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Cationic Saturation of Low Exchange Soils for Growth of Vegetable Crops

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INTRODUCTION

In spite of the fundamental advances that have been made in the fields of plant nutrition and soil science in recent years, continued improvement in vegetable fertilization is dependent upon obtaining experimental data correlating yields and quality with the concentration of specific nutrient elements that are present in the soil and available to the plant. Unfortunately, fertilizer recommendations still are frequently made on the basis of what a particular crop removes from the soil, with little consideration of such factors as the nutrient concentrations present before fertilization, the soil's ability to fix nutrients in a non-available state, the rate of release from the soil's colloidal fraction for the period of growth of the plant, and losses from leaching. Furthermore, because of the relative immobility of some mineral nutrients, their availability to the plant apparently is largely dependent upon the extent to which root contact is made with the soil particle. Thus knowledge of the root distribution of vegetable species and of the physico-chemical properties of root tissues is another essential but relatively unknown entity in the soil-plant relationship. Certainly this is a fertile field for future investigation.

Considering the improvement in fertilization practices in recent years, particularly in midwestern states, there can be little question as to the merits of using a reliable soil testing system as a fertilization guide. Not only are soil analyses a valuable index of the relative fertility of a particular soil and a valuable guide for diagnosing crop troubles and for applying fertilizers, but they are also valuable in avoiding improper fertilizer practices such as excessive total concentration or improper balance among the nutrients. Aside from the limitations of representative sampling and experience of testing personnel, the proper interpretation of test results remains perhaps the greatest limitation. For more effective use of soil test data, therefore, much work is yet to be done, in correlating plant response with concentrations of soil nutrients, taking such other factors as exchange capacity, root development, and species requirements into consideration. Only in this way can the calculated risks of plant nutrition limits in production be reduced.

With continued improvement in soil analysis techniques, including the exchangeable or buffer hydrogen test, it is now possible to evaluate rapidly and accurately enough for fertilizer practice, (a) the nutrient supply available initially, (b) the approximate rate of nutrient release or loss from the colloidal fraction, and (c) the approximate exchange capacity of the soil. However, since the nutrient concentration expressed as pounds per acre does not appear to indicate the same degree of availability on all soils, experiments must be performed to calibrate crop response to nutrient concentrations on soils representing the entire exchange capacity range.

In Missouri, vegetables are grown on soils varying from about 7 ½ milli-equivalents to about 30 milli-equivalents per 100 grams. The soils corresponding to this range include the various types from fine sandy loams to the heavy Wabash River bottom soils. Since the quantity of each cation available for uptake varies with its degree of saturation on the colloidal interface, as well as with the soil's exchange capacity, it would appear advisable to express cationic concentrations as percentages of the total cation exchange capacity when interpreting results on highly variable soils. From the standpoint of both the reserve fertility and the proper concentration of available nutrients at any particular time the optimum saturation levels (ranges) should be determined for both low exchange sandy soils which are fertilized more lightly and more frequently and for the heavier soils of higher exchange capacity and greater fertility reserves which, with the exception of nitrogen, may show response from only a light initial fertilizer application.

Aside from the total plant food available, proper plant nutrition requires that there be a proper balance between the nutrients, including the cationic elements. In this respect, reference must be made directly to the status of the soil colloid as providing a balanced supply for the plant root at a particular time in its development. Since physiologically, the plant is responsive to concentrations representing neither a deficiency nor an excess, it should be apparent that nutrient levels expressed as chemically-equivalent rather than weight-equivalent values should indicate better the proportions or balance of cationic elements held on the active colloids and available for exchange reactions. Consideration of the proportions of cations in relation to the soil's exchange capacity should assist the soil test interpreter in avoiding over-liming and unbalanced relationships among calcium, magnesium, and potassium which result from antagonistic effects of complementary ions.

Even a consideration this complete, however, can be criticized on the basis of the relatively unknown effect of anions. In the fertilization of vegetables, much difficulty is encountered in maintaining a proper relationship between exchangeable calcium and potassium. This relationship is made more difficult because of the effect of liming on soil pH. Aside from the problem of maintaining a favorable pH range (generally around 6.0 to 6.5) with some exchangeable hydrogen on the colloid, sufficient calcium must be available for proper plant response. On low exchange soils, deficient in calcium but having a favorable pH, information on the change in concentration of exchangeable calcium with small lime applications is very important in achieving proper balance, since with heavy applications over liming is likely to occur. On the bottom soils having high exchange capacities, largely of limestone origin and subject to overflow, difficulty is experienced with high exchangeable calcium concentrations, high pH, and frequently with free carbonates. On such soils, induced potash deficiencies may occur on vegetables with extremely high potash requirements. Under these circumstances, it is desirable that the exchangeable or buffer hydrogen be determined in addition to the pH, since it represents a measure of the colloidal contact stations devoid of bases and capable of exchange. In other words, knowledge of the reserve or total hydrogen available on the colloidal interface, as influenced by the soil's exchange capacity and relative saturation with hydrogen, will furnish a better picture of the calcium needs and the balance between the exchangeable calcium and other cations, magnesium, and potassium.

Because vegetables having different plant nutrient requirements are usually grown in short rotations, it appears desirable in fertilization practice to establish a basic fertility level, representing optimum ranges of concentrations of the various elements which are favorable for vegetables in general, and then meet the specific requirements in the annual fertilization program by varying the rates and analyses of fertilizers applied.

With these considerations and objectives in mind, several carefully controlled experiments were conducted on low-exchange soils to obtain more accurate and fundamental knowledge regarding the ideal exchange complexes for vegetable crops, especially those that appeared responsive to the higher levels of soil fertility.

REVIEW OF LITERATURE

In the search for better guides to fertilization practice, much consideration has been given to determining the nutrient requirements of various crops by analysis of their element content. From such work, with reference to total nutrient requirements, the approximate nutrient removal by various vegetables has been determined under conditions of variable climate and for different levels of fertility. The fact that different vegetable species differ in their requirements for certain nutrients and in the proportions of nutrients has also been verified.

Valuable as these considerations have been in determining nutrient requirements of plants, they are inadequate as a guide to fertilization practice where the soil's fixation capacity is unsatisfied or in areas having widely divergent inherent fertility or fertilization practices. With recent increase in knowledge concerning the contributions of the soil itself, the emphasis has shifted to correlating plant response with the concentrations of available nutrients, as indicated by soil test values (6, 7, 8, 18, 36, 41). Even here, the limitations of the soil testing technique, particularly those of sampling and proper interpretation of results, are widely recognized (13, 37, 38). Coleman (15) has summarized the major considerations when integrating fertilizer recommendations with soil test results.

The various soil testing systems differ chemically in the strength of extracting solutions, in their sensitivity, and the degree to which they indicate availability to the plant root. Consequently, they may give different concentration values for a given soil sample. Correlation experiments are therefore necessary for each system to "calibrate" soil test concentrations in terms of crop response. Generally, the concentration of nutrients are expressed as pounds per acre of available or exchangeable elements except where only the soluble nutrients are determined, in which case they are frequently given as parts per million.

Determination of the concentration of soluble nutrients (in the soil solution) by soil test determinations is insufficiently applicable to actual soil or colloidal systems since it does not reflect the reserve fertility or fixation capacity. Even where the extracting solution removes some "exchangeable" nutrients, consideration must be given to the soil's exchange capacity to evaluate reserve fertility.

Subsequent to the discovery of the physio-chemical properties of colloids and the quantitative relationship between base exchange phenomena and the degree of colloidal saturation (23), improved methods of soil analysis, including the exchangeable or buffer hydrogen test (45), it is possible to determine the soil's base exchange capacity with sufficient speed and accuracy and to express the concentration of cations as percentages of the total base exchange capacity. In this manner, the relative saturation (a measure of cation balance) of each cation on the colloidal interface can be expressed in chemically-equivalent terms.

With the advancement of knowledge concerning soil chemistry, the importance of the exchange of cations between soil colloids and the root colloidal surface became apparent (1, 18, 25, 28, 29). This phenomenon was termed " cation exchange" by Jenny and Overstreet (25) and demonstrated by means of calcium-hydrogen systems by Albrecht (1), Horner (21), Allaway (4), Mehlich and Colwell (31), and Mehlich (30). It has also been shown that plant growth in soils and artificial colloidal substrates is more closely related to the degree of base saturation than to the total supply of exchangeable bases (14, 23, 29, 31, 34).

Several papers indicating that more consideration should be given to the relation of degree of base saturation to plant growth have been reported in the last two decades. A number of investigators, including Gedroiz (17), found that the availability of exchangeable calcium for plant growth was significant only when its degree of saturation was relatively high. Results of a study made by Jenny and Cowan (24) showed that the growth of soybean plants in Ca-H clay suspensions was sharply reduced when the degree of calcium saturation fell below 30 percent of the total exchange capacity. Horner (21), also working with soybeans, found that when keeping the total amount of calcium constant, the growth of the plants, as measured by both height and weight, increased markedly as the degree of calcium saturation increased from 40 to 60 percent. In his discussion of degree of calcium saturation of clay and nitrogen fixation, Albrecht (2) concluded that plants absorbed calcium to a much greater extent from the same original total supply when it was on a nearly saturated clay than on one only partly saturated. Studies made by Mehlich and Reed (32) and Mehlich and Colwell (31) further indicated that delivery of calcium to plants varied with the base saturation of the soil. In a study of the relative significance of the degree of calcium saturation of serpentine soils as a factor in the calcium availability and its effect on the growth of romaine lettuce and barley, Vlamis (43) found that where magnesium was a complementary ion there was a sharp reduction in lettuce and barley growth as the degree of calcium saturation fell below 20 percent. Lettuce rosette did not appear when the calcium saturation was about 25 percent. Where potassium was the predominant complementary ion, the reduction in yield and the appearance of rosette in lettuce set in at 30 percent calcium saturation. Good yields of both crops were obtained with calcium saturation as high as 90 percent.

