DIFFERENTIAL CATION ABSORPTION AND YIELD RESPONSE BY VEGETABLE CROPS GROWN AT VARIOUS LEVELS OF CALCIUM, POTASSIUM, AND SODIUM

By

JOSEPH DEMPSEY CAMPBELL

A THESIS

Submitted to the School of Graduate Studies of Michigan
State College of Agriculture and Applied Science
in partial fulfillment of the requirements
for the degree of

DOCTOR OF PHILOSOPHY

Department of Horticulture

1953

ACKNOWLEDGMENTS

The author wishes to express his sincere appreciation for the support and encouragement of Dr. H. B. Tukey, and to Dr. R. L. Carolus, for his guidance and active assistance throughout the course of this investigation. Thanks are due Professor C. D. Ball, Drs. G. P. Steinbauer, S. H. Wittwer, L. M. Turk, and Kirk Lawton, members of the author's Guidance Committee. He is indebted to Messrs. F. M. Isenberg and S. Windham, graduate research assistants, each of whom co-operated in the growing of the crops and the subsequent preparation of the samples for chemical analysis.

Special thanks are due to Dr. Wilma D. Brewer and Dr. E. J. Benne, of the Foods and Nutrition and the Agricultural Chemistry Departments, respectively, who made available laboratory space and the use of their flame spectrophotometers.

The author is grateful to the American Potash Institute, Inc., for financial assistance during the course of these investigations.

TABLE OF CONTENTS

LIST OF TABLES

TABLE | Page

LIST OF FIGURES

INTRODUCTION

The study of plant nutrition can be traced back to Aristotle (3), who believed that plants, like animals, took in food "already elaborated." As recent as the seventeenth century, Van Helmont (63), due to an erroneous interpretation of his classic tree experiment, attempted to prove that all the substances of plants are formed from water alone. It remained for de Saussure, in 1804 (52), and Liebig (37), a few years later, to establish scientifically the inorganic requirements of plants.

Lawes and Gilbert (34) demonstrated that plant-nutrient composition could be varied by the application of "chemical manures." It was later realized that composition was affected by many factors, such as the physiological age of the plant and climatic, soil, and moisture conditions. Collander (11) showed that different species of plants grown under identical well-controlled conditions exhibited rather dramatically the property of selective absorption.

Fertilizer recommendations have been based largely on the results of empirical information which is of significance for a relatively limited locality. The work done by Collander (11), while of wider application, failed to consider the colloidal properties of the soil, since the plants were grown in nutrient solutions.

A study of the yield response, along with the cation contents of vegetable crops, produced under field conditions involving variations in fertilizer additions of these cations should give some indication of the extent to which composition is related to plant requirements. Does a high content of a particular cation in a crop reflect a need for a large application of fertilizer containing the element to promote optimum growth, or an inherent ability of that crop to accumulate the ion in large amounts?

It is quite conceivable that knowledge of this type could be useful in devising more-efficient fertilizer and crop-rotation practices for vegetables. With an expanding population and a practically static crop acreage, the need for greater efficiency in fertilizer use becomes obligatory. In addition, the necessity of learning more about composition control for the improvement of human diet is becoming more apparent.

REVIEW OF LITERATURE

The cations which are accumulated in plant tissues are usually first absorbed by the roots. Theories propounded by many workers seeking to explain this mechanism of absorption will be discussed. Since the investigation is concerned with the effect of single cations, as well as their interactive influence on composition and yield of various vegetable crops, the literature covering these subjects will be reviewed.

Factors Influencing Ion Absorption

Hoagland and Davis (28) demonstrated that nutrient absorption may take place against a concentration gradient of the nutrient under consideration. Steward (59), using potato slices, showed that absorption and accumulation of solutes is accomplished by living plant cells and that the greatest accumulations occur in areas of high metabolic activity. Lundergårdh and Burström (41) proposed that accumulation of solutes is dependent on anion respiration. Other workers preferred to use the term "salt respiration" in order to avoid attributing the effect specifically to the anion. The two terms are now used interchangeably. Discussing the quantitative relation between respiration and salt absorption, Lundergårdh (40) recognized two types of respiration other than anion (or salt) respiration. The cyanide-stable primary respiration, which has been recognized for a long time, is not thought to participate in salt accumulation, but to be associated with a system not containing cytochrome, and possibly with oxidations involving manganese. The other type recognized by Lundergårdh is present only in the lower 30 millimeters of the root and is inhibited by 0.001M hydrocyanic acid, but not by 0.001M alkali potassium cyanide.

Ludergårdh (39) proposed that the anion respiration was the driving force for accumulation, because, at the cytochrome stage, hydrogen ions and electrons derived from hydrogen atoms of respiratory substrates were separated. The electrons were transferred by the cytochrome system, while the hydrogen ions, it was assumed, were liberated into the intracellular environment. He suggested that the cytochrome which carried the electrons in one direction, because of the change in valency of the iron atom, could carry anions in the opposite direction. Simultaneously, the hydrogen ions liberated as a result of dehydrogenase activity would pass to the exterior of the cell and cations from the exterior would enter the cell by exchange with these hydrogen ions.

Overstreet and Jacobson (47), in reviewing and evaluating many conflicting views, concluded that ion absorption requires metabolic activity and does not occur in the absence of respiration. They maintained that ion absorption is an exchange process, and that cations are usually absorbed in exchange for H^+ ions ~~by~~ in the plants which are released to the culture medium. They felt that, due to the exchange character of the process, the ions enter the plant independently, either as anions or cations, and that ions are not necessarily absorbed at the same rates. On the basis of this, the cations K^+, NH_4^+, Rb^+, and Cs^+ are rapidly accumulated, while Ca^{++}, Mg^{++}, and Ba^{++} are much more slowly taken up. They also observed the marked influence of one ion of the culture medium upon the absorption of another. For ions of the same charge, this influence is usually of a competitive nature. They noted that the presence of ions such as Ca^{++}, Sr^{++}, Ba^{++}, Al^{+++}, and Fe^{+++}, under some conditions, exerted a stimulating effect on the absorption of K^+, Rb^+, Cs^+, and Br^-. Further, a slowly absorbed cation or anion exerted a depressing effect on the absorption of its associated ion.

The manner in which the energy is produced by metabolic respiration has been the subject of extensive investigation. Some investigators believe it is a chemical phenomenon, whereas others favor a physical or an electrical explanation. Spiegelman and Reiner (56), working with frog's muscle, in relation to potassium and sodium absorption, concluded that mobility differences could not offer an explanation for selection of one ion over another. For similar reasons they rejected the Donnan principle, polarization, and dispersion forces. Jacobson et al. (30) proposed a model which would serve as a working hypothesis in the study of ion absorption by roots. They observed that, for roots of plants grown in low-salt cultures, no appreciable quantities of ions were lost when they were immersed in distilled water, and this was true even when the cells were not metabolically active. This observation provides some grounds for supposing that the root cell probably has a connecting bond which is impermeable to certain organic compounds or chemical complexes. It follows that there must be an ion-binding or carrier substance. Thus, the initial steps in ion absorption proposed by Jacobson involve the reaction for cations ($Z^+ + HR \longrightarrow ZR + H^+$), in which Z^+ is the cation and HR is the carrier substance.

In this reaction, it is assumed that HR, the carrier substance, is produced on the outer side of the connecting link, and that the connecting link is permeable to ZR, but not to Z^+. The complex ZR is broken down on the inner side of the connecting link and the ion Z^+ is again liberated to the vacuole in the form of ions which quickly form soluble salts or acids. This theory differs from Lundergårdh's in that it assumes the same model for the absorption of both anions and cations. Jacobson et al. (32) suggested that HR might represent a single compound or family of compounds, each possessing a high degree of selectivity for a particular cation.

In order to critically evaluate the above theory, it would be important to study the competitive effect between two ions. If competition is assumed, the necessity for separate binding substances would be indicated. Epstein and Hagen (19) compared the absorption processes with enzyme reactions, and considered that the reaction of an ion with a binding substance is analogous to the combination of a substrate with an enzyme. In their interpretation, interfering ions assume the role of either inhibitors or alternate substrates. In this work they found that K^+ and Cs^+ interfered competitively with Rb^+ absorption, and concluded that these three ions were fixed at the same binding site or reactive center. These authors noted, on the other hand, that Na^+, except at high Rb^+ or Na^+ concentrations, did not interfere competitively with Rb^+ absorption.

Cooper (13) suggested the usefulness of a physical-chemical approach to the question of absorption. He proposed that energy be expressed by two values, representing capacity and intensity, which might be compared to volume and pressure in gas relations. In regard to the question of acidity, the capacity could be compared to titratable acidity, and intensity, to the pH value. He pointed out the significance of pH value in biological studies, and by analogy, the desirability of a similar concept in comparing the potential energy of absorbing ions. The methods he used for measuring their relative intensity were the standard oxidation-reduction potential and the ionization potential. Since the latter is not affected by concentration and energy of hydration, it should give a better measure. He arranged the ions in the following order, according to their relative strength: Cs, Rb, K, Na, Li, Ba, Sr, Ca, H, Mg, Mn, Fe, Co, Zn, Be, and Cu.

In further experiments he observed a very close correlation between the intensity of the removal of cations by electrodialysis from soil colloidal complexes and the standard electrode potentials. Electrodialysing fresh samples of cotton, corn, and soybean, he observed that the intensity of removal of the ions was comparable to that found in soil. Fairly good agreement was found between the compiled average composition of many plants and the relative strength of the same ions. Some plants did not follow this relationship in that they tended to selectively accumulate relatively large quantities of certain ions and exclude others. The low concentration of sodium in most plants, as compared to the relative strength of this ion, was the most obvious exception. He considered that this exception could possibly be explained on the basis of some inherent character.

Selective accumulation of calcium in legumes, as aided by the formation of organic compounds such as oxalates of relatively low solubility and energy value, according to Cooper, may be a possible mechanism that protects the plant from excessive accumulation of calcium. This phylogenetic tolerance mechanism may result in an inadequate absorption of some nutrients from solutions in which it is in relatively low concentration. He pointed out that the low content of calcium in seeds, fruits, and tubers, as examples of this mechanism, may be related to some ontogenetic characteristic of the plants.

Breazeale et al. (7) proposed a theory that ion absorption by plants is an electrical phenomenon. All ions possess a definite half-wave potential at which their conductance and diffusion reach a maximum. Using a polarograph with voltages of 2 to 3 volts and currents of 10^{-3} to 10^{-6} amperes, with electrodes attached to the plant and substrate, they determined for each ion that the maximum deflection was close to the $E_{1/2}$ given in standard references. When the plant was attached to the negative pole and the substrate $Ca(NO_3)_2$, to the positive pole with an applied voltage of -2.23 volts, they obtained an increase in calcium absorption. When the electrodes were reversed, there was no difference from the check plant, which was unattached to the electrode. Similar results were obtained with potassium and sodium, which led to the conclusion that ions are mobile and are probably absorbed and accumulated in response to an electrical impulse generated by the plant.

Selective Absorption

Although it had been known for about a hundred years that plants vary in their ability to absorb specific elements under similar circumstances, Newton (45) and Collander (11) drew particular attention to this phenomenon. The latter grew twenty species representing different ecological types in complete nutrient solutions containing several cations in equivalent amounts. He noted that the concentration of sodium and manganese, in species containing maximum values, were twenty to sixty times greater than in those with minimum values; for Li, Mg, Ca, and Sr, three to six times greater than the minimum; for K, Rb, and Cs, only two to three times greater than the minimum. In further experiments, in which he found a constancy in these concentration differences between species, he concluded that they were fairly specific for the species. Similar phenomena were found in soil studies, except that the variations were wider. These results agree with the work reported by Newton (45), Van Itallie (64), and Elgabaly and Wiklander (18). In addition, Drake _et al_. (17) showed that roots with low exchange capacity, such as barley, absorbed more monovalent than divalent cations, whereas pea roots with high exchange capacity tended to absorb relatively more divalent than monovalent cations.

Interrelationships in Cation Absorption

In the evolution of plant species, it might be assumed that mechanisms persisted which assisted the plants in obtaining certain essential elements in short supply and of repelling or excluding certain ions which might not be desirable. Because cultivated plants have often been transferred from their natural habitats in order to obtain satisfactory results, conditions similar to those under which they formerly existed should be simulated.

Until recently, it was considered unnecessary to lime tomatoes. Carolus (9), however, showed that when lime was applied in conjunction with increased amounts of potassium fertilizers, highly significant increases in yield resulted. By comparing the absorption of potassium and calcium, as well as yield, in the case of tomatoes and spinach he noted some interesting relationships, and proposed the following hypothesis. The tomato, during its early evolution, grew under conditions in which calcium was difficultly and potassium easily absorbed. As a consequence, these plants which had a strong mechanism for extracting their calcium requirements persisted. If now it is grown under high calcium and low potassium conditions, a disproportionate amount of calcium would be absorbed, and not enough potassium. If plants are grown under conditions in which adequate quantities of both are added, potassium will tend to depress excessive calcium absorption and ensure the plant its potassium requirements. Spinach, with quite a different phylogenetic background, tends to absorb potassium in excessive amounts unless adequate calcium is present to repress this characteristic.

Recently, much thought has been given to the cation balance concept proposed by such workers as Pierce and Appleman (48), and Shear et al. (54). The latter stated that, all other factors being constant, plant growth is a function of two variables: intensity and balance of nutrients. Lucas and Scarseth (38) pointed out that different cations may perform equally well in some plant functions, such as the regulation of salt concentrations. This property was given the name "mutual mechanical replacement."

Effect of Calcium on Yield and Absorption

Since calcium in most soils is the predominant ion and occupies the greatest proportion of the base exchange on soil colloids, it has the strongest influence on soil reaction. Truog (62) showed the relation between pH and nutrient availability. Bear and Toth (6), reporting on an eight-year study involving twenty important New Jersey soils and using alfalfa roots as cation-extracting agents, concluded that the ideal soil would contain the following proportions of the major cations: Ca, 65 per cent; Mg, 10 per cent; K, 5 per cent; H, 20 per cent. Allaway (2) pointed out that, in addition to considering the total amounts of available ions present in the soils, one must also consider the nature of clay minerals. Marshall (43), in a study of this problem, concluded that kaolimite clay has a higher calcium activity than montmorillinite. Elgabaly and Wiklander (18) found that soil colloids with a high exchange capacity, as compared to those of a low exchange capacity, released monovalent cations more readily than divalent ions. Thorne (61) found that soil colloids saturated with less than 35 per cent calcium resulted in a shortage in the plant. In view of the many functions calcium has, both in the soil and in the plant, it would be difficult to say what particular role might be most important, but certainly a deficiency of this element would have an adverse effect on plant growth, vigor, and crop production. As for its effect on absorption of other cations, Chu and Turk (10) showed that a relatively low percentage of calcium on the exchange complex generally had a repressive effect depending on the nature of the clay. Results of an investigation by Mehlich and Reed (44) showed that there was a greater absorption of calcium and potassium at higher degrees of calcium saturation, but was reversed at still higher levels.

The importance of calcium in relation to soil microorganisms has been stressed by Wynd (68). Hewitt (27) was of the opinion that potassium, along with calcium in a complimentary fashion, helps maintain cell organization, hydration, and permeability, and directly or indirectly influences many enzyme reactions such as the condensation or hydrolysis, which was also inferred by Cooil and Slattery (14). Calcium is apparently a direct activator for certain phosphatase enzymes identified by Kalckar (31) and Krishnan (33) in potato tubers. These enzymes catalyzed both the dismutation of two molecules of adenosinediphosphate (ADP) to give ATP and adenylic acid, and the removal of two phosphate radicles from ATP to give adenylic acid.

Effect of Potassium on Yield and Absorption

The exact role of potassium in plant growth is not completely understood. Without sufficient potassium in the soil, plants lose vigor, are more susceptible to disease, and fail to develop normally. Hewitt (27) believed that potassium, like calcium, helps to maintain cell organization, hydration, and permeability, and influences many plant processes. Steinberg et al. (58), in reporting accumulation of free amino acids in potassium-starved tobacco, suggested a function of potassium in protein synthesis. The uptake and loss of potassium by E. coli was studied under various conditions of carbohydrate metabolism by Roberts et al. (51). Their data showed that although the cell membrane is completely permeable to ionic potassium, potassium complexes which are not diffusible are formed during carbohydrate metabolism. In the presence of hexose sugar there is a rapid accumulation of these compounds giving an initial net increase in the quantity of bound potassium. As metabolism proceeds, an equilibrium is reached at which level potassium is released as rapidly as it is bound. The uptake by and release of potassium from the root cells is dependent on various conditions, including internal glucose concentration, external potassium concentration, temperature, pH, aeration, and the presence of metabolic poisons and other substances. According to Gilbert (22), the general opinion is that a high potassium content of the soil, when not in balance with other essential elements, especially calcium, tends to produce a plant especially high in carbohydrates. Albrecht (1) and Cooper (13) suggested that high-order plants (those developed last in the evolutionary process) contain higher concentrations of the monovalent cations and produce more carbonaceous material than some of the lower-order plants, which tend to accumulate divalent cations and produce more proteinaceous materials. An element of such importance to plant growth and organization as potassium would be expected to be closely related to yield.

Potassium exists in the three forms, water-soluble, exchangeable, and difficultly available or nonavailable. The latter forms part of the primary or secondary soil minerals. Attoe and Truog (5) grew corn and oats in a silt loam soil which had been deprived of the water-soluble fraction of potassium, yet the yield was 62 per cent as much as from the intact soil. However, when the exchangeable fraction was extracted, the yield decreased to about one-fifth of the normal, indicating that the exchangeable fraction is rather readily available to some plants.

In conformity with the balance and reciprocal relationships in plants described by Lucas and Scarseth (38), where one cation is increased relative to the others, the absorption of the cation is increased and others depressed, as calculated on an equivalent basis. In studying cation absorption from solutions of equal concentration, Cooper (13) noted the order of intensity of absorption was potassium, sodium, and calcium.

Effect of Sodium on Yield and Absorption

Since earliest recorded history, harmful and beneficial effects on plant growth have been noticed following the application of common salt (NaCl) to the soil. Selman (53) related that the Jews were said to have spread salt over the fields of their enemies to make the soil barren, and Pliny, in 23 to 79 A.D., recorded that pastures of a saline nature were preferred by cattle.

Osterhout (46) established that sodium is an essential element for marine plants, as well as animals. De Candolle (15) described the native habitat of a few wild ancestors of the most salt-responsive plants. In every case they originated near bodies of salt water. He found that the native habitat of celery is in the damp places from Sweden to Algeria, and parts of Asia. It is probable that the many varieties in use today originated in more than one part of the world. It would be logical to suppose, as Harmer (23) found, that celery varieties would vary in their response to sodium. Collander (11), in his study of twenty-one different species, showed that the highest sodium accumulators contained more than sixty times as much sodium as the lowest.

Kearney (32) reported that the injurious effects of sodium on closely related species were similar. Hurd-Karrer (29) noted that injury varied with age, environmental factors, and the species. Hayward (26), in an experiment in which he varied the concentrations of base salts, found the damage more related to increasing concentrations than the kind of salt.

Positive responses to sodium fertilization have been reported many times on various crops, especially when potassium was low. Lehr (35), working with beets on "artificial soil" in which he varied calcium, potassium, and sodium, reported increased yields from sodium. He noted that there was relatively more sodium in the leaves, while in the roots potassium was predominant. This is in agreement with results found in several other storage organs, one of which, the potato, was reported by Albrecht (1). Arnon and Hoagland (4) reported relatively higher concentrations of potassium in tomato fruit. Hartwell and Damon (25), reporting on work done with many crops, concluded that when potassium was insufficient, sodium was generally useful, but the improvement was not great enough to warrant its use over potassium. Lunt and Nelson (42) investigated the effect of sodium in the mineral nutrition of cotton, and found that yield increased 25 per cent when potassium was at deficient levels. No increase resulted, however, when potassium was adequate. They found no influence on fibre or seed quality from sodium, as occurred with potassium. Harmer and Benne (24) studied the effect of sodium on vegetable crops grown on Michigan organic soil. They divided the crops into those which were benefited by sodium in deficiency of potassium, and those which were benefited in sufficiency of potassium, and suggested that in the latter crops, sodium had a specific unknown function. In many crops they found that sodium improved yield, color of foliage, and vigor of the plants. It should be stressed that these results were found on organic soils, normally low in potassium. Dorph-Peterson and Steenbjerg (16) investigated the effect of sodium on some crops, using pot cultures as well as field experiments, and observed increases in yield when potassium was deficient. From an economic standpoint, they concluded that since beets are one of the few crops which do respond, it would not be practical to use sodium in preference to potassium, since, in an average rotation, the needs of all crops must be considered when applying fertilizer.

Considering the wide difference in sodium absorption already mentioned, there is evidence to indicate that many crops tend to exclude this element. While it has been amply demonstrated that in certain crops, such as sugar beets, sodium can to some extent replace potassium, it has not been shown to be superior to it. Harmer and Benne (24) found that upon adding sodium to organic soils, celery showed less wilting in hot weather. They suggested that, in adding sodium, the osmotic pressure increased, resulting in a decrease in transpiration. Richards (50) proposed that crops which respond to sodium do so because it prevents a toxic accumulation of calcium. The author listed the crops which Harmer and Benne (24) had rated in relation to sodium response, according to their position in the evolutionary scale, as given by Pool (49). It was found that the crops listed as sodium responsive were lower in the evolutionary scale which, according to Lewis and Eisenmenger (36), require relatively less calcium than high-order plants.

Gauch and Wadleigh (21) suggested that sodium accumulation is related to greater permeability of the cell to salts. Steinbach (57), however, suggested that the term "permeability" is too inclusive, and should be broken down into more-specific processes such as secretion and absorption. Dorph-Peterson and Steenbjerg

(16) stated that, with extremely small amounts of potassium, no increase in yield resulted from the addition of sodium. With the application of some potassium, sodium caused an increase in yield, after which greater amounts resulted in a decrease. Their conclusion was that sodium could not replace potassium in all of its functions, and that a certain amount of the essential element, potassium, must necessarily be present if the plant is to live and grow, after which it is able to utilize sodium in certain functions in which either element could perform equally well. This is in agreement with the cation-balance theory suggested by Lucas and Scarseth (38).

The work done by Epstein and Hagen (19) showed that potassium and sodium act quite differently in absorption by barley roots, and suggested that they are not bound at the same site. Cowie et al. (14) made a study of the absorption of radioactive sodium and potassium through the cell membrane of E. coli. They showed that there was no indication that sodium became part of any compound within the cells, even during high metabolic activity. This contrasts with potassium, which they found to be concentrated in the cells in nondiffusable potassium compounds during cellular metabolism, indicating a greater physiological significance of potassium in comparison to sodium.

Some cations are, by their physical nature, more easily removed from soil colloids, and each cation exerts an influence over the removal of others. However, in the evolution of species, mechanisms influencing this phenomenon were developed which made possible their survival under a great variety of conditions. The seemingly contradictory evidence concerning plant nutrition is probably due to the fact that species have developed quite different processes to meet their own peculiar needs and situations. The answer to many problems would appear to be through a more intimate knowledge of the plants, themselves. By including several species in nutrition experiments, perhaps plants can be classified into groups which have similar mechanisms and requirements from a nutritional standpoint. Certainly, the present botanical arrangement of crops by families leaves much to be desired in this respect.

STATEMENT OF PROBLEM

There is a need, as suggested in the Review of Literature, for a more intimate knowledge of plants in order to group them on the basis of nutritional habits and requirements. This problem revolved around that general premise.

Collander (11) studied the selective absorption of cations by about twenty species of plants, representing a variety of ecological types, in complete nutrient solutions containing several different cations in equivalent amounts. His results showed striking comparisons in the ability of different kinds of plants to selectively absorb cations. Harmer and Benne (24) made a similar study of ten vegetable crops grown on organic soil. In order to further clarify this problem, work of the same general nature was undertaken on mineral soil.

This investigation consisted of a study involving seventeen vegetable crops representing nine botanical families grown under similar environmental conditions. The influences of three levels of calcium, three of potassium, two of magnesium (not dealt with in this thesis), and two of sodium, on absorption and yield were determined. The essential difference between this and Collander's work was that the plants chosen were of economic significance and were grown under natural field conditions. It differed from work done by Harmer and Benne (24), chiefly because of its wider scope, and in being grown on mineral soil as compared to organic or "muck" soil.

Relating the yield data obtained to the concentration and total accumulations of the different cations, as influenced by treatment, should result in making it possible.

1. To determine the effect of the application to the soil of each of the cations (Ca, K, and Na) on their differential absorption by the seventeen crops and the interactive effect of the various levels of these ions on absorption.

2. To evaluate the effect of each cation applied to the soil on the total and individual cation removal by some of the crops.

3. To ascertain the relationship existing between either concentration or total accumulation of the cations (Ca, K, Mg, and Na) by each of the seventeen crops, and improvement in growth of the plant, as measured by yield.

4. To attempt the grouping of crops that behave similarly under the various treatments.

In addition, the results of this investigation should suggest practical considerations for the more effective use of fertilizers on the various crops.

PROCEDURES AND MATERIALS

Field Experimentation

This experiment was conducted on a plot which was approximately one acre in area. The treatments, consisting of three levels of calcium, three of potassium, two of magnesium, and two of sodium, were laid out as a factorial experiment in randomized blocks of Ca x K treatments, in which magnesium and sodium were superimposed as split plots. The ultimate size of each of the thirty-six plots was 58 feet by 22 feet. Each of the seventeen crops was planted across the 22-foot width in adjacent rows, with variation in widths between the rows depending on the nature of the crop.

This experiment was conducted on a plot of Hillsdale sandy loam, a soil widely distributed in Michigan. Veatch (65) described it as being a light brownish and yellowish surface soil underlain by yellowish friable, but moderately retentive, sandy loam and gritty clay of only an intermediate rating in fertility.

