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INTRODUCTION

The relative adaptation of varietal forms in crops to changes in the environmental complex is one of the most interesting phenomena in the whole range of agronomic study. Thus the strains or varieties of some common crop plants respond very differently to uniform conditions of growth; and when these same strains or varieties are grown under a different set of uniform conditions there may be a complete reversal in their relative response. Evidently this differential behavior is an important component of varietal adaptation. It may represent the success of a particular variety in one locality and failure in another.

The two external factors most involved with the adaptation of the variety are climate and soil. Of these two, climate, which is a composite of a number of effects such as day-length, moisture, temperature, humidity, etc., is probably the stronger factor in determining the boundaries within which a variety can be grown successfully. Within these boundaries, in most cases, soil, because of its effect on relative development of any variety, becomes the deciding factor in the choice of the variety or strain to be grown.

An excellent example of this differential varietal behavior has been noted with certain soybean varieties in Missouri field experiments. The Virginia variety, when grown on infertile soils has been found to give higher yields of total dry matter than the Morse variety grown on the same soil, but when these same two varieties are grown on more fertile soils Morse has invariably yielded more than Virginia. These varieties are otherwise very similar in many respects and seemed good subjects for a study of the problem of varietal response from the standpoint of plant nutrition.

The present study was undertaken, therefore, to determine the behavior of these two varieties of soybeans as grown under variable mineral nutrient conditions in the hope that certain specific requirements for their adaptation to different levels of soil fertility might thus be indicated.

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REVIEW OF LITERATURE

Little work has been done with the definite purpose of determining the differential reaction of varieties of a crop plant to variable fertility levels. Tests of crop requirements for fertilizer are usually confined to one variety, and tests of varieties are nearly always conducted on land as uniform as possible in order to reduce the variability due to soil differences. However, some studies have been made with the specific intention of ascertaining varietal behavior in relation to fertility level. These may be summarized as follows.

Beaven (1) working with two barley selections of the same ancestry in field plot experiments noted that a conclusive differential response to the fertility level occurred with one selection "responding better" to ammonium sulfate alone or combined with phosphorus and potash. However, under different weather conditions, in another year, less significant and different relative responses of the selections grown on the same plots were observed. This evidence of a difference in response with different seasons Beaven explains as due to other environmental factors, mainly climate, and concludes that "It is, in fact, evident that no two races of a cereal 'respond' quite equally to the same environment, and that, as between races, relative yields on unit area, whether of total produce or of seed, are influenced by *all* the environmental conditions and by their interactions. This seems, indeed, to be a corollary to the doctrine that survival of races of any species has been mainly dependent on Natural Selection. It is illustrated by innumerable facts, and may be summarized by the aphorism, 'what is food for one race may be, more or less, poison for another race of the same species.' "

Substantiating the results obtained by Beaven are those reported by Gregory and Crowther (11). They also found that barley varieties gave a differential yield response when grown in pot experiments with varied levels of available nutrients. Their results lead them to conclude that there is a possibility of developing varieties adapted to deficient soil types. Wheat varieties also show differential behavior when grown under varying fertility levels. Lamb and Salter (18) definitely established this fact in their work on field fertility plots. Wiegert and Fürst (25) also report evidence of differential response to fertilization with varieties of spring oats, spring barley, winter wheat, and winter rye, and recommended that farmers select varieties on the basis of the fertility of their farms.

A large part of the more recent work in this field has been done with inbred lines and hybrids of maize. Stringfield and Salter (23) in field plot experiments with maize varieties found a differential yield response of variety to season and fertility level. They concluded that some varieties may grow relatively better at low than at high fertility levels while other varieties may exhibit exactly the opposite response. Working with twenty-four inbred lines and twenty-three single crosses of maize in carefully controlled water culture experiments with varied supplies of phosphorus and nitrogen, Smith (22) also observed marked differences in growth behavior. He varied phosphorus from 0.0048 to 0.48 millimoles per liter of nutrient solution, and nitrogen from 0.035 to 3.5 millimoles per liter.* While only slight differential response was observed with low nitrogen supply, a few inbred lines showed distinct differences when grown in solutions low in phosphorus. The ability to absorb nutrients because of a well-branched root system was considered one of the factors responsible for this behavior since those lines having the greater number of secondary roots were able to yield better on a low phosphorus supply and those with few branch roots gave lowest yields.

Working with other inbred lines and their hybrids, Burkholder and McVeigh (3) were able to demonstrate differential response to nitrogen, particularly in the higher levels. They used sand cultures with nitrogen supply ranging from 0.2 to 9.6 millimoles per liter of nutrient solution, the higher levels being considerably higher than those used by Smith (22) which may account for the difference in results. Other results which agree rather closely with those reported by Smith on phosphorus were secured by Lyness (19). He also grew inbred lines and hybrids of maize in sand cultures under varied phosphorus supply and noted a large difference in the capacity of different lines to absorb phosphates from sand cultures of similar concentrations, and states that "there was a close correlation between phosphorus response and the number and character of secondary roots . . . which suggested a reason for the varietal differences in phosphorus feeding capacity" of the different lines. He also observed a close correlation between the phosphorus content of plant material and dry weight in the different lines.