Albrecht and Schroeder (3), in their studies of plant nutrition and the hydrogen ion, pointed out the importance of a significant degree of hydrogen ion saturation in mobilizing calcium, magnesium, and other cations into the plants. They reported no effect on the availability of potassium.

The controversy of late as to effects of degree of base saturation in relation to cation availability has been attributed, at least in part, to the differences in the nature of clay minerals. Delivery of Zn and K to barley roots was found by Elgabaly (16) definitely to be affected by the type of clay minerals constituting the plant medium. Chu and Turk (14) utilized three different clay mineral types in their recent study on growth and nutrition of plants. Objectives of their extensive investigations were to gain a better understanding of the significance of degree of base saturation and the nature of complementary ions in relation to the growth and composition of certain crops, and also to evaluate the effect of the nature of clay minerals on the availability of exchangeable cations. The investigations conducted by Chu and Turk (14) manifested the following:

1. With the same absolute amount of bases present in the Bentonite-sand mixtures having exchange capacities varying from 2.0 m.e. to 8.0 m. e., in every case the highest percentage of base saturation gave the best yield of oats and rye.

2. Similarity of results between the yields of rye grown on original Kaolin-sand mixtures and the yields of oats grown on diluted Kaolin-sand mixtures indicate that the growth of oats and rye is more closely associated with the base status than with the physical properties of the media. Enough available bases were supplied for maximum plant growth in the Kaolin-sand mixtures at a much lower base saturation as compared with plant response to a base saturation as high as 80 per cent in the Bentonite-sand mixtures. (Bentonite has a much higher exchange capacity than Kaolin.)

3. In growing tomatoes and oats on a Fox sandy loam soil having an exchange capacity of 9.8 m.e. per 100 grams and an original base saturation of 25 percent, but for which base saturations were increased to 50, 75, 100 and 150 percent, respectively, responses by the two crops differed widely. Maximum response by tomatoes was at the 75 percent base saturation level as compared to the maximum response by oats at about the 50 percent level. Thus, the growth of tomatoes and oats increased as the degree of base saturation of the soil increased but only up to a certain level.

4. As to effects of complementary ions on the uptake of exchangeable bases by plants, the results indicated that, referring to the H-ion as standard, the Ca-ion and Mg-ion tended to increase the availability of exchangeable K, while the K-ion tended to decrease the availability of exchangeable Ca and Mg. The well recognized fact that Ca and Mg ions have a mutual repressive effect was also observed.

Plant growth responses and composition are dependent upon the relative proportions as well as absolute amounts of variable nutrient elements in the media. That soils nearly saturated with bases such as sodium, ammonium, and potassium would not deliver adequate calcium to plants for good growth when the necessary or even an excess of necessary amounts of calcium were added to the cultures, was demonstrated by Gedroiz (17) and Bower and Turk (12). Mehlich and Reed (33), and others (5,26,44) have obtained results much in agreement with those of Chu and Turk (14) regarding effects of complementary ions on the uptake of exchangeable bases by plants. However, study regarding the delivery of elements into plants from colloidal systems appears to be only in its infancy. Besson (11), Lucas (27) and Jarusov (22) have demonstrated that there are many variables in soil-plant exchange relationships not yet understood. In some of the more intensive work along this line Baird and Mehlich (5) have, on a basis of c values (quotients of the Ca: Mg, Ca: K, or Ca:Na ratios in the soil divided by the respective ratios in the plant), been able to calculate the Ca requirement for Swiss Chard. These coefficients may be of great value in formulating more exacting lime and fertilizer recommendations. Thus, the significance of varied nutrient proportions on the soil colloid must not be overlooked. In fact, with the limitations noted, the relative nutrient saturation of the colloid determines, to a great extent, the amounts and proportions of nutrients available to the root. Recently, the percentage saturation concept has been applied in actual fertilization practice in most sections of the state on a great variety of crops. Workers in other states also have applied the principles in fertilization programs. Thus Bear and Wallace (10), in studying the mineral requirements and chemical composition of alfalfa, gained some confirmation that the exchange complex of the ideal soil should contain about 65 percent Ca, 10 percent Mg, 5 percent K and 20 percent H. Bear and Toth (9) concluded that such a soil was most favorable for tomatoes. A soil of these conditions would have a pH value near 6.5.

MATERIALS AND METHODS

In these investigations the soil testing techniques and methods of calculating cationic saturations described by Graham (18) were used. Although in some cases it was necessary to sacrifice a slight degree of accuracy in technique (as compared to more elaborate and lengthy methods), the advantages of using soil test values directly could not be underestimated. Also, it is believed that representative sampling generally presents a much more difficult problem than the accuracy of the tests themselves.

Wherever possible an experimental design was used that permitted statistical treatment and determination of the experimental error. Where close differences between treatment were anticipated or fundamental ideas were to be tested, greenhouse pot experiments were conducted, using crops such as Bibb lettuce which lend themselves well to pot culture. Randomized field plot techniques were used for further tests and in applying to actual fertilization practice.

Several species were grown, including short-season vegetative types and long-term vegetables which had reproductive parts of economic importance.

In view of the importance of inherent fertility level, the soil's exchange capacity, type of clay, and the relative immobility of most of the cationic elements, special attention was given to the selection of suitable soil samples for each experiment and to the method of distribution of the fertilizers. The soils used in these experiments contained a relatively high content of montmorillonitic (swelling) clays which have a high exchange capacity per unit weight. Hence it is possible to saturate the colloidal fraction to widely varying degrees by starting with a depleted sample. Due to the relative immobility of the exchangeable nutrients and their slow movement in the soil, the fertilizer ingredients were intimately mixed throughout the soil volume in the zone to be occupied by the plant roots. Nitrogen and phosphorus were supplied in sufficient quantities, according to the needs of the plants, that they did not become limiting factors.

To insure accuracy in representative sampling and testing, five or more separate determinations were made on composite samples of soil and the mean test values used in the calculations for each experiment. Concentrations of the four cations, calcium, magnesium, potassium, and hydrogen, were converted to the milli-equivalent basis and the sum of their values was used as an index of the cationic exchange capacities of the soils tested. Graham (18) points out that this value is somewhat higher than that obtained by the standard leaching with ammonium acetate since the calculations are based on divalent ions. The percent saturation of each cation was calculated by dividing the milli-equivalents of each cation by the total cationic exchange capacity expressed in milli-equivalents and multiplying by 100. Calculations were then made regarding the amounts of the various fertilizer salts theoretically required to bring the saturation of each cationic element to the desired level. Since, in most cases, the degrees of saturation, actually achieved were not determined, the results were interpreted in terms of the calculated values. In each experiment comparable amounts of other essential elements were added where it was considered necessary to establish non-limiting levels.

In experiments where it was desirable to know the cation uptake by the plant and the relationship between saturation on the colloid and content in the plant, chemical analyses were made of the plant tissue. After washing the plant tissue several times in distilled water, its dry weight was determined in a forced draft oven at 60° F. It was weighed, cut into small pieces with clean shears, dry-ashed at 450° C. overnight, and the ash weighed and put into solution with Hcl. The ash was then analyzed by the Lundegardh flame technique as given by Mitchell (35).

Precision of this method was probably within ± 5 percent of the amount present.

EXPERIMENTAL RESULTS

Greenhouse Pot Experiments

In the preliminary studies, greenhouse pot experiments permitted close correlation work with relatively low experimental error. Bibb lettuce was found to be an especially desirable test plant in establishing satisfactory base levels from which to plan future work.

Variable Potassium and Magnesium Saturation Effects on Growth and Mineral Composition of Bibb Lettuce

Experimental Plan: Bibb lettuce was grown under greenhouse culture on a Lintonia fine sandy loam soil at two magnesium saturation levels (6.8 and 10.0%) and three potassium levels (2.7, 5.4 and 8.1%). The corresponding milli-equivalent (m.e.) values are given in Table 2. Two nitrogen levels were included, equivalent to 100 pounds per acre and 200 pounds per acre. The phosphorus (P_2O_5) was increased in all treatments to the 300 pound per acre level and the calcium held constant at 66.4 percent of the exchange capacity (4.85 m.e. per 100 grams of soil). Es-Min-El, a trace element mixture, was added to all jars at the rate equivalent to 50 pounds per acre.

The lettuce was grown in one-gallon glazed earthenware pots with each treatment replicated five times and with the pots arranged at random on the greenhouse bench. The soil, by the Missouri method of testing, showed a total exchange capacity of 7.30 milli-equivalents per 100 grams with an organic matter content of 0.95 percent and a pH of 6.0.