In the spring of both 1950 and 1951 a uniform application of fertilizer was applied: phosphorus in the form of double superphosphate (42 to 45 per cent P_2O_5) at 300 pounds per acre, 200 pounds per acre of nitrogen in the form of NH_4NO_3, and 30 pounds per acre of potassium (K_2O), equally divided between KCl and K_2SO_4. All cation additions were made prior to planting in the 1950 season. Some of the young seedlings died, presumably from excessive concentrations of fertilizer. Consequently, in 1951, the fertilizer was applied in two applications, the first soon after the crop became established, and the second, four to six weeks later. In addition, as a result of pH determinations, as well as chemical analysis of the soil, the amount of lime necessary to achieve the desired pH values was calculated on a more precise basis than was the case in the first season. Table I indicates the fertility status of this plot according to the various treatments at the end of the first year (1950), as well as the fertilizer materials applied in order to provide the desired treatment levels.

The crops grown in each of the thirty-six plots, arranged according to botanical family in the order of the evolutionary development, as taken from Pool (49), are listed on page 30, with pertinent data in respect to spacing and variety.

TABLE I

SOIL FERTILITY VALUES FOUND IN AND FERTILIZER MATERIALS ADDED TO THE EXPERIMENTAL PLOTS

A. The Average Values for Various Soil Chemical Properties as Determined on Soils from the Experimental Plots[1]

Treatment Level	pH	% Base Saturation	Exchangeable Cations (m.e./100 gm. soil)				
			Total	Ca	K	Mg	Na
High	6.6	95.9	5.2	4.5	0.3	0.2	0.03
Medium	6.1	68.9	5.5	3.4	0.2		
Low	5.2	43.0	5.3	2.4	0.2	0.1	0.01

B. Quantities and Sources of Materials Applied for the Various Treatments (in both 1950 and 1951)

Cation	Application	Source
High Ca	$Ca(OH)_2$ to produce a pH of 6.5	$Ca(OH)_2$
Medium Ca	$Ca(OH)_2$ to produce a pH of 6.0	$Ca(OH)_2$
Low Ca	$Ca(OH)_2$ to produce a pH of 5.5	$Ca(OH)_2$
High K[2]	330 lbs. K_2O per acre	K_2SO_4 and KCl
Medium K[2]	180 lbs. K_2O per acre	K_2SO_4 and KCl
Low K[2]	30 lbs. K_2O per acre	K_2SO_4 and KCl
Mg[3]	100 lbs. MgO per acre	$MgSO_4 \cdot 7H_2O$
Na	200 lbs. Na_2O per acre	NaCl

[1] From samples of surface 6 inches taken at the end of the first year.

[2] The 30 lbs./acre general application is included in these figures.

[3] Not dealt with in this thesis.

Crop	Spacing (feet)	Variety	Botanical Family	Evolutionary Order
Onion	2	Brigham Yellow Globe	Liliaceae	Low
Cabbage	3	Racine Market	Cruciferae	Low
Cauliflower	3	Snow Ball	Cruciferae	Low
Pea	3	Progress	Leguminosae	Low
Lima Bean	2.5	Fordhook 242	Leguminosae	Low
Snap Bean	2.5	Topcrop	Leguminosae	Low
Beet	2	Detroit Dark Red	Chenopodiaceae	Medium
Spinach	3	Long Standing Bloomsdale	Chenopodiaceae	Medium
Celery	4	Summer Pascal	Umbelliferae	Medium
Carrot	2	Supreme Half Long	Umbelliferae	Medium
Sweet Corn	4	Golden Cross Bantam	Gramineae	Medium
Tomato	4.5	Stokesdale	Solanaceae	High
Potato	3	Chippewa	Solanaceae	High
Muskmelon	5	Delicious	Cucurbitaceae	High
Cucumber	5	National Pickling	Cucurbitaceae	High
Squash	5.5	Golden Delicious	Cucurbitaceae	High
Lettuce	2	Great Lakes	Compositae	High

In weeks following a precipitation of less than 1 inch, supplementary moisture was applied, using a portable irrigation system. Conventional cultural practices such as cultivation and insect and weed control were followed.

As crops reached marketable maturity, yield data were recorded and samples for chemical analysis were taken from the center 10-foot portion from each of the 612 plots. Representative samples were obtained of all parts of the plant above the soil. However, where root, bulb, and tuber crops were involved, the entire plant was used. In some cases, which will be indicated in the analytical results, separate samples were taken of the fruit.

Plant Analysis

Well-brushed samples of plant material were cut into pieces, thoroughly mixed, and a 100-gram aliquot was dried in a perforated paper bag, at approximately 70° F. The dried material was ground in a Wiley mill to pass through a 20-mesh screen. Duplicate 1-gram aliquots were taken for wet ashing, using the method described by Toth et al. (60), with some modifications. The samples were placed in a 125-milliliter beaker, to which 10 milliliters of concentrated nitric acid were added and heated carefully on an electric hot plate until oxidation was nearly complete. In order to avoid loss of material from spattering, beakers were covered with watch glasses. To the light-brown liquid 2.5 milliliters of 70 per cent perchloric acid was added, and the temperature of heating increased until dense white fumes appeared. The beakers were removed when the contents were almost colorless, and usually became perfectly clear upon cooling. The contents of the beaker were transferred, using about 25 milliliters of hot water to a number 30 Wattman filter paper, and the paper was washed thoroughly with hot dilute (1:19) HCl and the filtrate collected in a 100-milliliter volumetric flask.

For the analysis of calcium, potassium, magnesium, and sodium, the Beckman Model DU Flame Spectrophotometer was used. Procedure outlined by Brown et al. (8) was followed, with modifications. Hydrogen was used as a source of fuel in order to increase the accuracy of the magnesium determination. Standard solutions for comparative purposes were made to include varying concentrations of one cation, but with a fixed amount of the remaining three cations, the fixed amounts being: Ca, 200; K, 150; Mg, 75; and Na, 20 p.p.m. These fixed amounts represent the approximate concentrations of calcium, potassium, magnesium, and sodium found in vegetable crops, and, according to Brown et al. (8), have the effect of largely overcoming the interference arising from the presence of these cations. Due to wide variations in composition between crops and treatments, trial runs were necessary to ascertain the top standard in order to utilize the maximum portion of a standard curve for each crop. The wave lengths and photo tubes found most suitable for the instrument used were:

	Ca	K	Mg	Na
Wave Length	556	771.5	371	592
Photo Tube	Blue	Red	Blue	Blue

After the instrument was set at 100 per cent transmission with the top standard, it was balanced by adjusting the slit width to cause the needle to rest at zero. The other solutions necessary to give a smooth curve were determined and tested until the instrument was giving reproducible results. The readings of the plant-sample solutions were then observed, with frequent rechecking of the instrument with the standards. If variations in the standard values were observed, the hydrogen pressure was adjusted to cause the needle to settle at zero.

Ordinary graph paper was used to plot per cent transmission against parts per million of the element under study.

Because of inconsistent results with some of the crops in 1950, only the 1951 data are included for analysis.

Statistical Interpretation of the Data

The significance of the yield results and composition data was evaluated by the analysis of variance method for a factorial experiment involving a split plot, as described by Yates (69). Inasmuch as the influence of magnesium was not a part of this work, the two levels of magnesium were treated as replicates. Included in "error b" was the second order interaction between calcium, potassium, and sodium. The "t" values were those given by Fisher (20), and the "F" values were taken from Snedecor (55).

EXPERIMENTAL RESULTS

The Average Yields at All Levels of Calcium, Potassium, and Sodium

The average yield of thirty-six plots for each crop, expressed in pounds per plot and tons per acre, as well as in commercial units, and arranged in the order of the evolutionary development of plants, is presented in Table II. Satisfactory yields were obtained for most crops: irregular stands of carrots and peas make the information obtained from some treatments of doubtful value. The cucumber yield was extremely low, but this appeared to be due to the unfavorable growth response of the crop to many of the treatment combinations.

The following figures show the average yield of both the fresh and dry weights, respectively, of the crops arranged according to their position in the evolutionary scale, as listed in Table I.

Order	Crops	Avg. Yield (tons/acre)	Avg. Dry Weight (tons/acre)
Low	Onion - Snap Bean (incl.)	8.4	0.9
Medium	Beet - Sweet Corn (incl.)	9.1	1.3
High	Tomato - Lettuce (incl.)	11.6	1.0

TABLE II

YIELD OF SEVENTEEN VEGETABLE CROPS GROWN UNDER ALL LEVELS OF CALCIUM, POTASSIUM, MAGNESIUM, AND SODIUM
(average of thirty-six plots)

Crop	Yield		
	Lb. per Linear 10 ft.	Tons per Acre	Commercial Units per Acre*
Onion (plants)	6.3	6.7	248.2 bu. (54 lb.)
Cabbage (heads)	27.6	20.0	20.0 tons
Cauliflower (heads)	17.8	12.6	646.1 crates (39 lb.)
Pea (fruit)	2.1	1.7	113.3 bu. (30 lb.)
Lima Bean (fruit)	7.8	5.6	350.0 bu. (32 lb.)
Snap Bean (fruit)	5.1	3.7	246.6 bu. (30 lb.)
Beet (plants)	16.0	17.4	17.4 tons
Spinach (plants)	5.0	3.6	400.0 bu. (18 lb.)
Celery (plants)	15.8	11.8	363.1 crates (65 lb.)
Carrot (plants)	4.1	3.8	152.0 bu. (50 lb.)
Sweet Corn (ears)	11.8	8.5	8.5 tons
Tomato (fruit)	57.0	16.5	16.5 tons
Potato (tubers)	26.8	19.4	646.6 bu. (60 lb.)
Muskmelon (fruit)	16.8	7.6	202.7 crates (70 lb.)
Cucumber (fruit)	2.7	1.2	50.0 bu. (48 lb.)
Squash (fruit)	49.6	17.1	17.1 tons
Lettuce (heads)	7.0	7.8	208.0 crates (75 lb.)

* Taken from Agricultural Statistics, 1947.

Although the "high order" plants produced the highest fresh-weight yield, apparently their greater succulence offset this advantage when calculated in terms of the dry weight.

Tables which follow in the thesis are divided into parts A and B. The former shows the independent effects of pH, potassium, and sodium, as well as the interactive influence of pH with potassium and pH with sodium. The latter shows the interaction of potassium with sodium. All significant or highly significant results are indicated in the discussion, and also by means of asterisks in the Tables. Since the soil analysis indicated the close relationship of pH and calcium, for the sake of simplicity, these two terms will be considered as synonymous. All tables show the precise levels of the various treatments, but in the discussions to follow, high, medium, and low may be used to indicate these levels for pH and potassium; and for the levels of sodium, high and low may be used.

The Influence of Calcium, Potassium, and Sodium on the Yield of the Seventeen Crops

Onions. Yield was significantly increased by high calcium and significantly decreased by high potassium, whereas sodium very significantly reduced it (Table IIIA). Although the interaction between calcium and potassium failed to reach significance, it is of interest to note that the yield with high calcium and low potassium was almost three times that from low calcium and high potassium. When calcium and potassium were both at either the high or the low level, better-than-average yields occurred, indicating that this crop is sensitive to calcium-potassium levels.

Based on these results, it appears that onions respond to calcium as compared to potassium, which would agree with the theory Cooper (13) and others have proposed, that the "low order" plants do better when the divalent cations are relatively more abundant than the monovalent cations. However, the beneficial influence of calcium may be due in part to the indirect effects associated with an increased pH.

Cabbage. No yield differences of significance resulted from the independent influence of calcium, potassium, or sodium; however, the interaction between calcium and potassium resulted in highly significant results (Table IIIB). As in the case of onions, the lowest yield occurred with low calcium and high potassium, but the best yields were with either high calcium and medium

TABLE IIIA

THE INTERACTIVE INFLUENCE OF VARIOUS LEVELS OF LIME, POTASSIUM, AND SODIUM APPLICATIONS ON THE YIELD OF ONION BULBS AND TOPS

(expressed in pounds per 10 linear feet of row)

A. Sodium and Potassium Effect at Three pH Levels

Sodium (lb. Na_2O per acre)	Potassium (lb. K_2O per acre)	At pH Values Resulting from $Ca(OH)_2$ Treatment			Average
		6.5	6.0	5.5	
200	330	4.9[a]	4.1	2.9	4.0[b]
200	180	8.1	3.0	4.9	5.3
200	30	6.5	6.4	6.1	6.3
Avg. 200		6.7[b]	4.5	4.6	5.3**
0	330	9.2[a]	5.1	3.6	6.0
0	180	9.3	4.6	7.4	7.1
0	30	11.0	7.5	8.2	8.9
Avg. 0		9.8[b]	5.7	6.4	7.3**
	Avg. 330	7.0[c]	4.6	3.2	4.9**
	Avg. 180	8.7	3.8	6.1	6.2
	Avg. 30	9.0	6.9	7.1	7.7**
Average for each pH		8.2[d]**	5.1**	5.5	6.3

B. Sodium Effect at Three Potassium Levels

Sodium (lb. Na_2O per acre)	Potassium (lb. K_2O per acre)		
	330	180	30
200	3.9	5.3	6.5
0	5.9	7.1	8.9

L. S. D. at 5%: Ca and K, 1.8; Na, 0.9.
L. S. D. at 1%: Ca and K, 2.7; Na, 1.3.
a, b, c, d: Averages of 2, 6, 4, and 12 plots, respectively.
* Only significant or
**Highly significant extremes in yield values for effects or interactions are indicated.

TABLE IIIB

THE INTERACTIVE INFLUENCE OF VARIOUS LEVELS OF LIME, POTASSIUM, AND SODIUM APPLICATIONS ON THE YIELD OF CABBAGE HEADS

(expressed in pounds per 10 linear feet of row)

A. Sodium and Potassium Effect at Three pH Levels

Sodium (lb. Na_2O per acre)	Potassium (lb. K_2O per acre)	At pH Values Resulting from $Ca(OH)_2$ Treatment			Average
		6.5	6.0	5.5	
200	330	22.4[a]	33.0	17.2	24.2[b]
200	180	34.9	21.7	25.5	27.4
200	30	20.7	26.2	33.1	26.7
Avg. 200		26.5[b]	26.9	25.2	26.2
0	330	32.4[a]	33.3	19.5	28.4
0	180	35.6	26.0	26.7	29.4
0	30	24.8	25.0	37.1	29.0
Avg. 0		30.9[b]	28.1	27.7	28.9
	Avg. 330	27.4[c]	33.1	18.4**	26.5
	Avg. 180	35.2**	23.8	26.1	28.4
	Avg. 30	22.8	25.6	35.1	27.8
Average for each pH		28.7[d]	27.5	26.5	27.5

B. Sodium Effect at Three Potassium Levels

Sodium (lb. Na_2O per acre)	Potassium (lb. K_2O per acre)		
	330	180	30
200	24.7	27.3	26.6
0	28.4	29.4	28.9

L. S. D. at 5%: (Ca x K), 5.4.
L. S. D. at 1%: (Ca x K), 7.8.
a, b, c, d: Averages of 2, 6, 4, and 12 plots, respectively.
** Highly significant.

potassium or low calcium and low potassium. Sodium tended to depress the yield, but not as markedly as with the onion.

Cauliflower. As indicated in Table IIIC, the independent influence of potassium at the high rate was to significantly depress the yield. Although the independent effect of sodium was practically nil, when potassium was low, the application of sodium tended to increase the yield over the average.

Pea. In Table IIID, no consistent trend was to be found, and this is borne out by a lack of significance in any of the treatments or interactions. This may be due to uneven stands, mentioned earlier. Of interest is the observation that sodium had no appreciable influence on the yield.

Lima beans. As revealed in Table IIIE, there was very little difference in yield response, irrespective of treatment, indicating that this crop has a wide range of tolerance for variable levels of the three cations under study. This is in striking contrast to the snap bean, in spite of the close botanical relationship.

Snap bean. An important difference between snap beans and lima beans, as shown in this study, was that snap beans showed

TABLE IIIC

THE INTERACTIVE INFLUENCE OF VARIOUS LEVELS OF LIME, POTASSIUM, AND SODIUM APPLICATIONS ON THE YIELD OF CAULIFLOWER HEADS
(expressed in pounds per 10 linear feet of row)

A. Sodium and Potassium Effect at Three pH Levels

Sodium (lb. Na_2O per acre)	Potassium (lb. K_2O per acre)	At pH Values Resulting from $Ca(OH)_2$ Treatment			Average
		6.5	6.0	5.5	
200	330	15.0[a]	14.8	16.2	15.3[b]
200	180	18.8	22.1	19.9	20.3
200	30	20.1	16.3	18.8	18.4
Avg. 200		17.9[b]	17.7	18.3	18.0
0	330	15.0[a]	19.4	14.3	16.2
0	180	19.4	17.0	24.2	20.2
0	30	13.7	14.8	21.4	16.6
Avg. 0		16.0[b]	17.1	20.0	17.7
	Avg. 330	15.0[c]	17.1	15.3	15.8*
	Avg. 180	19.1	19.5	22.0	20.2*
	Avg. 30	16.9	15.6	20.1	17.5
Average for each pH		17.0[d]	17.4	19.1	17.8

B. Sodium Effect at Three Potassium Levels

Sodium (lb. Na_2O per acre)	Potassium (lb. K_2O per acre)		
	330	180	30
200	15.3	20.2	18.4
0	16.2	20.2	16.6

L. S. D. at 5%: K, 3.2.
L. S. D. at 1%: K, 4.7.
a, b, c, d: Averages of 2, 6, 4, and 12 plots, respectively.
* Significant.

TABLE IIID

THE INTERACTIVE INFLUENCE OF VARIOUS LEVELS OF LIME, POTASSIUM, AND SODIUM APPLICATIONS ON THE YIELD OF PEA FRUIT

(expressed in pounds per 10 linear feet of row)

A. Sodium and Potassium Effect at Three pH Levels

Sodium (lb. Na_2O per acre)	Potassium (lb. K_2O per acre)	At pH Values Resulting from $Ca(OH)_2$ Treatment			Average
		6.5	6.0	5.5	
200	330	3.6[a]	1.1	2.4	2.4[b]
200	180	1.7	2.0	2.1	1.9
200	30	1.9	2.2	2.5	2.2
Avg. 200		2.4[b]	1.7	2.3	2.1
0	330	3.5[a]	1.3	2.9	2.6
0	180	1.1	1.8	2.5	1.8
0	30	2.5	1.6	2.3	2.1
Avg. 0		2.4[b]	1.5	2.6	2.2
	Avg. 330	3.5[c]	1.2	2.6	2.4
	Avg. 180	1.4	1.9	2.3	1.9
	Avg. 30	2.2	1.9	2.4	2.2
Average for each pH		2.4[d]	1.7	2.5	2.2

B. Sodium Effect at Three Potassium Levels

Sodium (lb. Na_2O per acre)	Potassium (lb. K_2O per acre)		
	330	180	30
200	2.3	1.9	2.2
0	2.6	1.8	2.1

a, b, c, d: Averages of 2, 6, 4, and 12 plots, respectively.

TABLE IIIE

THE INTERACTIVE INFLUENCE OF VARIOUS LEVELS OF LIME, POTASSIUM, AND SODIUM APPLICATIONS ON THE YIELD OF LIMA BEAN FRUIT
(expressed in pounds per 10 linear feet of row)

A. Sodium and Potassium Effect at Three pH Levels

Sodium (lb. Na_2O per acre)	Potassium (lb. K_2O per acre)	At pH Values Resulting from $Ca(OH)_2$ Treatment 6.5	6.0	5.5	Average
200	330	8.8[a]	8.8	7.2	8.3[b]
200	180	7.8	8.5	7.0	7.8
200	30	7.2	9.4	7.8	8.1
Avg. 200		7.9[b]	8.9	7.3	8.0
0	330	7.1[a]	8.8	8.0	8.0
0	180	7.7	8.0	7.9	7.9
0	30	6.3	7.3	7.8	7.1
Avg. 0		7.0[b]	8.0	7.9	7.6
	Avg. 330	7.9[c]	8.8	7.6	8.1
	Avg. 180	7.7	8.2	7.5	7.8
	Avg. 30	6.7	8.3	7.8	7.6
Average for each pH		7.5[d]	8.5	7.6	7.9

B. Sodium Effect at Three Potassium Levels

Sodium (lb. Na_2O per acre)	Potassium (lb. K_2O per acre) 330	180	30
200	8.2	7.7	8.1
0	8.0	7.9	7.1

a, b, c, d: Averages of 2, 6, 4, and 12 plots, respectively.

extreme sensitiveness to sodium, and, as is seen in Table IIIF, yield was very significantly depressed by sodium addition. Although no interaction reached a significant level, nevertheless, the yield with high calcium and low potassium produced only about half the yield that was obtained from high calcium and high potassium. The low-yielding combination of high calcium and low potassium resulted in stunted necrotic plants, and the visible symptoms appeared to be more noticeable when sodium was high. The necrotic condition observed gave evidence of boron toxicity. An analysis for this element, using a method described by Windsor (67), was made, and boron was found to be excessively high in the necrotic plants. An identical cation combination had been earlier reported by Shear _et al_. (54) to give rise to boron toxicity.

Beet. This crop is the first to be considered in the intermediate group according to the evolutionary scale, and one might expect it to react somewhat differently from the preceding crops. As Table IIIG reveals, calcium application caused a significant increase in yield.

Potassium and sodium applications tended to increase yield, which is a reversal of the trend found in the previously reported

TABLE IIIF

THE INTERACTIVE INFLUENCE OF VARIOUS LEVELS OF LIME, POTASSIUM, AND SODIUM APPLICATIONS ON THE YIELD OF SNAP BEAN FRUIT

(expressed in pounds per 10 linear feet of row)

A. Sodium and Potassium Effect at Three pH Levels

Sodium (lb. Na_2O per acre)	Potassium (lb. K_2O per acre)	At pH Values Resulting from $Ca(OH)_2$ Treatment			Average
		6.5	6.0	5.5	
200	330	6.0[a]	4.2	4.0	4.7[b]
200	180	4.3	5.2	4.2	4.6
200	30	3.3	6.3	4.0	4.5
Avg. 200		4.5[b]	5.2	4.0	4.6**
0	330	6.1[a]	6.3	5.0	5.8
0	180	6.8	6.3	6.0	6.4
0	30	3.0	5.6	6.6	5.1
Avg. 0		5.3[b]	6.1	5.8	5.7**
	Avg. 330	6.0[c]	5.2	4.5	5.2
	Avg. 180	5.5	5.7	5.1	5.4
	Avg. 30	3.1	5.9	5.3	4.8
Average for each pH		4.9[d]	5.6	5.0	5.2

B. Sodium Effect at Three Potassium Levels

Sodium (lb. Na_2O per acre)	Potassium (lb. K_2O per acre)		
	330	180	30
200	4.7	4.6	4.5
0	5.8	6.3	5.1

L. S. D. at 5%: Na, 0.7.
L. S. D. at 1%: Na, 0.9.
a, b, c, d: Averages of 2, 6, 4, and 12 plots, respectively.
** Highly significant.

TABLE IIIG

THE INTERACTIVE INFLUENCE OF VARIOUS LEVELS OF LIME, POTASSIUM, AND SODIUM APPLICATIONS ON THE YIELD OF BEET PLANTS

(expressed in pounds per 10 linear feet of row)

A. Sodium and Potassium Effect at Three pH Levels

Sodium (lb. Na_2O per acre)	Potassium (lb. K_2O per acre)	At pH Values Resulting from $Ca(OH)_2$ Treatment			Average
		6.5	6.0	5.5	
200	330	19.3[a]	17.9	11.8	16.3[b]
200	180	13.2	13.4	17.4	14.7
200	30	20.2	16.5	19.1	18.6
Avg. 200		17.6[b]	15.9	16.1	16.5
0	330	22.4[a]	20.4	13.2	18.7
0	180	16.6	11.5	15.8	14.6
0	30	16.9	10.4	11.9	13.1
Avg. 0		18.6[b]	14.1	13.6	15.4
	Avg. 330	20.8[c]**	19.1	12.5**	17.5
	Avg. 180	14.9	12.4	16.6	14.6
	Avg. 30	18.5	13.4	15.5	15.8
Average for each pH		18.1[d]*	15.0	14.9*	16.0

B. Sodium Effect at Three Potassium Levels

Sodium (lb. Na_2O per acre)	Potassium (lb. K_2O per acre)		
	330	180	30
200	16.3	14.6	18.6
0	18.7**	14.6	13.1**

L. S. D. at 5%: Ca, 2.5; (Ca x K), 4.5; (Na x K), 2.4.
L. S. D. at 1%: Ca, 3.7; (Ca x K), 6.6; (Na x K), 3.4.
a, b, c, d: Averages of 2, 6, 4, and 12 plots, respectively.
* Significant.
** Highly significant.

"low order" crops. Although the independent effects of these two elements failed to reach significance, the interactions of both calcium with potassium and sodium with potassium were statistically significant. With both high and medium calcium and high potassium, the maximum yield responses were obtained, whereas, with low calcium and low potassium, the poorest yield occurred. As Lehr (35) and Harmer (23) have observed, beet yields increase significantly from sodium application when potassium is low, but not when potassium is adequate. Similar results are to be observed in Table IIIG.

Spinach. The yield of spinach was increased significantly by potassium and highly significantly by calcium (Table IIIH), which is in agreement with earlier work done by Carolus (9). The effect of calcium is very marked and may be due in part to the indirect influence resulting from an increase in pH associated with high calcium. There was a significant interaction between sodium and potassium, and, as with beets, yield was increased as a result of the application of sodium when potassium was low. However, when potassium was high, sodium had little effect. Harmer and Benne (24), on the other hand, concluded that spinach

TABLE IIIH

THE INTERACTIVE INFLUENCE OF VARIOUS LEVELS OF LIME, POTASSIUM, AND SODIUM APPLICATIONS ON THE YIELD OF SPINACH PLANTS
(expressed in pounds per 10 linear feet of row)

A. Sodium and Potassium Effect at Three pH Levels

Sodium (lb. Na_2O per acre)	Potassium (lb. K_2O per acre)	At pH Values Resulting from $Ca(OH)_2$ Treatment			Average
		6.5	6.0	5.5	
200	300	8.3[a]	7.2	2.4	6.0[b]
200	180	6.8	4.7	1.0	4.2
200	30	5.5	5.4	3.5	4.8
Avg. 200		6.9[b]	5.8	2.3	5.0
0	330	9.6[a]	4.5	2.5	5.5
0	180	8.7	4.3	5.1	6.0
0	30	4.6	4.5	1.0	3.4
Avg. 0		7.6[b]	4.4	2.9	5.0
	Avg. 330	9.0[c]	5.8	2.4	5.7*
	Avg. 180	7.7	4.5	3.1	5.1
	Avg. 30	5.1	4.9	2.2	4.1*
Average for each pH		7.3[d]**	5.1	2.6**	5.0

B. Sodium Effect at Three Potassium Levels

Sodium (lb. Na_2O per acre)	Potassium (lb. K_2O per acre)		
	330	180	30
200	5.9	4.2	4.8
0	5.5	6.0**	3.3**

L. S. D. at 5%: Ca and K, 1.1; (Na x K), 1.7.
L. S. D. at 1%: Ca and K, 1.7; (Na x K), 2.4.
a, b, c, d: Averages of 2, 6, 4, and 12 plots, respectively.
* Significant.
** Highly significant.

was very little affected by the addition of sodium when potassium was deficient.