These results definitely seem to indicate that there is a wide variation in the growth behavior of inbred lines and hybrids of maize in relation to fertility level. While there is not complete agreement with reference to all nutritive elements, it is probable that the origins of the inbred lines in the various experiments were different. Other studies which lend confirmation to the existence of varietal variation in inbred lines and hybrids of maize are those of Hoffer (13), Mooers (20), and DeTurk, Holbert, and Howk (4).

Poehlman (21) investigated the problem of varietal response of soybeans to fertility level in both field and greenhouse experiments. He used the same varieties that were used in the present investigation, Morse and Virginia, and although he secured differential results in the field, he was unable to isolate any condition in the greenhouse under which he could duplicate the field results. He suggests, however, that soil fertility is probably one of the most important factors in determining the behavior of the two varieties, since no differential

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*"Millimoles per liter" means thousandths (0.001) of a molal weight of the ion referred to per liter of nutrient solution.

varietal response was exhibited in his other experiments on day-length and soil moisture. Also working with soybeans, Earley (6) grew sixteen different varieties in sub-irrigated gravel cultures and noted that few of these varieties showed any similarity in reaction to zinc concentrations. The Peking variety grew normally at a zinc concentration of 0.1 part per million in the nutrient solution, but was killed at a concentration of 0.8 part per million. The Hudson Manchu, on the other hand, showed no signs of toxicity at the 0.8 part per million concentration. Earley concludes from the results of this experiment that there seems to be no valid reason for believing that soybean varieties do not exhibit a differential response to concentrations of at least some of the minor nutrient elements.

While the number of studies pertaining to this problem are not large, they are very specific in demonstrating that differential response to fertility level may be just as likely to occur among varieties of a species as between the species themselves. Thus the species can no longer be regarded as a physiologically homogeneous population, and the fact that one variety of a species succeeds under certain nutrient conditions is no guarantee that all other varieties of the same species will succeed equally as well. On the contrary, it is probable that each variety will develop best under rather definite combinations of climatic and nutritive conditions. Assuming that the nutrient conditions in the environmental complex can be controlled more readily than any of the remaining factors, an investigation of the optimum fertility level for specific varieties should be of value in determining their adaptation. By supplying two varieties of soybeans with variable amounts of the major nutritive elements it should be possible to demonstrate that differential response to some of the nutrient elements does occur among soybean varieties.

METHODS AND MATERIALS

Culture Media

There are several advantages and disadvantages in the use of sand as a culture medium over the use of water alone in mineral nutrition work. The sand furnishes support for the plants, requires no apparatus for aeration, gives more normal root development, and, in some respects, is more comparable to soil as a medium for plant growth. However, sand of even the highest quality contains traces of impurities in sufficient quantity to affect the results of the very exacting minor or "trace" element studies, and water cultures will probably continue to be the most satisfactory medium for this type of work.

With the major element studies, however, a high grade quartz sand seems to be entirely satisfactory. Preliminary deficiency experiments run with soybeans grown in the white quartz sand, which was used in all the following experiments, revealed that the usual deficiency symptoms (9) of all the major elements and even iron, manganese, and boron were readily secured. Therefore, it was assumed that for the type of experiments conducted in this investigation sand would offer an entirely satisfactory medium for the growth of soybean plants. This white quartz sand, which was obtained from the Tamms Silica Company, 228 North La Salle Street, Chicago, Illinois, was thoroughly washed with a stream of tap water from a nozzle until all dust, organic matter, and other impurities were removed. It was next washed with a large amount of distilled water and then rinsed several times with more distilled water before being placed in the culture vessels.

Culture Apparatus

Three-gallon, round bottom, glazed stoneware urns with a 1 5/8 inch hole in the bottom were used as culture vessels. A large one-hole rubber stopper, with a three-inch length of 8-millimeter "Pyrex" glass tubing fitted through it so that the upper end protruded 1/8 inch above the level of the stopper, was fitted snugly into the hole in the urn. Taking care not to fill the glass tubing, which was to serve as a drain for the culture vessel, hot paraffin was poured over the bottom of the vessel and the rubber stopper, covering the rubber completely and rounding the bottom of the vessel so that all excess solution would drain through the glass tube. A small pad of glass wool was then placed over the drain tube to prevent loss of sand, and the urn was filled with sand prepared as described above. A diagram of the rather simple arrangement devised by which the desired amount of nutrient solution could be added to all the cultures of a series with an accuracy of ± one per cent is shown in Figure 1. It consisted of a 5-gallon bottle (A) containing the nutrient solution and placed under the culture bench (B), an 8-millimeter "Pyrex" glass tube (c) leading up from the bottle and bent over the culture vessel (D) above, and a compressed air line (E) connected to all culture bottles. The glass tube carried the nutrient solution up from the bottle to the culture when compressed air was introduced into the system. In order to secure uniformity of flow to all cultures, a one-inch length of one-millimeter capillary glass tubing (F) was attached to the end of the glass tube (C) over the culture by a short length of gum rubber tubing (G). To facilitate the removal of the solution bottles to replenish the nutrient solutions, a joint in the glass tube (C) was made just above the top of the bottle and another short length of gum rubber tubing (H) was used as a connection. The upper part of the tube (C) was held securely, but elastically, in place by fitting it throgh a large rubber stopper (I) which was nailed to the culture bench (B). Control of the nutrient solution flow to the cultures was secured by regulation of the air pressure coming from a compressed air tank through the use of a regulatory valve. To determine the amount of solution flowing to the cultures at each application, one tube was designed to flow into a 500 cc. graduate cylinder and, after being measured, the solution was poured on one culture by hand. Two applications of 500 cc. each were added to the cultures at 8:00 a. m. and 1:00 p. m. making a total of a liter per day per culture.