In establishing nutrient levels the following fertilizer salts were used in addition to the Es-Min-El; ammonium nitrate, super phosphate (45 percent), potassium sulphate and magnesium sulfate. The salts were finely pulverized, weighed, added in dry form to weighed amounts of shredded air dry soil and carefully mixed to be consistent throughout the entire soil volume. The soil moisture was brought to near optimum before seeding (November 18, 1950) and maintained near that point until harvest (January 31, 1951). No artificial light was supplied. The pH varied slightly in the range 6.2 to 6.5.

Results (Table 1): The results show increasing yields with increasing potassium saturation to the 8.1 percent level. Furthermore, the highly significant linear response in lettuce yield with increasing increments of potassium (0.315 grams increase in dry weight of lettuce per 2.7 percent increase in potassium), suggests that the potassium level could have been

TABLE 1 -- EFFECT OF VARIABLE SATURATION LEVELS OF K AND MG ON THE YIELD OF BIBB LETTUCE AT TWO NITROGEN LEVELS

(Average Dry Weight grams/jar)
November 18, 1950 - Jan. 31, 1951

	Magnesium Saturation 6.85%			10.0%		
N 100 lb./A.	3.18	3.90	3.94	3.10	3.35	3.57
N 200 lb./A.	2.55	2.74	3.34	2.66	2.71	3.16
Potassium Saturation	2.7%	5.4%	8.1%	2.7%	5.4%	8.1%

Analysis of Variance of Data
(12 Treatments - 5 Replications)

Source of Variation	d.f.	s.s.	m.s.
Between Treatments	11	12.0112	1.0919**
N	1	6.3310	6.3310**
K	2	3.9698	
Linear Effect	1	3.9690	3.9690**
Quadratic Effect	1	0.0008	
NK	2	0.4833	
Mg	1	0.4987	
NMg	1	0.3330	
KMg	2	0.3046	
NKMg	2	0.3954	
Within Treatments	48	12.2648	0.2555
S. E. = 0.506			
C. V. = 15.9%			

*P = .05
**P = .01

increased still more before the optimum level was attained. There was no appreciable decline in response due to increasing the magnesium level to the 10 percent level, nor any evidence of interaction. Increase in the nitrogen additions from the 100 lb. per acre to the 200 lb. per acre level resulted in a highly significant decrease in the lettuce yield at all levels of potassium and magnesium. The greatest decrease with increasing nitrogen, however, occurred at the 5.4 percent potassium level.

It is apparent from the data that the best lettuce yield in the series was obtained at a potash saturation of 5.4 to 8.1 percent, magnesium saturation of 6.8 percent, and a nitrogen level of 100 lb. per acre.

Effects on the Mineral Composition of the Plant Tops: As is evident from Table 2, increased potassium saturation of the soil from 2.7 to 8.1 percent of its base exchange capacity, and irrespective of the nitrogen and magnesium levels, resulted in an increased plant ash content. Moreover, by direct comparison of the dry weights and ash content of the plants, it is apparent that a considerable part of the increase in dry weight is accounted for by the ash constituents, especially by potassium. This marked accumulation of minerals, particularly potassium, can hardly be considered luxury consumption since in this case there was a simultaneous increase in dry weight of the plant.

Of the three mineral elements tested in the ash, the greatest variation occurred with potassium. Except in the treatments with 200 lb. N plus 8.1 percent K, the potassium content of the ash increased with increasing K saturation of the soil, varying from 14.5 percent with the treatment using 100 lb. N plus 10 percent Mg plus 2.7 percent K to 45.0 percent of the total ash in the 100 lb. N plus 6.8 percent Mg plus 8.1 percent K series.

The calcium content of the ash showed an inverse relationship to that of potassium, in all cases decreasing with increasing potassium content of the ash. The magnesium content of the ash, with the exception of the series receiving 200 lb. N plus 6.8 percent Mg series showed a parabolic relationship with increasing potash saturation.

The effect of nitrogen fertilization was more apparent in decreasing the dry weight of the plant than in affecting the amount and composition of the ash. These data do not suggest a reason as the non-ash constituents were not determined. However, since the potash uptake did not decrease with increasing nitrogen, the growth reduction cannot be accounted for by the repressive influence of the ammonium ion from the ammonium nitrate.

Certain complementary ion effects are readily reflected in the mineral composition of the tissue when the concentration of the cations Ca, Mg, and K are expressed and compared on a chemically equivalent basis as m.e. per 100 grams dry matter.

The potassium content of the plant shows an almost identical relationship to that shown by the percentage composition of the ash. In only one

TABLE 2 -- EFFECT ON THE ASH CONTENT AND THE PERCENTAGE COMPOSITION OF THE ASH

Nitrogen lb./A.	Percent K saturation	Percent Mg saturation	m.e./100 gms. soil		Percent ash	Percent Element in the ash			m.e./100 gm. dry matter		
			K	Mg		K	Mg	Ca	K	Mg	Ca
100	2.7	6.8	0.20	0.50	14.6	22.0	5.35	6.1	82.0	64.1	44.5
	5.4	6.8	0.39	0.50	17.5	37.9	1.92	4.5	140.5	27.6	39.3
	8.1	6.8	0.59	0.50	24.8	45.0	2.79	3.6	285.5	56.7	44.6
	2.7	10.0	0.20	0.73	14.6	14.5	6.07	5.3	53.7	72.6	38.5
	5.4	10.0	0.39	0.73	20.0	36.3	1.83	3.6	185.9	30.2	35.9
	8.1	10.0	0.59	0.73	23.2	43.2	2.28	2.8	257.1	43.5	32.5
200	2.7	6.8	0.20	0.50	15.9	30.4	3.27	5.3	123.6	42.9	42.1
	5.4	6.8	0.39	0.50	17.8	40.1	2.53	4.8	183.4	36.9	42.7
	8.1	6.8	0.59	0.50	22.5	34.8	1.27	2.8	200.3	23.4	31.4
	2.7	10.0	0.20	0.73	15.8	21.8	7.40	7.0	88.6	96.1	55.3
	5.4	10.0	0.39	0.73	20.3	34.5	2.25	3.9	178.8	37.6	39.5
	8.1	10.0	0.59	0.73	21.1	19.9	2.85	3.3	107.9	49.4	34.8

treatment, 200 lb. N plus 10 percent Mg plus 8.1 percent K, did increasing potash saturation fail to increase the potassium concentration in the dry tissue.

The inverse relationship between calcium content of the tissue and potash saturation of the soil also held on the m.e. basis except at the level of 100 lb. N plus 6.8 percent Mg. Compared with potassium and magnesium, the calcium concentration was limited to a much narrower range.

The magnesium concentration decreased with increasing potash saturation to the 5.4 percent level, then increased to the 8.1 percent level except in the series receiving 200 lb. N plus 6.8 percent Mg, a trend which is identical with that shown in the percentage composition of the ash.

These antagonistic effects and cation relationships, in general, are in agreement with results obtained by other investigators with other plant species (23, 26, 32). The concentrations of cations expressed as m.e. per 100 grams of dry material, however, do not indicate cation equivalent constancy for Bibb lettuce.

Yield and Composition of Bibb Lettuce as Influenced by Potassium Level, Soil Type (Exchange Capacity) and Form of Potash

In investigating further the response by Bibb lettuce to potash saturation, it was desirable to include soils varying in exchange capacity in the range 7.0 to 15.0 milliequivalents (m.e.)/100 grams and, because of a possible anion influence, to supply the additional potash in both the chloride and sulfate forms.

Experimental Plan: Bibb lettuce was grown under greenhouse pot culture on Lintonia fine sandy loam (7.30 m.e./100 gms.), Menfro silt loam (14.69 m.e./100 gms.) and Ray silt loam (12.95 m.e./100 gms.) at four potassium levels, 2.7, 5.4, 8.1 and 10.8 percent of the total base exchange capacity.

The concentrations of nutrients before treatment in each of the three soils, are summarized in Table 3. With all three soils the calcium was established at 86.8 percent and the magnesium at 9.3 percent of the base exchange capacity. By ammonium nitrate and superphosphate additions, the nitrogen and phosphate levels were established at 100 lb. per acre and 300 lb. per acre, respectively. Es-Min-El trace element mixture was added to all treatments at a rate equivalent to 50 lb. per acre. A split block design was used, including five replications of each treatment.

Results (Table 4): indicate a statistically significant yield response with soil type and source of potash. Yields decreased with increasing exchange capacity of the soil. Since no clear-cut responses to potash level are indicated, this decreased growth must have been due to the lowered availability of phosphorus and nitrogen on the higher exchange soils. The nitrogen and phosphorus were brought to the same absolute level (lb. per acre) for each soil at the start of the experiment.