Celery. The yield of celery varied widely, as indicated in Table III I, although consistent trends were lacking. The effect of calcium was highly significant, but best yields were at the medium and high levels, dropping off sharply at the low level. There was a significant interaction between calcium and potassium. The yield from high potassium and high calcium was four times that with high potassium and low calcium. Although the interaction between sodium and potassium did not reach significance, it is interesting to note that, at low potassium, sodium gave a 50 per cent increase in yield, showing a similar response to that of beets. This is in agreement with the findings of Harmer and Benne (23), who listed celery as being responsive to sodium.

Carrot. The values for carrots, shown in Table IIIJ, indicate a highly significant independent response of this crop to calcium and sodium, as well as a significant interaction between calcium and potassium. The response to sodium was negative; this is in marked contrast to the influence of sodium on beets, especially at low potassium levels.

TABLE III I

THE INTERACTIVE INFLUENCE OF VARIOUS LEVELS OF LIME, POTASSIUM, AND SODIUM APPLICATIONS ON THE YIELD OF CELERY PLANTS

(expressed in pounds per 10 linear feet of row)

A. Sodium and Potassium Effect at Three pH Levels

Sodium (lb. Na_2O per acre)	Potassium (lb. K_2O per acre)	At pH Values Resulting from $Ca(OH)_2$ Treatment 6.5	6.0	5.5	Average
200	330	22.1[a]	18.9	3.7	14.9[b]
200	180	13.0	23.4	17.2	17.9
200	30	21.0	20.3	12.8	18.0
Avg. 200		18.7[b]	20.8	11.2	16.9
0	330	20.4[a]	21.4	5.8	15.9
0	180	12.7	21.8	12.6	15.7
0	30	11.1	11.0	14.8	12.3
Avg. 0		14.7[b]	18.1	11.1	14.6
	Avg. 330	21.2[c]	20.1	4.7*	15.3
	Avg. 180	12.8	22.6*	14.9	16.8
	Avg. 30	16.1	15.6	13.8	15.2
Average for each pH		16.7[d]	19.4**	11.1**	15.8

B. Sodium Effect at Three Potassium Levels

Sodium (lb. Na_2O per acre)	Potassium (lb. K_2O per acre) 330	180	30
200	14.9	17.8	18.0
0	15.8	15.7	12.3

L. S. D. at 5%: Ca, 4.2; (Ca x K), 7.2.

L. S. D. at 1%: Ca, 6.0; (Ca x K), 10.5.

a, b, c, d: Averages of 2, 6, 4, and 12 plots, respectively.

* Significant.

** Highly Significant.

TABLE IIIJ

THE INTERACTIVE INFLUENCE OF VARIOUS LEVELS OF LIME, POTASSIUM, AND SODIUM APPLICATIONS ON THE YIELD OF CARROT PLANTS
(expressed in pounds per 10 linear feet of row)

A. Sodium and Potassium Effect at Three pH Levels

Sodium (lb. Na_2O per acre)	Potassium (lb. K_2O per acre)	At pH Values Resulting from $Ca(OH)_2$ Treatment			Average
		6.5	6.0	5.5	
200	330	4.0[a]	1.9	2.9	2.9[b]
200	180	6.0	2.1	1.4	3.2
200	30	5.7	1.5	4.0	3.7
Avg. 200		5.2[b]	1.8	2.8	3.3**
0	330	7.5	4.4	4.7	5.5
0	180	7.0[a]	3.1	3.8	4.6
0	30	5.3	4.3	3.9	4.5
Avg. 0		6.6[b]	3.9	4.1	4.9**
	Avg. 330	5.7[c]	3.2	3.8	4.2
	Avg. 180	6.5*	2.6*	2.6*	3.9
	Avg. 30	5.5	2.9	4.0	4.1
Average for each pH		5.9[d]**	2.9**	3.5	4.1

B. Sodium Effect at Three Potassium Levels

Sodium (lb. Na_2O per acre)	Potassium (lb. K_2O per acre)		
	330	180	30
200	2.9	3.1	3.7
0	5.5	4.6	4.5

L. S. D. at 5%: Ca, 0.5; (Ca x K), 0.9; Na, 1.1.
L. S. D. at 1%: Ca, 0.7; (Ca x K), 1.3; Na, 1.5.
a, b, c, d: Averages of 2, 6, 4, and 12 plots, respectively.
* Significant.
** Highly significant.

<u>Sweet corn</u>. Results shown in Table IIIK indicate that this crop does not show decided trends in yields as related to treatment. However, with calcium at a low level, sodium very significantly reduced the yield.

<u>Tomato</u>. The data in Table IIIL reveal that the addition of lime resulted in a significant yield increase, whereas sodium very significantly reduced it. There was a significant interaction between calcium and potassium; the highest yields resulted from high calcium and medium or high potassium, whereas the lowest yield resulted from the combination of low calcium and high potassium. This is in accord with work reported by Carolus (9).

<u>Potato</u>. Table IIIM indicates that the application of either calcium, potassium, or sodium failed to influence tuber yield significantly, although, in the case of the medium level of potassium, it approached significance. However, there was a significant interaction between calcium and potassium. The highest yield resulted with medium calcium and medium potassium, and the lowest yield was with high calcium and low potassium, indicating that the potato is sensitive to an unbalanced condition in relation to these two elements.

TABLE IIIK

THE INTERACTIVE INFLUENCE OF VARIOUS LEVELS OF LIME, POTASSIUM, AND SODIUM APPLICATIONS ON THE YIELD OF SWEET CORN EARS
(expressed in pounds per 10 linear feet of row)

A. Sodium and Potassium Effect at Three pH Levels

Sodium (lb. Na_2O per acre)	Potassium (lb. K_2O per acre)	At pH Values Resulting from $Ca(OH)_2$ Treatment			Average
		6.5	6.0	5.5	
200	330	14.2[a]	12.3	3.2	9.9[b]
200	180	12.4	13.1	11.3	12.3
200	30	13.8	11.0	11.4	12.1
Avg. 200		13.5[b]	12.1	8.6**	11.4
0	330	17.1[a]	11.7	11.7	13.5
0	180	12.0	8.8	14.4	11.7
0	30	12.2	13.3	8.8	11.4
Avg. 0		13.8[b]**	11.3	11.6	12.2
	Avg. 330	15.6[c]	12.0	7.4	11.7
	Avg. 180	12.2	10.9	12.8	12.0
	Avg. 30	13.0	12.1	10.1	11.7
Average for each pH		13.6[d]	11.7	10.1	11.8

B. Sodium Effect at Three Potassium Levels

Sodium (lb. Na_2O per acre)	Potassium (lb. K_2O per acre)		
	330	180	30
200	9.9	12.2	12.1
0	13.5	11.7	11.4

L. S. D. at 5%: (Na x Ca), 3.7.
L. S. D. at 1%: (Na x Ca), 5.1.
a, b, c, d: Averages of 2, 6, 4, and 12 plots, respectively
** Highly significant.

TABLE IIIL

THE INTERACTIVE INFLUENCE OF VARIOUS LEVELS OF LIME, POTASSIUM, AND SODIUM APPLICATIONS ON THE YIELD OF TOMATO FRUIT

(expressed in pounds per 10 linear feet of row)

A. Sodium and Potassium Effect at Three pH Levels

Sodium (lb. Na_2O per acre)	Potassium (lb. K_2O per acre)	At pH Values Resulting from $Ca(OH)_2$ Treatment			Average
		6.5	6.0	5.5	
200	330	64.8[a]	42.4	26.7	44.6[b]
200	180	69.7	52.3	46.6	56.2
200	30	55.8	48.6	53.2	52.5
Avg. 200		63.4[b]	47.8	42.2	51.1**
0	330	82.5[a]	69.9	46.7	66.4
0	180	78.3	61.2	77.7	72.4
0	30	56.4	27.7	66.6	50.2
Avg. 0		72.4[b]	52.9	63.6	63.0**
	Avg. 330	73.7[c]	56.1	36.7*	55.5
	Avg. 180	74.0*	56.8	62.2	64.3
	Avg. 30	56.1	38.1	59.9	51.4
Average for each pH		67.9[d]*	50.3*	52.9	57.1

B. Sodium Effect at Three Potassium Levels

Sodium (lb. Na_2O per acre)	Potassium (lb. K_2O per acre)		
	330	180	30
200	44.6	56.2	52.5
0	66.3	72.4	50.2

L. S. D. at 5%: Ca, 11.3; (Ca x K), 19.6; Na, 8.4.
L. S. D. at 1%: Ca, 16.4; (Ca x K), 28.5; Na, 11.8.
a, b, c, d: Averages of 2, 6, 4, and 12 plots, respectively.
* Significant.
** Highly significant.

TABLE IIIM

THE INTERACTIVE INFLUENCE OF VARIOUS LEVELS OF LIME, POTASSIUM, AND SODIUM APPLICATIONS ON THE YIELD OF POTATO TUBERS
(expressed in pounds per 10 linear feet of row)

A. Sodium and Potassium Effect at Three pH Levels

Sodium (lb. Na_2O per acre)	Potassium (lb. K_2O per acre)	At pH Values Resulting from $Ca(OH)_2$ Treatment			Average
		6.5	6.0	5.5	
200	330	31.3[a]	26.8	21.5	26.5[b]
200	180	26.0	28.3	28.5	27.6
200	30	16.0	23.4	28.3	22.6
Avg. 200		24.4[b]	26.1	26.1	25.5
0	330	29.8[a]	29.7	25.2	28.2
0	180	25.8	34.7	32.8	31.1
0	30	23.3	19.1	31.8	24.7
	Avg. 330	30.5[c]	28.2	23.3	27.3
	Avg. 180	25.9	31.7**	30.6	29.4
	Avg. 30	19.6**	21.2	30.0	23.6
Average for each pH		25.3[d]	27.0	28.0	26.8

B. Sodium Effect at Three Potassium Levels

Sodium (lb. Na_2O per acre)	Potassium (lb. K_2O per acre)		
	330	180	30
200	26.5	27.6	22.5
0	28.2	31.3	24.7

L. S. D. at 5%: (Ca x K), 8.1.
L. S. D. at 1%: (Ca x K), 11.8.
a, b, c, d: Averages of 2, 6, 4, and 12 plots, respectively.
* Significant.

<u>Muskmelons</u>. From Table IIIN, it can be seen that none of the treatments resulted in any significant yield response in this crop. There were no significant interactive effects, although with high calcium there was a decided trend towards higher yields as potassium application was increased.

<u>Cucumber</u>. The cucumber (Table IIIO) showed an extreme sensitivity towards various combinations of calcium with potassium, and the most striking example of yield reduction occurred with high calcium and low potassium. The yield in this case was only 17 per cent of the average yield, and less than 9 per cent of the highest yield which occurred when both calcium and potassium were low. Cucumber yield was significantly reduced by the addition of sodium. Field observations during both the 1950 and 1951 growing seasons indicated that several treatments produced toxic conditions, as evidenced by the visible plant damage.

<u>Squash</u>. A study of the data of Table IIIP shows that this crop tended to produce higher yields with high calcium; medium potassium with no sodium resulted in a higher-than-average yield, but the results failed to reach significance. Since cucumbers and melons are classified in the genus <u>Cucumis</u>, and squash, in the

TABLE IIIN

THE INTERACTIVE INFLUENCE OF VARIOUS LEVELS OF LIME, POTASSIUM, AND SODIUM APPLICATIONS ON THE YIELD OF MUSKMELON FRUIT

(expressed in pounds per 10 linear feet of row)

A. Sodium and Potassium Effect at Three pH Levels

Sodium (lb. Na_2O per acre)	Potassium (lb. K_2O per acre)	At pH Values Resulting from $Ca(OH)_2$ Treatment			Average
		6.5	6.0	5.5	
200	330	27.2[a]	14.8	13.1	18.4[b]
200	180	24.4	13.6	12.8	16.9
200	30	11.2	20.5	8.6	13.4
Avg. 200		20.9[b]	16.3	11.5	16.2
0	330	24.8[a]	21.7	11.2	19.2
0	180	15.2	14.7	17.7	15.9
0	30	12.4	17.2	21.2	16.9
Avg. 0		17.4[b]	17.9	16.7	17.3
	Avg. 330	26.0[c]	18.3	12.1	18.8
	Avg. 180	19.8	14.2	15.3	16.4
	Avg. 30	11.8	18.9	14.9	15.2
Average for each pH		19.2[d]	17.1	14.1	16.8

B. Sodium Effect at Three Potassium Levels

Sodium (lb. Na_2O per acre)	Potassium (lb. K_2O per acre)		
	330	180	30
200	18.4	16.9	13.4
0	19.2	15.9	16.9

a, b, c, d: Averages of 2, 6, 4, and 12 plots, respectively.

TABLE IIIO

THE INTERACTIVE INFLUENCE OF VARIOUS LEVELS OF LIME, POTASSIUM, AND SODIUM APPLICATIONS ON THE YIELD OF CUCUMBER FRUIT
(expressed in pounds per 10 linear feet of row)

A. Sodium and Potassium Effect at Three pH Levels

Sodium (lb. Na_2O per acre)	Potassium (lb. K_2O per acre)	At pH Values Resulting from $Ca(OH)_2$ Treatment			Average
		6.5	6.0	5.5	
200	330	0.7[a]	3.6	0.5	1.6[b]
200	180	2.6	0.9	1.1	1.5
200	30	0.3	1.5	5.9	2.6
Avg. 200		1.2[b]	2.0	2.5	1.9**
0	330	4.5[a]	5.7	2.7	4.3
0	180	3.1	2.2	3.6	3.0
0	30	0.7	4.1	4.8	3.2
Avg. 0		2.7[b]	4.0	3.7	3.5**
	Avg. 330	2.6[c]	4.6	1.6	2.9
	Avg. 180	2.8	1.5	2.3	2.2
	Avg. 30	0.5**	2.8	5.3**	2.9
Average for each pH		2.0[d]	3.0	3.1	2.7

B. Sodium Effect at Three Potassium Levels

Sodium (lb. Na_2O per acre)	Potassium (lb. K_2O per acre)		
	330	180	30
200	1.6	1.5	2.5
0	4.3	2.9	3.2

L. S. D. at 5%: (Ca x K), 2.4; Na, 1.1.
L. S. D. at 1%: (Ca x K), 3.5; Na, 1.5.
a, b, c, d: Averages of 2, 6, 4, and 12 plots, respectively.
* Significant.
** Highly significant.

TABLE IIIP

THE INTERACTIVE INFLUENCE OF VARIOUS LEVELS OF LIME, POTASSIUM, AND SODIUM APPLICATIONS ON THE YIELD OF SQUASH FRUIT
(expressed in pounds per 10 linear feet of row)

A. Sodium and Potassium Effect at Three pH Levels

Sodium (lb. Na_2O per acre)	Potassium (lb. K_2O per acre)	At pH Values Resulting from $Ca(OH)_2$ Treatment			Average
		6.5	6.0	5.5	
200	330	59.3[a]	32.3	39.8	43.8[b]
200	180	48.9	48.8	61.7	53.1
200	30	48.1	50.8	36.2	45.0
Avg. 200		52.1[b]	44.0	45.9	47.3
0	330	46.0[a]	55.4	34.3	45.2
0	180	74.9	60.2	47.7	60.9
0	30	42.5	53.8	53.1	49.8
Avg. 0		54.5[b]	56.5	45.0	52.0
	Avg. 330	52.7[c]	43.8	37.0	44.5
	Avg. 180	61.9	54.5	54.7	57.0
	Avg. 30	45.3	52.3	44.6	47.4
Average for each pH		53.3[d]	50.2	45.4	49.6

B. Sodium Effect at Three Potassium Levels

Sodium (lb. Na_2O per acre)	Potassium (lb. K_2O per acre)		
	330	180	30
200	43.8	53.1	45.0
0	45.2	60.9	49.8

a, b, c, d: Averages of 2, 6, 4, and 12 plots, respectively.

genus Cucurbita, it might be expected that cucumbers and melons would show similarities in their response to the treatments under study. Actually, this was not the case, as squash and muskmelon behavior was somewhat similar, while that of the cucumber was quite different. It was noted in the field that whereas certain treatments gave rise to conditions which appeared to be toxic for the cucumber, as indicated in a tendency of the plants to wilt, no adverse visible effects were noticeable in the case of either muskmelon or squash.

Lettuce. Although there was no significant yield response resulting from the independent influence of calcium, potassium, or sodium, the interaction between calcium and potassium did reach a significant level. As may be seen in Table IIIQ, applications of high calcium with low potassium resulted in a significant reduction in yield, whereas with high calcium and medium potassium, yield was increased. It appears that lettuce is more sensitive to potassium than either calcium or sodium. Since lettuce is rated as a "high order" plant, this observation would be in agreement with the theory Cooper (13) proposed, that high-order plants have developed a greater ability to procure their potassium requirements than the "low order" plants.

TABLE IIIQ

THE INTERACTIVE INFLUENCE OF VARIOUS LEVELS OF LIME, POTASSIUM, AND SODIUM APPLICATIONS ON THE YIELD OF LETTUCE PLANTS
(expressed in pounds per 10 linear feet of row)

A. Sodium and Potassium Effect at Three pH Levels

Sodium (lb. Na_2O per acre)	Potassium (lb. K_2O per acre)	At pH Values Resulting from $Ca(OH)_2$ Treatment			Average
		6.5	6.0	5.5	
200	330	7.0[a]	7.2	5.7	6.6[b]
200	180	12.6	6.3	5.6	8.2
200	30	4.6	7.1	7.5	6.4
Avg. 200		8.0[b]	6.8	6.2	7.0
0	330	10.7[a]	7.5	6.6	8.3
0	180	8.1	7.0	6.5	7.2
0	30	4.9	6.2	5.9	5.7
Avg. 0		7.9[b]	6.9	6.3	7.0
	Avg. 330	8.8[c]	7.3	6.1	7.4
	Avg. 180	10.3**	6.6	6.0	7.6
	Avg. 30	4.7**	6.6	6.7	6.0
Average for each pH		7.9[d]	6.8	6.3	7.0

B. Sodium Effect at Three Potassium Levels

Sodium (lb. Na_2O per acre)	Potassium (lb. K_2O per acre)		
	330	180	30
200	6.6	8.2	6.4
0	8.2	7.2	5.6

L. S. D. at 5%: (Ca x K), 2.9.
L. S. D. at 1%: (Ca x K), 4.3.
a, b, c, d: Averages of 2, 6, 4, and 12 plots, respectively.
* Significant.

Summary of Yield Results

The summarized yield data, Table IV, expresses in relative numbers, as compared to the average yields, the differential responses of seventeen crops to various cation treatments. Six crops of the seventeen were significantly benefited by the application of calcium under the conditions of this experiment. The yields of five other crops were improved by calcium additions, but the differences were not statistically significant. Yields of the remaining six crops were decreased by calcium applications, but not significantly. On the basis of the yield data, it is impossible to determine whether the results were due to the direct effect of calcium or to the indirect influence of liming.

Considered on the basis of response to pH, as indicated in this study, the crops have been grouped in Table V. As indicated in Table V, nine of the crops correspond to the grouping given by Watts and Watts (66). Of the eight remaining crops, only tomatoes differed widely from the rating given by these authors. It has been shown by Carolus (9) that lime is beneficial to tomatoes when potassium is adequate.

In this work, the application of potassium significantly increased the yield of spinach and significantly decreased the yield

TABLE IV

THE SUMMARIZED INFLUENCE OF CALCIUM, POTASSIUM, AND SODIUM ON THE RELATIVE YIELDS OF SEVENTEEN VEGETABLE CROPS

Crop	pH Value (Ca)				Potassium (lb. K_2O per acre)			
	6.5	6.0	5.5	F	330	180	30	F
Onion	131	81	87	**	79	99	122	*
Cabbage	104	100	96		96	103	101	
Cauliflower	95	98	107		88	113	98	*
Pea	111	76	113		114	86	100	
Lima Bean	95	108	97		103	100	97	
Snap Bean	95	109	96		101	106	93	
Beet	113	94	93	*	109	91	99	
Spinach	146	102	52	**	116	102	82	*
Celery	106	123	71	**	97	107	96	
Carrot	145	70	85	**	104	95	101	
Sweet Corn	115	99	86		99	102	99	
Tomato	119	88	93	*	97	113	90	
Potato	95	101	104		102	110	88	
Muskmelon	114	102	84		112	98	90	
Cucumber	73	112	115		109	83	107	
Squash	107	101	92		90	115	95	
Lettuce	113	97	89		106	109	85	
Average	110	98	92		101	102	97	

* Significant differences between two or more values.

** Highly significant differences between two or more values.

TABLE IV (Continued)

Sodium (lb. Na_2O per acre)			Interactions (F values)		
200	0	F	Ca x K	Na x K	Na x Ca
96	104	**			
95	105		**		
101	99				
100	100				
102	98				
89	111	**			
103	97		**	**	
100	100			**	
107	93		**		
80	120	**	**		
96	104				**
90	110	**	*		
95	105		**		
97	103				
70	130	**	**		
95	105				
100	100		**		
95	105				

TABLE V

CROPS ARRANGED ACCORDING TO THEIR YIELD RESPONSE TO SOIL REACTION

High pH	Medium pH	Low pH
Onion*	Cabbage*	Cauliflower
Beet*	Sweet Corn	Pea*
Spinach*	Muskmelon*	Potato*
Celery*	Squash	Cucumber*
Carrot	Lima Bean	
Tomato	Snap Bean	
	Lettuce	

* In agreement with a similar rating by Watts and Watts (66).

of onion and cauliflower. In the other crops, the yield responses from potassium were not significant. Under the conditions of this experiment, the potassium in the soil even at the low level was presumably adequate for most crops. This supposition is strengthened by the fact that the variation in yield from the application of potassium was only 5 per cent on the average of the seventeen crops.

The application of sodium failed to significantly increase the yield of any crop. However, the yields of onion, snap bean, carrot, tomato, and cucumber were significantly reduced by sodium application. In snap beans and cucumbers, this reduction in yield was associated with visible toxic symptoms, such as a necrotic condition in the foliage. The range in effect from the application of sodium varied from a 7 per cent increase in the case of celery to a 30 per cent decrease with cucumbers.

The interactive influence of calcium with potassium resulted in significant yield responses in eight crops. In most of them, highest yields resulted from the application of high calcium with medium potassium, which is an indication that the highest potassium level probably produced a toxic condition. The largest yield of cucumbers was produced under conditions of both low calcium and low potassium, indicating the necessity of caution in the use of lime and potassium on this crop.

There was a significant interactive effect of sodium with potassium on the yield of beets and spinach. When the level of potassium was low, the application of sodium resulted in an increased yield of both beets and spinach. With the application of increasing quantities of potassium, sodium applications depressed spinach yields at lower potassium levels than beets, indicating that beets are more tolerant to both sodium and potassium than spinach.

A significant interaction of sodium with calcium on sweet corn occurred, resulting in a reduction of yield upon the addition of sodium at the low calcium level.

The Differential Accumulation of Calcium, Potassium, Magnesium, and Sodium by Seventeen Vegetable Crops

The calcium, potassium, magnesium, and sodium contents of the seventeen crops, as well as tomato and pea fruits, were determined from plants grown in adjacent rows under thirty-six fertility treatments; the complete data is found in the Appendix. Listed below are the portions of the plants involved:

Part of Plant Analyzed	Crop
Bulb (untopped)	Onion
Head (untrimmed)	Cabbage and lettuce
Curd and leaves (untrimmed)	Cauliflower
Enlarged roots (untopped)	Beet and carrot
Leaves, stems, and pods	Lima bean and snap bean
Leaves and stems	Pea, spinach, celery, sweet corn, tomato, potato, muskmelon, cucumber, and squash
Fruit	Tomato and pea

When considering the total nutrients removed from the soil by crops, it is essential to consider each nutrient in terms of the per cent of dry or fresh weight, whereas in studying nutrient absorption by plants, it is desirable from a physiological standpoint to evaluate the results on the basis of equivalent weights. Since both of these aspects are involved in this investigation, data will be shown in terms of per cent of dry weight and milliequivalents (m.e.) per 100 grams of dry matter.

In order to obtain comparisons between the different crops in relation to the average cation composition under all levels of calcium, potassium, magnesium, and sodium, Table VI is presented.