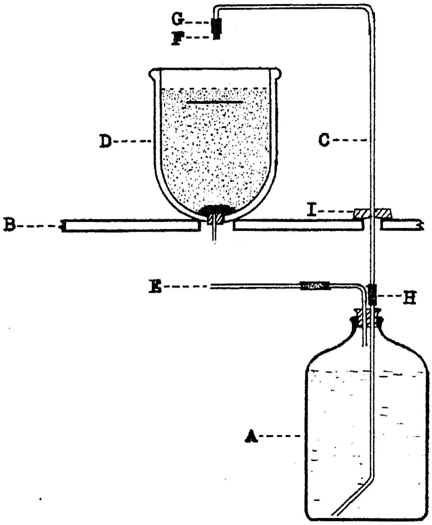

Fig. 1.—A diagram of the nutrient culture apparatus.

Nutrient Solution Preparation

Only "C. P." or "Analytical" grade salts were used in all experiments. Each salt was dissolved in distilled water to make a molar or part molar stock solution and stored in a large "Pyrex" glass container. To facilitate speed and accuracy in measuring out the appropriate volumes of each stock solution when making up the nutrient solutions, each stock solution storage bottle was connected to a separate burette clearly labeled as to the stock solution it contained.

Distilled water, which was condensed from live steam by a Baeuerle and Morris still and stored in a tin-lined copper tank was utilized in making up all nutrient solutions. The procedure employed in making up nutrient solutions was to measure out the appropriate volumes of the stock solutions and mix them with a large volume of distilled water in the solution bottles. The volume of solution was then brought to 1800 cc. by adding distilled water. (The solution bottles were placed on an A. H. Thomas Company beam balance, No. 1931, which was sensitive to one gram, and distilled water added until a total of 1800 grams of solution was secured).

Culture Methods

Uniform, good quality, soybean seeds were germinated in well-washed quartz sand and watered with tap water until the roots were about two inches long. Vigorous, healthy seedlings were then selected for uniformity, washed thoroughly in distilled water, and transplanted to the culture jars. Nutrient solutions were applied immediately and continued at the rate of one liter per day until the plants were harvested at an age of five weeks. In order to secure as much uniformity of environment as possible for both varieties, three plants of each variety were grown in every culture. This practice may be open to criticism from the standpoint of competition between varieties, but with the small number of plants used per culture, and the relatively short period of time they were grown, this effect would probably be negligible, or at least not nearly so important as the uniformity of environment which was secured by growing the varieties together. Depending upon the amount of space available when each series was grown, the number of cultures per treatment in a series ranged from two to six. Six cultures per treatment were grown in the Calcium, Magnesium, and Potassium Series, while only two were grown per treatment in the Nitrate, Phosphate, and Sulfate Series.

All the series grown in the fall and winter months prior to 1941 were supplied with supplementary light in the form of 200-watt Mazda lamps placed at four-foot intervals over the culture bench. In 1941, the Mazda type lamps were replaced by fluorescent type lamps equipped with two 40-watt daylight type tubes per each four feet of length. These lamps were maintained at a uniform height of about 18 inches above the plants throughout the experiments and were placed end to end over the entire length of the culture bench. They proved a more satisfactory source of supplementary light than the Mazda type, since the intensity of light was the same the entire length of the culture bench thus producing more uniformity in plant growth.

A preliminary experiment to determine the approximate optimum nutrient requirements of the two varieties of soybeans was started in January, 1939, according to the system described by Beckenbach and others (2). Upon completion of this preliminary series the following series were started: Nitrogen, March, 1939; Potassium, November, 1939; Sulfate, March, 1940; Phosphate, March, 1940; Calcium, February, 1941; and Magnesium, April, 1941.

The concentrations of iron, manganese, zinc, and boron supplied to the cultures were the same in all experiments and were the following as recommended by Trelease and Trelease (24): iron, 0.00005 molal; manganese, 0.11 part per million; zinc, 0.05 part per million; and boron, 0.07 part per million. These elements were supplied in the form of ferric citrate, manganese sulfate, zinc sulfate, and boric acid. In

TABLE A. PARTIAL VOLUME MOLECULAR CONCENTRATIONS OF THE NUTRIENT SOLUTIONS IN THE PRELIMINARY SERIES

Nutrient solution number	KH_2PO_4	$Ca(NO_3)_2$	$MgSO_4$	$CaH_4(PO_4)_2$	$MgH_4(PO_4)_2$	KNO_3	$Mg(NO_3)_2$	K_2SO_4	$CaSO_4$
1	.0031	.00075	.0014						
2	.0010	.00225	.0014	.0015	.0043				
3	.0010	.00075	.0057			.0021	.0043		
4	.0031	.00225	.0057					.0021	.0015
5	.0010	.00600	.0014						
6	.0010	.00225	.0014	.0015					.0015
7	.0010	.00075	.0014						.00525
8	.0010	.00075	.0014	.00525					
9	.0082	.00075	.0014						
10	.0031	.00075	.0014			.0021		.0021	
11	.0010	.00075	.0014			.0072			
12	.0010	.00075	.0014					.0072	
13	.0010	.00075	.0112						
14	.0010	.00075	.0042		.0043		.0043		
15	.0010	.00075	.0014				.0098		
16	.0010	.00075	.0014		.0098				