TABLE 3 -- SOIL TEST SUMMARY; CONCENTRATIONS OF CATIONIC ELEMENTS EXPRESSED AS POUNDS PER ACRE AND AS PERCENTAGES OF THE CATION EXCHANGE CAPACITY

Soil Type	% O.M.	Concentration				pH	Buffer Hydrogen ($CaCO_3$ equiv.) Lb./A.	Total C.E.C. (M.E./100 gms.)
		P_2O_5	K	Mg	Ca			
Lintonia f.s.l.								
Available or								
Exc. Nutrients (lb./A)	0.95	60	120	120	1940	6.0	1800	
M.E./100 gm.			0.155	0.50	4.85		1.80	7.30
% of C.E.C.			2.12	6.85	66.43		24.65	
Ray S.L.								
Available or								
Exc. Nutrients (lb./A)	1.0	272	217	225	4500	6.5	500	
M.E./100 gm.			0.27	0.93	11.25		0.50	12.95
% of C.E.C.			2.12	7.18	86.8		3.86	
Menfro S.L.								
Available or								
Exc. Nutrients (lb./A)	0.40	280	168	330	4440	6.2	2000	
M.E./100 gm.			0.22	1.37	11.10		2.00	14.69
% of C.E.C.			1.49	9.32	75.54		13.65	

TABLE 4 -- BIBB LETTUCE YIELD AS INFLUENCED BY POTASH LEVEL SOIL TYPE AND SOURCE OF POTASH
Growing Period November 9 -- January 28, 1952
Yields as Av. Dry Wt. Plant Tops (gms./jar)

K Level Established as % of Cation Exchange Capacity		Lintonia f.s.l.			Ray S. L.			Menfro S. L.		
AS K_2SO_4	as KCl	K as Lb/A.	pH	Yield	Kas Lb./A	pH	Yield	K as Lb./A	pH	Yield
2.7	---	155	6.5	3.94	278	5.7	3.98	310	7.6	3.65
----	2.7		6.4	3.83		5.6	3.57		7.8	3.53
5.4	---	310	6.3	5.06	556	5.6	3.86	620	7.3	4.06
----	5.4		6.2	4.42		5.7	3.99		7.5	3.34
8.1	---	465	6.3	4.80	834	5.7	4.43	930	7.4	3.35
----	8.1		6.2	4.69		5.8	2.97		7.6	3.38
10.8	---	620	6.3	5.04	1112	5.7	4.04	1240	7.2	4.08
			Mean	4.54		Mean	3.83		Mean	3.63

Analysis of Variance of Yields

Source of Variation	df.	S.S.		M.S.	F.
Reps.	4	1.6010		0.4002	
Soil Type (ST)	2	16.1276		8.0638	28.23**
Error (a)	8	2.2847		0.2856	
Treatments (T)	6	8.2807		1.3801	
7 v. rest	1		2.5997	2.5997	7.21**
Source (S)	1		3.2300	2.2300	8.96**
Level (L)	2		2.1056	1.0528	2.92
Linear	1		0.5264	0.5264	
Dev.	1		1.5792	1.5792	4.38*
S X L	2		0.3455	0.1728	
ST X T	12	8.5562		0.7130	
ST X (7 vs. rest)	2		0.2981	0.1490	
ST X S	2		0.4411	0.2206	
ST X L	4		3.6465	0.9116	2.53*
ST X S X L	4		4.1704	1.0426	2.89*
Error (b)	70 (72-2)	25.2295		0.3609	
Total	104.2	62.0797			

*P = .05
**P = .01

Irrespective of exchange capacity and potash level, lettuce growth was better where the sulfate form of potash was applied. This suggests that lettuce, like several other vegetable species, may be sensitive to effects by chlorides. The most striking differences in mineral composition of the lettuce tissue were in the Cl and S content. The tissue concentrations of these elements were indicative of the form of potash applied. On an oven-dry basis, the Cl content of the lettuce grown with the sulfate form was 0.56 percent while that of the muriate fertilized treatments was 2.89 percent. In most instances, there was a progressive increase in the chloride content with increasing rates of fertilization as the muriate form. The potassium sulfate treatments also were reflected by the sulfur content of the tissue, although to a lesser degree. The average sulfur content (oven-dry basis) of the plants fertilized with muriate was 0.35 percent and the content of those fertilized with the sulfate form 0.44 percent. In general, these findings are in accordance with those of other workers such as Schuphan (39), Hayward and Long (19) and Hill (20). The chloride ion appears to be much more mobile and, if present in high concentrations, may be preferentially absorbed. Hence the necessity of considering anions as well as cations in work of this nature. The desirability of continued fertilization with chloride forms of fertilizer also should be questioned.

The F value for "linear" response to potash level was not significant; however, the F value for "deviations" from linearity was significant at $P = 0.05$, indicating substantial deviations from a linear response curve. There were some suggestions of a quadratic regression of yield with levels of potash but this hypothesis could not be tested. This lack of response to potash fertilization is not in agreement with the results obtained in the previous experiment under conditions of lower calcium saturation. Though no response was obtained, heavy fertilization with potassium sulfate (up to 10.8 percent saturation) was not unfavorable for good lettuce growth.

Onions

During 1951 the study of response to potassium saturation was extended to the onion, a vegetative structure modified for the storage of carbohydrates.

Experimental Plan: Southport red globe onions were grown under greenhouse pot culture on Lintonia fine sandy loam (7.30 m.e./100 gms. soil) under all combinations of N-P-K treatments with N at 100 lb. per acre and 200 lb. per acre; P_2O_5 at 100 lb. per acre, 200 lb. per acre and 300 lb. per acre and K at 2.7, 5.4 and 8.1 percent of the cation exchange capacity. The soil test summary before fertilizer treatment is in Table 5.

In this experiment, the calcium and magnesium levels were not altered. The nitrogen level was increased by addition of ammonium nitrate, phosphorus by addition of 45 percent superphosphate and potassium by addition of potassium sulfate. Es-Min-El trace element mixture was added to all treatments at a rate equivalent to 50 lb. per acre. Plants were grown from seed and transplanted in triplicate to 1-gallon glazed jars on March 3, 1951. Treatments were replicated 4 times and the pots randomized on the greenhouse bench. No artificial light was applied. Mature plants were harvested on July 23 and records kept of weight of "bulbs and tops" and "bulbs only".

Results (Table 6): As would be expected, the effect of increasing phosphorus is very evident, with the yields increasing in a linear trend (P_1 is highly significant) for both "bulbs only" and "bulbs and tops." This suggests that a further increase in the rate of application of phosphorus would raise the yields even higher.

TABLE 5 -- SOIL TEST SUMMARY LINTONIA FINE SANDY LOAM

	%	Nutrient Concentration					Buffer	Total C.E.C.
	O.M.	P_2O_5	K	Mg	Ca	pH	Hydrogen	M.E./100 gms.
Available or Exchangeable Nutrients (Lbs./A.)	0.95	29	160	120	1940	6.0	1750	
M.E./100 gms.			0.20	0.50	4.85		1.75	7.30
% of C.E.C.			2.7	6.8	66.4		23.2	

Increasing the amount of nitrogen from 100 lb. per acre to 200 lb. per acre significantly decreased the yield but, since only two nitrogen levels were used, it was impossible to determine whether the response was linear.

The significant interactions between nitrogen and phosphorus and between NK and PK (bulbs and tops) again indicate the necessity of considering joint effects or balance among nutrients in investigations of this type.

Considering the experiment in its entirety, increases in potassium above the initial saturation level of 2.7 percent did not result in statistically significant differences in yield.

TABLE 6 -- AVERAGE YIELD SOUTHPORT RED GLOBE ONION AS INFLUENCED BY NITROGEN, PHOSPHORUS AND POTASH LEVELS
(Growing Period March 3 - July 23, 1951)

		Potassium			Average Yield (Gms./Pot)	
N #/A	P_2O_5/A.	% of C.E.C.	#/A	pH	Bulbs & Tops	Bulbs only
100 #/A	100 #/A	2.7%	155	6.4	94.9	62.8
100 #/A	100 #/A	5.4%	310	5.8	102.5	56.1
100 #/A	100 #/A	8.1%	465	6.2	113.9	75.4
100 #/A	200 #/A	2.7%	155	6.3	103.1	66.4
100 #/A	200 #/A	5.4%	310	6.0	114.0	74.8
100 #/A	200 #/A	8.1%	465	6.8	108.4	67.0
100 #/A	300 #/A	2.7%	155	6.0	109.9	71.6
100 #/A	300 #/A	5.4%	310	5.8	120.9	75.4
100 #/A	300 #/A	8.1%	465	6.0	134.0	81.9
200 #/A	100 #/A	2.7%	155	5.9	80.5	39.8
200 #/A	100 #/A	5.4%	310	5.9	62.6	25.0
200 #/A	100 #/A	8.1%	465	5.8	47.3	24.2
200 #/A	200 #/A	2.7%	155	6.4	103.8	64.9
200 #/A	200 #/A	5.4%	310	5.9	110.5	66.9
200 #/A	200 #/A	8.1%	465	5.8	87.8	50.3
200 #/A	300 #/A	2.7%	155	5.9	102.0	72.4
200 #/A	300 #/A	5.4%	310	5.9	123.5	80.8
200 #/A	300 #/A	8.1%	465	5.9	120.3	78.5

Summary Analysis of Variance of Data, Bulbs Only

			df	ss	ms	Means	
Treatments			17	21 121.90	1 242.46*(Almost**)	p0	47.2
						p1	65.0
N	1			3 698.00	3 698.00**	p2	76.8
P	2			10 665.12	5 332.56**		
P1		1)		10 516.88)	10 516.88**	k0	63.0
P2		1)		148.23)	148.23	k1	63.1
NP	2			4 174.56	2 087.28**	k2	62.9
K	2			0.95	0.475		
K1		1)		0.09)	0.09	n0	70.2
K2		1)		0.86)	0.86	n1	55.8
NK	2			839.31	419.66		
PK	4			1 432.45	358.11		
NPK	4			311.51	77.88		
Among pots treated alike			53	9 483.18	178.93		
Total			70	30 605.08			

