	0.49
	2	5030		2555	2.84	20550		90	7.84
	3	0		0	0	15035		0	5.54
	Total	17015	191	9255	9.60	36555	38	435	13.86
(4) 1 2 0 1 2 1	1	9580		5805	5.48	885		1385	0.81
	2	4960		2780	2.75	17180		350	6.72
	3	0		0	0	12465		0	4.43
	Total	14540	173	8585	8.23	30530	36	1735	11.95
(5) 0 0 2 1 2 1	1	10790		6550	6.28	3385		3180	2.45
	2	1500		2140	1.30	16830		275	7.19
	3	0		0	0	6620		0	2.37
	Total	12290	173	8690	7.59	26835	33	3455	12.01
(6) 1 0 2 1 2 1	1	14200		4200	6.67	3505		2674	2.32
	2	1650		1240	1.07	17780		375	7.05
	3	0		0	0	10195		0	3.73
	Total	15850	174	5440	7.74	31480	36	3049	13.10
(7) 0 2 2 1 2 1	1	11265		4615	5.44	1847		925	1.20
	2	4270		4455	3.23	20365		160	7.46
	3	330		0	0.13	16460		0	6.16
	Total	15865	203	9070	8.80	38672	40	1085	14.82
(8) 1 2 2 1 2 1	1	9185		3665	4.79	780		495	0.66
	2	7960		2710	3.99	20210		270	7.85
	3	0		200	0.08	15845		0	5.90
	Total	17145	182	6575	8.85	36835	41	765	14.41
(9) 1 1 2 1 2 1	1	11325		6605	6.27	1580		1090	0.93
	2	3160		4140	2.56	22710		40	8.49
	3	0		0	0	10785		0	3.77
	Total	14485	175	10745	8.83	35075	38	1130	13.19
(10) 1 2 1 1 2 1	1	11600		5755	5.99	1720		815	0.87
	2	3530		4780	2.84	21055		0	7.62
	3	0		0	0	13875		0	4.76
	Total	15130	187	10535	8.83	36650	37	815	13.26
(11) 1 1 1 1 2 1	1	10835		5635	5.81	935		1510	0.97
	2	3605		3520	2.69	20620		610	8.37
	3	0		0	0	12945		0	4.68
	Total	14440	172	9155	8.50	34500	39	2120	14.02
(12) 1 0 1 1 2 1	1	8600		3795	4.67	890		1185	0.94
	2	5330		2240	2.85	15360		100	6.29
	3	0		0	0	14355		0	5.41
	Total	13930	170	6035	7.52	30605	37	1285	12.63
(13) 1 1 0 1 2 1	1	11145		4775	5.76	1260		1140	0.88
	2	3070		4525	2.82	16100		210	6.35
	3	0		0	0	11580		0	4.28
	Total	14215	182	9300	8.59	28940	37	1350	11.51
(14) 2 2 0 1 2 1	1	9290		4410	4.75	1190		375	0.61
	2	4790		3780	2.93	15080		285	5.67
	3	0		0	0	13700		0	4.70
	Total	14080	162	8190	7.68	29970	37	660	10.98
(15) 2 2 2 1 2 1	1	6115		4020	3.53	530		690	0.46
	2	7890		5550	4.85	13190		590	5.17
	3	250		0	0.10	15105		0	5.52
	Total	14255	193	9570	8.49	28825	41	1280	11.15

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Appendix Table 7 (continued)

Treatments[1] LKMg NPS	Group[2]	Wt. of No. 1 Heads (g.)	Average Wt. No. 1 Heads (g./head)	Wt. of No. 2 Heads (g.)	Total[4] Wt. Heads (T/A)	Wt. of No. 1 Spears (g.)	Average Wt. No. 1 Spears (g./spears)	Wt. of No. 2 Spears (g.)	Total[4] Wt. of Spears (T/A)
(16) 1 2 0 2 2 1	1	9155		2115	4.14	490		630	0.46
	2	5580		4630	3.82	17340		30	6.73
	3	0		0	0	15875		0	5.91
	Total	14735	173	6745	7.96	33705	38	660	13.10
(17) 1 2 2 2 2 1	1	9390		6155	5.38	345		575	0.31
	2	8530		4260	4.41	21910		1445	8.44
	3	0		0	0	15920		0	5.51
	Total	17920	208	10415	9.79	38175	39	2020	14.27
(18) 2 2 0 2 2 1	1	10140		3700	4.80	430		290	0.26
	2	5810		3700	3.40	20820		60	7.72
	3	0		60	0.02	20340		0	7.28
	Total	15950	185	7460	8.22	41590	40	350	15.26
(19) 2 2 2 2 2 1	1	8025		1620	3.52	610		375	0.37
	2	7040		5270	4.71	19160		490	7.73
	3	80		0	0.03	12895		0	4.92
	Total	15145	176	6890	8.26	32665	40	865	13.01
(20) 1 2 0 1 2 0	1	11365		5835	5.90	220		655	0.31
	2	5365		3160	3.11	17175		0	6.32
	3	0		0	0	13235		0	4.72
	Total	16730	182	8995	9.02	30630	38	655	11.35
(21) 1 2 0 2 2 0	1	10265		2830	4.75	1395		355	0.71
	2	3960		5080	3.28	18210		250	7.13
	3	0		0	0	12540		0	4.54
	Total	14225	180	7910	8.03	32145	38	605	12.38
(22) 1 2 2 1 0 1	1	6045		1790	2.79	135		440	0.31
	2	6180		4260	3.69	7760		0	2.93
	3	0		0	0	12035		0	4.25
	Total	12225	131	6050	6.47	19930	33	440	7.49
(23) 1 2 2 2 0 1	1	4880		1030	2.02	0		180	0.06
	2	5720		4630	3.59	5353		0	1.93
	3	0		0	0	9715		0	3.35
	Total	10600	131	5660	5.61	15068	33	180	5.33
(24) 1 2 2 1 1 1	1	11895		3750	5.60	1185		590	0.64
	2	4445		1850	2.37	18890		310	7.20
	3	0		0	0	11660		0	4.31
	Total	16340	186	5600	7.98	31735	41	900	12.14
(25) 1 2 2 2 1 1	1	9125		6540	5.53	230		940	0.53
	2	4860		2400	2.63	19590		260	7.42
	3	260		0	0.09	15010		0	5.42
	Total	14245	183	8940	8.25	34830	40	1200	13.36