TABLE VI

COMPOSITION OF VEGETABLE CROPS GROWN UNDER VARIED LEVELS OF CALCIUM, POTASSIUM, MAGNESIUM, AND SODIUM
(average for thirty-six plots)

Crop	A. Per Cent of Dry Weight				
	Ca	K	Mg	Na	Total
Onion	0.88	1.56[b]	0.21[b]	0.22	2.87[b]
Cabbage	0.55	3.85	0.34	0.29	5.03
Cauliflower	1.63	3.28	0.28	0.43	5.62
Pea	1.61	1.59	0.29	0.06	3.55
Lima Bean	3.00	2.03	0.76	0.06	5.85
Snap Bean	2.36	1.96	0.63	0.02[b]	4.97
Beet	1.24	4.94	1.16	1.59[a]	8.88
Spinach	0.97	6.93[a]	0.83	0.42	9.15
Celery	1.61	3.38	0.41	1.09	6.49
Carrot	0.93	3.78	0.40	0.47	5.58
Sweet Corn	0.70	2.11	0.33	0.04	3.18
Tomato	5.35	2.29	1.81	0.28	9.73
Potato	3.02	3.32	2.87	0.05	9.26
Muskmelon	7.27	2.45	2.39	0.39	12.50
Cucumber	3.71	2.96	2.29	0.28	9.24
Squash	9.96[a]	3.07	8.96[a]	0.05	22.04[a]
Lettuce	0.43	3.50	0.41	0.20	4.54
Pea Pod	2.79	3.51	2.10	0.03	8.43
Tomato Fruit	0.09[b]	4.25	0.30	0.08	4.72
Average	2.53	3.30	1.30	0.32	7.45
Relative %	34.0	44.3	17.5	4.3	100.1
Max./min.	110.70	4.40	42.70	79.50	7.70

[a] Maximum figures.

[b] Minimum figures.

[c] Order of magnitude of totals in preceding column.

TABLE VI (Continued)

B. m.e./100 gm. of Dry Matter					
Ca	K	Mg	Na	Total	Order[c]
43.9	40.0[b]	17.3[b]	9.6	110.8[b]	19
27.4	98.5	28.0	12.6	166.5	14
81.3	83.4	23.0	18.7	206.9	12
80.3	40.7	23.8	2.6	147.4	16
149.7	51.9	62.5	2.6	266.7	9
117.8	50.1	51.8	0.9[b]	220.6	11
61.9	126.3	95.4	69.1[a]	352.7	7
48.4	177.2[a]	68.3	18.3	312.2	8
80.3	86.4	33.7	47.4	247.8	10
46.4	96.7	32.9	20.4	196.4	13
34.9	54.0	27.1	1.7	117.7	18
267.0	58.6	148.8	12.2	486.6	3
150.7	84.9	236.0	2.2	473.8	4
362.8	62.6	196.5	17.0	638.9	2
185.1	75.7	188.3	12.2	461.3	5
497.0[a]	78.5	736.8[a]	2.2	1,314.5[a]	1
21.5	89.5	33.7	8.7	153.4	15
139.2	89.8	172.7	1.3	403.0	6
4.5[b]	108.7	24.7	3.5	141.4	17
126.3	81.8	115.9	13.9	337.8	
37.4	24.2	34.3	4.1	100.0	
110.4	4.4	42.6	76.8	11.9	

Table VIA shows the per cent of calcium, potassium, magnesium, and sodium found in each crop in terms of the dry weight, and Table VIB shows the results calculated in terms of milliequivalents per 100 grams of dry material. To assist in making a comparison, the average calcium, potassium, magnesium, and sodium figures are given in terms of relative per cent of the total of all four. The ratio of maximum to minimum values of each cation determined is also shown.

As shown in Table VIA, the average composition of calcium, potassium, magnesium, and sodium in dry plant matter for all crops was 7.45 per cent, with the ratio between the two extremes, squash (22.04%) and onions (2.87%) being 7.7.

The average calcium content in all crops was 2.45 per cent, or 34.0 per cent of the total for all four cations. The selective properties of the different crops, and even different parts of plants, is illustrated in the wide variation of this cation found in the various crops. A ratio of 110 between the extremes, squash (9.96%) and tomato fruit (0.09%), emphasizes the above statement. In tomato fruit there would appear to be an exclusion mechanism operating, similar to that which Cooper (13) pointed out in relation to such plant parts as seeds.

The average potassium content in all crops was the highest of any of the four cations, and amounted to 3.3 per cent, or 44.3 per cent of the total. The evidence of the essentiality of potassium in such plant processes as metabolism is indicated by the stability in the content of this cation in the dry plant matter of all the crops. The ratio of the extremes, spinach (6.93%) to onion (1.56%) was only 4.4, in contrast to calcium, with over 110.

The relative per cent of magnesium was 17.5, and the ratio (42.7) between the extremes, squash (8.96%) to onion (0.21%) was quite wide.

The comparatively unimportant role of sodium in plant nutrition is illustrated in the small quantity of this element found in most of the crops. The average composition was only 0.32 per cent, or 4.3 per cent of the total. However, the ratio (79.5) between the extremes, beet (1.59%) and snap bean (0.02%) indicates a marked variability between crops in their ability to appropriate the ion. These comparisons offer an explanation for the fact that snap bean yields were significantly reduced by the application of sodium, since, for all practical purposes, this element tends to be excluded. It was shown that sodium was beneficial to yield at low potassium levels. The relatively high sodium content in beets would tend to substantiate observations by Lehr (35), that sodium can replace potassium to some extent in beets. Although beets and snap beans are adjacent to each other in the evolutionary scale, it would appear that the beet has developed a mechanism which enables it to accumulate sodium, whereas snap bean has developed a completely different mechanism, which enables the plant to practically exclude the element. This emphasizes the selective properties of plants and the fact that the ability to accumulate ions probably has little bearing on botanical relationships.

Table VIB portrays the results of the analysis in terms of milliequivalents. The relative content of these cations on the basis of both per cent dry weight and milliequivalents is shown below.

% of the Dry Weight		m.e./100 gm. of Dry Matter	
Cation	Relative %	Cation	Relative %
K	44	Ca	37
Ca	34	Mg	34
Mg	18	K	24
Na	4	Na	4

On the basis of equivalents which are perhaps influential in certain physiological reactions, both calcium and magnesium became more important than potassium; however, in terms of quantity or weight, which is the basis on which the elements are applied as fertilizer, potassium is the most important single constituent.

Probably the wide variation in the ability to accumulate ions, as illustrated in this study, is overemphasized due to the fact that some crops, such as squash and muskmelon, have translocated the greater part of their organic contents to the developing fruit, resulting in a rather skeletonized foliage structure rather high in minerals. On the other hand, the onion plant, as analyzed, was predominantly a storage organ which contains a larger proportion of translocated organic substances in relation to minerals than the foliage of many of the fruiting crops. Sweet corn differs from such crops as squash, melon, and potato, in that its relative accumulation of the cations was quite low, which indicates that complex organic compounds are considerably higher in it than in some of the others. Perhaps this is characteristic of some of the monocots. Root crops such as beets and carrots differ widely in their ability to accumulate ions, and this difference cannot be attributed to fundamental differences in their nature, as both are storage organs, and both were harvested at comparable physiological stages of growth. In this study, the total milliequivalent content in carrots was approximately one-half that found in beets. Perhaps this difference is related to the fact that beets--termed halophytes--developed in areas where the salt content in the soils was high.

Because of the wide variation in the total accumulation, in terms of milliequivalents, the contents were calculated on the basis of the per cent of each ion relation to the total, and the results are shown in Table VII. Although the figures shown in Table VII give no indication of total amounts of nutrients absorbed, they do provide a valuable clue as to the relative importance of the cations in each crop. More than 64 per cent of the total content of cations in the tomato plant is calcium, while in the tomato fruit, the amount is only 3.4 per cent. More than 84 per cent of the total content of cations in tomato fruit is potassium, whereas, in the foliage only, 14.2 per cent of the total is potassium. A similar comparison for magnesium shows that this element comprises 56.1 per cent of the total cation content of the squash, whereas, with carrot and cabbage, it is only 9.2 per cent of the total. Beet, with sodium accounting for 19.6 per cent of the total accumulation of the four cations, varies widely from squash, with magnesium comprising only 2 per cent of the total. Other investigators (45, 11) have also shown widely differing relationships in composition of crops

TABLE VII

RELATIVE COMPOSITION OF VEGETABLE CROPS GROWN UNDER VARIED LEVELS OF CALCIUM, POTASSIUM, MAGNESIUM, AND SODIUM

Crop	Relative Per Cent Composition (based on m.e. per 100 gm. dry matter)			
	Ca	K	Mg	Na
Onion	39.6	35.9	15.8	8.7
Cabbage	17.8	64.2	9.2[b]	8.8
Cauliflower	39.6	40.8	11.0	8.6
Pea	55.1	27.9	15.3	1.7
Lima Bean	56.2	19.5	23.3	1.0
Snap Bean	53.4	22.8	23.5	0.3
Beet	17.5	35.9	27.0	19.6[a]
Spinach	15.8	57.6	21.5	5.1
Celery	31.9	36.0	13.2	18.9
Carrot	25.7	53.7	9.2[b]	11.4
Sweet Corn	29.8	46.0	22.8	1.4
Tomato	64.6[a]	14.2	18.2	3.0
Potato	31.8	18.0	49.8	0.4
Muskmelon	56.8	9.8	30.8	2.6
Cucumber	40.1	16.4	40.8	2.7
Squash	37.8	6.0[b]	56.1[a]	0.2[b]
Lettuce	13.8	58.7	21.6	5.9
Pea Fruit	44.0	28.3	27.3	0.4
Tomato Fruit	3.4[b]	84.5[a]	9.4	2.7
Average	35.5	35.6	23.5	5.4
Maximum/Minimum	19.0	14.1	6.1	98.0

[a] Maximum figures.

[b] Minimum figures.

that are closely related botanically; however, in peas, lima, and snap beans--all in the same family--there are indications that with the exception of sodium, the relative proportions of their calcium, potassium, and magnesium contents are fairly comparable. The relative proportion of sodium to the total content in the three legumes varies quite strikingly. In peas, sodium is in a relative concentration 70 per cent higher than in lima beans, and approximately six times higher than in snap beans.

The average relative proportion of the four cations on the basis of all crops (Table VII) reveals that calcium and potassium each comprise approximately 35 per cent, magnesium, approximately 24 per cent, with sodium accounting for only 5.4 per cent.

The Interactive Influence of the Application of Different Quantities of Calcium, Potassium, and Sodium to the Soil on the Calcium, Potassium, and Sodium Contents of the Crops

The effects of application at various levels of calcium as hydrated lime, potassium as KCl and K_2SO_4, and sodium as NaCl on the calcium, potassium, and sodium contents, expressed in terms of milliequivalents per 100 grams of dry weight of the crop, were analyzed statistically. The results for calcium, potassium, and sodium were placed on a relative basis, as compared to the average for each crop in order to facilitate comparisons between crops, and are arrayed in Tables VIII, IX, and X.

The data in Tables VIII indicate that the application of various quantities of calcium significantly affected the calcium content in only two crops. Consistent and significant increases in the calcium content of squash vines and tomato fruit resulted from applications of lime to the soil on which the plants were grown. The fact that squash yield was not affected by calcium would indicate that this increase of calcium content in leaves and stems had no direct bearing on the yield. The tomato fruit showed a significantly higher calcium content as the calcium level was raised, but this is probably of little importance since, relatively speaking, calcium in the fruit represents only 3.4 per cent of the total major cation content (Table VII).

The yield increases, resulting from calcium application, for the onion, beet, spinach, celery, and carrot crops were significant (Table IV), but were not related significantly to the calcium content in the plant, and therefore are probably associated with some indirect effect of the change in pH values of the soils in which the crops were grown.

TABLE VIII

THE RELATIVE CALCIUM CONTENT OF SEVENTEEN VEGETABLE CROPS AS INFLUENCED BY VARIOUS LEVELS OF CALCIUM, POTASSIUM, AND SODIUM

(based on m.e./100 gm. dried material; average of 12 samples for Ca and K, and 18 samples for Na)

Crop	pH Value (Ca)				Potassium (lb. K_2O/acre)				Sodium (lb. Na_2O/acre)		
	6.5	6.0	5.5	F	330	180	30	F	200	0	F
Onion	97	93	110		97	91	112		96	104	
Cabbage	104	111	85		84	99	117		89	111	
Cauliflower	95	102	103		101	111	88		103	97	
Pea	100	96	104		96	96	108		98	102	
Lima Bean	97	105	98		99	89	112	**	104	96	
Snap Bean	97	110	96		92	101	107		101	99	
Beet	107	100	93		98	86	116		87	113	**
Spinach	80	90	130		88	85	127		95	105	
Celery	103	100	97		89	102	109	**	92	108	*
Carrot	102	104	94		87	97	116	**	87	113	**
Sweet Corn	112	103	85		95	102	103		98	102	
Tomato	104	99	97		96	103	101		104	96	
Potato	99	105	96		97	96	107		98	102	
Muskmelon	102	101	97		98	89	113		100	100	
Cucumber	111	107	82		95	102	103		100	100	
Squash	112	100	88	**	96	100	104		96	104	
Lettuce	123	88	89		98	103	99		103	97	
Pea Fruit	101	106	93		95	88	117	**	102	98	
Tomato Fruit	163	86	51	*	125	75	100		104	96	
Average	106	100	94		96	96	108		98	102	

* Significant differences between two or more values.

** Highly significant differences between two or more values.

TABLE IX

THE RELATIVE POTASSIUM CONTENT OF SEVENTEEN VEGETABLE CROPS AS INFLUENCED BY VARIOUS LEVELS OF CALCIUM, POTASSIUM, AND SODIUM

(based on m.e./100 gm. dried material; average of 12 samples for Ca and K, and 18 samples for Na)

Crop	pH Value (Ca)				Potassium (lb. K_2O/acre)				Sodium (lb. Na_2O/acre)		
	6.5	6.0	5.5	F	330	180	30	F	200	0	F
Onion	98	106	96		136	101	63	**	95	105	
Cabbage	102	97	101		114	110	76	**	100	100	
Cauliflower	99	109	92	**	120	106	74	**	100	100	
Pea	101	105	94		108	102	90	**	101	99	
Lima Bean	102	94	104		118	106	76	**	103	97	
Snap Bean	102	93	105	**	110	106	84	**	100	100	
Beet	98	105	97		124	109	67	**	88	112	**
Spinach	103	109	88	**	119	114	67	**	101	99	
Celery	99	106	95		131	103	66	**	101	99	
Carrot	91	106	103	**	115	116	69	**	96	104	
Sweet Corn	88	102	110	*	127	99	74	**	99	101	
Tomato	100	94	107		137	99	64	**	97	103	
Potato	99	104	97		121	101	78	*	98	102	
Muskmelon	106	104	90		141	119	40	**	95	105	*
Cucumber	107	92	101		138	100	62	**	101	99	
Squash	86	105	109		131	111	58	**	104	96	
Lettuce	103	100	97		124	106	70	**	104	96	
Pea Fruit	97	94	109		147	113	40	**	101	99	
Tomato Fruit	108	97	95		114	109	77	**	100	100	
Average	99	101	100		125	107	68		99	100	

* Significant differences between two or more values.

** Highly significant differences between two or more values.

TABLE X

THE RELATIVE SODIUM CONTENT OF SEVENTEEN VEGETABLE CROPS AS INFLUENCED BY VARIOUS LEVELS OF CALCIUM, POTASSIUM, AND SODIUM

(based on m.e./100 gm. dried material; average of 12 samples for Ca and K, and 18 samples for Na)

Crop	pH Value (Ca)				Potassium (lb. K_2O/acre)				Sodium (lb. Na_2O/acre)		
	6.5	6.0	5.5	F	330	180	30	F	200	0	F
Onion	93	111	96		82	80	138	**	147	53	**
Cabbage	100	102	98		68	76	156	**	149	51	**
Cauliflower	97	84	119		64	103	133	**	150	50	**
Pea	115	73	112	*	89	88	123		153	47	**
Lima Bean	113	88	99	*	98	92	110		109	91	**
Snap Bean	121	91	88		102	88	110		125	75	*
Beet	99	101	100		88	95	117	*	159	41	**
Spinach	118	79	103		48	88	164	**	178	22	**
Celery	87	102	111		67	107	126		168	32	**
Carrot	108	102	90		60	78	162	**	144	56	**
Sweet Corn	127	89	84	*	113	102	85		110	90	*
Tomato	87	103	110		44	83	173	**	159	41	**
Potato	108	102	90		106	99	95		98	102	
Muskmelon	114	85	101		67	67	166	*	171	29	**
Cucumber	121	74	105	*	134	82	84	**	171	29	**
Squash	130	92	78		110	117	73		142	58	*
Lettuce	92	98	110		65	79	156	**	155	45	**
Pea Fruit	118	100	82		90	91	119		114	86	*
Tomato Fruit	91	99	110		65	77	158	**	149	51	**
Average	107	93	100		82	89	129		145	55	

* Significant differences between two or more values.

** Highly significant differences between two or more values.

Table VIII indicates that potassium application to the soil was more effective than calcium in altering calcium content in the plant; however, the influence was to reduce the calcium content in the plant. The calcium content of lima beans, celery, carrots, and pea pods was highly significantly reduced by the addition of potassium to the soil on which these crops were grown. Since the potassium addition was not related to yield (Table IV), apparently the depressing effect of potassium application on calcium accumulation was not injurious.

The calcium content in beets, celery, and carrots was depressed (Table VIII) as a result of sodium application to the soil in which the crops were grown, but only in carrots was this decrease associated with a depression of yield (Table IV).

Table IX reveals that the application of calcium to the soil significantly affected the potassium content of cauliflower, snap beans, spinach, sweet corn, and tomato. With cauliflower, spinach, and carrots, the highest potassium content occured at the medium level of calcium application, while with snap bean and sweet corn, the highest potassium content occured at the low level of calcium application to the soil. The increased potassium content in spinach, which resulted from the application of calcium, was associated with a significant increase in yield. It is of interest to note that, whereas calcium application resulted in an increase in potassium content in spinach, the reverse situation occurred in carrots in which calcium application to the soil was also associated with a yield increase (Table IV). This certainly indicates an inherent difference in the ability of plants to accumulate ions, as influenced by their application to the soil.

Table IX discloses that the application of potassium significantly increased the potassium content of every crop. The range of increase in potassium content with potassium additions varied among the crops from a low of 18 per cent in pea vines, through 101 per cent in muskmelon, to 107 per cent in pea fruits. However, in no instance except with spinach was an increase in potassium related to an increase in yield, and with onion and cauliflower it was even associated with a significant reduction in yield. As indicated earlier, there is a strong probability that the application of potassium at the highest level resulted in a "luxury consumption" of this element by most crops. The application of sodium resulted in the significant reduction of potassium content in only two crops, beets and muskmelon, which, however, did not significantly influence yield.

The highest application of calcium to the soil significantly increased the sodium content (Table X) in the pea, lima bean, sweet corn, and cucumber, and with the same crops the intermediate application of calcium resulted in a decrease of the element. The average sodium values for all crops indicate a decline in the sodium content with the intermediate level of calcium application, and an increase with the addition of the highest level of calcium. Evidently, at the higher pH associated with higher calcium applications and a more completely saturated base exchange, sodium is more accumulable, which is in agreement with several workers (18, 10). It is difficult to explain the fact that a higher sodium content is associated with the low level of calcium, rather than with the medium level of application. Because of the doubt cast by some workers (19, 14) concerning the nature and essentiality of sodium, as compared to potassium, in plant nutrition, it is not surprising that these two elements respond so differently. For example, in sweet corn, squash vine, and pea and tomato fruit, the calcium level in the soil that promoted the highest potassium accumulation in the plant resulted in the lowest sodium accumulation.

In eleven of the nineteen crops, the application of potassium to the soil significantly depressed the sodium content of the crop (Table X). However, in the cucumber, the application of potassium resulted in an increase of the sodium content of the plant. Althought potassium application to the soil significantly reduced the sodium content of onion and cauliflower, its application also resulted in significantly lower yields in these two crops. Evidently, in these crops the increased sodium content at the higher potassium levels was not in itself directly related to the yield decrease. Spinach, on the other hand, was benefited in yield from the application of potassium, and since it likewise depressed sodium content, these two facts may be related. However, since sodium applications had no effect on yield (Table IV), it would appear that spinach selectively absorbs potassium over sodium when the former is available, but that when it absorbs sodium, the effect of this ion is neither beneficial nor detrimental to the crop.

In every crop except the potato, the application of sodium increased the sodium content of the crops (Table X); however, in no instance was this increase in sodium content beneficial in respect to yield. In the case of onion, snap bean, carrot, tomato, and cucumber, the increase in sodium content resulting from sodium application appeared to be detrimental to yield (Table IV), and on the basis of the above results, these crops could be termed as sodium sensitive.

Although in many cases the application of an element increased yield significantly, but not composition, and in other cases affected composition significantly, but not yield; however, it is probable that the addition of those materials to the soil had physiological effects on the plant which possibly could be related to quality values.

The Influence of Calcium, Potassium, and Sodium Application on Total Cation Removal by Some Vegetable Crops

The yields, as well as the influence of calcium, potassium, and sodium applications on the total cation removal by some crops, were determined. Total green weight of the whole mature plants for a 10-foot row was obtained from onion, cabbage, pea, lima bean, beet, spinach, celery, carrot, and lettuce. The total cation accumulation was determined for each of the nine crops in which the total growth and yield could be conveniently obtained in a single harvest, as shown in Table XI. The results were based on the total green weight of plants from a 10-foot section of row.

TABLE XI

THE INFLUENCE OF CALCIUM, POTASSIUM, AND SODIUM APPLICATION TO THE SOIL ON THE TOTAL CATION REMOVAL BY NINE VEGETABLE CROPS
(relative figures based on total cation [Ca, K, Mg, & Na] removal)

Crop	pH Value (Ca)				Potassium (lb. K_2O/acre)				Sodium (lb. Na_2O/acre)		
	6.5	6.0	5.5	F	330	180	30	F	200	0	F
Onion	127	86	87		91	95	114		86	114	**
Cabbage	107	102	91		106	110	84	*	99	101	
Pea	113	75	112		121	76	103		99	101	
Lima Bean	94	109	97		103	97	100		102	98	
Beet	118	92	90		117	95	88		99	101	
Spinach	129	106	65	**	124	102	74	*	96	104	
Celery	103	135	62	**	112	109	79		108	92	
Carrot	141	74	85	*	109	103	88		77	123	**
Lettuce	150	75	75		97	93	110		105	95	
Average	120	95	85		109	98	93		97	103	

* Significant differences between two or more values.

** Highly significant differences between two or more values.

In order to determine if the yield of these crops was correlated with the total cation removal under averages of all levels of treatment, correlation coefficients were calculated from the thirty-six comparisons, and are indicated in the results given below.

Crop	Correlation Coefficient	Crop	Correlation Coefficient
Onion	0.87**	Spinach	0.88**
Cabbage	0.89**	Celery	0.90**
Pea	0.92**	Carrot	0.96**
Lima Bean	0.67**	Lettuce	0.14
Beet	0.83**		

** Significant at the 1% level.

As might have been expected, with the exception of lettuce, there was a highly significant positive correlation between total cation removal and crop yield. Data in Table VI indicate that lettuce is a crop with a relatively low total cation concentration, and in addition, has the lowest per cent dry weight. The low average values for the two factors would probably account for the inconsistency in the correlative ability of yield with composition in this crop.

Although the results are comparable to the yield results shown in Table IV, the values have been accentuated by those treatments which promoted cation accumulation. The average for all crops indicates that either yield or accumulation was enhanced by the additions of the higher levels of calcium and potassium, whereas sodium application probably reduced the yield to such an extent that accumulation was decreased (Table XI).

In studying the effect on accumulation of the cations by the various calcium applications, there seems to be a direct relation between cation removal by the plant and the calcium level of the soil, except in celery, where the highest crop yields which influenced total cation accumulation were obtained at the intermediate calcium level. This is in agreement with the work done by Chu and Turk (10), who observed that plants accumulate larger quantities of cation as the level of base saturation of the soil increases. Except for onions and lettuce, potassium application to the soil tended to increase the cation removal by the crops.

The fact that applications of sodium resulted in an increase in its own concentration in the plant, but reduced the total cation removal, indicates the relative unimportance of this cation to the nutriton of most vegetable crops. Figures in Table VII indicate that the average relative sodium composition for these nine crops is only 9.0 per cent, whereas for potassium it is 45.7 per cent of the total.

The ability of the different species to accumulate cations has been shown to vary with the levels of application of these ions; however, it is probable that under lower natural levels of soil fertility, these differences would probably have been accentuated.

DISCUSSION

In the presentation of the results, yield data have been dealt with in considerable detail. Since yield is, in general, directly related to plant growth, it is a useful measure in evaluating the differential response of the crops to cation absorption.

In considering all the crops in this investigation, the application of lime resulted in increasing yield, whereas potassium application had little effect, and the application of sodium in most cases reduced yield. Both the application of lime and of potassium resulted in an increase in the total cation removal, whereas the application of sodium had the opposite effect.

In order to evaluate the relationship between the growth responses and cation absorption, the effect of each ion was considered independently, followed by the interactive influences of the other ions under study.

Although calcium was the most influential ion in relation to growth response and total cation removal, this influence did not appear to be in any way related to the absorption of calcium, as reflected in composition. Further, in the squash foliage and tomato fruit, although the application of lime markedly influenced the concentration of calcium, based on dry matter content, this was not associated with yield. These results indicate that, even at the lowest calcium level, these plants had sufficient calcium to meet their requirements, and that the beneficial effects from the application of this element are of an indirect nature. The fact that calcium did not tend to be absorbed beyond the plant's requirements is probably associated with the fact that more energy is required for its absorption (13, 7) than for the more mobile cations such as potassium and sodium.

One of the indirect effects resulting from the application of lime was an increase in both the yield and the potassium content of spinach. The increase in the per cent of base saturation resulting from the addition of lime presumably increased the availability of potassium.

A significant increase in yield of carrots was obtained as a result of a high application of lime and an intermediate application of potassium to the soil, which significantly lowered the sodium content of the crop. With the beet, a high application of both lime and potassium resulted in a significantly higher yield than the average, as well as a reduction in the sodium content.

The fact that high yield in beets is associated with a reduced absorption of sodium when both calcium and potassium are high is worthy of emphasis, in view of the published work on the beneficial effects of the application of sodium to the sugar beet (35).

The striking difference between crop response to various cation balances is illustrated by the cucumber, which produced significantly higher yields than the average when both lime and potassium applications were at the minimum levels, which combination resulted in a significantly lower sodium content. Perhaps this relationship between high yields and low sodium content with the various calcium-potassium combinations is related to species, and under conditions resulting in an optimum balance of calcium to potassium for the particular species, maximum growth occurs, which is associated with a reduction in sodium accumulation by the crop.