* P = .05
** P = .01

Summary Analysis of Variance of Data, Bulbs and Tops

				ss	ms	Means	
Treatments			17	31 563.06	1 856.65**	p0	83.6
N	1			5 893.36	5 893.36**	p1	104.6
P	2			14 735.95	7 367.98**	p2	118.4
P1		1		14 535.96)	14 535.96**		
P2		1		199.99)	199.9		
NP	2			4 437.14	2 218.57**	k0	99.0
K	2			523.75	261.88	k1	105.6
K1		1		101.79)	101.79	k2	102.0
K2		1		421.96)	421.96		
NK	2			2 282.87	1 141.44**	n0	111.3
PK	4			2 469.30	617.32*	n1	93.2
NPK	4			1 220.69	305.17		
Among pots treated alike			53	11 337.02	213.91		
Total			70	42 900.08			

* P = .05
** P = .01

Field Experiments

Cantaloupes

Experimental Plan: The response of Purdue 44 cantaloupe to fertilization with calcium, magnesium, potassium and boron on Lintonia fine sandy loam was evaluated in a randomized field planting at the Campbell Vegetable Experiment Field. This soil, believed to be deficient in calcium, magnesium, potassium and possibly boron, tested as follows:

	Lbs./A.	Per Cent of Cation Exchange Capacity
O.M. 1.0% pH 5.5		
Phosphorus (P_2O_5)	135	
Exchangeable K	140	3.06
Exchangeable Ca	1580	67.10
Exchangeable Mg	60	4.25
(Buffer Hydrogen), $CaCO_3$ equivalent	1500	25.50

The phosphorus level was increased to 300 lb. P_2O_5 per acre in all treatments and the equivalent of 40 lb. per acre of nitrogen was applied as NH_4NO_3 to all plots. Each treatment plot contained 12 hills and was replicated 5 times. Where included, the calcium was increased by 400 lb. per acre, magnesium by 72 lb. per acre, boron 2.5 lb. per acre and potassium to 5 percent (220 lb./A.) and 7 percent (320 lb./A.) of the cation exchange capacity. Various combinations of the following fertilizer amendments were applied in establishing these treatments; calcareous limestone, dolomitic limestone, Sul-Po-Mag, muriate of potash and sodium borate.

The melons were picked on nine separate harvest dates, counted, and weighed separately by treatments. Soluble solids content was determined by refractometer on five representative melons of each treatment on each harvest date.

TABLE 7 -- CANTALOUPE YIELDS WITH VARIABLE CATIONIC FERTILIZATION

Fertilizer Additions	Treatment Designation	Av. Yield of Marketable Melons Number/A	Av. Yield of Marketable Melons Pounds/A	% Marketable Melons
None	Minus all	1857	3398	75
Ca, Mg, B	Minus K	2488	5268	75
Ca, Mg, B, K (to 5%)	Complete	2462	6444	95
Ca, Mg, B, K (to 7%)	2 K	2612	6085	91
Ca, Mg, K (to 5%)	Minus B	2550	5563	83
Ca, B, K (to 5%)	Minus Mg	2240	5535	82
Mg, B, K (to 5%)	Minus Ca	941	2760	76
B, K (to 5%)	Minus Mg, Ca	1942	4305	78
F value		3.09*	3.24*	
required for sign at 5%		2.36	2.37	
required for sign at 1%		3.36	3.39	
Diff. between treatment means				
for sign at 5%		725	1664	
for sign at 1%		978	2249	

*P = .05
**P = .01

Results (Table 7): As indicated by the statistical treatment, the cantaloupe yield as measured by either number of marketable melons or pounds of marketable melons per acre varied significantly (5% level) with differential cationic fertilization. The greatest yields and highest percentages of marketable melons were obtained by increasing the Ca saturation above 67 percent and K to the 5 percent level. Considered individually, the addition of calcium was most effective in increasing yields and appeared to be necessary before fertilization with the other elements was fully effective. This evidence, together with the fact that yields were depressed below the yield of the control (none added) when calcium was omitted and magnesium and potash added in the acid (sulfate) form, suggests a pH effect was involved. Earlier experiments on this soil indicated manganese toxicity at pH's of 5.5 or lower.

Although these data indicate no statistically significant response to potash above 3 percent of the cation exchange capacity, there are suggestions of increased production up to the 5 percent level. The relatively large, unaccountable error and possibilities of nitrogen and moisture shortages prevented the detection of small degrees of response.

There was no response to magnesium above the base level (4.25%) when applied in either the carbonate or sulfate form and no definite response to boron.

Although the complete treatment (Ca, Mg, B, K) resulted in the greatest yield and the highest percentage of marketable melons, no significant differences were apparent in soluble solids content of the melon fruit.

Sweet Potatoes

Experimental Plan: During the 1950 season, the interaction of nitrogen and potash and its effect on the yield of sweet potatoes were investigated in a randomized planting at the Campbell Experiment Field. Because of a possible effect, the Mg and trace element fertilization was also varied.

Sixteen treatments with 5 replications were included in the planting. Each treatment plot consisted of 8 rows, 40 feet in length and spaced 42 inches apart. The plants were transplanted on May 12 and the roots harvested October 8th. Before treatment, the soil tested as follows:

	%	Concentration Lbs./A					Buffer Hydrogen	Total C.E.C.
	O.M.	P_2O_5	K	Mg	Ca	pH	#/A	M.E./100 gms.
Available or exchangeable nutrients	0.95	110	185	48	2510	5.8	2180	
M.E./100 gms.			0.24	0.20	6.28		2.18	8.90
% of C.E.C.			2.7	2.3	70.0		24.5	

TABLE 8 -- MARKETABLE YIELD, UNIT I PORTO RICO SWEET POTATOES GROWN AT VARIABLE LEVELS OF NITROGEN, POTASSIUM AND MAGNESIUM. YIELDS BU./A (55 LB.)

N lb./A	K % of C.E.C.	K lb./A	Mg % C.E.C.	Mg lb./A	Es-Min-El lb./A	Yield Marketable Roots Bu./A
50	2.7	185	2.3	48		474
50	2.7	185	2.3	48	50	496
150	2.7	185	2.3	48		355
150	2.7	185	2.3	48	50	355
50	7.0	495	2.3	48		474
50	7.0	495	2.3	48	50	489
150	7.0	495	2.3	48		459
150	7.0	495	2.3	48	50	489
50	2.7	185	4.6	96		548
50	2.7	185	4.6	96	50	442
150	2.7	185	4.6	96		357
150	2.7	185	4.6	96	50	354
50	7.0	495	4.6	96		526
50	7.0	495	4.6	96	50	459
150	7.0	495	4.6	96		389
150	7.0	495	4.6	96	50	437

Summary Analysis of Variance

Source	D.F.	EX^2	Variance	F.
Total	15	61,133		
Mg	1	390	390	
K	1	7,263	7,268	7.88*
N	1	31,773	31,773	34.43**
T	1	233	233	
Mg x K	1	915	915	
Mg x N	1	1,659	1,659	1.80
Mg x T	1	2,376	2,376	2.57
K x N	1	8,326	8,326	9.02*
K x T	1	797	797	
N x T	1	2,782	2,782	3.01
Remainder	5	4,614	922.8	

Difference Required Sign. 5% level 27.5 bu./A.
Difference Required Sign. 1% level 43.1 bu./A.

The fertility variables were nitrogen at 50 lb. per acre and 150 lb. per acre, Mg at 2.3 and 4.6 percent, K at 2.7 and 7.0 percent of the cation exchange capacity. All combinations of these variables were duplicated to include Es-Min-El treatment at 50 lb. per acre. No additional calcium was added. Phosphorus (P_2O_5) was increased to the 300 lb. per acre level in all treatments.

Results (Table 8): It is apparent from these data that the yields of marketable roots were decreased significantly as the nitrogen was increased from 50 lb. per acre to 150 lb. per acre. However, as indicated by the interaction K x N, this difference was significantly less (5% level) when the potash was increased to 7 percent of the cation exchange capacity. This indicates that the tendency toward excessive vine growth and stringy (long slender) roots associated with nitrogen-rich soils can be partially overcome by increasing the potash supply available to the plants. The response to high potassium saturation in this case was not surprising, considering the high potassium requirement of the crop and the low exchange capacity of this soil. No significant response to magnesium was found above the base (2.3%) level nor any beneficial effects from the addition of Es-Min-El trace element mixture. Since the magnesium was added in an acid (SO_4) form, it is possible that a high manganese concentration may have precluded a response to this cation at a pH below 5.8.

Tomatoes

A field experiment was conducted during the 1951 season to determine whether an association could be found between tomato yields and exchangeable potash level on badly depleted Clarksville stony loam soils.

Experimental Plan: A summary of the fertility levels of the untreated soil and of those established by the treatments is given in Table 9.

Each treatment plot of 0.027 acres contained 96 unstaked plants of the Rutgers variety spaced 3.5 feet x 3.5 feet. Each treatment was set up in triplicate. The estimate of nitrogen available from the organic matter was based upon the consideration that 5 percent of the organic matter was nitrogen and that 2 percent of the nitrogen was released during the season. An effective insect and disease program made losses from these causes insignificant. In this case, the experimental design did not permit statistical treatment of results.