[1] See Table 1 for rates of fertilizer application.

[2] Group 1 includes harvests 1 and 2; group 2, harvests 3 and 4; and group 3, harvests 5 and 6.

[3] Yield categories defined in "Experimental Methods" section.

[4] Cull heads or spears are not tabulated but are included in Total Weights of Heads or Spears.

Appendix Table 8. Tabulation of Yield, Plant Composition, and Soil Analysis Data from 1960 Used in Multiple Regression Analysis. Tabulations Are by Replication. Willamette Soil.

Treatments[1]		Group 1 Yields		Season Total Yields[2]		Plant Composition m. e. /100 g. dry matter - old leaves						Exch. Cations m. e. /100		
						1st Sampling[3]			2nd Sampling[3]			Sampled July		
LKMg NPS	Rep.	Heads (T/A)	Total (T/A)	Heads (T/A)	Total (T/A)	Mg	Ca	K	Mg	Ca	K	Mg	Ca	K
(1) 0 0 0 1 2 1	1	1.97	2.67	2.11	4.76	32.9	313.0	47.1	17.3	301.5	51.2	1.16	8.5	0.55
	2	2.23	3.39	2.23	5.27	40.3	296.5	64.0	18.9	279.5	60.9	1.21	6.5	0.60
	3	2.36	3.71	2.42	6.00	32.1	280.0	61.4	18.1	294.0	54.0	1.25	7.9	0.51
	4	2.19	3.50	2.23	5.11	29.6	284.5	60.0	18.9	300.5	49.9	1.30	7.6	0.61
(2) 1 0 0 1 2 1	1	2.18	2.98	2.18	5.56	27.1	331.5	49.9	15.6	328.0	58.1	1.16	11.8	0.46
	2	1.92	2.61	2.10	5.50	27.1	313.5	58.6	18.9	280.5	60.9	1.16	12.3	0.60
	3	1.86	2.77	2.03	5.32	29.6	300.5	54.2	20.6	364.5	55.0	1.25	17.0	0.63
	4	2.20	3.00	2.20	5.51	24.7	310.0	53.0	18.1	268.5	49.9	1.12	12.0	0.55
(3) 0 2 0 1 2 1	1	1.97	2.85	2.12	4.98	28.8	276.5	62.2	14.8	286.5	75.7	1.00	8.9	0.96
	2	2.25	3.29	2.36	5.88	29.6	290.0	93.4	17.3	280.0	73.9	1.16	7.2	0.90
	3	1.90	3.03	2.13	5.25	35.3	259.0	81.1	28.8	331.0	74.7	1.58	7.9	0.64
	4	1.64	2.06	1.80	4.44	34.5	271.5	73.4	23.8	262.0	76.5	1.33	7.7	0.85
(4) 1 2 0 1 2 1	1	2.24	3.14	2.24	5.22	23.8	274.0	72.4	11.5	311.5	74.4	1.00	10.7	0.93
	2	2.32	3.40	2.37	5.81	24.7	298.0	82.6	19.7	308.0	67.5	1.12	10.8	0.97
	3	2.26	3.10	2.26	4.85	27.9	255.5	87.7	23.8	314.5	75.7	1.16	11.5	0.83
	4	2.22	3.85	2.29	5.26	22.2	265.0	76.5	18.9	302.0	67.3	1.18	12.4	0.99
(5) 0 0 2 1 2 1	1	2.10	2.91	2.26	4.69	44.4	296.0	51.9	27.9	276.5	56.3	1.88	6.2	0.65
	2	2.03	2.65	2.07	4.90	51.8	263.0	64.0	40.3	270.0	60.9	2.03	5.2	0.65
	3	2.17	3.28	2.21	4.54	38.6	261.0	65.2	35.3	264.0	66.8	2.05	5.5	0.40
	4	2.10	3.28	2.10	4.93	36.2	256.0	62.2	33.7	257.0	41.4	1.84	7.6	0.62
(6) 1 0 2 1 2 1	1	1.71	1.94	1.92	4.91	37.8	274.0	62.7	23.8	330.5	56.0	1.51	11.4	0.65
	2	1.75	2.39	1.86	4.65	36.2	297.0	60.9	23.0	274.0	53.0	1.68	11.4	0.58
	3	3.06	3.94	2.31	5.09	37.8	267.5	57.3	32.1	359.0	55.8	1.72	10.3	0.45
	4	1.48	1.88	1.92	4.84	37.0	279.5	60.4	32.1	272.5	55.8	1.88	12.3	0.65
(7) 0 2 2 1 2 1	1	2.28	3.49	2.28	4.80	44.4	228.0	82.6	28.8	280.5	69.1	1.72	5.8	0.91