TABLE B. PARTIAL VOLUME MOLECULAR CONCENTRATIONS OF THE NUTRIENT SOLUTIONS IN THE NITROGEN, PHOSPHATE, SULFATE, POTASSIUM, CALCIUM, AND MAGNESIUM SERIES

	Molal concentration of salts per liter of nutrient solution											
Series	KH_2PO_4	K_2SO_4	KCl	$Ca(NO_3)_2$	$CaSO_4$	$CaCl_2$	$MgH_4(PO_4)_2$	$MgSO_4$	$MgCl_2$	NH_4NO_3	$(NH_4)_2$	$SO_4Na_2SO_4$
Nitrogen	.001	.001				.003		.002		0-.01*		
Phosphate**		.001	.003	.002		.002		.003		.0005		
Sulfate	.001		.002	.002		.002			.003	.0005		0-.02
Potassium			0-.01	.0015	.001	.0015	.0005	.002			.001	
Calcium	.001	.0015				0-.02		.002			.0025	
Magnesium	.001	.0015		.0015	.0015				0-.02	.001		

* See respective tables of yield results of the different series for actual millimoles of varied ion per each culture.

**97.5% of $-PO_4$ supplied as NaH_2PO_4 and 2.5% as Na_2HPO_4 which gave a pH of approximately 5.3.

some of the experiments, particularly those cultures which received large amounts of phosphate, it was sometimes necessary to add, from time to time, small amounts of ferric citrate to the cultures which showed signs of iron deficiency (9) due to precipitation in the solution reservoirs of the available iron by the phosphate. The molal concentrations of the nutrient salts used in the preliminary experiment are given in Table A and those of the other six series are given in Table B.

In order that the results obtained should be indicative of the actual amounts of nutrients supplied in the nutrient solutions, all cotyledons were removed from the plants as soon as the first trifoliate leaf appeared, since considerable quantities of some elements are contained in the cotyledons. Precautions were also taken to insure that no plants would be inoculated with nitrogen-fixing bacteria and thus introduce an unknown factor into the amount of nitrogen supplied the plants. Since nodules were never found on any of the plants in this study, it is assumed that the precautions were successful.

EXPERIMENTAL RESULTS

For convenience in presentation the experimental results are divided as follows: Preliminary Series; Nitrogen Series; Phosphate Series; Sulfate Series; Potassium Series; Calcium Series; and Magnesium Series. Each of these divisions represents a separate experiment. The dates when each series was started were given earlier.

Preliminary Series

In order to determine the approximate concentrations of the different major nutrient elements that soybeans need for normal growth, a preliminary series was set up according to the Modified Triangle System described by Beckenbach and others (2). In this system, the

TABLE 1. EFFECT OF THE RATIO OF NUTRIENT IONS IN THE NUTRIENT SOLUTION UPON THE AVERAGE HEIGHT, FRESH WEIGHT, AND DRY WEIGHT OF PLANTS PER CULTURE (THREE PLANTS OF EACH VARIETY PER CULTURE)

Culture Number	Ionic Ratio cations			anions			Height in cms.		Fresh Weight in grams		Dry Weight in grams	
	K:	Ca:	Mg	PO_4:	NO_3:	SO_4	Morse	Virginia	Morse	Virginia	Morse	Virginia
1	3	3	4	3	3	4	53	45	12.0	8.3	4.93	2.96
2	3	3	4	8	1	1	45	30	5.7	2.1	2.43	.91
3	3	3	4	1	8	1	57	44	14.8	7.8	5.88	2.86
4	3	3	4	1	1	8	58	50	12.7	8.2	5.17	3.13
5	1	8	1	1	8	1	55	48	10.9	8.2	4.92	2.98
6	1	8	1	3	3	4	47	32	7.1	2.9	2.80	1.02
7	1	8	1	1	1	8	52	53	8.5	8.2	3.73	3.34
8	1	8	1	8	1	1	13	14	...	...	0.36	0.19
9	8	1	1	8	1	1	43	32	7.7	3.8	2.97	1.41
10	8	1	1	3	3	4	49	42	12.5	10.0	5.02	2.52
11	8	1	1	1	8	1	54	41	15.2	7.7	5.96	2.58
12	8	1	1	1	1	8	50	43	11.8	6.3	4.94	2.31
13	1	1	8	1	1	8	45	39	8.4	4.0	3.40	1.60
14	1	1	8	3	3	4	30	23	3.5	1.6	1.42	.63
15	1	1	8	1	8	1	46	35	8.1	5.1	3.42	1.98
16	1	1	8	8	1	1	34	30	3.1	2.4	1.43	1.44

total concentration of the nutrient ions is kept approximately at ten millimoles each of anions and cations per liter of nutrient solution. By using the various combinations of the nine salts as shown in Table 1, it was possible to vary the proportionate concentration of both anions and cations without changing the total concentration.