Results: With total nitrogen in the control established at an estimated 88 lb. per acre and soluble phosphorus and exchangeable potassium at relatively low levels, plant growth was poor and the yield of fruit low. The low phosphate content of the soil apparently had a more limiting effect on growth and yield than the somewhat higher levels of nitrogen and potassium.

TABLE 9 -- FERTILITY LEVELS FOR RUTGERS TOMATOES ON CLARKSVILLE STONY LOAM, ELKLAND, MO., 1951
(Total Cation Exchange Capacity: 9.10 M.E./100 gms. - pH 5.8)

ORIGINAL LEVELS

NUTRIENTS	% Organic Matter	lb./A	% of CEC
Organic Matter or	2.6		
Nitrogen (estimated)		52	
P_2O_5		11	
Ca		2000	55.0
K		280	4.0
Mg		300	14.0
H (buffer)		2500	27.0

LEVELS ESTABLISHED

Treat. No.	N lb./A.	P lb./A.	K lb./A.	K % CS	Yields Tons/A.
1	111	348	296	4.1	5.86
2	111	348	447	6.1	9.10
3	111	448	447	6.1	10.10
4*	88	59	296	4.1	1.42

CS (Cation saturation) *(control)

The fertilizers added to establish these levels were:

Treatment No.

1. 200 #/A of 8-24-8 as starter
   75 #/A of NH_4NO_3
   645 #/A of 45% superphosphate
   60 #/A of NH_4NO_3(as side dressing)
2. 200 #/A of 8-24-8 as starter
   75 #/A of NH_4NO_3
   645 #/A of 45% superphosphate
   296 #/A of Muriate of potash
   60 #/A of NH_4NO_3 as side dressing
3. 200 #/A of 8-24-8 as starter
   75 #/A of NH_4NO_3
   815 #/A of 45% superphosphate
   296 #/A of Muriate of potash
   60 #/A of NH_4NO_3 as side dressing
4. 200 #/A of 8-24-8 as starter
   60 #/A of NH_4NO_3 as side dressing

The increased amounts of nitrogen and phosphorus provided by treatment 1 were effective in producing healthy, vigorous plants, but the yield was not as much as desired in economical production of canning tomatoes. The effect on growth and yield of the moderate increase in available nitrogen and the greater increase in soluble phosphorus to nearly 350 pounds per acre further confirms the high nutrient requirements of this vegetable.

In comparing the effects of level of potash (4% in treatment 1 with 6% saturation in treatments 2 and 3), the difference in yield suggested that a level of 300 pounds per acre or a saturation of 4 percent by exchangeable potash was limiting on this soil. The yield of 9.1 tons per acre obtained with established levels of 111 lb. per acre N, 348 lb. per acre P_2O_5 and 6 percent/K saturation (447 lb./A) approached a more desirable commercial yield. This response was obtained where the bulk of the fertilizer was plowed deep.

The yield was augmented one ton per acre where the phosphorus was increased to 448 lb. per acre, along with use of the high K level of 6 percent saturation (treatment 3). The comparison suggests there would not likely be a significant additional response by tomatoes to soluble phosphorus at a level much higher than 400 pounds per acre, assuming the other elements were present at non-limiting concentrations.

Response of Several Vegetable Species to Variable Cationic Levels on Lintonia Fine Sandy Loam

A detailed field study was conducted in 1953 to obtain more data relating to the optimum cation saturation levels on low-exchange soils, also to compare the relative response among various vegetable species to specific cation concentrations.

Experimental Plan: A Lintonia fine sandy loam, apparently deficient in calcium, magnesium, and potassium provided an ideal medium for establishing variable Ca, Mg and K saturation levels. The soil test values using the standard Missouri procedures, were as follows; Ca 60.5 percent or 1833 lb. per acre; K 3 percent or 177 lb. per acre; Mg 4 percent saturation or 75 lb. per acre; exchangeable hydrogen 32.5 percent or 2500 lb. per acre; phosphorus (P_2O_5) 112 lb. per acre. The organic matter content was 1.5 percent, the pH 5.6 and the total base exchange capacity 7.70 m.e./100 gm. of soil.

The eight treatments were:

1. Control (Phosphorus to 418 lb./A, 100lb./A ammonium nitrate added in all treatments)
2. $MnSO_4$ added at the rate of 13.5 lb/A.
3. Potassium increased to 5% saturation by addition of 269 lb./A K_2SO_4.
4. Calcium increased to 80% saturation by adding 1500 lb./A finely ground $CaCO_3$.

5. Calcium increased to 80% saturation by adding $CaCO_3$; potassium increased to 5% saturation by adding K_2SO_4.
6. Dolomitic lime added at the rate of 1500 lb./A.
7. Dolomitic lime added at the rate of 1500 lb./A.
   Potassium increased to 5% saturation by adding K_2SO_4.
8. Dolomitic lime added at the rate of 1500 lb./A.
   Potassium increased to 8% saturation by adding K_2SO_4.

The dolomitic lime used was 48.9 percent $CaCO_3$ and 36.6 percent Mg CO_3 by volume. Its $CaCO_3$ equivalent was 92.3 percent.

The phosphorus level of the experimental tract was increased to 418 lb. per acre by adding 47 percent superphosphate at the rate of 170 lb. per acre and 62 percent metaphosphate at the rate of 365 lb. per acre. These phosphorus carriers were used for two reasons, first, to supply a portion of readily available phosphorus and second, to apply the major part of the necessary phosphorus in a form which would be furnishing a minimum amount of calcium. Ammonium nitrate was applied at the rate of 100 lb. per acre before planting. Additional nitrogen was supplied as each crop needed it from planting to harvest.

Treatment 2 was included to permit further study of effects on plant growth of high manganese concentrations believed to be toxic to some crops grown on unlimed soils more acid than pH 5.8.

Special emphasis was placed on incorporating the fertilizers throughout the root zone. All fertilizers were distributed on the plots through a regulated, small volume fertilizer spreader, except for the manganese sulphate which was dissolved in water and sprayed, after seedbed preparation, on the plots receiving treatment 2. The calcareous limestone, dolomitic limestone and the heaviest rate of potassium sulfate were added in split applications, one-half of the total being applied before plowing and the remainder between the first and second diskings.

A randomized block design was used involving 5 replications and both single and multiple variables. Each treatment block was 40 feet x 60 feet in size with rows spaced 3.5 feet or 7 feet apart, according to the crop's requirement. The following crops were grown to maturity; sweet potatoes, cucumbers, radishes, lettuce, kale, swiss chard, onions and irish potatoes. Fresh weight records were taken on representative sections of rows, 40 ft. for sweet potatoes, irish potatoes and cucumbers and 20 ft. for the other crops. All plots were kept weed-free and sprayed at 14-day intervals following a recommended insecticide-fungicide program. Natural rainfall was supplemented by enough sprinkler irrigation to supply 1 inch of water per week.

Complete soil tests were run on composite soil samples taken from three plots of each treatment near the end of the growing season (3 months after application) to evaluate changes in availability of nutrients.

TABLE 10 -- EFFECT OF VARIABLE CATIONIC FERTILIZATION ON VEGETABLE YIELDS

Vegetable Experimental Field, Campbell, Mo., 1953

Treat.	Average Yields of Marketable Products (Treatment Means)							
	Cucumbers Lb./40 ft.	Sw. Potato Lb./40 ft.	Radish Oz./20 ft.	Lettuce Oz./20 ft.	Kale Oz./20 ft.	Sw. Chard Oz./15 Plants	Onion Oz./40 Plants	Irish Potato Lb/40 ft.
1	40.55	41.55	92.75	129.00	178.00	73.75	117.50	22.00
2	40.02	43.55	88.25	154.00	149.25	93.75	143.00	22.00
3	62.38	54.40	103.25	133.50	139.75	76.25	129.50	19.00
4	51.92	32.98	87.25	144.75	157.00	83.75	154.50	22.75
LSD (5%)	7.94	1.97	N.S.	N.S	N.S.	N.S.	12.89	N.S.
LSD (1%)	11.40	2.83					18.52	
5	57.52	64.85	87.25	151.00	144.00	74.50	127.00	20.50
6	46.38	43.20	87.75	140.00	122.00	66.00	107.25	21.50
7	53.92	64.62	74.75	99.00	135.75	61.50	107.75	15.25
8	46.40	53.98	84.75	91.25	158.50	64.50	80.25	20.50
LSD (5%)	5.61	3.43	N.S.	N.S.	N.S.	N.S.	17.17	N.S.
LSD (1%)	8.06	4.94					24.66	

Statistical treatment of these data indicates significant responses to fertilizer treatment only by sweet potatoes, cucumbers and onions. The treatment means were analyzed separately to determine effects of single and multiple treatments.

Results (Table 10): Effects of the single treatment variables (Treatments 1-4) indicate significant differences for sweet potatoes, cucumbers, and onions, all relatively long season crops. However, the same fertilizer treatment did not give the highest yield with all three crops. Increasing the potash level to 5 percent gave increased yields of marketable sweet potatoes and cucumbers whereas raising calcium to the 80 percent level was most favorable for onions. The response by sweet potatoes to potash above the 3 percent level serves to confirm results in the earlier investigation. With onions, too, the lack of response to potash above the 5 percent level is in agreement with results obtained in a previous greenhouse pot experiment.