	2	2.15	2.60	2.38	5.05	41.1	287.5	98.2	24.7	287.0	81.1	1.88	5.5	0.93
	3	1.54	1.71	1.87	3.60	42.7	239.0	76.5	42.7	335.0	87.7	1.70	6.2	0.83
	4	2.03	2.99	2.03	5.65	50.1	225.0	76.5	37.0	298.5	76.2	2.01	5.7	1.04
(8) 1 2 2 1 2 1	1	2.09	2.48	2.14	5.42	32.1	328.5	70.3	26.3	306.5	76.7	1.58	10.0	0.84
	2	2.05	2.62	2.11	5.52	33.7	320.0	73.4	21.4	294.5	77.0	1.77	11.3	0.78
	3	2.09	2.64	2.42	4.88	28.8	275.0	71.9	30.4	311.0	87.7	1.70	10.7	0.85
	4	1.82	2.32	2.21	4.94	33.7	293.0	82.6	37.0	324.0	74.9	1.77	11.9	1.00
(9) 1 1 2 1 2 1	1	1.95	2.43	2.29	5.06	41.1	292.0	70.3	22.2	309.5	66.8	1.70	12.7	0.78
	2	2.40	3.73	2.40	5.20	37.8	307.0	71.9	23.8	321.5	61.4	1.77	10.7	0.78
	3	1.64	2.23	1.64	3.71	33.7	295.0	66.8	27.1	299.0	66.0	1.68	11.0	0.72
	4	2.09	3.01	2.13	5.52	28.8	291.0	67.5	30.4	259.0	68.0	1.65	11.5	0.70
(10) 1 2 1 1 2 1	1	2.23	2.52	2.32	5.48	23.8	302.5	70.3	17.3	276.0	78.8	1.23	10.5	0.97
	2	2.03	3.31	2.03	5.12	32.1	303.0	77.5	12.3	265.0	63.4	1.33	10.7	0.91
	3	2.40	3.33	2.52	5.73	27.1	280.0	82.6	24.7	315.0	69.8	1.25	10.7	0.96
	4	2.01	2.78	2.13	5.49	30.4	278.0	66.0	17.3	275.5	76.5	1.38	10.3	0.80
(11) 1 1 1 1 2 1	1	1.98	2.67	2.09	4.96	27.9	268.0	62.2	23.0	340.0	67.5	1.30	11.8	0.78
	2	1.92	2.36	1.97	4.22	27.9	292.0	67.5	24.7	309.5	57.3	1.21	12.5	0.88
	3	2.43	3.79	2.54	6.35	24.7	282.0	66.0	24.7	326.5	62.4	1.23	10.7	0.55
	4	2.12	3.04	2.14	4.22	32.0	287.5	47.1	30.4	314.5	66.0	1.35	11.3	0.67
(12) 1 0 1 1 2 1	1	1.67	2.22	1.86	5.36	28.8	275.5	49.9	19.7	323.5	54.2	1.16	11.4	0.58
	2	2.36	2.79	2.45	5.38	31.2	304.5	64.0	13.9	271.5	56.0	1.18	13.2	0.66
	3	1.57	2.64	1.69	4.32	23.0	299.5	60.9	29.6	374.5	57.6	1.38	10.7	0.47
	4	2.03	3.41	2.03	4.99	31.2	324.5	53.5	22.2	308.5	49.4	1.42	13.1	0.63
(13) 1 1 0 1 2 1	1	2.11	2.68	2.25	5.25	21.4	297.0	71.9	13.2	284.0	57.3	0.93	11.8	0.65
	2	1.69	1.90	1.98	3.97	28.8	300.0	68.0	19.7	336.5	69.8	1.06	13.3	0.90
	3	2.15	3.37	2.18	5.15	21.4	288.5	62.7	23.0	252.0	66.8	1.06	12.2	0.88
	4	2.19	3.23	2.25	4.50	22.2	297.0	64.0	15.6	269.0	65.2	1.23	11.3	0.70
(14) 2 2 0 1 2 1	1	2.15	2.90	2.55	4.90	22.2	277.5	67.5	14.8	329.5	70.6	1.00	12.3	0.93
	2	2.05	2.55	2.24	5.46	24.7	305.5	74.9	16.4	282.0	79.6	1.05	14.7	1.00
	3	2.25	3.66	2.42	5.32	22.2	320.0	71.9	19.7	328.0	76.5	1.18	14.7	0.55
	4	1.79	2.16	1.87	4.09	24.7	295.5	67.5	22.2	294.0	56.5	1.40	13.1	0.93
(15) 2 2 2 1 2 1	1	2.29	3.06	2.29	4.53	36.2	314.0	70.9	22.2	279.0	78.8	1.40	13.6	1.07
	2	2.88	3.62	2.94	5.56	29.6	328.0	74.9	19.7	307.0	67.5	1.77	17.1	1.18
	3	1.82	2.16	2.12	4.88	26.3	256.0	79.3	31.2	349.5	74.2	1.49	11.3	0.75
	4	1.77	2.04	2.45	4.23	31.2	267.5	71.9	29.6	330.0	69.8	1.74	12.5	1.01