The results of this experiment as measured by fresh weight, dry weight, and average height are recorded in Table 1. The data in this table, as in all following tables which deal with yield results, represent the averages of the replications in each treatment. The fresh weight and dry weight values are given as grams per culture, and since each culture contained three plants of each variety, these values represent the average fresh and dry weights of three plants. The values for height are given in terms of centimeters per plant.

A more illustrative presentation of the results of this experiment is shown in Figure 2 through the use of a composite photograph of the different cultures at the time of harvest. This composite of photographs is arranged according to the ionic concentration of the nutrient solution which the plants received. The top row received high nitrogen, the second row high sulfate, the third high phosphate, and the bottom row these three anions in approximately the same concentration. Then, from left to right in the vertical columns, the first received high calcium, the second high potassium, the third high magnesium, and the fourth, and last, approximately equal concentrations of cations. Picking any culture at random, the ionic concentration of the nutrient solution which it received can be ascertained immediately by determining which column and row it occupies in this composite photograph. Using the results in Table 8 and the appearance of the cultures in the composite picture as criteria, it is immediately evident that a high concentration of phosphate is not compatible with normal growth in soybeans. Of the cations, magnesium also seems, at least in the combinations used in this experiment, to have a depressing effect upon the yields when used in the higher concentrations. That this effect may be due, in part, to the particular salt in which the magnesium is added to the culture, and also to the concentrations of the other nutrient ions, is borne out in later experiments. In no culture were there observed symptoms of any deficiency, and all injuries seemed to be due to an excess of one or two particular ions. The culture receiving high calcium and high phosphate provides an excellent example of the response to a lethal combination. However, neither of these ions when used in the same concentration with any of the remaining ions had such a deleterious effect upon growth.

Judging from the results of this experiment it was concluded that in all later experiments the concentration of phosphates must be kept at a low level. Since concentrations of 8.0 millimoles of magnesium and calcium per liter of nutrient solution also caused injury to plants

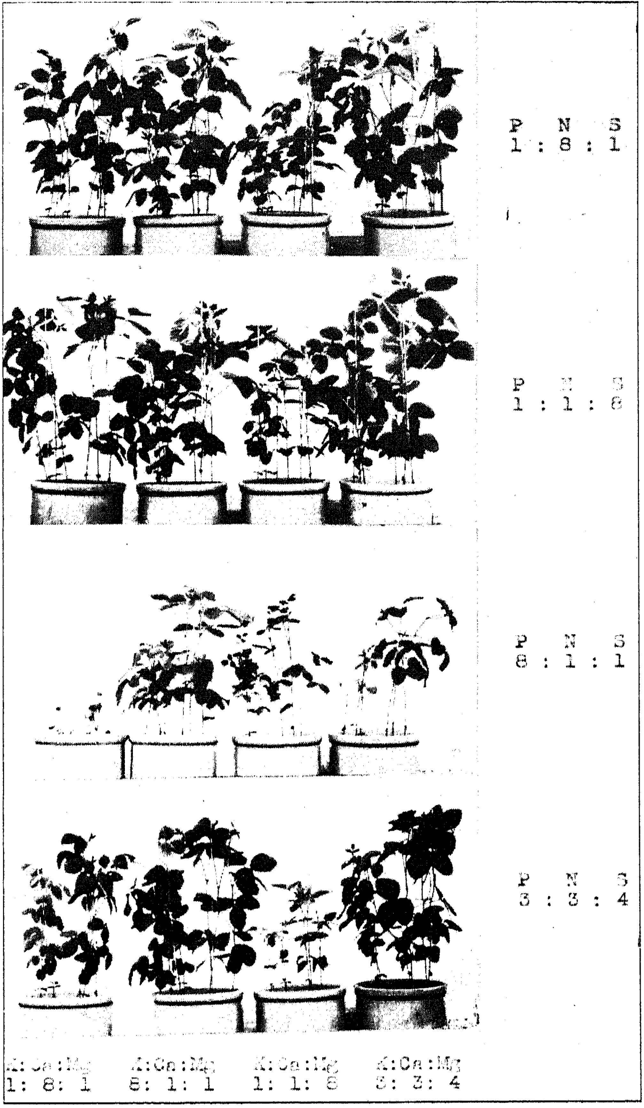

Fig. 2.—Soybeans of the preliminary series. Morse at right and Virginia at left in each culture.

in some cultures, it seemed best to keep these ions at moderate levels of from 2.0 to 4.0 millimoles in later experiments. Potassium and nitrogen gave best results when applied at the rate of 8.0 millimoles per liter in this experiment, and sulfate appeared to have little effect after one or more millimoles per liter were added. These observations were borne in mind when making up nutrient solutions for later series.

Nitrogen Series

Using the results obtained in the Preliminary Series to estimate the approximate optimum concentrations of ions, a Nitrogen Series was begun. In this experiment, all essential elements except nitrogen remained constant at ample levels for normal growth throughout the series, and nitrogen was varied from a complete deficiency to 20.0 millimoles per liter of nutrient solution.