In the multiple treatment variables (treatments 5-8), significant treatment effects are apparent for sweet potatoes. The largest sweet potato yields were obtained where the soil was limed (either calcareous or dolomitic) and potash increased to 5 percent of the cation exchange capacity. A significant difference is found by comparing treatment 5 with the average of treatments 6, 7, and 8. Thus yields were better with finely ground calcareous lime and potash at 5 percent than with dolomitic lime and potash at an average level of 5.33 percent. By comparison of treatments 6, 7, and 8 a quadratic effect of potash is found on dolomitic limestone treated soil.

From these data it would appear desirable on a low-exchange acid sandy loam to increase the calcium saturation above 60 per cent and the potash to at least 5 percent of the base exchange capacity, especially where long season vegetables or those with high potash requirements are to be grown. Liming without the simultaneous application of potash is likely to result in cation unbalance and reduced yields of these crops. From these data it is highly questionable whether the short-term vegetables are responsive to higher cation saturation levels; at least no significant responses were apparent above the experimental error inherent in this study. A considerable part of the unaccountable error was believed to be associated with micro-depressions in the plots and irregular plant stands.

Effect of Fertilizer Treatments on Changes in Concentration of Cationic Nutrients

Methods: Soil tests for the cationic elements Ca, Mg, and K were made before fertilizing and again toward the end of the growing season, approximately three months later. Special effort was made to obtain representative sampling. Six separate determinations were run for each test on representative samples of each treatment.

Results (Table 11): An analysis of these changes in nutrient concentrations may be helpful in interpreting the responses obtained from fertilization. Most favorable yields of sweet potatoes and cucumbers were obtained from those treatments which increased the available potash concentration in

TABLE 11 -- CHANGES IN CATIONIC CONCENTRATIONS BY FERTILIZER TREATMENT AS INDICATED BY SOIL TEST VALUES

Fertilizer Treatment	Change in Concentration over unfertilized soil K	Ca	Mg	Effect on soil pH
Control	-----	-------	-----	none
$MnSO_4$ 13.5#/A.	-----	-------	-----	none
K_2SO_4 269#/A.	(+25)	none	none	-0.1
$CaCO_3$ 1500#/A.	(-25)	(+1350)	(+25)	+0.4
$CaCO_3$ 1500#/A. K_2SO_4 269#/A.	(+39)	(+650)	(+20)	+0.3
Ca Mg $(CO_3)_2$ 1500#/A.	(-25)	(+350)	(+47)	+0.1
Ca Mg $(CO_3)_2$ 1500#/A. K_2SO_4 269#/A.	(+14)	(+250)	(+28)	-0.1
Ca Mg $(CO_3)_2$ 1500#/A. K_2SO_4 670#/A	(+83)	none	(+21)	-0.2

the soil and the poorest yields where liming suppressed the availability of potash. The only exception noted was where very heavy fertilization with an acid form of potash (K_2SO_4) over-balanced the effect of liming and resulted in a lowering of pH to a point considered to be critical on this high manganese soil. Onions, although not responding to the increased potash supply, responded favorably to liming but very unfavorably where the pH was reduced below that of the control plot (5.6). Manganese toxicity has been noted on several crops at pH's below 5.6.

SUMMARY AND CONCLUSIONS

Continued improvement in vegetable fertilization recommendations based upon soil tests is dependent upon establishing more accurate correlations between nutrient concentrations and plant response on soils representing the entire exchange capacity range.

Experiments were conducted using both greenhouse pot and field plot techniques over a period of years. Fertility was made a limiting factor in these tests to correlate vegetable yields and quality with the concentration of available nutrients, as indicated by the soil testing procedures used in Missouri.

Because plant response under these conditions is associated with the total available nutrient supply, a function of both the soil's exchange capacity and the degree of colloidal saturation, cationic concentrations were expressed as percentages of the total cation exchange capacity and on a pounds per acre scale. Expression on this chemically-equivalent basis aids in the interpretation of test results on highly variable soils, particularly where problems of cation unbalance exist.

In the preliminary greenhouse studies on a low exchange soil saturated to 66 percent with Calcium and 6.8 to 10.0 percent with Magnesium, highly significant linear responses in yield were obtained with potassium brought to 8.1 percent of the cation exchange capacity. Increase in nitrogen additions from the 100-pound per acre to the 200-pound per acre level resulted in a highly significant decrease in lettuce yield at all levels of potassium and magnesium. Potassium saturation levels above 2.7 percent also resulted in increases in plant ash content and percentage of potassium in the ash. Where the calcium saturation was increased to 86 percent in another experiment on the Lintonia soil, the linear response to increased potassium saturation was not apparent.

With equivalent amounts of nitrogen and phosphorous, Bibb lettuce yield decreased with increasing exchange capacity of the soil in the range of 7.30 to 14.69 milli-equivalents per 100 grams. Since the potassium, magnesium, and calcium saturations were held constant on the three soils, this apparently was due to lowered availability of nitrogen and phosphorous at the high exchange levels. In this experiment, there were suggestions of a quadratic regression of yields with increasing potash. However, this hypothesis could be confirmed. Irrespective of exchange capacity and potash level, Bibb lettuce growth was significantly better with potassium sulphate fertilization than with the muriate form. This suggests the importance of considering anions as well as cations in studying these relationships.

With the calcium saturation of Lintonia fine sandy loam at 66 percent and magnesium at 6.8 percent, Southport Red Globe onions grown in greenhouse pot culture failed to respond to potassium concentrations above 155 pounds per acre or 2.7 percent of the cation exchange capacity. This was later confirmed under field conditions. Onion yields increased linearly to the 300 pounds per acre phosphorous (P_2O_5) level, suggesting possible responses to even higher concentrations. Yields of bulbs were decreased significantly by increasing the nitrogen from 100 to 200 pounds per acre.

Yields of Purdue 44 cantaloupe, as measured either by number of marketable melons or pounds of marketable melons per acre, varied significantly (5 percent level) with differential cationic fertilization in field studies on Lintonia fine sandy loam. The largest yield and highest percentage of marketable melons was obtained by increasing the calcium saturation above 67 percent and potash to the 5 percent level. Considering the effect of the individual treatments, the addition of calcium in this study was most effective in increasing yields and appeared to be necessary before fertilization with the other elements was fully effective. Increasing the magnesium and potassium saturations (as the acid sulphate form) on unlimed soil depressed the yields below the yield of the control, apparently by increasing the soluble manganese to a toxic concentration. No response to magnesium was obtained above the base level (4.25%) when this element was applied as either the carbonate or sulphate form.

Increases in the yields of sweet potatoes and cucumbers accompanied increases in potassium saturations up to the 5 percent level when the calcium saturation was 60.5 percent and the magnesium saturation was 4.0 percent. The best sweet potato yields were obtained where the soil was limed (either calcareous or dolomitic) to saturate the exchange complex with calcium to approximately 80 percent and the exchangeable potash was increased to the 5 percent level. The application of lime without the simultaneous application of potash on this soil reduced the yields significantly. Soil tests made three months after fertilization indicated high calcium-low potash balance was involved.

On high nitrogen soil (150 lb. per acre), the high potassium saturation (7% level) significantly reduced the tendency toward excessive vine growth and stringy roots, although it had no significant effect on yields at lower nitrogen levels (50 lb. per acre).

Under both greenhouse pot and field plot culture, onions failed to respond to potassium levels above 3 percent. Statistically significant responses to calcium saturation as high as 80 percent were attributed to higher soil pH and reduced availability of manganese.

Under the same variation and cationic fertilization, no significant yield differences were found among the following short-term vegetables; radish, lettuce, kale, swiss chard, and irish potato. Either these vegetables are not responsive to cationic levels above control level or the experimental error was sufficiently great to preclude detection of small order responses. In any case, it is doubtful if these possible responses are sufficient to be of much concern in fertilization practice.

The yield of Rutgers tomatoes on a badly depleted Clarksville stony loam soil (9.1 m.e./100 gms.) was found to increase from 5.86 tons per acre to 9.10 tons per acre as the potash level was increased from 4.1 percent (296) lbs. per acre) to 6.1 percent (447 lb. per acre). Higher yields were possibly limited in this case by the low calcium saturation of 55 percent.

Considered in their entirety, these data would suggest that the following saturations of the exchange complex by cations be established on low-exchange soils where a great variety of vegetables are grown: Calcium 65-75 percent, magnesium 4-6 percent, potassium 5 percent, and (exchangeable) hydrogen 15-20 percent.

It is to be expected that on mineral-depleted soils having a relatively high content of montmorillonitic clays, this will normally require repeated deep applications of fertilizers because of the great fixation capacity, slow mobility of the cationic nutrients, and slow release of nutrients from some fertilizer materials. At this time, annual soil tests are most valuable in determining the fertilizers required to establish the desired nutrient levels and thereby reduce the likelihood of fertility being the limiting factor in production.

Once this favorable foundation level has been established in the soil, small variations in species requirements or modifications to maintain these soil concentrations can be met by the regular annual applications to "feed the crop." Soil tests at intervals of 3 or 4 years are then very helpful in maintaining balance by detecting major changes in nutrient concentrations.