[1] See Table 1 for rates of fertilizer applications.

[2] Yield categories defined in "Experimental Methods" section.

[3] Sampling dates and procedure described in "Experimental Methods" section.

Appendix Table 9. Tabulation of Yield, Plant Composition, and Soil Analysis Data from 1960 Used in Multiple Regression Analysis. Tabulations are by Replication. Olympic Soil.

Treatments[1]		Group I Yields		Season Total Yields[2]		Plant Composition m. e. /100 g. dry matter - old leaves						Exch. Cations m. e. /100		
						1st Sampling[3]			2nd Sampling[3]			Sampled July		
LKMg NPS	Rep.	Heads (T/A)	Total (T/A)	Heads (T/A)	Total (T/A)	Mg	Ca	K	Mg	Ca	K	Mg	Ca	K
(1) 0 0 0 1 2 1	1	2.17	3.62	2.17	5.09	28.8	319.0	22.8	23.8	291.5	23.5	0.81	7.3	0.35
	2	2.02	4.76	2.02	5.85	12.4	319.5	19.2	18.1	251.0	21.7	0.82	5.6	0.22
	3	2.30	3.77	2.30	5.93	18.1	265.0	45.5	15.7	284.0	47.3	0.78	7.2	0.40
	4	1.87	2.72	2.01	4.93	15.7	288.5	24.3	18.1	292.0	28.1	0.82	6.9	0.34
(2) 1 0 0 1 2 1	1	1.50	2.99	1.54	4.13	17.3	319.0	18.2	21.4	335.5	18.2	0.92	20.3	0.33
	2	1.96	2.94	1.96	4.88	13.2	309.0	22.8	17.3	288.0	27.6	0.90	12.1	0.24
	3	2.30	3.66	2.30	5.38	12.4	313.5	38.4	9.1	283.0	31.7	0.92	17.8	0.52
	4	1.56	2.39	1.56	4.05	13.2	282.5	35.8	15.7	311.0	36.3	1.05	15.8	0.48
(3) 0 2 0 1 2 1	1	2.52	3.92	2.52	5.89	11.5	284.5	62.7	20.6	292.5	50.4	0.86	7.8	1.07
	2	2.60	3.51	2.60	6.33	17.3	257.0	81.9	18.1	275.0	50.6	0.85	5.4	0.56
	3	1.94	2.12	2.29	5.75	14.8	302.0	78.8	15.7	274.5	72.4	1.01	8.6	1.31
	4	2.20	3.34	2.20	5.51	17.3	259.0	73.7	8.2	248.5	54.0	0.96	7.2	0.92
(4) 1 2 0 1 2 1	1	1.80	2.32	1.80	4.74	19.8	241.5	81.9	9.9	294.0	67.4	1.07	20.2	1.10
	2	1.85	2.38	1.92	5.05	10.7	271.0	76.2	10.7	234.5	75.5	1.00	10.3	0.98
	3	1.82	2.32	1.82	4.43	21.4	297.0	34.0	14.8	296.5	58.6	1.04	17.2	1.16
	4	2.69	4.18	2.69	5.96	7.4	282.5	74.2	10.7	296.0	58.8	1.01	14.6	0.81
(5) 0 0 2 1 2 1	1	1.58	3.55	1.58	4.55	45.3	229.0	17.9	46.1	304.5	22.5	1.92	6.3	0.33
	2	1.76	3.22	1.76	3.70	51.9	288.5	16.4	45.3	277.0	19.7	1.02	5.5	0.21
	3	2.20	4.14	2.20	5.92	33.0	257.5	45.5	31.3	273.0	39.9	2.02	7.1	0.97
	4	2.04	3.42	2.04	5.43	33.0	245.5	35.8	31.3	273.0	31.5	1.83	5.9	0.46
(6) 1 0 2 1 2 1	1	1.95	3.11	1.95	5.49	37.9	272.5	40.4	25.5	335.5	24.6	1.86	16.5	0.42
	2	1.68	3.44	1.68	5.06	31.3	403.5	29.7	24.7	343.5	24.6	1.10	10.1	0.24
	3	2.00	3.05	2.04	5.04	23.9	261.5	46.8	19.8	308.0	37.1	2.05	7.2	1.26
	4	2.07	3.83	2.07	5.24	23.9	295.0	26.3	17.3	303.5	30.7	1.48	11.4	0.40
(7) 0 2 2 1 2 1	1	2.03	3.91	2.03	6.07	37.1	258.0	66.5	33.8	282.0	53.0	1.83	5.8	0.96