A further analysis of the interactive influence of calcium and potassium reveals that the most advantageous combinations, from the standpoint of improved growth, generally occur when calcium and potassium are at comparable levels. With beets, carrots, and cucumbers, in which a significant interaction between the effect of calcium with potassium was observed, yields were highest when the two cations had been applied at comparable levels, and the sodium contents of the plants were reduced.

A different situation occurred in the tomato, where an application to the soil of low calcium with high potassium significantly lowered the yield and significantly increased the potassium content of the plant.

The only crop which produced a significantly higher yield as a result of the application of potassium to the soil was spinach; however, in all crops, with the exception of lettuce, the application of potassium resulted in a significant increase in potassium content. With the exception of spinach, there was no association between potassium application, yield, and potassium content, indicating an adequacy of that element in the soil used in this experiment. In addition to strongly influencing potassium absorption, the application of potassium to the soil had a fairly marked and consistent influence in depressing the absorption of both calcium and sodium, but this also was not related to yield.

In no case did the application of sodium to the soil result in any significant beneficial effects to the crops in this study, but the onion, snap bean, carrot, tomato, and cucumber crops were adversely affected, as indicated in yield depressions. The snap bean showed extreme sensitivity towards this element, as evidenced by a yellowing and browning of the leaves of this crop on the plots which had received an application of 200 pounds of sodium per acre.

In the case of beets, the combination of a low sodium and high potassium application to the soil resulted in both a significantly higher yield and potassium content than the average. In connection with beets, it is worth noting that the combination of calcium and potassium application which resulted in highest yield likewise resulted in a reduction in sodium absorption, whereas the combination of sodium and potassium applications which was most beneficial to yield resulted in a significantly higher potassium absorption than the average. It would appear that for optimum growth of beets, potassium should be adequately supplied; it is only when potassium is in short supply that sodium is beneficial, which is in agreement with other workers (25, 42).

Crops such as cauliflower, pea, and lettuce appeared to be little affected by the high application of sodium, in spite of their high sodium contents.

From yield data it was shown that the beet responded about equally well when either sodium or potassium was high, under all levels of calcium. However, in relating the significant interactions of calcium with potassium, as well as sodium with potassium, in relation to both yield and composition, it was exhibited that the combinations resulting in highest yields in these crops were related to low sodium and high potassium content, respectively. These data point out that even the beet, in its physiological functions, prefers potassium to sodium. Recent work done by Cowie et al. (14) and Roberts et al. (51) in connection with cation absorption through the semipermeable plant root membranes presents evidence which indicates that potassium is taken into the plant and soon bound, presumably in complex metabolic compounds, whereas sodium did not become bound, implying that for the plants they studied, sodium could not replace potassium in most plant functions. Perhaps this would provide an explanation for the opposite behavior of these two elements, especially the more beneficial responses by several crops to potassium, compared to sodium, with the various combinations of the cation applications.

Cooper (13) proposed a theory concerning the relative strength of ions, in which he listed from the strongest to the weakest: potassium, sodium, and calcium. In equivalent amounts it would be expected that potassium would exert the strongest influence on its own absorption. This is certainly brought out by the results in this investigation. Potassium most strongly affected its own absorption, followed closely by sodium, with calcium having the least influence on its own absorption. In most crops the application of potassium resulted in reducing the absorption of calcium and sodium; the application of sodium to the soil resulted in a decreased absorption of calcium and potassium in only a few instances. The effect of the addition of lime, however, resulted in little change in potassium absorption and a slight increase in sodium absorption. The theory of cation balance and reciprocal relationships discussed by Lucas and Scarseth (38) and Shear _et al_. (54) would appear to be operating in the case of potassium, which tended to induce its own absorption with a concomitant depression in the absorption of calcium and sodium.

From these observations, the possibility is suggested that this difference in accumulative ability for the ions is not only related to the difference in relative strength of absorption of the ions, but also to their relative usefulness, as reflected in the uniformly high content of potassium found in plants, as compared to the other ions. Plants which persisted during the evolutionary development were those that developed mechanisms which facilitated a relatively high potassium accumulation. This may be related to the observation made by Lewis and Eisenmenger (36) that with increasing evolutionary development, plants show an increasing ability to acquire potassium.

Perhaps a study of the potassium-to-sodium ratios of the crops might offer some indication of the ability of sodium to replace potassium in some of the latter's functions, as has been suggested by Lehr (35). The calculated ratios from average concentrations in terms of milliequivalents found in the crops are arrayed in Table XII, as well as values reported by Collander (11) and Harmer and Benne (24). In making comparisons between the ratios calculated from the chemical analysis reported by the above investigators, and from those obtained in this work (Table XII), obvious differences could be related to differences in the culture of crops. Collander (11) grew his plants in nutrient solutions and made his analysis on immature plants, whereas Harmer and Benne (24) produced their crops on organic soil and analyzed mature plants. The calculated values obtained under the three different conditions show similar trends in their relative potassium-sodium ratios. The ratio of potassium to sodium concentrations varied widely, with the potassium being only 1.83 times as high as sodium in beets, to snap beans, in which the potassium content is 76 times

TABLE XII

A COMPARISON OF POTASSIUM-TO-SODIUM RATIOS IN PLANTS GROWN UNDER DIFFERENT CONDITIONS
(based on m.e./100 gm. of dry material)

Crops Arranged in Descending Order of Potassium-to-Sodium Ratios (mature plants)	Ratio K/Na	Ratio (K/Na) Found by Collander (11) (immature plants)	Ratio (K/Na) Found by Harmer and Benne (24) (mature plants)
Beet (Beta vulgaris)	1.83		0.91
Celery (Apium graveolens)	1.90		0.78
Muskmelon (Cucumis melo	3.77		
Onion (Allium cepa)*	4.08		12.60
Carrot (Daucus carota)*	4.71		
Tomato (Lycopersicon esculentum)*	4.73	4.29	
Cauliflower (Brassica oleracea)	4.74		
Cucumber (Cucumis sativus)*	6.07		
Cabbage (Brassica oleracea)	7.77		3.21
Lettuce (Lactuca sativa)	9.95	4.21	
Spinach (Spinacia oleracea)	11.54	5.00	
Pea (Pisum sativum)	16.41	16.43	
Lima Bean (Phaeseolus limensis)	19.50		
Sweet Corn (Zea Mays)	32.86	44.29	
Potato (Solanum tuberosum)	44.75		
Squash (Cucurbita maxima)	60.00		
Snap Bean (Phaseolus vulgaris)*	76.00		

* Crops in which additional sodium, under the conditions of this investigation, reduced yield.

as high as sodium, and indicates that the relative potassium-to-sodium content in plant composition does not provide a simple measure of the sensitivity of a crop to sodium.

In order to get a clearer picture of the influence of sodium on crops, they have been classified with respect to their sodium content, and on their yield responses to sodium applications.

A. Crop accumulating comparatively large quantities of sodium --greater than 0.25 per cent of dry weight.

   1. No apparent injury and frequently with favorable results on yield: beets and celery.

   2. No apparent effect on yield: cauliflower and spinach.

   3. With some apparent injury and no yield response: carrot,* muskmelon, cabbage, tomato,* and cucumber.*

B. Crops that accumulate very low quantities or show some mechanism for excluding sodium--less than 0.25 per cent.

   1. Those not injured: lettuce, pea, and lima bean.

   2. Those injured: onion,* squash, potato, sweet corn, and snap bean.*

---

* Yields depressed significantly.

It is probably of significance that, with the exception of onions, all the crops with a ratio lower than eight contained more than 0.25 per cent sodium, and that all the crops with a ratio higher than eight, with the exception of spinach, contained less than 0.25 per cent. It is interesting to note that, in this connection, onion was injured by sodium application, whereas spinach was not. This may be related to the relatively low potassium content of the onion and the relatively high potassium content of spinach.

In this classification, the crops that were significantly injured by sodium application were tomato and cucumber, each containing 0.28 per cent of the dry weight as sodium, and onion, with 0.22 per cent sodium, whereas the snap bean contained only 0.02 per cent of the dry weight as sodium. This indicates that crops with above-average sodium content were not significantly injured by sodium, but crops with both intermediate and low sodium content were injured from sodium.

From these groupings one could postulate that the injurious effect of sodium on those crops that were injured and which contained an intermediate level of sodium might be due to internal factors, and that the injurious effects on snap bean might be associated with some permeability relationships, either at the interface between the root and the soil, or just inside the root hair cells.

To determine the variability between the effectiveness of maximum and minimum applications of the four cations on yield and its relation to total cation concentration, ratios between these two values have been calculated. The yields of the plots receiving maximum additions of the four cations were divided by the yields of the plots receiving minimum applications of the cations, and the crops were arranged in Table XIII, according to the descending magnitude of these ratios. Similar ratios were calculated in respect to the cation concentrations, and facilitate a ready comparison between the two ratios (Table XIII). Yield-ratio variations were of a magnitude of forty-four, whereas variations in concentration ratios were much less, showing a maximum magnitude in variation of only three--cauliflower, with a ratio of 2.4, compared to snap bean, with a ratio of 0.8.

It is of significance to note that in these comparisons, very wide variations in yield response are associated with maximum cation additions, but that these additions are not usually associated with wide variations in concentration. On the other hand, in those crops in which maximum cation additions resulted in a reduction

TABLE XIII

COMPARISON OF CATION CONCENTRATION AND YIELD OF VEGETABLE CROPS BETWEEN TREATMENTS CONTAINING MAXIMUM (H) AND MINIMUM (L) QUANTITIES OF THE FOUR CATIONS

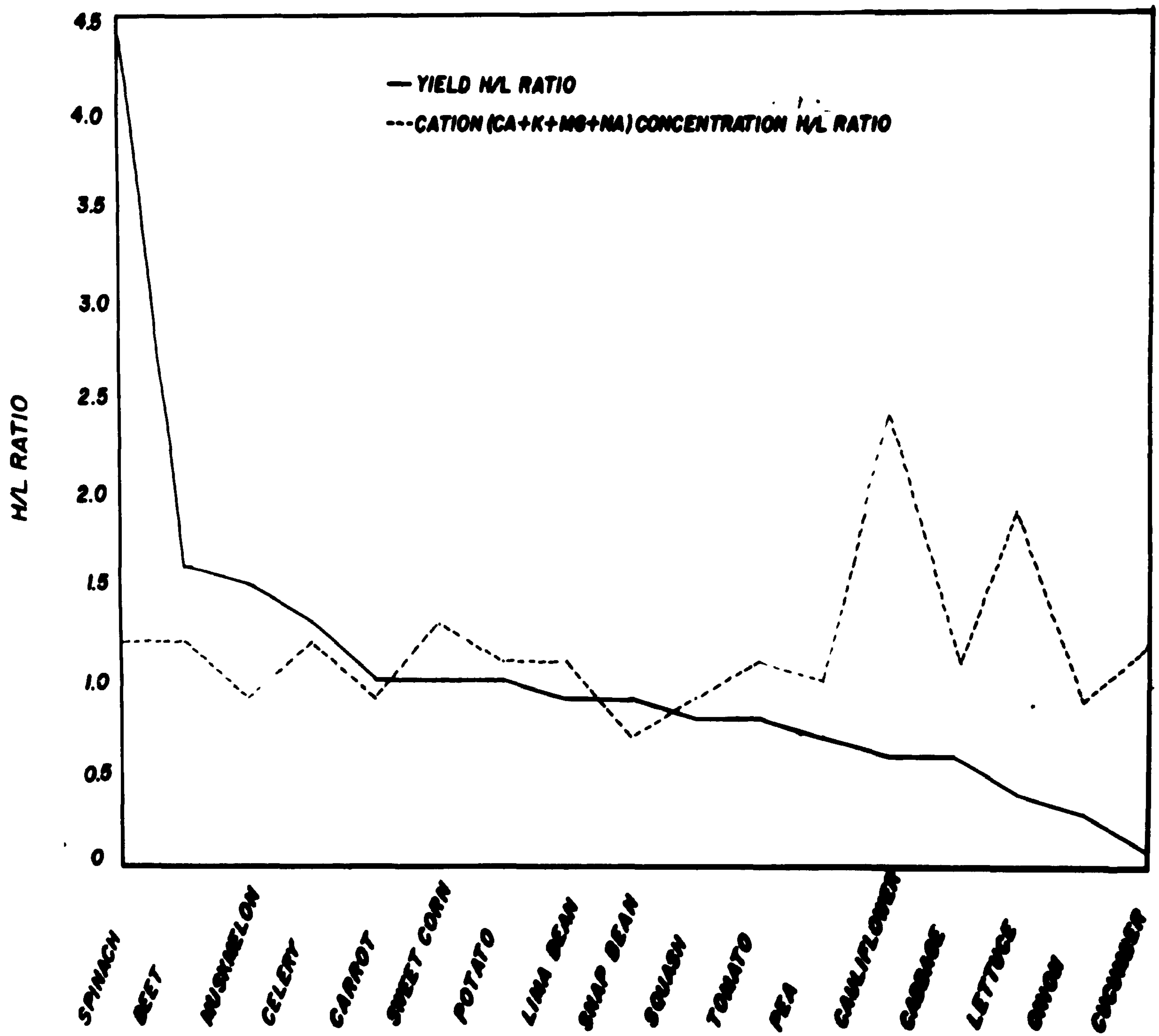
Crops Arranged in Descending Order of H/L Yield Ratio	Yield (expressed in lbs./10 ft.)		Ratio H/L	Concentration (expressed as m.e./100 gms. dried material)		Ratio H/L
	High	Low		High	Low	
Spinach	8.0	1.8	4.4	340	293	1.2
Beet	20.7	13.0	1.6	306	263	1.2
Muskmelon	27.6	18.5	1.5	545	629	0.9
Celery	18.9	14.7	1.3	225	185	1.2
Carrot	4.3	4.4	1.0	151	159	0.9
Sweet Corn	12.5	12.7	1.0	110	88	1.3
Potato	28.2	28.7	1.0	472	423	1.1
Lima Bean	9.2	9.8	0.9	265	244	1.1
Snap Bean	5.7	6.2	0.9	184	219	0.8
Squash	44.3	53.7	0.8	1204	1279	0.9
Tomato	51.8	65.4	0.8	421	400	1.1
Pea	2.0	2.8	0.7	165	161	1.0
Cauliflower	13.1	22.6	0.6	237	100	2.4
Cabbage	22.9	38.8	0.6	154	140	1.1
Lettuce	3.0	9.9	0.4	216	113	1.9
Onion	2.5	9.9	0.3	118	129	0.9
Cucumber	0.6	5.1	0.1	768	625	1.2
Average	16.2	18.6		346	321	

in the yield ratios, the concentration of cations increased in most cases, and frequently in quantities detrimental to their growth and development.

Figure I shows graphically the data presented in Table XIII, and indicates that crops appear to fall into three groups. The first includes spinach through celery, in which greatest yield increases occurred from high cation applications over low. The second group, including carrots through peas, showed little response in either yield or concentration to soil application of the cations. The last group, including cauliflower through cucumber, comprised those which were reduced in yield by high cation applications which, however, generally resulted in an increase in total concentration of these cations in the plants.

The growth of some crops is apparently benefited by concentrations of cations in the soil that prove entirely too high for other crops. It might be hypothesized that the reason some crops tolerate and even do better under high cation applications, in contrast to those which appear sensitive, is that they have developed a successful mechanism for maintaining the concentrations of various ions below toxicity levels.

Figure 1. A comparison of the yield and total cation concentration ratios obtained from crops on plots receiving the maximum and minimum cation application.



This might have a practical application in the care used in applying fertilizers to vegetable crops. The results of this experiment indicate that in the crops, spinach, beet, muskmelon, and celery, high applications of fertilizers are not generally associated with toxic concentrations in the plant, but increase in yield, whereas high applications to such crops as cucumber, onion, lettuce, and cauliflower result in high concentrations in the plant, which were associated under the conditions of this experiment with reduction in yield. This indicates that care should be exercised to provide a satisfactory balance in fertilizer constituents to the last-mentioned crops in order to avoid bringing about excessive accumulations which, in this experiment, resulted in greatly reducing the yield.

Although the results of this experiment contribute to a better understanding of the influence of potassium, calcium, and sodium nutrition of the crops with respect to yield, the effect of the application of these ions on composition at different stages of growth and on different organs of the plant might lead to more definite conclusions. Furthermore, other nutrients would alter the effects shown in this experiment, and differences in the physical and chemical properties of the soil would undoubtedly modify the phenomena observed. Certainly, the effect of the application on composition should also be related to variations in physiological responses which might alter such factors as quality, drought, disease, and insect resistance.

SUMMARY

Seventeen vegetable crops were grown in adjacent rows in a factorially designed field experiment in which three levels of both calcium and potassium and two levels of both magnesium and sodium were attained through the application of lime, equal parts of potassium chloride and potassium sulphate, magnesium sulphate and sodium chloride to the soil. As the crops reached the marketable stage, yields were recorded and samples were taken from each of the thirty-six treatments for chemical analysis of the cations involved. With the exception of magnesium, which was used as a replicate in the statistical analysis, the effects of the other treatments were analyzed in order to determine the differential response by the various crops to the absorption of these four cations.

Averaging all crops, it was found that the milliequivalent percentages of the four cations were 36, 35, 24, and 5 for potassium, calcium, magnesium, and sodium, respectively. Sodium absorption varied most widely, with a maximum of 19.6 per cent of the total for squash, and a low of 0.2 per cent of the total

for snap beans, which resulted in a ratio of 98 between the maximum and minimum percentages of sodium. With the other nutrients the ratios between the maximum and minimum percentages of the crops for the relative calcium, potassium, and magnesium absorption were 19, 14, and 6, respectively. Crops, in addition to showing wide variations in absorption, exhibited great differences in the concentrations found in their foliage and fruit, as observed in pea and tomato.

The relative ability of the cations to influence absorption of the four cations was of the order potassium, sodium, and calcium. The application of relatively large quantities of potassium significantly increased the accumulation of potassium by all crops, significantly influenced the accumulation of sodium by eleven crops, and reduced the calcium accumulation by lima beans, celery, and pea fruit. The addition of sodium significantly increased the accumulation of sodium in all crops except the potato, and reduced potassium accumulation by beets and muskmelon, as well as the calcium accumulation by beet, celery, and carrot. The application of calcium significantly increased calcium accumulation in only two crops, squash and tomato fruit, and influenced the accumulation of potassium by cauliflower, snap beans, spinach, carrot, and sweet corn, and generally increased sodium accumulation by peas, lima beans, sweet corn, and cucumber.

For eight of the nine crops tested, it was found that the total cation removal was positively correlated with plant growth, as measured in terms of yield.

Crops varied widely in the benefit they derived from high cation applications, and those that were most benefited showed an ability to maintain a fairly constant cation composition.

There was not only a wide difference in the tolerance of crops to sodium, but also in the concentration of this element in the plant. Some crops, especially "halophytes," absorbed the element when potassium was low, with apparently beneficial results. Other crops absorbed the element with no apparent effect on growth. Still other crops tended to exclude the absorption of sodium, thus preventing deleterious effects. Snap bean tended to exclude sodium, but, in spite of the very small amount absorbed, the effect of sodium application was injurious.

When the optimum balance of calcium to potassium was obtained by certain plants, the plant increased in growth and its ability to exclude sodium.

LITERATURE CITED

1. Albrecht, W. A. Calcium - potassium - phosphorus relation as a possible factor in ecological array of plants. Jour. Amer. Soc. Agron., 32:411-18. 1940.

2. Allaway, W. H. Availability of replaceable calcium from different types of colloids as affected by degrees of calcium saturation. Soil Sci., 59:207-17. 1945.

3. Aristotle. De partibus animalis. (Trans. by Ogle.) 11, Cap. 3,250a. Cited in Mineral Nutrition, Gilbert, F. A. p. 5. Norman: Univ. of Oklahoma Press. 1948.

4. Arnon, D. I., and D. R. Hoagland. Composition of tomato plant as influenced by nutrient application in relation to fruiting. Bot. Gaz., 104:576-90. 1943.

5. Attoe, O. J., and E. Truog. Exchangeable and acid soluble potassium as regards availability and reciprocal relationships. Soil Sci. Amer. Proc., 10:81-86. 1946.

6. Bear, F. E., and S. J. Toth. Influence of calcium on availability of other soil cations. Soil Sci., 65:69-74. 1948.

7. Breazeale, E. L., W. T. McGeorge, and J. F. Breazeale. Nutrition of plants considered as an electrical phenomenon - a new approach. Soil Sci., 71:371-75. 1951.

8. Brown, J. S., O. Lilleland, and R. K. Jackson. Further notes on the use of flame methods for the analysis of plant material for potassium, calcium, magnesium and sodium. Proc. Amer. Soc. Hort. Sci., 56:12-22. 1950.

9. Carolus, R. L. Calcium and potassium relationships in tomatoes and spinach. Proc. Amer. Soc. Hort. Sci., 54: 281-85. 1949.

10. Chu, T. S., and L. M. Turk. Growth and nutrition of plants as affected by degree of base saturation of different types of clay minerals. Mich. Agr. Expt. Sta. Tech. Bul. 214. 1947.

11. Collander, R. Selective absorption of cations by higher plants. Plant Physiol., 16:691-720. 1941.

12. Cooil, B. J., and M. C. Slattery. Effects of potassium deficiency and excess upon certain carbohydrates and nitrogenous constituents in guayule. Plant Physiol., 23: 425-42. 1948.

13. Cooper, H. P. Effects of energy properties of some plant nutrients on availability, on rate of absorption, and on intensity of certain oxidation-reduction reactions. Soil Sci., 69:7-39. 1950.

14. Cowie, D. B., R. B. Roberts, and I. Z. Roberts. Potassium metabolism in Escherichia coli. Permeability to sodium and potassium ions. J. Cellular and Comp. Physiol., 34:243-57. 1949.

15. De Candolle, A. Origin of cultivated plants. New York: D. Appleton & Co. 1914.

16. Dorph-Petersen, K., and F. Steenbjerg. Investigation of the effect of fertilizers containing sodium. Plant and Soil, 2:283-300. 1950.

17. Drake, M., J. Vengris, and W. G. Colby. Cation-exchange capacity of plant roots. Soil Sci., 72:139-47. 1951.

18. Elgabaly, M. M., and L. Wiklander. The effect of exchange capacity of clay mineral and acidoid content of plant on uptake of sodium and calcium by excised barley and pea roots. Soil Sci., 67:419-24. 1949.

19. Epstein, E., and C. E. Hagen. A kinetic study of the absorption of alkali cations by barley roots. Plant Physiol., 27:457-74. 1952.

20. Fisher, R. A. Statistical methods for research workers. Edinburough, Scotland: Oliver & Boyd. 1936.

21. Gauch, H. G., and C. H. Wadleigh. The influence of saline substrate upon the absorption of nutrient by bean plants. Proc. Amer. Soc. Hort. Sci., 41:365-69. 1942.

22. Gilbert, F. A. Mineral nutrition of plants and animals. Norman: Univ. of Oklahoma Press. 1948.

23. Harmer, P. M. The muck soils of Michigan, their management and uses. Mich. Agr. Expt. Sta. Spec. Bul. 314. 1943.

24. Harmer, P. M., and E. J. Benne. Sodium as a crop nutrient. Soil Sci., 60:137-48. 1945.

25. Hartwell, B. L., and S. C. Damon. The value of sodium when K is insufficient. Rhode Island Sta. Bul. 177, pp. 4-32. 1919.

26. Hayward, H. E., and E. H. Long. Anatomical and physiological response of the tomato to varying concentrations of sodium chloride, sodium sulphate, and nutrient solution. Bot. Gaz., 102:437-62. 1941.

27. Hewitt, E. J. The role of the mineral element in plant nutrition. Ann. Rev. of Plant Physiol., 2:25-52. 1951.

28. Hoagland, D. R., and A. R. Davis. The composition of the cell sap of the plant in relation to the absorption of ions. Jour. Gen. Physiol., 5:629-46. 1923.

29. Hurd-Karrer, A. M. Comparative susceptibility of crop plants to sodium chlorate injury. USDA Tech. Bul. 648. 1940.

30. Jacobson, L., R. Overstreet, H. M. King, and R. Handley. A study of potassium by barley roots. Plant Physiol., 25:639-47. 1950.

31. Kalckar, H. M. Adenylpyrophosphatase and myokinase. J. Biol. Chem., 153:355. 1944.

32. Kearney, T. H., and L. L. Harter. Comparative tolerance of various plants for the salts common in alkali soil. USDA Bur. Plant Indus. Bul. 113. 1907.

33. Krishnan, P. S. Studies on apyrases. II. Some properties of potato apyrase. Arch. Biochem., 20:272-75. 1949.

34. Lawes, J. B., and J. H. Gilbert. On the composition of the ash of wheat grain and wheat straw, grown at Rothamsted, in different seasons, and by different manures. Chem. Soc. Jour., 45:305-407. 1884.

35. Lehr, J. J. The importance of sodium for plant nutrition. III. The equilibrium of cations in the beet. Soil Sci., 53:399-411. 1942.

36. Lewis, C. C., and W. S. Eisenmenger. Relationship of plant development to the capacity to utilize potassium in orthoclase feldspar. Soil Sci., 65:495-500. 1948.

37. Liebig, J. Die Chemie in ihrer Anwendung auf Agrikultur and Physiologie. Braunschweig, 1864. Cited in Mineral Nutrition, F. A. Gilbert. Norman: Univ. of Oklahoma Press. 1948.

38. Lucas, R. E., and G. D. Scarseth. K, Ca and Mg balance and reciprocal relationship in plants. Journ. of Amer. Soc. of Agron., 39:887-96. 1947.

39. Lundegårdh, H. Mechanism of absorption and transport of inorganic nutrients in plants. Arkiv. Botan., 32:1-139. 1945.

40. ________. Quantitative relations between respiration and salt absorption. Ann. Royal Agr. Coll. of Sweden, 16:372-403. 1949.