Since these experiments were performed for the most part on low exchange soils, generalized recommendations on soils in the higher exchange ranges must await the accumulation of more experimental data. This work is now in progress. In the meantime, widespread demonstrational plantings on differing soil types where the cationic requirements suggested above were met have been encouraging.

LITERATURE CITED

1. Albrecht, Wm. A. "Adsorbed Ions on the Colloidal Complex and Plant Nutrition", *Soil Sci. Soc. Amer. Proc.* 5:8-16, 1940.
2. Albrecht, Wm. A. "Soil Factors in Nitrogen Fixation by Legumes", *Trans. 3rd Comm. Internl. Soc. Soil Sci.* A: 71-84, 1939.
3. Albrecht, Wm. A., and R. A. Schroeder, "Plant Nutrition and the Hydrogen Ion: I. Plant Nutrients Used Most Effectively in the Presence of a Significant Concentration of Hydrogen Ions," *Soil Sci.* 53: 313-327, 1942.
4. Allaway, W. H. "Availability of Replaceable Calcium from Different Types of Colloids as Affected by Degree of Calcium Saturation", *Soil Sci.* 59: 207-217, 1945.
5. Baird, G. B., and A. Mehlich, "The Effect of Soil Exchangeable Cations on Swiss Chard and Cotton", *Soil Sci. Soc. Amer. Proc.* 15: 201-205, 1951.
6. Bauer, L. D. and F. H. Bruner, "Rapid Soil Tests for Estimating the Fertility Needs of Missouri Soils", *Mo. Agr. Expt. Sta. Bul.* 404 (April, 1939). Reprinted April, 1946.
7. Bear, Firman E. *Theory and Practice in the Use of Fertilizers,* Second edition: London, England: John Wiley and Sons, Inc., Chapman and Hill, Ltd. 1938. 360 pp.
8. Bear, Firman E., and Roger H. Bray and others, *Diagnostic Techniques for Soils and Crops.* Washington 6, D. C.: The American Potash Institute, 1948. 308 pp.
9. Bear, Firman., and Stephen J. Toth, "Influence of Calcium on Availability of other Soil Cations," *Soil Sci.* 65:69-74, 1948.
10. Bear, Firman E., and Arthur Wallace, "Alfalfa—Its Mineral Requirements and Chemical Composition", *N. J. Agr. Exp. Sta. Bul. 748,* 1950.
11. Besson, Kenneth C. "The Mineral Composition of Crops with Particular Reference to the Soils in Which They Were Grown (A Review and Compilation)," *U.S. D.A. Miscellaneous Publication* 369, 1941.
12. Bower, C. A., and L. M. Turk, "Calcium and Magnesium Deficiencies in Alkali Soils", *Jour. Amer. Soc. Agron.* 38: 723-727, 1946.
13. Bray, Roger H. "Requirements for Successful Soil Tests", *Soil Sci.* 66: 83-89, 1948.
14. 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. Exp. Sta. Tech. Bul.* 214. 1949. x
15. Coleman, O. T. "Fertilizer Recommendations Based on Soil Tests". Better Crops with Plant Food. Nov. 1951.
16. Elgabaly, M.M., H. Jenny and R. Overstreet, "Effect of Type of Clay Mineral on the Uptake of Zinc and Potassium by Barley Roots", *Soil Sci.* 55: 257-263, 1943.
17. Gedroiz, K. K. "Exchangeable Cations of the Soil and the Plant: I Relation to plant to Certain Cations Fully Saturating the Soil Exchange Capacity", *Soil Sci.* 32: 51-63, 1931.
18. Graham, E. R. "Testing Missouri Soils", *Mo. Agr. Exp. Sta., Circ.* 345, 1950.
19. Hayward, H. E., and E. M. Long, "Vegetative Responses of the Elberta Peach on Lovell and Shalil Rootstocks to High Chloride and Sulfate Solutions", *Proc. Amer. Soc. Hort. Sci.* 41: 149-155, 1942.
20. Hill, H. "Some Aspects of Fertilizer Use for Potato Production and Tuber Quality", Amer. Potash Institute, Inc. Reprint O-4-53.
21. Horner, G. M. "Relation of the Degree of Base Saturation of Colloidal Clay by Calcium to the Growth, Nodulation and Composition of Soybeans", *Mo. Agr. Exp. Sta. Res. Bul.* 232, 1936.
22. Jarusov, S. S. "On the Mobility of Exchangeable Cations in the Soil", *Soil Sci.* 43: 285-303, 1937

23. Jenny, H. and A. D. Ayers. "The Influence of the Degree of Saturation of Soil Colloids on the Nutrient Intake by Roots", *Soil Sci.* 48: 443-459, 1939.

24. Jenny, H., and E. W. Cowan. "Uber Die bedeutung der in Boden adsorbierten Kationen fur das Pflansenwackgtum. Ztschr. Pflanzenernahr., Dungung, u. Bodenk.", (A) 31: 57-67. (Original not seen. Data cited by Chu and Turk in *Mich. Agr. Exp. Sta. Tech. Bul.* 214 June 1949)

25. Jenny, H., and R. Overstreet. "Cation Interchange Between Plant Roots and Soil Colloids", *Soil Sci.* 47: 257-272, 1939.

26. Lucas, R. E., and G. D. Scarseth. "Potassium, Calcium and Magnesium Balance and Reciprocal Relationships in Plants", *Jour. Amer. Soc. Agron.* 39: 887-896, 1947.

27. Lucas, R. E., G. D. Scarseth, and D. H. Sieling. "Soil Fertility level as it Influences Plant Nutrient Composition and Consumption" *Ind. Agr. Exp. Sta. Bul.* 468 1942.

28. Marshall, C. E. "Cationic Activities, Exchangeable Bases and Uptake by Plants", *Soil Sci. Soc. Amer. Proc.* 8: 175-178, 1944.

29. Mehlich, A. "The Significance of Percentage Base Saturation and pH. in Relation to Soil Difference", *Soil Sci. Soc. Amer. Proc.* 7: 167-174, 1943.

30. Mehlich, A. "Soil Properties Affecting the Proportionate Amounts of Calcium, Magnesium and Potassium in Plants and in HCL Extracts", *Soil Sci.* 62: 393-409. 1946

31. Mehlich, A., and W. E. Colwell. Influence of Nature of Soil Colloids and Degree of of Base Saturation on Growth and Nutrient Uptake by Cotton and Soybeans", *Soil Sci. Soc. Amer. Proc.* 8: 179-184, 1944.

32. Mehlich, A., and J. F. Reed. "The Influence of Type of Colloid and Degree of Calcium Saturation on Fruit Characteristics of Peanuts", *Soil Sci. Soc. Amer. Proc.* 11: 201-205, 1947.

33. Mehlich, A., and J. F. Reed. Effects of Cation-exchange Properties of Soil on the Cation Content of Plants", *Soil Sci.* 66: 289-306 1948.

34. Mehlich, A., and J. F. Reed. "The Influence of Degree of Saturation, Potassium Level and Calcium Additions on Removal of Calcium, Magnesium and Potassium". *Soil Sci. Soc. Amer. Proc.* 10: 87-93, 1946.

35. Mitchell, R. L. "The Spectrographic Analysis of Soils, Plants and Related Materials." Commonwealth Bureau of Soil Science, Hurpender, England. 1948

36. Morgan, M. F. "The Universal Soil Testing System", *Conn. Agr. Exp. Sta. Bul.* (New Haven) 372. June 1935.

37. Nelson, W. L., and C. D. Welch. "Soil Testing Reduces Guesswork" American Potash Institute Reprint A-1-51.

38. Scarseth, G. D. "Value and Limitations of Methods of Diagnosing Plant Nutrient Needs". Purdue Agric. Expt. Sta. Journal Paper 56.

39. Schuphan, Werner. "The Influence of Chloride and Sulfate Fertilizer on the Yield, Marketability and Biological Value of Various Vegetables, Taking Into Consideration Edaphic and Climatic Factors", Bodenkunle U. Pflanzenernahr. 19, 265-315 (1940); Chem. Zentr. 1940, II 3246, (C. A. 36, 7211). (Abstract).

40. Schuphan, Werner. "The Effect of Chloride and Sulfate Ions on Quality of Various Vegetables", *Fartschr.* Landv. Chem. 1937, 175-83. (C. A. 33, 3950). (Abstract).

41. Spencer, Ernest L. and J. R. Beckenbach, "The Value of Soil Testing Kits in Vegetable Crop Production", Fla. Agr. Expt. Sta. Circ. S-48, Apr., 1952

42. Thorne, D. W. "Growth and Nutrition of Tomato Plants as Influenced by Exchangeable Sodium, Calcium and Potassium". *Soil Sci. Soc. Amer. Proc.* 9: 185-189-1944.

43. Vlamis, J. "Growth of Lettuce and Barley as Influenced by Degree of Calcium Saturation of the Soil", *Soil Sci.* 67: 453-466, 1949.

44. Wiklander, Lambert and J. E. Gieseking. "Exchangeability of Adsorbed Cations as Influenced by the Degree of Saturation and the Nature of the Complementary Ions with Special Reference to Trace Concentrations", *Soil Sci.* 66: 377-384, 1948.
45. Woodruff, C. M. "Testing Soils for Lime Requirement by Means of a Buffered Solution and the Glass Electrode", *Soil Sci.* 66: 53-63, 1948.