	2	2.80	4.07	2.80	6.01	38.7	232.5	93.1	32.1	257.5	73.7	1.17	5.1	0.75
	3	1.22	1.40	2.02	6.42	19.8	271.5	102.3	23.9	248.5	77.5	1.94	7.2	1.46
	4	1.94	3.08	1.94	5.10	35.4	223.5	67.8	33.0	328.5	46.8	1.76	6.2	0.78
(8) 1 2 2 1 2 1	1	2.45	3.37	2.83	7.05	27.2	276.5	71.1	14.8	326.5	43.5	1.98	14.1	0.98
	2	1.75	3.02	1.92	5.21	28.8	273.5	70.3	22.2	279.5	63.4	1.13	11.1	0.48
	3	1.94	3.04	1.94	5.49	22.2	299.0	70.3	21.4	322.5	55.5	1.72	12.2	1.03
	4	2.15	3.15	2.15	5.40	16.5	279.5	64.0	17.3	327.5	48.6	1.67	12.8	0.78
(9) 1 1 2 1 2 1	1	2.17	3.48	2.17	5.22	17.3	272.5	47.6	21.4	264.0	44.0	1.85	17.3	0.78
	2	2.46	3.56	2.69	6.65	29.7	283.0	59.6	21.4	290.0	41.4	1.55	12.0	0.56
	3	1.77	2.72	1.77	4.41	28.8	241.5	63.4	18.1	324.0	44.8	1.88	15.4	0.75
	4	2.03	2.99	2.19	5.73	34.6	247.0	66.0	19.8	302.5	43.7	1.70	12.8	0.66
(10) 1 2 1 1 2 1	1	2.12	3.21	2.12	5.32	25.5	302.0	55.8	18.9	286.5	56.8	1.35	16.0	1.04
	2	2.41	3.40	2.41	5.77	22.2	285.5	92.1	12.4	224.5	70.6	1.33	11.7	1.00
	3	2.14	3.26	2.19	6.08	17.3	247.0	78.3	9.9	281.5	58.3	1.37	15.8	1.11
	4	1.99	2.62	2.11	4.92	12.4	266.0	76.7	4.9	267.0	70.3	1.27	14.8	0.93
(11) 1 1 1 1 2 1	1	2.04	3.10	2.04	4.99	23.1	294.5	44.8	27.2	355.0	24.3	1.23	16.8	0.63
	2	1.94	2.59	2.03	5.60	18.9	315.0	86.5	18.9	244.5	81.6	1.35	10.6	0.84
	3	1.76	2.32	2.08	6.18	15.7	282.5	83.1	21.4	310.5	54.0	1.50	19.1	1.08
	4	2.31	3.60	2.35	5.75	14.8	269.0	51.2	16.5	315.5	39.6	1.15	14.3	0.60
(12) 1 0 1 1 2 1	1	1.56	2.78	1.68	4.40	27.2	340.5	23.0	18.1	376.5	20.0	1.40	21.1	0.35
	2	2.46	2.73	2.56	6.16	21.4	326.5	84.2	9.9	259.5	73.7	1.22	10.3	0.78
	3	1.36	1.62	1.43	4.52	17.3	297.0	68.6	18.1	286.0	59.6	1.54	16.0	0.65
	4	1.76	2.44	1.85	5.07	7.4	269.0	63.4	12.4	288.0	59.6	1.39	16.3	0.63
(13) 1 1 0 1 2 1	1	2.20	3.62	2.20	5.68	23.0	302.0	48.6	16.5	335.0	28.1	0.92	15.2	0.35
	2	2.26	3.28	2.26	4.75	11.5	315.0	54.5	19.8	345.0	27.6	1.02	10.8	0.40
	3	2.15	3.01	2.26	5.27	15.7	278.5	64.0	10.7	298.0	42.7	1.07	17.8	0.89
	4	1.86	2.63	1.86	4.40	9.9	247.0	82.6	9.9	226.5	99.5	1.06	13.7	0.79
(14) 2 2 0 1 2 1	1	2.06	2.53	2.06	4.75	13.2	261.5	59.6	11.5	310.0	60.6	1.15	18.9	0.96
	2	1.67	2.37	1.83	4.75	10.7	312.0	89.0	10.7	246.5	56.8	0.90	14.8	0.59
	3	1.75	2.71	1.81	4.56	5.8	288.5	87.0	8.2	251.5	60.9	1.27	20.5	1.07
	4	1.98	2.70	1.98	4.60	14.8	258.5	88.8	4.9	242.0	79.3	1.14	17.2	1.13
(15) 2 2 2 1 2 1	1	2.15	3.20	2.35	4.97	12.4	261.5	91.6	20.6	296.0	85.2	1.98	17.1	1.27
	2	2.32	2.73	2.39	5.13	20.6	251.0	81.3	22.2	294.5	54.2	1.38	11.7	0.56
	3	1.26	1.34	1.88	4.22	16.5	248.5	94.6	14.8	288.5	64.7	2.05	19.3	1.34
	4	1.46	2.05	1.87	5.32	20.6	279.5	74.2	15.7	316.5	60.9	1.83	17.5	1.03