41. Lundegårdh, H., and H. Burström. Bioch. Z., 261:235-51. 1933. Cited in R. N. Robertson. Mechanism of absorption and transport of inorganic nutrients in plants. Ann. Rev. Plant Physiol., 2:1-24. 1951.

42. Lunt, O. R., and W. L. Nelson. Studies on the value of sodium in the mineral nutrition of cotton. North Carolina Agr. Expt. Sta. Paper 364. 1950.

43. Marshall, C. E. Ionization of calcium from soil colloids and its bearing on soil-plant relationships. Soil Sci., 65: 57-68. 1948.

44. Mehlich, A., and J. F. Reed. The influence of degree of saturation, K level and Ca additions on removal of Ca, Mg and K. Soil Sci. Amer. Proc., 10:87-93. 1945.

45. Newton, J. D. The selective absorption of inorganic elements by various crops. Soil Sci., 26:85-91. 1928.

46. Osterhout, W. J. V. Plants which require sodium. Bot. Gaz., 54:532-36. 1912.

47. Overstreet, R., and L. Jacobson. Mechanisms of ion absorption by roots. Ann. Rev. Plant Physiol., 3:189-206. 1952.

48. Pierce, E. G., and G. O. Appleman. Role of ether soluble organic acids in the cation-anion balance in plants. Plant Physiol., 18:224-38. 1943.

49. Pool, R. J. Flowers and flowering plants. New York: McGraw-Hill. 1929.

50. Richards, F. J. The mineral nutrition of plants. Ann. Rev. Biochem., 13:611-30. 1944.

51. Roberts, R. B., I. Z. Roberts, and D. B. Cowie. Potassium metabolism in Escherichia coli. J. Cellular and Comp. Physiol., 34:259-91. 1949.

52. Saussure, T. de. Chemische Untersuchungen über die Vegetation, 2. German Translation by A. Wieher, Wilhelm Engelmann, Leipzig, Germany. 1890.

53. Selman, I. W. The use of common salt as a fertilizer. Jour. Min. Agr. (Eng.), 45:237-46. 1938.

54. Shear, C. B., H. L. Crane, and A. T. Myers. Nutrient-element balance: A fundamental concept in plant nutrition. Proc. Amer. Soc. Hort. Sci., 47:239-48. 1946.

55. Snedecor, G. W. Statistical methods. Ames, Iowa: The Iowa State College Press. 1946.

56. Spiegelman, S., and J. M. Reiner. A kinetic analysis of potassium accumulation and sodium exclusion. Growth, 6: 367-89. 1942.

57. Steinbach, H. B. Permeability. Ann. Rev. of Plant Physiol., 2:323-42. 1951.

58. Steinberg, R. A., J. D. Bowling, and J. E. McMurtrey. Accumulation of free amino acids as a chemical basis for morphological symptoms in tobacco manifesting frenching and mineral deficiencies. Plant Physiol., 25:279. 1950.

59. Steward, F. C. The absorption and accumulation of solutes by living plant cells. 1. Experimental condition which determines salt absorption by storage tissue. Protoplasm, 15:29-58. 1932.

60. Toth, S. J., A. L. Prince, and D. S. Mikkelsen. Rapid quantitative determination of eight mineral elements in plant tissue by a systematic procedure involving the use of a flame photometer. Soil Sci., 66:459-66. 1948.

61. Thorne, D. W. Growth and nutrition of tomato plants as influenced by exchangeable sodium, calcium and potassium. Proc. Soil Sci. Soc. of Amer., 9:185-89. 1944.

62. Truog, Emil. Lime in relation to availability of plant nutrients. Soil Sci., 65:1-7. 1948.

63. Van Helmont, Jean B. Workes (Trans. by J. Chandler). London, 1664. Cited in F. A. Gilbert. Mineral Nutrition, p. 6. Norman: Univ. of Oklahoma Press. 1948.

64. Van Itallie, Th. B. The rate of sodium in the cation balance of different plants. Trans. Third Internat. Congr. Soil Sci., 1:191-94. 1935.

65. Veatch, J. O. Agricultural land classification and land types of Michigan. Mich. State College Agr. Exp. Sta. Spec. Bull. 231 (First Rev.). 1941.

66. Watts, R. L., and G. S. Watts. The vegetable growing business. New York: Orange Judd. 1949.

67. Winsor, H. W. Boron micro determination in fresh plant tissue. Annal. Chem., 20:176-81.

68. Wynd, F. L. Feed the soil. Sci. Monthly, 74:223-29. 1952.

69. Yates, F. The design and analysis of factorial experiments. Imp. Bur. of Soil Sci. Tech. Commun., 35. 1937.

APPENDIX

Complete Data for Plant Weight or Yield, Percentage Dry Weight and Per Cent Calcium, Potassium, Magnesium, and Sodium in the Plant and Fruit from Each of the Seventeen Crops Grown with the Thirty-six Fertilizer Treatments

Table 1. The plant weight or yield of onion, cabbage, cauliflower, pea, lima bean, and snap bean, as influenced by each of the thirty-six fertilizer treatments (expressed in pounds per 10 linear feet).

Treatment*				Crop					
Ca	K	Mg	Na	Onion (plant)	Cab-bage (head)	Cauli-flower (head)	Pea (fruit)	Lima Bean (fruit)	Snap Bean (fruit)
3	3	2	2	2.5	22.9	13.1	2.0	9.2	5.7
3	3	2	1	7.3	36.7	15.3	2.9	7.7	6.4
3	3	1	2	7.3	24.8	16.8	5.2	8.3	6.2
3	3	1	1	11.0	28.0	14.7	4.0	6.4	5.8
3	2	2	2	8.0	34.8	17.8	2.8	9.1	3.8
3	2	2	1	7.3	40.5	23.0	1.8	6.7	6.2
3	2	1	2	8.1	34.9	19.7	0.6	6.4	4.8
3	2	1	1	11.2	30.6	15.8	0.4	8.7	7.3
3	1	2	2	7.2	16.8	15.0	2.0	6.2	1.1
3	1	2	1	12.7	27.4	12.2	2.0	5.3	1.1
3	1	1	2	6.8	24.6	25.1	1.8	8.1	5.4
3	1	1	1	9.2	22.2	15.1	3.0	7.3	4.9
2	3	2	2	4.1	35.6	15.1	0.6	8.6	3.6
2	3	2	1	6.1	36.1	18.8	1.0	9.9	6.6
2	3	1	2	4.0	30.3	14.4	1.5	9.0	4.7
2	3	1	1	4.0	30.5	20.0	1.6	7.7	5.9
2	2	2	2	2.5	20.2	22.2	2.2	8.3	5.1
2	2	2	1	3.8	26.4	12.9	2.1	8.7	6.5
2	2	1	2	3.5	23.1	21.9	1.8	8.6	5.2
2	2	1	1	5.4	25.5	21.1	1.4	7.3	6.1
2	1	2	2	7.5	27.2	18.2	3.2	9.7	6.1

Table 1 (Continued)

Treatment*				Crop					
Ca	K	Mg	Na	Onion (plant)	Cab-bage (head)	Cauli-flower (head)	Pea (fruit)	Lima Bean (fruit)	Snap Bean (fruit)
2	1	2	1	7.6	25.9	14.7	1.9	8.1	4.8
2	1	1	2	5.2	25.1	14.4	1.1	9.0	6.4
2	1	1	1	7.3	24.0	14.9	1.2	6.4	6.4
1	3	2	2	3.2	17.6	12.8	2.5	7.3	3.5
1	3	2	1	2.9	16.7	13.8	2.9	8.3	4.9
1	3	1	2	2.5	16.8	19.6	2.2	7.0	4.4
1	3	1	1	4.2	22.3	14.8	2.9	7.7	5.0
1	2	2	2	4.7	29.7	19.6	2.7	7.3	6.0
1	2	2	1	7.4	21.8	28.6	2.4	9.4	6.4
1	2	1	2	5.0	21.2	20.2	1.4	6.7	2.4
1	2	1	1	7.3	31.5	19.7	2.6	6.4	5.5
1	1	2	2	6.4	29.8	20.9	2.6	6.3	3.3
1	1	2	1	6.4	35.3	20.2	1.8	5.7	7.0
1	1	1	2	5.7	36.3	16.7	2.3	9.2	4.6
1	1	1	1	9.9	38.8	22.6	2.8	9.8	6.2
Average				6.3	27.6	17.8	2.1	7.8	5.1

* Ca (3) = pH 6.5; (2) = pH 6.0; (1) = pH 5.5.
K (3) = 330; (2) = 180; (1) = 30 lbs. K_2O per acre.
Mg (2) = 100; (1) = 0 lbs. MgO per acre.
Na (2) = 200; (1) = 0 lbs. Na_2O per acre.

Table 2. The plant weight or yield of beet, spinach, celery, carrot, sweet corn, and tomato, as influenced by each of the thirty-six fertilizer treatments (expressed in pounds per 10 linear feet).

Treatment*				Crop					
Ca	K	Mg	Na	Beet (plant)	Spin-ach (plant)	Cel-ery (plant)	Car-rot (plant)	Sweet Corn (ears)	To-mato (fruit)
3	3	2	2	20.7	8.0	18.9	4.3	12.5	51.8
3	3	2	1	23.2	10.2	18.0	7.0	18.2	93.4
3	3	1	2	17.9	8.6	25.3	3.6	15.8	77.8
3	3	1	1	21.5	9.0	22.7	8.0	16.0	71.6
3	2	2	2	17.2	6.3	15.9	4.9	14.2	69.8
3	2	2	1	20.8	10.8	12.9	6.7	12.7	79.5
3	2	1	2	9.2	7.2	10.0	7.0	10.6	69.6
3	2	1	1	12.3	6.6	12.4	7.2	11.3	77.0
3	1	2	2	20.5	5.6	18.8	6.5	17.6	52.8
3	1	2	1	18.2	4.5	10.0	4.9	8.7	52.0
3	1	1	2	19.8	5.4	23.2	4.9	10.0	58.8
3	1	1	1	15.6	4.7	12.2	5.7	15.7	60.7
2	3	2	2	17.3	7.4	20.6	1.6	10.8	40.0
2	3	2	1	19.1	4.1	24.3	3.2	15.0	71.4
2	3	1	2	18.4	6.9	17.1	2.2	13.8	44.8
2	3	1	1	21.7	4.9	18.5	5.6	8.4	68.3
2	2	2	2	16.1	4.4	20.1	3.6	8.3	52.1
2	2	2	1	12.2	3.8	19.3	3.7	7.2	67.6
2	2	1	2	10.6	5.0	26.6	0.5	17.8	52.5
2	2	1	1	10.8	4.7	24.5	2.4	10.4	54.8
2	1	2	2	18.1	6.3	20.3	1.1	10.7	55.4

Table 2 (Continued)

Treatment*				Crop					
Ca	K	Mg	Na	Beet (plant)	Spin-ach (plant)	Cel-ery (plant)	Car-rot (plant)	Sweet Corn (ears)	To-mato (fruit)
2	1	2	1	9.3	4.9	12.0	2.8	16.2	35.5
2	1	1	2	14.8	4.5	20.2	1.8	11.2	41.8
2	1	1	1	11.5	4.0	9.9	5.7	10.3	19.8
1	3	2	2	11.3	2.5	2.0	2.3	2.6	28.6
1	3	2	1	13.7	2.6	5.9	4.0	12.6	48.5
1	3	1	2	12.3	2.2	5.3	3.5	3.7	24.8
1	3	1	1	12.7	2.4	5.6	5.4	10.8	44.8
1	2	2	2	19.8	0.3	18.3	1.4	7.7	44.4
1	2	2	1	15.2	3.4	13.8	2.9	16.3	59.8
1	2	1	2	14.9	1.7	16.1	1.3	14.8	48.8
1	2	1	1	16.3	6.8	11.4	4.7	12.5	95.6
1	1	2	2	22.4	4.3	5.0	4.4	11.3	73.2
1	1	2	1	10.7	0.1	14.9	3.4	4.8	67.7
1	1	1	2	15.8	2.7	20.5	3.6	11.5	33.1
1	1	1	1	13.0	1.8	14.7	4.4	12.7	65.4
Average				16.0	5.0	15.8	4.1	11.8	57.0

* See Table 1.

Table 3. The plant weight or yield of potato, muskmelon, cucumber, squash, and lettuce, as influenced by each of the thirty-six fertilizer treatments (expressed in pounds per 10 linear feet).

Treatment*				Crop				
Ca	K	Mg	Na	Potato (tubers)	Muskmelon (fruit)	Cucumber (fruit)	Squash (fruit)	Lettuce (head)
3	3	2	2	28.2	27.6	0.6	44.3	3.0
3	3	2	1	29.3	21.1	1.5	51.5	13.1
3	3	1	2	34.3	26.8	0.8	74.3	10.9
3	3	1	1	30.3	28.5	7.4	40.5	8.3
3	2	2	2	27.9	37.8	2.9	62.2	14.1
3	2	2	1	22.3	18.1	3.4	85.3	7.6
3	2	1	2	24.1	10.9	2.3	35.5	11.1
3	2	1	1	29.3	12.2	2.7	64.5	8.5
3	1	2	2	13.1	4.1	0.2	41.8	4.7
3	1	2	1	18.3	6.7	0.1	44.4	5.5
3	1	1	2	18.8	18.2	0.3	54.3	4.4
3	1	1	1	28.3	18.0	1.2	40.5	4.3
2	3	2	2	26.7	11.9	4.5	23.0	5.7
2	3	2	1	35.3	20.0	4.7	53.4	5.3
2	3	1	2	26.8	17.7	2.6	41.6	8.6
2	3	1	1	24.0	23.4	6.6	57.3	9.6
2	2	2	2	25.9	12.8	0.6	40.0	6.2
2	2	2	1	35.8	17.4	2.7	55.8	8.3
2	2	1	2	30.6	14.4	1.1	57.5	6.4
2	2	1	1	34.6	12.0	1.6	64.6	5.6
2	1	2	2	25.0	18.5	1.3	57.7	6.5

Table 3 (Continued)

Treatment*				Crop				
Ca	K	Mg	Na	Potato (tubers)	Musk-Melon (fruit)	Cucumber (fruit)	Squash (fruit)	Lettuce (head)
2	1	2	1	21.1	21.8	2.7	33.8	5.4
2	1	1	2	21.7	22.5	1.7	43.9	7.6
2	1	1	1	17.0	12.6	5.5	73.8	6.9
1	3	2	2	23.9	13.6	0.7	32.2	5.6
1	3	2	1	29.6	5.9	2.4	38.0	5.7
1	3	1	2	19.1	12.5	0.2	47.4	5.7
1	3	1	1	20.7	16.5	2.9	30.5	7.4
1	2	2	2	29.8	12.9	0.8	75.7	5.6
1	2	2	1	33.4	16.8	1.9	41.3	4.2
1	2	1	2	27.1	12.7	1.3	47.7	5.5
1	2	1	1	32.2	18.6	5.3	54.0	8.8
1	1	2	2	30.5	8.2	2.9	42.5	10.6
1	1	2	1	34.8	23.8	4.4	52.5	4.3
1	1	1	2	26.0	8.9	8.8	29.8	4.4
1	1	1	1	28.7	18.5	5.1	53.7	7.4
Average				26.8	16.8	2.7	49.6	7.0

Table 4. The per cent dry weight and the calcium, potassium, magnesium, and sodium composition of onion (plant), as influenced by each of the thirty-six fertilizer treatments (expressed as per cent dry weight).

Treatment*				% Dry Weight	Ca	K	Mg	Na	Total
Ca	K	Mg	Na						
3	3	2	2	14.0	0.88	1.73	0.22	0.26	3.09
3	3	2	1	12.5	0.58	2.12	0.25	0.11	3.06
3	3	1	2	14.0	0.99	1.73	0.20	0.24	3.16
3	3	1	1	12.0	0.94	1.93	0.26	0.12	3.25
3	2	2	2	12.0	0.70	1.40	0.21	0.15	2.46
3	2	2	1	15.0	0.28	1.65	0.32	0.09	2.34
3	2	1	2	16.0	0.66	1.60	0.18	0.23	2.67
3	2	1	1	14.0	1.10	1.73	0.23	0.10	3.16
3	1	2	2	15.0	0.84	1.13	0.21	0.38	2.56
3	1	2	1	14.0	1.07	1.33	0.19	0.21	2.80
3	1	1	2	19.0	0.79	1.18	0.14	0.34	2.45
3	1	1	1	16.0	1.41	0.87	0.18	0.27	2.73
2	3	2	2	16.0	0.79	2.39	0.25	0.19	3.62
2	3	2	1	15.0	0.55	2.40	0.19	0.14	3.28
2	3	1	2	17.0	0.93	2.02	0.22	0.26	3.43
2	3	1	1	16.0	1.09	2.43	0.25	0.12	3.89
2	2	2	2	18.0	0.86	1.53	0.25	0.34	2.98
2	2	2	1	15.0	1.03	1.91	0.23	0.13	3.30
2	2	1	2	16.0	0.70	1.55	0.17	0.26	2.68
2	2	1	1	16.0	0.60	1.99	0.17	0.11	2.87
2	1	2	2	16.0	1.05	0.99	0.25	0.65	2.94

Table 4 (Continued)

Treatment*				% Dry Weight	Ca	K	Mg	Na	Total
Ca	K	Mg	Na						
2	1	2	1	16.0	0.34	0.89	0.15	0.11	1.49
2	1	1	2	15.0	0.82	0.92	0.17	0.58	2.49
2	1	1	1	14.0	1.15	0.82	0.29	0.11	2.37
1	3	2	2	16.0	0.58	1.99	0.17	0.25	2.99
1	3	2	1	18.0	0.99	3.10	0.31	0.09	4.49
1	3	1	2	15.0	0.92	1.92	0.20	0.35	3.39
1	3	1	1	16.0	1.04	1.70	0.18	0.08	3.00
1	2	2	2	16.0	0.89	1.21	0.19	0.25	2.54
1	2	2	1	16.0	0.94	1.67	0.20	0.08	2.89
1	2	1	2	12.5	1.18	1.40	0.19	0.34	3.11
1	2	1	1	13.5	0.69	1.27	0.15	0.08	2.19
1	1	2	2	14.0	0.73	1.20	0.20	0.27	2.40
1	1	2	1	12.5	1.03	0.78	0.32	0.09	2.22
1	1	1	2	18.0	1.03	0.93	0.16	0.61	2.73
1	1	1	1	15.0	1.64	0.92	0.24	0.10	2.90
Average				15.2	0.88	1.56	0.21	0.22	2.89
Relative %					30.61	54.20	7.40	7.78	100.00

* See Table 1.

Table 5. The per cent dry weight and the calcium, potassium, magnesium, and sodium composition of cabbage (head), as influenced by each of the thirty-six fertilizer treatments (expressed as per cent dry weight).

Treatment*				% Dry Weight	Ca	K	Mg	Na	Total
Ca	K	Mg	Na						
3	3	2	2	6.0	0.46	4.04	0.34	0.31	5.15
3	3	2	1	6.0	0.59	4.13	0.35	0.07	5.14
3	3	1	2	5.0	0.45	5.27	0.47	0.34	6.53
3	3	1	1	6.0	0.52	4.65	0.43	0.06	5.66
3	2	2	2	6.0	0.48	4.60	0.40	0.33	5.81
3	2	2	1	5.0	0.49	4.58	0.35	0.14	5.56
3	2	1	2	6.0	0.52	4.35	0.36	0.27	5.50
3	2	1	1	6.0	0.40	4.10	0.35	0.08	4.93
3	1	2	2	6.0	0.47	2.52	0.31	0.72	4.02
3	1	2	1	5.0	0.90	3.04	0.36	0.29	4.59
3	1	1	2	6.0	0.42	2.77	0.28	0.61	4.08
3	1	1	1	5.0	1.14	2.94	0.28	0.28	4.64
2	3	2	2	6.0	0.50	3.76	0.36	0.28	4.90
2	3	2	1	6.0	0.40	4.22	0.32	0.07	5.01
2	3	1	2	6.0	0.49	4.28	0.32	0.29	5.38
2	3	1	1	6.0	0.38	4.30	0.29	0.09	5.06
2	2	2	2	6.0	0.55	4.35	0.45	0.27	5.62
2	2	2	1	6.0	1.10	4.20	0.42	0.09	5.81
2	2	1	2	6.0	0.43	4.49	0.33	0.22	5.47
2	2	1	1	6.0	0.84	4.00	0.42	0.27	5.53
2	1	2	2	6.0	0.50	3.05	0.40	0.76	4.71

Table 5 (Continued)

Treatment*				% Dry Weight	Ca	K	Mg	Na	Total
Ca	K	Mg	Na						
2	1	2	1	6.0	0.50	2.50	0.33	0.17	3.50
2	1	1	2	5.0	0.71	2.68	0.38	0.70	4.47
2	1	1	1	5.0	0.87	3.11	0.30	0.37	4.65
1	3	2	2	6.0	0.56	4.16	0.47	0.42	5.61
1	3	2	1	6.0	0.43	4.65	0.34	0.11	5.53
1	3	1	2	6.0	0.35	4.35	0.31	0.28	5.29
1	3	1	1	6.0	0.36	4.60	0.32	0.07	5.35
1	2	2	2	5.0	0.35	4.80	0.28	0.40	5.83
1	2	2	1	5.0	0.48	3.94	0.30	0.09	4.81
1	2	1	2	6.0	0.46	3.84	0.31	0.42	5.03
1	2	1	1	6.0	0.42	3.71	0.28	0.08	4.49
1	1	2	2	6.0	0.24	2.64	0.27	0.65	3.80
1	1	2	1	5.0	0.51	2.96	0.36	0.14	3.97
1	1	1	2	6.0	0.84	3.51	0.30	0.56	5.21
1	1	1	1	5.0	0.60	3.50	0.26	0.24	4.60
Average				5.7	0.55	3.85	0.34	0.29	5.03
Relative %					10.87	76.54	6.84	5.77	100.00

* See Table 1.

Table 6. The per cent dry weight and the calcium, potassium, magnesium, and sodium composition of cauliflower (head), as influenced by each of the thirty-six fertilizer treatments (expressed as per cent dry weight).

Treatment*				% Dry Weight	Ca	K	Mg	Na	Total
Ca	K	Mg	Na						
3	3	2	2	8.0	1.37	4.46	0.40	0.50	6.73
3	3	2	1	8.0	2.00	3.47	0.41	0.10	5.98
3	3	1	2	8.0	0.97	3.50	0.23	0.23	4.93
3	3	1	1	9.5	0.79	3.63	0.18	0.05	4.65
3	2	2	2	9.0	2.09	4.46	0.34	0.93	7.82
3	2	2	1	8.0	1.76	4.09	0.30	0.31	6.46
3	2	1	2	9.0	1.75	3.48	0.17	0.62	6.02
3	2	1	1	7.5	1.59	3.76	0.18	0.18	5.71
3	1	2	2	8.0	1.69	2.01	0.26	1.36	5.32
3	1	2	1	8.5	1.17	1.64	0.14	0.15	3.10
3	1	1	2	10.0	1.69	2.14	0.18	1.01	5.02
3	1	1	1	8.5	1.81	2.14	0.13	0.21	4.29
2	3	2	2	8.0	3.00	4.09	0.52	0.70	8.31
2	3	2	1	9.5	1.77	4.81	0.29	0.13	7.00
2	3	1	2	7.0	1.72	3.63	0.18	0.34	5.87
2	3	1	1	8.5	1.98	4.34	0.23	0.16	6.71
2	2	2	2	8.0	0.84	3.16	0.19	0.18	4.37
2	2	2	1	8.0	1.29	3.98	0.24	0.12	5.63
2	2	1	2	7.0	2.11	3.55	0.50	0.37	6.53
2	2	1	1	9.0	1.48	3.63	0.32	0.30	5.73
2	1	2	2	7.0	1.63	2.60	0.46	0.99	5.68

Table 6 (Continued)

Treatment*				% Dry Weight	Ca	K	Mg	Na	Total
Ca	K	Mg	Na						
2	1	2	1	11.0	0.70	3.45	0.18	0.09	4.42
2	1	1	2	10.0	1.71	2.96	0.34	0.49	5.50
2	1	1	1	11.5	1.63	2.76	0.22	0.25	4.86
1	3	2	2	8.0	1.72	3.76	0.35	0.45	6.28
1	3	2	1	6.5	1.20	4.00	0.19	0.05	5.44
1	3	1	2	8.0	1.68	3.90	0.20	0.33	6.11
1	3	1	1	9.5	1.52	3.74	0.22	0.08	5.56
1	2	2	2	8.0	2.23	2.90	0.41	0.65	6.19
1	2	2	1	8.0	2.57	2.88	0.54	0.27	6.26
1	2	1	2	8.0	1.91	3.09	0.32	0.92	6.24
1	2	1	1	9.0	2.14	2.76	0.29	0.18	5.37
1	1	2	2	9.0	0.93	2.53	0.27	0.99	4.72
1	1	2	1	8.0	1.34	2.30	0.19	0.43	4.26
1	1	1	2	8.5	1.18	2.63	0.18	0.82	4.81
1	1	1	1	8.0	1.80	1.89	0.21	0.60	4.50
Average				8.5	1.63	3.28	0.28	0.43	5.62
Relative %					29.03	58.37	4.92	7.68	100.00

* See Table 1.

Table 7. The per cent dry weight and the calcium, potassium, magnesium, and sodium composition of pea (foliage), as influenced by each of the thirty-six fertilizer treatments (expressed as per cent dry weight).