TABLE 2. EFFECT OF NITROGEN CONCENTRATION IN THE NUTRIENT SOLUTION UPON AVERAGE HEIGHT, FRESH WEIGHT, AND DRY WEIGHT OF PLANTS PER CULTURE

Millimoles of nitrogen	Height cms.		Fresh Weight grams		Dry Weight grams	
	Morse	Virginia	Morse	Virginia	Morse	Virginia
.00	21	19	6.5	4.5	1.63	.87
.16	22	19	6.7	3.7	1.45	.73
.31	27	23	11.1	7.6	2.07	1.10
.62	29	24	11.0	8.6	1.90	1.13
1.25	37	32	17.3	14.6	2.72	2.02
2.50	43	39	24.0	24.5	4.10	3.32
5.00	48	44	42.0	32.5	6.49	4.08
10.00	49	42	49.9	34.6	6.77	4.58
20.00	42	37	39.9	25.5	5.17	3.25

Results of this experiment are presented in Table 2. To facilitate better comprehension of these results, the average dry weight of plants per culture is plotted against the concentration of nitrogen in the nutrient solution in Figure 3. In this and all following figures a rectilinear scale was used with ordinates and a logarithmic scale with abscissae in order to best show the results graphically. A study of the data presented in Figure 3 indicates that the Morse variety is more efficient in utilizing the higher concentrations of nitrogen than the Virginia variety if dry weight of plants is used as a criterion. In all concentrations up to and including 2.5 millimoles of nitrogen per liter, not a large amount of difference is apparent. In fact, if the natural or average size of plants of the two varieties are taken into consideration, one could say that the Virginia variety "responded" fully as well as the Morse variety at the lowest levels of nitrogen. (Using the average of all the yields of all the series in this study as a basis of determining the average size of plant for each of the varieties, it was calculated that the Virginia plant is only about 60 per cent as large as the Morse plant, since the average dry weights per plant were 1.75 grams for Morse and 1.04 grams for Virginia).

The reduction of yield at the highest level of nitrogen with both varieties can probably be ascribed to the increased quantities of ammonium ions in the nutrient solution.

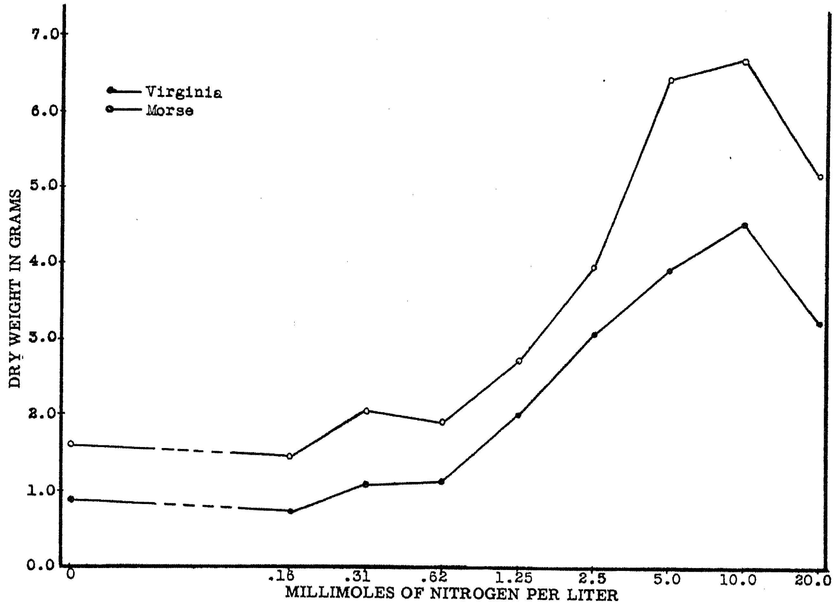

Fig. 3.—Effect of nitrogen concentration in the nutrient solution upon the dry weight of plants per culture.

Phosphate Series

In this series the phosphate ion was varied from a complete deficiency to 10.0 millimoles per liter in the nutrient solution with other essential nutrient ions being held constant throughout the series. In order that approximately the same pH could be maintained throughout the series, 97.5 per cent of the phosphate was added as mono-sodium-phosphate (NaH_2PO_4), and 2.5 per cent as di-sodium-phosphate (Na_2HPO_4). This combination, regardless of the phosphate concentration, gave a pH of about 5.3 in all cultures which proved satisfactory for the growth of soybeans. The results are presented in Table 3 and Figure 4, and show that Morse responded more rapidly to an increase in the concentration of phosphate, showed a larger percentage increase over the no-phosphate treatment, and reached the maximum yield at a higher concentration of phosphate than did Virginia. This behavior, as in the Nitrogen Series, would seem to indicate that Morse was more efficient in utilizing the higher concentrations of these nutrient ions. If so, and this observation is substantiated in the other series, then this should be at least a part of the explanation for the fact that Morse yields higher on the better types of soil than Virginia. Since the better, or in other words, the more fertile types of soil

TABLE 3. EFFECT OF PHOSPHATE CONCENTRATION IN THE NUTRIENT SOLUTION UPON AVERAGE HEIGHT, FRESH WEIGHT, AND DRY WEIGHT OF PLANTS PER CULTURE

Millimoles of Phosphate	Height cms.		Fresh Weight grams		Dry Weight grams	
	Morse	Virginia	Morse	Virginia	Morse	Virginia
.00	33	34	20.7	13.2	3.66	2.05
.08	59	59	66.4	43.4	8.53	5.29
.16	60	64	72.0	43.8	8.46	5.25
.31	62	60	71.9	44.0	9.17	5.10
.62	58	58	66.4	42.0	8.50	4.80
1.25	60	60	65.1	36.6	8.33	4.27
2.50	56	53	50.3	32.0	6.41	3.89
5.00	52	41	39.7	14.8	5.14	1.97
10.00	40	27	25.2	6.4	3.41	.96