[1] See Table 1 for rates of fertilizer application.

[2] Yield categories defined in "Experimental Methods" section.

[3] Sampling dates and procedure described in "Experimental Methods" section.

Appendix Table 10. Chemical Composition of Broccoli Leaves in Percentage Dry Matter. Tabulated by Sampling Date and Type of Leaf. Willamette Soil. 1959. Mean of 3 Replications.

Treatments[1]				1st Sampling - Aug. 27. 1959[2]						2nd Sampling-Sept. 16. 1959[2]		
				Old Mature Leaves			Recently Matured Leaves			Old Mature Leaves		
	L	K	Mg	%Ca	%Mg	%K	%Ca	%Mg	%K	%Ca	%Mg	%K
(1)	0	0	0	5.28	0.52	3.0	2.38	0.29	2.9	6.86	0.58	1.8
(2)	1	0	0	5.21	0.48	2.9	2.76	0.31	2.7	7.17	0.54	2.1
(3)	0	2	0	4.75	0.49	3.7	2.24	0.29	3.4	5.96	0.52	2.7
(4)	1	2	0	4.89	0.48	3.9	2.38	0.26	3.1	6.44	0.51	2.8
(5)	0	0	2	4.60	0.64	3.3	2.28	0.36	2.5	6.34	0.81	2.2
(6)	1	0	2	4.46	0.52	3.0	2.41	0.32	2.8	6.62	0.65	2.1
(7)	0	2	2	4.29	0.59	4.2	2.13	0.34	3.3	5.86	0.68	3.2
(8)	1	2	2	5.21	0.58	3.3	2.23	0.30	2.8	6.33	0.62	2.5
(9)	1	1	2	4.53	0.53	3.5	2.37	0.34	3.0	6.65	0.66	2.4
(10)	1	2	1	4.77	0.47	3.9	2.30	0.26	3.3	6.17	0.48	2.9
(11)	1	1	1	4.96	0.49	3.1	2.45	0.31	2.8	6.27	0.56	2.1
(12)	1	0	1	5.19	0.50	3.0	2.31	0.32	2.7	6.54	0.52	2.3
(13)	1	1	0	5.03	0.45	3.3	2.40	0.27	2.9	6.93	0.50	2.8
(14)	2	2	0	4.97	0.45	3.6	2.49	0.27	3.3	6.31	0.45	2.8
(15)	2	2	2	4.59	0.50	3.5	2.29	0.30	3.3	6.30	0.56	2.8

Treatments[1]				2nd Sampling - Sept. 16. 1959[2]						3rd Sampling-Oct. 9. 1959[2]		
				Middle Leaves[2]			Recently Matured Leaves[2]			Recently Matured Leaves		
	L	K	Mg	%Ca	%Mg	%K	%Ca	%Mg	%K	%Ca	%Mg	%K
(1)	0	0	0	4.56	0.38	1.8	2.82	0.25	1.8	3.32	0.29	2.6
(2)	1	0	0	4.55	0.36	1.9	3.00	0.25	1.9	3.31	0.27	2.4
(3)	0	2	0	3.99	0.37	2.6	2.61	0.26	2.6	2.99	0.28	3.1
(4)	1	2	0	4.52	0.35	2.6	3.21	0.27	2.4	3.21	0.27	2.8
(5)	0	0	2	4.33	0.53	1.9	2.85	0.29	1.9	3.17	0.35	2.6
(6)	1	0	2	4.06	0.39	2.0	2.82	0.28	1.9	3.60	0.27	2.7
(7)	0	2	2	3.78	0.46	3.0	2.82	0.30	2.6	2.92	0.34	3.0
(8)	1	2	2	4.41	0.41	2.6	2.76	0.27	2.3	3.16	0.31	3.1
(9)	1	1	2	4.99	0.51	2.3	3.02	0.31	2.2	3.01	0.30	3.0
(10)	1	2	1	4.40	0.34	2.5	2.81	0.24	2.5	2.94	0.26	3.0
(11)	1	1	1	4.33	0.36	2.1	2.70	0.25	2.1	3.50	0.32	2.9
(12)	1	0	1	4.44	0.37	2.0	2.80	0.29	2.0	3.62	0.31	2.7
(13)	2	2	0	4.64	0.36	2.4	3.01	0.24	2.2	3.76	0.25	2.9
(14)	2	2	0	4.48	0.32	2.6	2.90	0.23	2.5	3.27	0.26	2.9
(15)	2	2	2	4.20	0.35	2.7	2.87	0.26	2.6	3.53	0.31	3.2