Treatment*				% Dry Weight	Ca	K	Mg	Na	Total
Ca	K	Mg	Na						
3	3	2	2	16.5	1.72	1.85	0.32	0.12	4.01
3	3	2	1	15.5	1.19	1.75	0.26	0.02	3.22
3	3	1	2	15.5	1.47	1.99	0.27	0.05	3.78
3	3	1	1	18.0	1.68	1.83	0.26	0.02	3.79
3	2	2	2	16.5	1.05	1.45	0.72	0.08	3.30
3	2	2	1	19.5	1.12	1.62	0.67	0.03	3.44
3	2	1	2	17.5	1.51	1.54	0.59	0.08	3.72
3	2	1	1	14.5	2.06	1.78	0.31	0.02	4.17
3	1	2	2	20.5	1.66	1.19	0.21	0.17	3.23
3	1	2	1	20.0	1.62	1.42	0.17	0.04	3.25
3	1	1	2	18.5	1.74	1.32	0.21	0.13	3.40
3	1	1	1	19.5	2.48	1.52	0.21	0.06	4.27
2	3	2	2	16.5	1.51	1.68	0.19	0.06	3.44
2	3	2	1	18.5	1.59	1.88	0.29	0.04	3.80
2	3	1	2	15.5	1.46	1.63	0.23	0.04	3.36
2	3	1	1	18.5	1.63	1.52	0.24	0.03	3.42
2	2	2	2	18.5	1.40	1.60	0.25	0.05	3.30
2	2	2	1	20.0	1.69	1.33	0.24	0.01	3.27
2	2	1	2	20.5	1.60	1.64	0.26	0.05	3.55
2	2	1	1	17.5	1.49	1.87	0.29	0.04	3.69
2	1	2	2	15.5	1.56	1.83	0.29	0.05	3.73

Table 7 (Continued)

Treatment*				% Dry Weight	Ca	K	Mg	Na	Total
Ca	K	Mg	Na						
2	1	2	1	14.5	1.23	1.81	0.24	0.02	3.30
2	1	1	2	15.0	1.90	1.84	0.27	0.06	4.07
2	1	1	1	16.5	1.57	1.39	0.21	0.06	3.23
1	3	2	2	20.0	1.79	1.77	0.28	0.10	3.94
1	3	2	1	21.5	1.26	1.48	0.21	0.01	2.96
1	3	1	2	20.5	1.62	1.68	0.24	0.10	3.64
1	3	1	1	17.5	1.73	1.68	0.24	0.02	3.67
1	2	2	2	15.0	1.92	1.66	0.34	0.10	4.02
1	2	2	1	16.5	1.45	1.67	0.26	0.02	3.40
1	2	1	2	15.5	1.67	1.93	0.26	0.12	3.98
1	2	1	1	16.0	1.51	1.49	0.20	0.02	3.22
1	1	2	2	18.5	1.31	1.21	0.26	0.15	2.93
1	1	2	1	15.5	1.95	1.28	0.33	0.02	3.58
1	1	1	2	17.5	1.67	1.11	0.21	0.08	3.07
1	1	1	1	18.5	2.22	1.14	0.24	0.02	3.62
Average				17.5	1.61	1.59	0.29	0.06	3.55
Relative %					45.35	44.79	8.17	1.69	100.00

* See Table 1.

Table 8. The per cent dry weight and the calcium, potassium, magnesium, and sodium composition of lima bean (plant), as influenced by each of the thirty-six fertilizer treatments (expressed as per cent dry weight).

Treatment*				% Dry Weight	Ca	K	Mg	Na	Total
Ca	K	Mg	Na						
3	3	2	2	20.0	2.78	2.20	0.82	0.06	5.86
3	3	2	1	22.0	2.84	1.83	0.66	0.06	5.39
3	3	1	2	20.0	2.88	2.10	0.50	0.07	5.55
3	3	1	1	20.0	2.48	2.58	0.61	0.07	5.74
3	2	2	2	22.0	1.78	2.03	0.71	0.06	4.58
3	2	2	1	23.0	1.68	2.13	0.99	0.07	4.87
3	2	1	2	24.0	2.98	2.08	0.68	0.07	5.81
3	2	1	1	22.0	2.04	2.79	0.58	0.06	5.47
3	1	2	2	22.0	3.61	1.80	0.86	0.10	6.37
3	1	2	1	22.0	3.88	1.78	0.89	0.07	6.62
3	1	1	2	22.0	5.26	1.57	0.85	0.08	7.76
3	1	1	1	20.0	2.84	1.91	0.61	0.06	5.42
2	3	2	2	21.0	2.62	2.54	0.82	0.05	6.03
2	3	2	1	21.0	3.72	2.38	0.83	0.05	6.98
2	3	1	2	20.0	3.20	2.48	0.79	0.05	6.52
2	3	1	1	20.0	2.84	2.13	0.86	0.06	5.89
2	2	2	2	20.0	2.30	2.18	0.74	0.06	5.28
2	2	2	1	20.0	3.38	1.57	0.78	0.05	5.78
2	2	1	2	20.0	3.24	1.73	0.69	0.05	5.71
2	2	1	1	20.0	3.30	2.18	0.78	0.05	6.31
2	1	2	2	20.0	2.77	1.71	0.68	0.06	5.22

Table 8 (Continued)

Treatment*				% Dry Weight	Ca	K	Mg	Na	Total
Ca	K	Mg	Na						
2	1	2	1	23.0	3.11	0.94	1.00	0.05	5.10
2	1	1	2	23.0	3.62	1.90	0.69	0.06	6.27
2	1	1	1	22.0	3.75	1.16	0.82	0.06	5.79
1	3	2	2	20.0	2.98	2.47	0.86	0.07	6.38
1	3	2	1	20.0	2.46	2.37	0.70	0.05	5.58
1	3	1	2	19.0	3.60	2.92	0.82	0.08	7.42
1	3	1	1	18.0	3.28	2.83	0.74	0.05	6.90
1	2	2	2	20.0	3.53	2.54	0.88	0.06	7.01
1	2	2	1	20.0	2.20	2.60	0.63	0.05	5.48
1	2	1	2	22.0	2.87	1.89	0.70	0.05	5.51
1	2	1	1	20.0	2.88	1.97	0.74	0.05	5.64
1	1	2	2	22.0	2.95	1.68	0.82	0.11	5.56
1	1	2	1	23.0	2.48	1.00	0.79	0.05	4.32
1	1	1	2	19.0	3.02	1.73	0.60	0.06	5.41
1	1	1	1	20.0	2.95	1.42	0.71	0.05	5.13
Average				26.3	3.00	2.03	0.76	0.06	5.85
Relative %					51.28	34.70	12.99	1.03	100.00

* See Table 1.

Table 9. The per cent dry weight and the calcium, potassium, magnesium, and sodium composition of snap bean (plant), as influenced by each of the thirty-six fertilizer treatments (expressed as per cent dry weight).

Treatment*				% Dry Weight	Ca	K	Mg	Na	Total
Ca	K	Mg	Na						
3	3	2	2	12.0	1.81	2.03	0.50	0.02	4.36
3	3	2	1	10.0	1.30	2.12	0.48	0.01	3.91
3	3	1	2	10.0	2.51	2.17	0.55	0.04	5.27
3	3	1	1	10.5	2.08	2.36	0.54	0.01	4.99
3	2	2	2	10.5	1.92	2.14	1.63	0.02	5.71
3	2	2	1	16.0	1.71	1.82	1.80	0.01	5.34
3	2	1	2	10.5	2.68	2.26	0.85	0.03	5.82
3	2	1	1	14.0	3.02	1.83	0.79	0.01	5.65
3	1	2	2	13.0	2.07	1.92	0.60	0.05	4.64
3	1	2	1	15.0	2.55	1.88	0.46	0.01	4.90
3	1	1	2	11.5	2.42	1.61	0.45	0.01	4.49
3	1	1	1	11.5	2.43	1.81	0.45	0.01	4.70
2	3	2	2	10.0	2.22	2.01	0.55	0.01	4.79
2	3	2	1	11.0	2.50	2.09	0.52	0.01	5.12
2	3	1	2	12.0	2.41	1.98	0.52	0.01	4.92
2	3	1	1	10.0	1.98	2.21	0.62	0.02	4.83
2	2	2	2	11.6	3.48	1.76	0.75	0.02	6.01
2	2	2	1	15.0	1.85	1.96	0.50	0.01	4.32
2	2	1	2	11.6	2.88	1.73	0.50	0.01	5.12
2	2	1	1	11.0	2.90	2.07	0.46	0.01	5.44
2	1	2	2	12.0	3.02	1.51	0.67	0.01	5.21

Table 9 (Continued)

Treatment				% Dry Weight	Ca	K	Mg	Na	Total
Ca	K	Mg	Na						
2	1	2	1	11.0	2.49	1.32	0.78	0.02	4.61
2	1	1	2	10.0	2.89	1.73	0.48	0.03	5.13
2	1	1	1	12.0	2.65	1.39	0.55	0.01	4.60
1	3	2	2	12.0	2.10	2.07	0.48	0.03	4.68
1	3	2	1	12.5	2.54	2.23	0.49	0.01	5.27
1	3	1	2	11.0	1.90	2.27	0.39	0.01	4.57
1	3	1	1	12.0	2.69	2.22	0.52	0.01	5.44
1	2	2	2	11.0	2.34	2.18	0.56	0.01	5.09
1	2	2	1	11.0	1.74	2.31	0.53	0.01	4.59
1	2	1	2	11.0	1.53	2.38	0.44	0.02	4.37
1	2	1	1	10.5	2.42	2.49	0.42	0.02	5.35
1	1	2	2	12.0	2.60	1.64	0.64	0.02	4.90
1	1	2	1	12.0	2.91	1.57	0.90	0.01	5.39
1	1	1	2	11.0	1.91	1.70	0.61	0.01	4.23
1	1	1	1	12.0	2.45	1.73	0.63	0.02	4.83
Average				11.7	2.36	1.96	0.63	0.02	4.97
Relative %					47.48	39.44	12.68	0.40	100.00

* See Table 1.

Table 10. The per cent dry weight and the calcium, potassium, magnesium, and sodium composition of beet (plant), as influenced by each of the thirty-six fertilizer treatments.

Treatment*				% Dry Weight	Ca	K	Mg	Na	Total
Ca	K	Mg	Na						
3	3	2	2	12.0	0.89	4.60	0.85	1.70	8.04
3	3	2	1	15.0	1.59	6.56	1.13	0.64	9.92
3	3	1	2	11.5	1.13	5.10	0.86	1.84	8.93
3	3	1	1	12.5	1.20	6.56	0.92	0.49	9.17
3	2	2	2	13.5	0.37	4.95	0.99	1.54	7.85
3	2	2	1	14.0	0.69	6.65	2.88	0.61	10.83
3	2	1	2	13.0	0.86	5.35	0.86	2.30	9.37
3	2	1	1	16.0	1.36	5.43	0.72	0.42	7.93
3	1	2	2	13.0	2.33	2.45	2.73	4.15	11.66
3	1	2	1	16.0	2.01	3.37	1.60	0.95	7.93
3	1	1	2	12.0	1.35	3.70	0.95	3.74	9.74
3	1	1	1	12.0	2.09	3.57	0.78	0.47	6.91
2	3	2	2	11.5	1.14	5.88	1.36	1.88	10.26
2	3	2	1	12.0	1.16	7.55	1.16	0.54	10.41
2	3	1	2	11.5	0.81	5.41	0.86	2.28	9.36
2	3	1	1	12.0	1.35	7.37	1.18	0.52	10.42
2	2	2	2	14.0	1.16	4.56	1.03	2.35	9.10
2	2	2	1	13.5	1.46	6.36	1.13	0.64	9.59
2	2	1	2	12.5	1.35	4.25	1.17	2.81	9.58
2	2	1	1	12.0	1.50	7.33	1.61	1.35	11.79
2	1	2	2	12.0	1.02	3.70	0.79	2.70	8.21

Table 10 (Continued)

Treatment*				% Dry Weight	Ca	K	Mg	Na	Total
Ca	K	Mg	Na						
2	1	2	1	14.0	1.32	2.95	1.23	0.41	5.91
2	1	1	2	12.0	1.08	3.35	0.77	2.02	7.22
2	1	1	1	14.0	1.59	3.25	0.99	1.68	7.51
1	3	2	2	13.5	1.30	4.35	1.35	2.79	9.79
1	3	2	1	14.0	1.35	7.19	1.46	0.72	10.72
1	3	1	2	13.5	1.04	5.81	0.94	2.68	10.47
1	3	1	1	13.0	1.69	7.35	1.45	0.76	11.25
1	2	2	2	12.5	0.81	4.36	0.99	2.62	8.78
1	2	2	1	13.0	0.89	5.60	1.03	0.43	7.95
1	2	1	2	12.0	1.04	3.92	0.81	2.68	8.45
1	2	1	1	14.0	1.23	5.90	1.08	0.41	8.62
1	1	2	2	12.0	0.53	3.52	0.86	2.44	7.35
1	1	2	1	12.0	1.08	3.70	1.45	0.46	6.69
1	1	1	2	12.0	1.21	2.91	0.87	2.84	7.83
1	1	1	1	16.0	1.62	3.10	1.08	0.33	6.13
Average				13.0	1.24	4.94	1.11	1.59	8.94
Relative %					13.87	49.43	11.09	15.89	100.00

* See Table 1.

Table 11. The per cent dry weight and the calcium, potassium, magnesium, and sodium composition of spinach (plant), as influenced by each of the thirty-six fertilizer treatments (expressed as per cent dry weight).

Treatment*				% Dry Weight	Ca	K	Mg	Na	Total
Ca	K	Mg	Na						
3	3	2	2	8.5	0.68	8.70	0.85	0.31	10.54
3	3	2	1	6.5	0.45	9.43	0.93	0.04	10.85
3	3	1	2	8.0	0.78	8.30	0.70	0.20	9.98
3	3	1	1	8.0	0.62	9.08	0.69	0.03	10.42
3	2	2	2	6.5	0.62	8.75	1.53	0.42	11.32
3	2	2	1	7.5	0.66	8.50	1.54	0.07	10.77
3	2	1	2	7.0	0.97	8.50	0.84	0.33	10.64
3	2	1	1	7.0	0.53	6.30	0.45	0.03	7.31
3	1	2	2	9.5	0.71	4.83	0.56	1.47	7.57
3	1	2	1	11.0	0.70	4.15	0.46	0.07	5.38
3	1	1	2	9.0	1.30	3.78	0.65	2.02	7.75
3	1	1	1	11.5	1.26	5.34	0.60	0.06	7.26
2	3	2	2	5.5	0.93	10.15	0.96	0.10	12.14
2	3	2	1	8.5	1.30	9.13	1.07	0.08	11.58
2	3	1	2	8.5	1.15	8.90	0.90	0.34	11.29
2	3	1	1	9.5	0.63	8.15	0.82	0.05	9.65
2	2	2	2	11.0	1.09	6.90	0.82	0.65	9.46
2	2	2	1	12.0	1.41	8.60	1.17	0.06	11.24
2	2	1	2	9.5	0.55	7.05	0.46	0.21	8.27
2	2	1	1	11.5	0.79	7.45	0.58	0.14	8.96
2	1	2	2	8.5	0.71	6.88	0.65	0.92	9.16

Table 11 (Continued)

Treatment*				% Dry Weight	Ca	K	Mg	Na	Total
Ca	K	Mg	Na						
2	1	2	1	10.5	0.72	4.24	0.43	0.05	5.44
2	1	1	2	8.5	0.49	6.25	0.52	0.50	7.76
2	1	1	1	10.0	0.78	6.63	0.52	0.30	8.23
1	3	2	2	11.5	1.02	6.92	0.75	0.46	9.15
1	3	2	1	12.0	1.25	7.23	0.82	0.05	18.50
1	3	1	2	12.5	0.63	5.71	0.45	0.36	7.15
1	3	1	1	12.0	0.79	7.23	0.59	0.05	8.16
1	2	2	2	8.0	1.46	9.08	1.27	1.16	12.97
1	2	2	1	11.0	0.62	8.06	0.67	0.09	9.44
1	2	1	2	8.5	0.60	6.75	0.63	0.51	8.49
1	2	1	1	7.5	0.56	8.70	0.85	0.09	10.20
1	1	2	2	10.5	0.92	4.43	0.93	1.22	7.50
1	1	2	1	7.5	2.47	1.88	1.60	0.07	6.02
1	1	1	2	11.5	2.05	4.24	0.83	2.34	9.46
1	1	1	1	14.0	2.74	3.35	0.81	0.10	7.00
Average				9.4	0.97	6.93	0.83	0.42	9.38
Relative %					10.34	73.88	8.85	4.48	100.00

* See Table 1.

Table 12. The per cent dry weight and the calcium, potassium, magnesium, and sodium composition of celery (plant), as influenced by each of the thirty-six fertilizer treatments (expressed as per cent dry weight).

Treatment*				% Dry Weight	Ca	K	Mg	Na	Total
Ca	K	Mg	Na						
3	3	2	2	12.0	0.70	4.82	0.40	0.78	6.70
3	3	2	1	15.0	1.50	5.07	0.49	0.24	7.30
3	3	1	2	11.2	1.66	5.19	0.51	1.36	8.72
3	3	1	1	12.0	1.57	5.59	0.51	0.23	7.90
3	2	2	2	13.0	1.28	3.23	0.50	2.01	7.02
3	2	2	1	15.0	1.45	3.35	0.49	0.30	5.59
3	2	1	2	13.0	1.58	3.56	0.45	1.91	7.50
3	2	1	1	15.0	2.49	3.48	0.43	0.28	6.68
3	1	2	2	15.0	1.81	2.60	0.26	0.44	5.11
3	1	2	1	15.0	1.71	1.68	0.37	0.31	4.07
3	1	1	2	13.0	1.72	1.62	0.38	3.25	6.97
3	1	1	1	12.0	2.34	1.85	0.26	0.27	4.72
2	3	2	2	12.0	1.44	4.85	0.43	1.50	8.22
2	3	2	1	12.0	1.35	4.85	0.39	0.37	6.96
2	3	1	2	12.0	1.30	5.23	0.42	1.30	8.25
2	3	1	1	16.0	1.61	4.47	0.40	0.31	6.79
2	2	2	2	13.0	1.30	4.00	0.48	1.69	7.47
2	2	2	1	13.0	1.50	4.22	0.38	0.31	6.41
2	2	1	2	13.0	2.10	4.21	0.48	2.11	8.90
2	2	1	1	13.0	1.74	3.97	0.32	0.89	6.92
2	1	2	2	11.0	1.07	4.00	0.36	1.54	6.97

Table 12 (Continued)

Treatment*				% Dry Weight	Ca	K	Mg	Na	Total
Ca	K	Mg	Na						
2	1	2	1	15.0	1.65	1.76	0.25	0.28	3.94
2	1	1	2	14.0	2.08	1.78	0.39	2.68	6.93
2	1	1	1	16.0	2.16	1.71	0.26	0.27	4.40
1	3	2	2	15.0	1.24	3.11	0.49	1.84	6.68
1	3	2	1	13.0	1.11	4.47	0.38	0.28	6.24
1	3	1	2	14.0	2.07	2.26	0.20	0.24	4.77
1	3	1	1	14.0	1.54	5.70	0.51	0.32	8.07
1	2	2	2	13.0	1.18	4.10	0.46	1.88	7.62
1	2	2	1	14.0	1.47	4.09	0.35	0.25	6.16
1	2	1	2	14.0	1.59	2.01	0.35	2.08	6.03
1	2	1	1	13.0	2.04	3.37	0.32	0.27	6.00
1	1	2	2	15.0	1.18	0.65	0.58	3.43	5.84
1	1	2	1	12.0	1.94	1.50	0.60	0.97	5.01
1	1	1	2	12.0	1.26	1.55	0.40	2.88	6.09
1	1	1	1	17.0	2.14	1.62	0.33	0.22	4.31
Average				13.5	1.61	3.38	0.41	1.09	6.49
Relative %					24.81	52.08	6.32	16.80	100.00

* See Table 1.

Table 13. The per cent dry weight and the calcium, potassium, magnesium, and sodium composition of carrot (plant), as influenced by each of the thirty-six fertilizer treatments (expressed as per cent dry weight).

Treatment*				% Dry Weight	Ca	K	Mg	Na	Total
Ca	K	Mg	Na						
3	3	2	2	14.5	0.72	3.51	0.23	0.37	4.83
3	3	2	1	14.5	0.96	4.36	0.34	0.14	5.79
3	3	1	2	14.0	0.42	3.91	0.28	0.39	5.00
3	3	1	1	14.0	0.74	4.50	0.34	0.17	5.75
3	2	2	2	13.5	0.66	4.00	0.53	0.49	5.68
3	2	2	1	14.0	0.89	4.54	0.65	0.09	6.17
3	2	1	2	14.5	0.79	3.92	0.37	0.49	5.57
3	2	1	1	14.5	1.40	3.93	0.46	0.18	5.97
3	1	2	2	14.0	1.11	2.25	0.41	1.42	5.19
3	1	2	1	14.0	1.14	2.25	0.42	0.46	4.27
3	1	1	2	14.5	0.90	1.97	0.29	1.38	4.54
3	1	1	1	14.5	1.60	2.48	0.47	0.53	5.08
2	3	2	2	14.5	0.80	4.28	0.43	0.42	5.93
2	3	2	1	14.0	0.75	4.56	0.51	0.12	5.94
2	3	1	2	14.5	0.77	3.90	0.46	0.48	5.61
2	3	1	1	13.5	1.06	4.57	0.48	0.16	6.27
2	2	2	2	14.5	0.90	3.96	0.46	0.57	5.89
2	2	2	1	14.5	0.82	6.16	0.48	0.23	7.69
2	2	1	2	15.0	0.81	3.96	0.32	0.68	5.77
2	2	1	1	14.5	1.29	4.86	0.47	0.24	6.86
2	1	2	2	14.5	1.08	2.86	0.46	1.03	5.43

Table 13 (Continued)

Treatment*				% Dry Weight	Ca	K	Mg	Na	Total
Ca	K	Mg	Na						
2	1	2	1	13.5	1.10	2.87	0.38	0.40	4.75
2	1	1	2	14.5	1.06	3.55	0.29	0.67	5.57
2	1	1	1	14.5	1.18	2.36	0.38	0.75	4.67
1	3	2	2	14.5	0.68	4.22	0.43	0.48	5.81
1	3	2	1	14.5	1.02	4.80	0.51	0.12	6.45
1	3	1	2	14.5	0.72	4.96	0.34	0.35	6.37
1	3	1	1	14.5	0.99	4.49	0.29	0.20	5.97
1	2	2	2	13.5	0.91	4.74	0.38	0.58	6.61
1	2	2	1	14.5	0.64	4.32	0.38	0.15	5.49
1	2	1	2	14.5	0.75	3.91	0.31	0.55	5.52
1	2	1	1	14.5	0.94	4.16	0.31	0.18	5.59
1	1	2	2	14.0	0.50	2.47	0.43	1.11	4.51
1	1	2	1	15.0	1.30	2.85	0.46	0.32	4.93
1	1	1	2	14.5	0.95	2.67	0.38	0.80	4.80
1	1	1	1	14.5	1.04	3.08	0.38	0.28	4.78
Average				14.3	0.93	3.78	0.40	0.47	5.58
Relative %					16.67	67.74	7.17	8.42	100.00

* See Table 1.

Table 14. The per cent dry weight and the calcium, potassium, magnesium, and sodium composition of sweet corn (leaves and stems), of the thirty-six fertilizer treatments (expressed as per cent dry weight).

Treatment*				% Dry Weight	Ca	K	Mg	Na	Total
Ca	K	Mg	Na						
3	3	2	2	20.2	0.64	2.33	0.19	0.06	3.22
3	3	2	1	20.2	1.01	2.20	0.31	0.04	3.56
3	3	1	2	20.5	0.52	2.32	0.19	0.06	3.09
3	3	1	1	20.5	0.70	2.03	0.22	0.05	3.00
3	2	2	2	23.0	0.55	2.18	0.50	0.05	3.28
3	2	2	1	23.5	0.28	1.82	0.38	0.05	2.53
3	2	1	2	20.0	0.94	2.51	0.39	0.06	3.90
3	2	1	1	21.5	1.34	2.23	0.49	0.05	4.11
3	1	2	2	21.5	1.04	1.80	0.36	0.04	3.24
3	1	2	1	21.0	0.55	0.80	0.29	0.04	1.68
3	1	1	2	23.5	0.93	0.79	0.31	0.03	2.06
3	1	1	1	22.0	0.92	1.33	0.28	0.04	2.57
2	3	2	2	20.0	0.88	2.54	0.37	0.05	6.41
2	3	2	1	22.2	0.87	2.64	0.36	0.04	3.91
2	3	1	2	23.0	0.75	2.37	0.26	0.04	3.42
2	3	1	1	22.5	0.67	1.98	0.19	0.02	2.86
2	2	2	2	23.2	0.45	1.97	0.22	0.04	2.68
2	2	2	1	22.5	0.46	2.50	0.31	0.03	3.30
2	2	1	2	22.0	0.90	2.17	0.34	0.04	3.45
2	2	1	1	24.0	0.90	3.11	0.40	0.03	4.44
2	1	2	2	26.0	0.41	1.50	0.23	0.03	2.17

Table 14 (Continued)

Treatment*				% Dry Weight	Ca	K	Mg	Na	Total
Ca	K	Mg	Na						
2	1	2	1	27.0	1.18	2.08	0.59	0.02	3.87
2	1	1	2	24.0	0.78	1.70	0.28	0.03	2.79
2	1	1	1	24.0	0.43	1.42	0.20	0.03	2.08
1	3	2	2	22.0	0.33	3.04	0.26	0.05	3.68
1	3	2	1	22.0	0.45	3.59	0.30	0.02	4.36
1	3	1	2	21.5	0.47	3.39	0.27	0.06	4.19
1	3	1	1	22.0	0.71	3.85	0.38	0.02	4.96
1	2	2	2	22.2	0.79	1.57	0.35	0.02	2.73
1	2	2	1	26.0	0.52	1.92	0.25	0.02	2.71
1	2	1	2	26.0	0.70	1.57	0.60	0.03	2.90
1	2	1	1	23.0	0.79	1.49	0.62	0.04	2.94
1	1	2	2	23.2	0.77	1.98	0.24	0.03	3.02
1	1	2	1	26.0	0.51	1.90	0.27	0.03	2.71
1	1	1	2	24.2	0.61	2.08	0.26	0.02	2.97
1	1	1	1	22.2	0.58	1.42	0.26	0.04	2.30
Average				22.7	0.70	2.11	0.33	0.04	3.25
Relative %					21.63	65.01	10.01	1.15	100.00

* See Table 1.