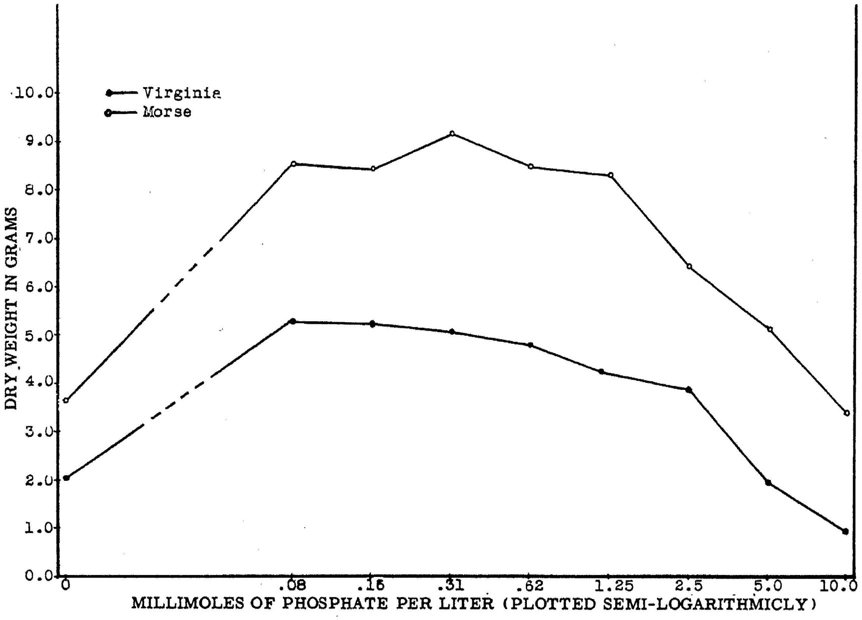

Fig. 4.—Effect of phosphate concentration in the nutrient solution upon the dry weight of plants per culture.

would be expected to contain more of the nutrient ions in available form, then the higher levels of these series are comparable in that respect with the soil types in which the Morse variety does best.

In the highest levels of phosphate nutrition, there was distinct evidence of toxicity in both varieties. The yields were even lower than they were with the deficiency level. This would seem to indicate that an unbalanced condition occurred through the high concentration of phosphate which kept some of the other ions either from being available or from being taken up by the plants in sufficient quantities. The fact that the deficiency cultures were able to support such a remarkable growth was probably due to the utilization of phosphate which could have been transferred to the plant tissues from the cotyledons before the latter were removed.

Sulfate Series

The Sulfate Series was set up in the same manner as the other series. Sulfate was the only variable, and the other ions were maintained at ample levels throughout the series.

TABLE 4. EFFECT OF SULFATE CONCENTRATION IN THE NUTRIENT SOLUTION UPON THE AVERAGE HEIGHT, FRESH WEIGHT, AND DRY WEIGHT OF PLANTS PER CULTURE

Millimoles of Sulfate	Height cms.		Fresh Weight grams		Dry Weight grams	
	Morse	Virginia	Morse	Virginia	Morse	Virginia
.00	53	55	52.8	37.0	6.86	4.47
.16	63	67	71.0	46.3	9.01	4.96
.31	62	57	71.6	35.9	9.26	4.23
.62	59	59	66.6	39.0	8.38	4.62
1.25	53	56	54.1	37.3	6.87	4.43
2.50	56	60	53.8	38.8	7.10	4.69
5.00	58	58	61.8	41.2	8.45	5.08
10.00	57	58	54.1	35.9	7.55	4.60
20.00	50	47	42.5	26.7	6.24	3.65

Results of this series, shown by data in Table 4 and also in Figure 5 where the average dry weights of plants per culture are plotted against concentration of sulfate in the nutrient solution, indicate that the sulfate ion has little effect upon the growth of soybeans when the concentration is above deficiency levels. Beckenbach and others (2) report similar results with corn grown under different levels of sulfate. In the lower concentrations the results of this series resemble those of the Phosphate Series. Although the cotyledons were removed, evidently enough sulfate remained in the plants to give fairly large yields. The plants in the minus-sulfate cultures were not as succulent as normal soybean plants and the stems were hard and slender. The same appearance in the minus-phosphate cultures would seem to indicate that plants in both series at deficiency levels were abnormal even though they produced fairly large yields.

Evidently the soybean plant is able to utilize either phosphate or sulfate much more efficiently if other nutrient elements are present in ample quantities.