[1] All plots at $N_1P_2S_1$. See Table 1 for rates of fertilizer application.

[2] Sampling dates and procedure are described in "Experimental Methods" section.

Appendix Table 11 Chemical Composition of Broccoli Leaves in Percentage Dry Matter.. Tabulated by Sampling Date and Type of Leaf. Olympic Soil. 1959. Mean of 3 Replications.

			1st Sampling - Aug. 27. 1959[2]						2nd Sampling-Sept. 16. 1959[2]		
Treatments[1]			Old Mature Leaves			Recently Matured Leaves			Old Mature Leaves		
L	K	Mg	%Ca	%Mg	%K	%Ca	%Mg	%K	%Ca	%Mg	%K
(1) 0	0	0	6.13	0.41	1.0	2.57	0.24	1.5	8.06	0.42	0.7
(2) 1	0	0	5.94	0.27	1.0	3.03	0.20	1.9	7.51	0.26	0.8
(3) 0	2	0	5.43	0.36	3.4	2.34	0.22	3.0	6.43	0.30	2.3
(4) 1	2	0	6.21	0.31	2.4	2.48	0.16	2.5	7.36	0.23	1.9
(5) 0	0	2	5.53	0.66	1.4	2.35	0.37	1.5	7.17	0.68	0.9
(6) 1	0	2	6.47	0.44	1.3	2.75	0.23	1.8	7.62	0.43	0.7
(7) 0	2	2	5.33	0.57	3.2	2.26	0.33	2.9	7.05	0.68	2.3
(8) 1	2	2	5.59	0.46	2.6	2.53	0.27	2.5	7.73	0.49	1.6
(9) 1	1	2	6.01	0.48	2.1	2.92	0.29	2.2	7.42	0.45	1.5
(10) 1	2	1	5.75	0.36	2.9	2.40	0.20	2.6	7.32	0.32	2.1
(11) 1	1	1	5.89	0.37	2.0	2.50	0.20	2.0	7.43	0.36	1.6
(12) 1	0	1	5.96	0.40	1.9	2.81	0.23	2.1	7.21	0.35	1.4
(13) 1	1	0	6.62	0.33	2.1	2.55	0.17	2.3	7.70	0.28	1.6
(14) 2	2	0	5.81	0.28	3.1	2.43	0.18	2.6	7.84	0.22	1.9
(15) 2	2	2	5.43	0.38	3.3	2.50	0.22	2.9	7.26	0.39	2.3

			2nd Sampling - Sept. 16. 1959[2]						3rd Sampling-Oct. 9. 1959[2]		
Treatment[1]			Middle Leaves[2]			Recently Matured Leaves[2]			Recently Matured Leaves		
L	K	Mg	%Ca	%Mg	%K	%Ca	%Mg	%K	%Ca	%MG	%K
(1) 0	0	0	4.99	0.29	0.9	3.09	0.21	1.4	4.17	0.22	1.3
(2) 1	0	0	4.66	0.20	1.1	2.88	0.17	1.4	4.31	0.17	1.3
(3) 0	2	0	4.12	0.24	2.4	2.40	0.18	2.3	3.84	0.18	2.8
(4) 1	2	0	4.10	0.17	1.8	2.57	0.15	1.8	4.05	0.16	2.6
(5) 0	0	2	4.36	0.42	1.1	2.82	0.34	1.3	4.37	0.43	1.4
(6) 1	0	2	4.98	0.32	1.0	2.92	0.23	1.5	4.47	0.27	1.6
(7) 0	2	2	4.34	0.46	2.5	2.41	0.28	2.4	3.71	0.31	2.9
(8) 1	2	2	4.46	0.33	2.0	2.73	0.24	2.1	4.11	0.25	2.3
(9) 1	1	2	4.28	0.30	1.6	2.38	0.22	1.8	3.87	0.24	2.0
(10) 1	2	1	4.39	0.21	2.1	2.58	0.17	2.3	4.01	0.19	2.5
(11) 1	1	1	4.46	0.26	1.8	2.52	0.18	1.9	4.05	0.19	2.1
(12) 1	0	1	4.10	0.23	1.5	2.67	0.19	1.6	4.13	0.21	2.0
(13) 1	1	0	4.68	0.21	1.7	2.88	0.19	2.0	4.09	0.17	2.3
(14) 2	2	0	4.16	0.15	2.3	2.54	0.14	1.7	4.04	0.14	2.4
(15) 2	2	2	4.40	0.27	2.6	2.61	0.21	2.5	3.43	0.21	2.6

1 All plots at $N_1P_2S_1$. See Table 1 for rates of fertilizer application.

2 Sampling dates and procedure are described in "Experimental Methods" section.

Appendix Table 12. Chemical Composition of Broccoli Leaves in Percentage Dry Matter. Tabulated by Sampling Date and Type of Leaf[2]. Olympic Soil. 1960. Means of 4 Replications.