Table 15. The per cent dry weight and the calcium, potassium, magnesium, and sodium composition of tomato (leaves and stems), as influenced by each of the thirty-six fertilizer treatments (expressed as per cent dry weight).

Treatment*				% Dry Weight	Ca	K	Mg	Na	Total
Ca	K	Mg	Na						
3	3	2	2	13.5	5.55	2.58	1.66	0.23	10.02
3	3	2	1	12.0	5.46	2.47	2.29	0.02	10.24
3	3	1	2	11.5	5.48	2.70	1.25	0.23	9.66
3	3	1	1	12.5	5.39	3.23	1.86	0.02	10.50
3	2	2	2	12.5	4.10	2.35	2.59	0.41	9.45
3	2	2	1	12.0	5.01	1.88	4.56	0.07	11.52
3	2	1	2	14.0	7.05	2.02	1.76	0.43	11.26
3	2	1	1	15.0	5.64	2.83	1.54	0.03	10.04
3	1	2	2	13.5	5.98	1.54	2.42	0.59	10.53
3	1	2	1	13.0	4.90	1.80	1.78	0.17	8.65
3	1	1	2	13.0	6.46	2.26	1.36	0.44	10.52
3	1	1	1	15.5	6.00	1.68	1.62	0.29	9.59
2	3	2	2	12.0	5.20	2.86	1.90	0.15	10.11
2	3	2	1	12.5	5.47	2.82	1.93	0.03	10.25
2	3	1	2	14.0	5.58	2.58	1.79	0.29	10.24
2	3	1	1	13.0	4.97	3.29	1.63	0.07	9.96
2	2	2	2	11.0	5.86	1.99	2.06	0.42	10.33
2	2	2	1	15.0	5.04	2.08	1.94	0.07	9.13
2	2	1	2	11.5	4.85	2.67	1.88	0.23	9.63
2	2	1	1	12.5	5.95	2.55	1.51	0.13	10.14
2	1	2	2	10.5	5.49	0.88	1.90	0.82	9.09

Table 15 (Continued)

Treatment*				% Dry Weight	Ca	K	Mg	Na	Total
Ca	K	Mg	Na						
2	1	2	1	15.0	4.24	1.32	2.14	0.13	7.83
2	1	1	2	12.0	6.78	1.27	1.59	0.67	10.31
2	1	1	1	14.5	4.25	1.49	1.16	0.48	7.38
1	3	2	2	10.0	4.62	3.36	1.70	0.17	9.85
1	3	2	1	13.0	4.72	3.35	1.87	0.06	10.00
1	3	1	2	12.5	4.62	4.20	1.26	0.18	10.26
1	3	1	1	12.0	4.65	4.05	0.94	0.03	9.67
1	2	2	2	12.5	5.15	2.42	1.71	0.32	9.60
1	2	2	1	12.5	5.21	2.44	1.39	0.08	9.12
1	2	1	2	12.0	6.07	2.24	0.96	0.51	9.78
1	2	1	1	12.0	6.28	1.75	1.48	0.13	9.64
1	1	2	2	10.0	5.04	0.86	2.75	0.87	9.52
1	1	2	1	14.0	3.83	2.00	2.02	0.12	7.97
1	1	1	2	14.0	5.90	1.00	1.22	1.09	9.21
1	1	1	1	15.0	5.79	1.58	1.59	0.13	9.09
Average				12.8	5.35	2.29	1.81	0.28	9.72
Relative %					55.01	23.53	18.57	2.89	100.00

* See Table 1.

Table 16. The per cent dry weight and the calcium, potassium, magnesium, and sodium composition of potato (leaves and stems), as influenced by each of the thirty-six fertilizer treatments (expressed as per cent dry weight).

Treatment*				% Dry Weight	Ca	K	Mg	Na	Total
Ca	K	Mg	Na						
3	3	2	2	10.0	3.03	4.34	2.52	0.06	9.95
3	3	2	1	10.0	3.01	2.20	4.82	0.03	10.06
3	3	1	2	12.0	3.02	4.09	2.82	0.04	9.97
3	3	1	1	12.0	3.06	3.74	1.60	0.09	8.49
3	2	2	2	11.0	2.49	3.12	2.12	0.05	7.78
3	2	2	1	14.0	2.48	5.10	2.28	0.05	9.91
3	2	1	2	11.0	3.32	2.97	3.48	0.05	9.82
3	2	1	1	13.0	3.15	2.18	1.55	0.06	6.94
3	1	2	2	14.0	2.61	2.63	2.21	0.04	7.49
3	1	2	1	14.0	3.29	1.78	3.42	0.04	8.53
3	1	1	2	15.0	3.59	2.93	1.75	0.02	8.29
3	1	1	1	14.0	2.92	4.35	1.96	0.06	9.29
2	3	2	2	12.0	3.16	4.71	2.24	0.06	10.17
2	3	2	1	14.0	2.88	4.37	2.22	0.03	9.50
2	3	1	2	12.0	3.02	4.85	1.89	0.06	9.82
2	3	1	1	14.0	2.47	4.11	1.68	0.03	8.29
2	2	2	2	12.0	2.96	3.25	5.96	0.06	12.23
2	2	2	1	14.0	2.71	3.73	4.52	0.03	10.99
2	2	1	2	12.0	2.93	4.00	2.10	0.05	9.08
2	2	1	1	12.0	2.58	2.96	2.72	0.03	8.29
2	1	2	2	14.0	3.40	3.01	4.14	0.07	10.62

Table 16 (Continued)

Treatment*				% Dry Weight	Ca	K	Mg	Na	Total
Ca	K	Mg	Na						
2	1	2	1	14.0	3.75	1.95	5.24	0.03	10.97
2	1	1	2	12.0	4.11	1.80	1.48	0.08	7.47
2	1	1	1	16.0	3.95	2.72	1.56	0.03	8.26
1	3	2	2	13.0	2.64	4.15	2.41	0.03	9.23
1	3	2	1	12.0	3.09	3.09	2.43	0.07	8.68
1	3	1	2	11.0	2.92	4.44	0.99	0.03	8.38
1	3	1	1	13.0	2.94	4.19	1.63	0.05	8.81
1	2	2	2	12.0	3.24	2.90	1.96	0.03	8.13
1	2	2	1	12.0	3.24	3.99	1.96	0.06	9.25
1	2	1	2	11.0	2.81	1.96	1.09	0.02	5.88
1	2	1	1	12.0	2.66	4.08	1.24	0.05	8.03
1	1	2	2	11.0	2.62	1.84	10.60	0.02	15.08
1	1	2	1	14.0	2.42	3.45	6.28	0.04	12.19
1	1	1	2	14.0	2.98	1.80	4.14	0.03	8.95
1	1	1	1	16.0	3.10	2.88	2.34	0.06	8.38
Average				12.8	3.02	3.32	2.87	0.05	9.26
Relative %					32.58	35.91	31.02	0.49	100.00

* See Table 1.

Table 17. The per cent dry weight and the calcium, potassium, magnesium, and sodium composition of muskmelon (leaves and stems), as influenced by each of the thirty-six fertilizer treatments (expressed as per cent dry weight).

Treatment*				% Dry Weight	Ca	K	Mg	Na	Total
Ca	K	Mg	Na						
3	3	2	2	10.0	5.86	3.22	1.82	0.47	11.37
3	3	2	1	11.5	8.38	3.11	5.52	0.04	17.05
3	3	1	2	10.0	8.28	3.23	1.55	0.73	13.79
3	3	1	1	11.0	6.98	3.70	1.88	0.08	12.64
3	2	2	2	10.0	5.91	2.83	2.21	0.45	11.40
3	2	2	1	12.5	5.25	3.66	1.62	0.06	10.59
3	2	1	2	11.5	5.73	2.41	1.39	0.79	10.32
3	2	1	1	13.5	6.08	3.58	0.80	0.07	10.53
3	1	2	2	10.0	10.05	1.00	1.82	1.54	14.41
3	1	2	1	14.0	7.90	1.33	1.66	0.18	11.07
3	1	1	2	11.5	10.07	1.41	1.24	0.64	13.36
3	1	1	1	13.0	8.58	1.80	1.21	0.28	11.87
2	3	2	2	10.0	7.03	4.00	3.40	0.41	14.84
2	3	2	1	10.0	7.17	3.68	1.95	0.05	12.85
2	3	1	2	12.0	6.59	3.91	1.36	0.40	12.26
2	3	1	1	10.0	5.70	3.74	1.28	0.06	10.78
2	2	2	2	11.5	6.49	2.81	2.20	0.33	11.83
2	2	2	1	12.0	8.58	2.47	5.40	0.05	16.50
2	2	1	2	10.5	7.24	2.81	1.61	0.24	11.90
2	2	1	1	12.0	5.83	3.88	1.45	0.11	11.27
2	1	2	2	11.5	8.89	0.88	3.72	0.84	14.33

Table 17 (Continued)

Treatment*				% Dry Weight	Ca	K	Mg	Na	Total
Ca	K	Mg	Na						
2	1	2	1	10.0	8.63	0.66	6.80	0.10	16.19
2	1	1	2	12.0	7.92	1.02	1.45	0.85	11.24
2	1	1	1	12.5	8.06	0.79	1.52	0.54	10.91
1	3	2	2	11.5	8.04	2.67	3.72	0.37	14.80
1	3	2	1	10.5	6.65	3.53	2.86	0.04	13.08
1	3	1	2	10.0	7.16	3.03	1.40	0.44	12.03
1	3	1	1	12.0	7.75	3.72	1.52	0.05	13.04
1	2	2	2	10.0	6.65	2.61	1.87	0.45	11.58
1	2	2	1	12.0	6.35	3.36	2.20	0.11	12.02
1	2	1	2	10.5	7.42	2.18	1.34	0.41	11.35
1	2	1	1	13.5	6.40	2.32	1.25	0.07	10.04
1	1	2	2	10.0	5.45	0.92	4.75	0.71	11.83
1	1	2	1	13.5	7.24	0.60	7.00	0.07	14.91
1	1	1	2	11.5	6.33	0.78	1.26	1.90	10.27
1	1	1	1	12.0	9.01	0.52	1.97	0.10	11.60
Average				11.5	7.27	2.45	2.39	0.39	12.50
Relative %					58.16	19.60	19.12	3.12	100.00

* See Table 1.

Table 18. The per cent dry weight and the calcium, potassium, magnesium, and sodium composition of cucumber (leaves and stems), as influenced by each of the thirty-six fertilizer treatments (expressed as per cent dry weight).

Treatment*				% Dry Weight	Ca	K	Mg	Na	Total
Ca	K	Mg	Na						
3	3	2	2	10.0	5.00	4.24	4.69	0.65	14.58
3	3	2	1	9.0	5.25	3.96	5.62	0.50	15.33
3	3	1	2	10.5	3.35	5.86	1.46	1.04	11.71
3	3	1	1	10.5	3.58	4.35	1.95	0.03	9.91
3	2	2	2	11.5	3.26	2.13	1.54	0.25	7.18
3	2	2	1	11.0	4.63	3.09	2.44	0.02	10.18
3	2	1	2	10.5	4.91	2.74	1.72	0.35	9.72
3	2	1	1	11.5	2.76	1.88	0.83	0.02	5.49
3	1	2	2	11.0	3.22	2.36	1.48	0.49	7.55
3	1	2	1	9.5	4.00	2.88	2.22	0.27	9.37
3	1	1	2	9.5	4.01	2.42	1.33	0.43	8.19
3	1	1	1	11.5	5.49	2.08	1.63	0.05	9.25
2	3	2	2	9.5	3.47	3.34	1.68	0.25	8.74
2	3	2	1	9.0	5.00	3.08	2.23	0.06	10.37
2	3	1	2	9.0	2.92	2.99	0.89	0.32	7.12
2	3	1	1	10.0	2.64	4.97	0.89	0.05	8.55
2	2	2	2	9.0	3.65	2.75	5.12	0.59	12.11
2	2	2	1	8.5	3.48	3.24	2.59	0.03	9.34
2	2	1	2	9.5	4.56	2.87	2.21	0.11	9.75
2	2	1	1	10.0	4.73	4.21	2.07	0.13	11.14
2	1	2	2	12.0	4.25	1.24	2.82	0.47	8.78

Table 18 (Continued)

Treatment*				% Dry Weight	Ca	K	Mg	Na	Total
Ca	K	Mg	Na						
2	1	2	1	12.0	3.70	1.43	4.56	0.04	9.73
2	1	1	2	12.0	4.76	1.19	1.40	0.41	7.76
2	1	1	1	11.5	4.19	1.38	1.27	0.06	6.90
1	3	2	2	9.5	3.66	4.01	3.20	0.87	11.74
1	3	2	1	10.0	2.00	3.76	1.19	0.05	7.00
1	3	1	2	9.5	2.81	4.85	1.44	0.70	9.80
1	3	1	1	8.5	2.60	3.78	1.12	0.03	7.53
1	2	2	2	9.5	3.82	2.97	4.66	0.48	11.93
1	2	2	1	8.0	2.85	2.63	2.17	0.03	7.68
1	2	1	2	10.0	3.67	4.34	2.29	0.72	11.02
1	2	1	1	10.0	3.00	2.51	1.44	0.03	6.98
1	1	2	2	10.0	2.90	1.75	2.92	0.30	7.87
1	1	2	1	9.0	2.44	1.52	2.31	0.03	6.30
1	1	1	2	10.0	2.03	2.04	0.85	0.25	5.17
1	1	1	1	8.0	4.89	1.69	4.08	0.04	10.70
Average				10.0	3.71	2.96	2.29	0.28	9.24
Relative %					40.15	32.03	24.78	3.04	100.00

* See Table 1.

Table 19. The per cent dry weight and the calcium, potassium, magnesium, and sodium composition of squash (leaves and stems), as influenced by each of the thirty-six fertilizer treatments (expressed as per cent dry weight).

Treatment*				% Dry Weight	Ca	K	Mg	Na	Total
Ca	K	Mg	Na						
3	3	2	2	9.0	8.92	2.93	8.30	0.04	20.19
3	3	2	1	12.5	9.55	4.12	12.20	0.03	25.90
3	3	1	2	8.0	13.37	4.12	9.76	0.13	27.38
3	3	1	1	10.5	8.19	3.92	3.80	0.02	15.93
3	2	2	2	12.0	7.89	4.03	7.90	0.07	19.89
3	2	2	1	10.0	11.01	3.18	19.45	0.04	33.68
3	2	1	2	9.0	12.20	1.97	4.65	0.22	19.04
3	2	1	1	9.0	10.10	2.26	2.55	0.04	14.95
3	1	2	2	12.0	10.10	1.11	8.45	0.04	19.70
3	1	2	1	11.0	12.97	1.33	9.80	0.02	24.12
3	1	1	2	10.0	15.92	1.29	8.16	0.04	25.41
3	1	1	1	8.5	13.60	1.30	2.00	0.03	16.93
2	3	2	2	11.0	9.83	3.91	16.35	0.11	30.20
2	3	2	1	9.0	10.79	3.72	14.00	0.03	28.54
2	3	1	2	8.0	8.85	4.10	2.50	0.03	15.48
2	3	1	1	10.5	13.80	4.07	8.45	0.04	26.36
2	2	2	2	8.0	11.06	4.14	13.10	0.05	28.35
2	2	2	1	11.0	12.21	2.79	11.10	0.03	26.13
2	2	1	2	10.0	9.27	4.06	5.70	0.04	19.07
2	2	1	1	10.5	10.99	3.91	7.91	0.02	22.83
2	1	2	2	11.0	7.42	2.69	7.15	0.07	17.33

Table 19 (Continued)

Treatment*				% Dry Weight	Ca	K	Mg	Na	Total
Ca	K	Mg	Na						
2	1	2	1	11.0	8.24	1.91	24.00	0.02	34.17
2	1	1	2	13.0	10.37	1.82	5.52	0.05	17.76
2	1	1	1	14.0	7.00	1.67	1.68	0.02	10.37
1	3	2	2	10.0	6.52	4.89	5.99	0.03	17.43
1	3	2	1	9.5	7.94	3.71	3.77	0.02	15.44
1	3	1	2	10.0	8.68	3.98	4.30	0.10	17.06
1	3	1	1	9.0	8.48	4.76	4.03	0.03	17.30
1	2	2	2	10.2	6.52	4.51	7.10	0.04	18.17
1	2	2	1	10.0	9.42	3.40	15.00	0.02	27.84
1	2	1	2	8.0	8.87	3.53	4.52	0.06	16.98
1	2	1	1	11.5	9.42	3.10	4.48	0.02	17.02
1	1	2	2	11.0	7.89	2.20	23.50	0.03	33.62
1	1	2	1	11.5	11.20	1.54	22.50	0.03	35.27
1	1	1	2	9.0	8.98	2.36	4.65	0.03	16.02
1	1	1	1	14.0	11.05	2.12	8.18	0.02	21.37
Average				10.3	9.96	3.07	8.96	0.05	22.03
Relative %					45.21	13.94	40.67	0.20	100.02

* See Table 1.

Table 20. The per cent dry weight and the calcium, potassium, magnesium, and sodium composition of lettuce (plant), as influenced by each of the thirty-six fertilizer treatments (expressed as per cent dry weight).

Treatment*				% Dry Weight	Ca	K	Mg	Na	Total
Ca	K	Mg	Na						
3	3	2	2	4.7	0.46	5.60	0.50	0.19	6.75
3	3	2	1	4.5	0.44	3.88	0.31	0.05	4.68
3	3	1	2	4.5	0.59	5.02	0.42	0.23	6.26
3	3	1	1	6.2	0.39	4.03	0.31	0.05	4.78
3	2	2	2	4.7	0.24	3.55	0.36	0.11	4.26
3	2	2	1	5.0	0.29	3.64	0.44	0.05	4.42
3	2	1	2	4.5	0.78	4.02	0.54	0.28	5.62
3	2	1	1	5.3	0.76	3.64	0.49	0.04	4.93
3	1	2	2	5.9	0.64	2.91	0.50	0.54	4.59
3	1	2	1	3.8	0.52	3.55	0.48	0.07	4.62
3	1	1	2	4.8	0.53	2.27	0.34	0.59	3.73
3	1	1	1	4.9	0.64	1.93	0.30	0.14	3.01
2	3	2	2	4.6	0.29	4.40	0.46	0.21	5.36
2	3	2	1	5.1	0.32	3.88	0.31	0.05	4.56
2	3	1	2	4.6	0.42	3.08	0.54	0.14	4.18
2	3	1	1	4.5	0.45	4.70	0.51	0.07	5.73
2	2	2	2	5.5	0.39	3.94	0.53	0.31	5.17
2	2	2	1	4.2	0.46	4.04	0.53	0.08	5.11
2	2	1	2	4.7	0.35	3.93	0.50	0.21	4.99
2	2	1	1	5.7	0.43	3.81	0.49	0.10	4.83
2	1	2	2	5.1	0.57	2.85	0.54	0.53	4.49

Table 20 (Continued)

Treatment*				% Dry Weight	Ca	K	Mg	Na	Total
Ca	K	Mg	Na						
2	1	2	1	5.9	0.33	1.95	0.26	0.07	2.61
2	1	1	2	4.9	0.26	2.31	0.26	0.21	3.04
2	1	1	1	4.8	0.22	1.57	0.29	0.53	2.61
1	3	2	2	5.8	0.34	3.24	0.44	0.22	4.24
1	3	2	1	5.2	0.32	4.15	0.20	0.06	4.73
1	3	1	2	5.9	0.46	3.90	0.40	0.34	5.10
1	3	1	1	4.7	0.53	4.81	0.48	0.06	5.88
1	2	2	2	5.0	0.37	3.92	0.43	0.33	5.05
1	2	2	1	5.8	0.51	3.61	0.45	0.09	4.66
1	2	1	2	4.7	0.45	3.81	0.40	0.34	5.00
1	2	1	1	5.8	0.26	3.14	0.24	0.07	3.71
1	1	2	2	5.1	0.30	3.22	0.38	0.42	4.32
1	1	2	1	5.5	0.19	2.52	0.32	0.07	3.10
1	1	1	2	6.0	0.48	2.56	0.36	0.19	3.59
1	1	1	1	5.4	0.37	2.55	0.30	0.11	3.33
Average				5.1	0.43	3.50	0.41	0.20	4.53
Relative %					9.49	77.26	9.05	4.42	100.00

* See Table 1.

Table 21. The calcium, potassium, magnesium, and sodium composition of pea (fruit), as influenced by each of the thirty-six fertilizer treatments (expressed as per cent dry weight).

Treatment* Ca	K	Mg	Na	Ca	K	Mg	Na	Total
3	3	2	2	2.68	4.96	1.58	0.03	9.25
3	3	2	1	2.41	5.16	1.58	0.03	9.18
3	3	1	2	2.52	5.60	1.12	0.02	9.26
3	3	1	1	2.47	4.58	1.36	0.03	8.44
3	2	2	2	2.06	3.92	3.43	0.03	9.44
3	2	2	1	1.63	2.74	5.12	0.04	9.53
3	2	1	2	2.55	3.75	1.73	0.04	8.07
3	2	1	1	2.72	4.04	1.55	0.02	8.33
3	1	2	2	3.31	1.52	3.13	0.03	7.99
3	1	2	1	3.14	2.14	2.55	0.03	7.86
3	1	1	2	3.87	0.97	2.15	0.08	7.07
3	1	1	1	4.41	1.49	1.65	0.03	7.58
2	3	2	2	2.50	5.34	1.80	0.03	9.67
2	3	2	1	3.14	4.23	2.00	0.03	9.40
2	3	1	2	3.31	4.35	2.23	0.04	9.93
2	3	1	1	2.79	5.17	1.32	0.02	9.30
2	2	2	2	3.27	4.33	2.02	0.04	9.66
2	2	2	1	2.52	3.22	1.23	0.03	7.00
2	2	1	2	3.02	3.86	1.88	0.02	8.78
2	2	1	1	2.70	4.29	1.42	0.03	8.44
2	1	2	2	2.65	1.77	1.94	0.04	6.40

Table 21 (Continued)

Treatment*				Ca	K	Mg	Na	Total
Ca	K	Mg	Na					
2	1	2	1	2.70	0.85	2.27	0.02	5.84
2	1	1	2	3.20	1.09	1.77	0.04	6.10
2	1	1	1	3.78	0.90	1.82	0.03	6.53
1	3	2	2	2.48	5.34	1.62	0.03	9.47
1	3	2	1	2.73	5.35	2.02	0.03	10.13
1	3	1	2	2.46	5.64	1.35	0.03	9.48
1	3	1	1	2.21	6.10	1.48	0.02	9.81
1	2	2	2	2.46	3.96	1.89	0.03	8.34
1	2	2	1	1.97	4.75	1.65	0.02	8.39
1	2	1	2	2.45	4.38	1.33	0.02	8.18
1	2	1	1	2.30	4.28	1.48	0.02	8.08
1	1	2	2	2.73	0.98	4.62	0.04	8.37
1	1	2	1	2.69	1.17	5.65	0.03	9.54
1	1	1	2	3.54	2.32	1.98	0.04	7.88
1	1	1	1	3.14	1.82	1.96	0.03	6.95
Average				2.79	3.51	2.10	0.03	8.44
Relative %				33.06	41.59	24.88	0.36	100.00

* See Table 1.

Table 22. The calcium, potassium, magnesium, and sodium composition of tomato (fruit), as influenced by each of the thirty-six fertilizer treatments (expressed as per cent dry weight).

Treatment*				Ca	K	Mg	Na	Total
Ca	K	Mg	Na					
3	3	2	2	0.15	5.04	0.38	0.10	5.67
3	3	2	1	0.23	5.00	0.41	0.03	5.67
3	3	1	2	0.16	4.75	0.34	0.10	5.35
3	3	1	1	0.15	5.20	0.40	0.02	5.77
3	2	2	2	0.05	5.29	0.35	0.11	5.80
3	2	2	1	0.03	4.81	0.32	0.02	5.18
3	2	1	2	0.13	4.57	0.30	0.08	5.08
3	2	1	1	0.06	4.50	0.32	0.02	4.90
3	1	2	2	0.16	3.35	0.24	0.12	3.87
3	1	2	1	0.09	3.00	0.22	0.05	3.36
3	1	1	2	0.22	3.99	0.28	0.13	4.62
3	1	1	1	0.30	4.78	0.37	0.08	5.53
2	3	2	2	0.23	4.76	0.35	0.08	5.42
2	3	2	1	0.06	4.81	0.33	0.02	5.22
2	3	1	2	0.11	4.81	0.35	0.08	5.35
2	3	1	1	0.10	4.76	0.37	0.03	5.20
2	2	2	2	0.01	4.69	0.35	0.07	5.12
2	2	2	1	0.16	4.30	0.28	0.03	4.77
2	2	1	2	0.03	4.67	0.28	0.06	5.04
2	2	1	1	0.03	4.61	0.29	0.04	4.97
2	1	2	2	0.01	3.17	0.26	0.18	3.62

Table 22 (Continued)

Treatment*				Ca	K	Mg	Na	Total
Ca	K	Mg	Na					
2	1	2	1	0.01	2.69	0.20	0.05	2.95
2	1	1	2	0.11	3.83	0.24	0.18	4.36
2	1	1	1	0.05	2.95	0.21	0.14	3.35
1	3	2	2	0.03	4.60	0.29	0.07	4.99
1	3	2	1	0.03	4.80	0.28	0.02	5.13
1	3	1	2	0.01	4.50	0.28	0.07	4.86
1	3	1	1	0.06	4.39	0.28	0.02	4.75
1	2	2	2	0.11	4.61	0.34	0.08	5.14
1	2	2	1	0.03	4.40	0.29	0.03	4.75
1	2	1	2	0.05	4.34	0.32	0.12	4.83
1	2	1	1	0.10	4.65	0.34	0.06	5.15
1	1	2	2	0.01	3.03	0.22	0.21	3.47
1	1	2	1	0.01	2.87	0.19	0.04	3.11
1	1	1	2	0.08	3.36	0.22	0.29	3.95
1	1	1	1	0.02	3.10	0.20	0.04	3.36
Average				0.09	4.25	0.30	0.08	4.71
Relative %				1.87	90.23	6.37	1.70	100.00

* See Table 1.