Treatments[1]	1st Sampling[2] August 29. 1960 Recently Matured Leaves			2nd Sampling - September 23. 1960[2] Plants With Heads Recently Matured Leaves			2nd Sampling - September 23. 1960[2] Plants Without Heads Recently Matured Leaves			3rd Sampling[2] October 3. 1960 Recently Matured Leaves		
L K Mg	%Ca	%Mg	%K	%Ca	%Mg	%K	%Ca	%Mg	%K	%Ca	%Mg	%K
(1) 0 0 0	2.41	0.19	1.82	2.63	0.15	1.17	3.86	0.17	1.57	3.50	0.20	1.56
(2) 1 0 0	2 46	0 14	1.91	2.96	0.12	1.15	3.67	0.15	1.66	3.67	0.17	1.53
(3) 0 2 0	2.16	0.21	2.94	2.28	0.15	2.11	2.80	0.15	2.81	2.78	0.15	2.66
(4) 1 2 0	2.19	0.14	2.96	2.50	0.13	2.12	3.12	0.10	2.89	3.24	0.16	2.84
(5) 0 0 2	2.24	0.27	1.83	2.92	0.25	1.09	3.45	0.32	1.74	3.31	0.27	1.51
(6) 1 0 2	2.41	0.21	2.21	2.76	0.18	1.23	3.76	0.21	1.88	3.78	0.19	1.52
(7) 0 2 2	1.83	0.27	3.12	2.21	0.21	2.13	2.94	0.22	3.11	2.84	0.18	2.92
(8) 1 2 2	2.02	0.19	2.75	2.62	0.14	1.98	3.50	0.17	2.66	3.18	0.20	2.54
(9) 1 1 2	2.02	0.22	2.59	2.38	0.15	1.60	3.15	0.18	2.31	3.34	0.18	2.35
(10) 1 2 1	2.06	0.18	2.99	2.16	0.11	2.14	2.79	0.11	2.71	3.04	0.20	2.97
(11) 1 1 1	2.21	0.19	2.90	2.29	0.15	1.83	3.28	0.15	2.43	3.21	0.17	2.46
(12) 1 0 1	2.16	0.16	2.81	2.54	0.14	1.90	4.00	0.20	2.30	3.38	0.18	2.33
(13) 1 1 0	2.16	0.17	2.84	2.49	0.13	1.86	3.46	0.13	2.35	3.32	0.18	2.47
(14) 2 2 0	2.06	0.15	2.96	2.28	0.13	2.10	2.99	0.09	2.68	3.42	0.14	2.84
(15) 2 2 2	2.17	0.12	3.16	2.53	0.17	2.18	3.42	0.15	2.83	3.38	0.17	2.45

1 All plots at $N_1P_2S_1$ (See Table 1).

2 Sampling dates and procedures described in "Experimental Methods" section. Data for 1st sampling, oldest mature leaves and 2nd sampling, oldest mature leaves presented in body of thesis in "Effect of Treatment on Plant Composition".

Appendix Table 13. Percentage P in Recently Matured Leaves. 1st, 2nd, and 3rd Samplings. 1959 and 1960. Willamette and Olympic Soils. Means of 3 Replications in 1959 and 4 in 1960.

Treatment Combination[1] P	N	1st Sampling %P	2nd Sampling %P	3rd Sampling %P
		Willamette Soil. 1959		
0	1	0.41	0.42	0.40
1	1	0.45	0.45	0.42
2	1	0.51	0.50	0.41
0	2	0.38	0.44	0.38
1	2	0.43	0.46	0.40
2	2	0.51	0.50	0.45
		Olympic Soil. 1959		
0	1	0.23	0.24	0.18
1	1	0.50	0.38	0.32
2	1	0.56	0.48	0.36
0	2	0.30	0.25	0.18
1	2	0.48	0.38	0.32
2	2	0.50	0.45	0.36
		Olympic Soil. 1960		
0	1	0.36	0.27	0.24
1	1	0.65	0.47	0.33
2	1	0.66	0.51	0.39
0	2	0.34	0.26	0.20
1	2	0.59	0.50	0.34
2	2	0.66	0.52	0.39
		Willamette Soil. 1960[2]		

[1] All plots at $L_1 K_2 Mg_2$ (see Table 1).

[2] In 1960 only oldest mature leaves, 1st and 2nd samplings were analyzed. Samples were taken, but no analyses were performed.