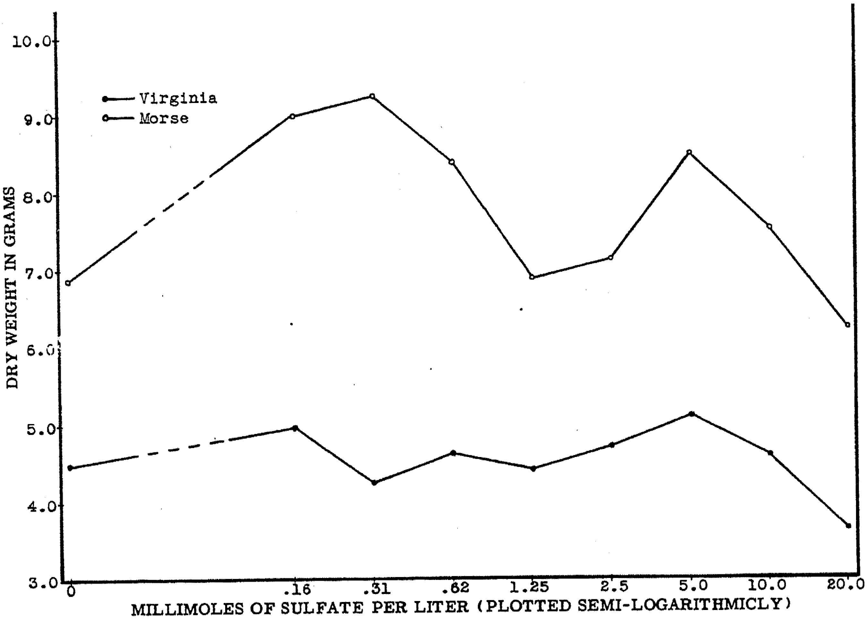

Fig. 5.—Effect of sulfate concentration in the nutrient solution upon the dry weight of plants per culture.

Potassium Series

Forage yields.—Some of the most interesting evidence of differential growth response with these soybean varieties was obtained in the Potassium Series. Results are given in Table 5, and the average dry weights of plants per culture are plotted against potassium concentration in the nutrient solution in Figure 6. This

TABLE 5. EFFECT OF POTASSIUM CONCENTRATION IN THE NUTRIENT SOLUTION UPON AVERAGE HEIGHT, FRESH WEIGHT, AND DRY WEIGHT OF PLANTS PER CULTURE

Millimoles of Potassium	Height cms.		Fresh Weight grams		Dry Weight grams	
	Morse	Virginia	Morse	Virginia	Morse	Virginia
.00	35	30	6.2	5.4	.97	.75
.12	50	37	14.1	11.6	1.99	1.54
.25	48	47	15.8	14.3	2.14	1.89
.50	68	63	20.4	18.0	2.90	2.30
1.00	78	68	36.1	25.2	5.00	3.26
2.00	76	76	39.0	32.9	5.59	4.16
4.00	85	77	49.5	35.2	7.51	4.26
8.00	101	91	51.4	35.4	7.91	4.28
10.00	97	91	48.8	34.0	7.42	4.33

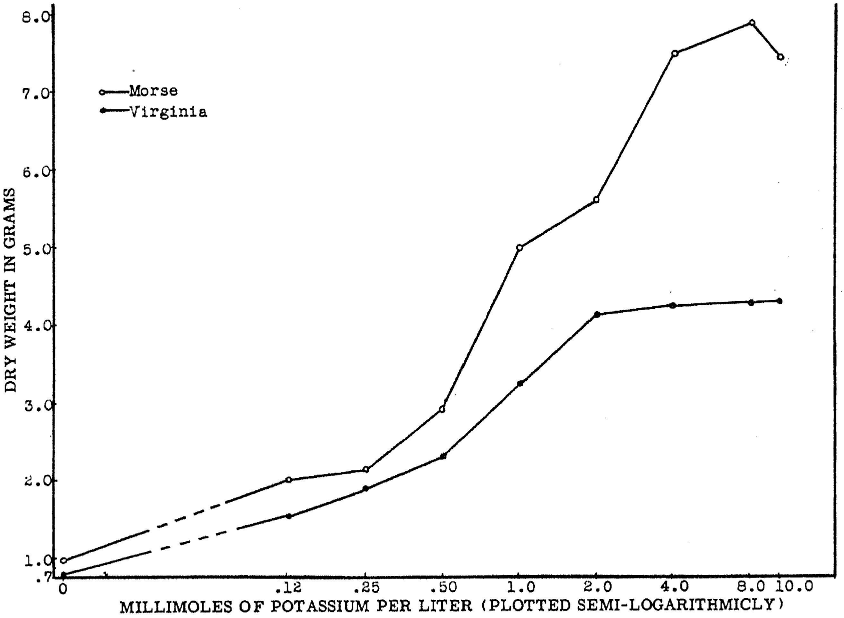

Fig. 6.—Effect of potassium concentration in the nutrient solution upon the dry weight of plants per culture.

graph shows that, while at the lower concentrations of potassium the yields of the two varieties were not significantly different, the Morse yields in the higher concentrations were almost double those of Virginia. The curve for the hay yield of Virginia levels off at 2.0 millimoles of potassium, and additional increases in the potassium concentration in the nutrient solution had no effect in increasing yields of hay. The Morse variety continued to show rapid increase in yield for each additional increment in potassium concentration, and reached its maximum yield of hay at 8.0 millimoles of potassium per liter.

These results would seem to indicate that the Morse variety is more efficient than the Virginia variety in utilizing higher concentrations of potassium in the production of plant material. In fact, it would seem that the Virginia variety was unable to utilize more than 2.0 millimoles of potassium per liter of nutrient solution if hay yields are a criterion of its ability.

Analytical results.—In view of the above results it was considered desirable to know the composition of the plant material from this series with reference to potassium, calcium, and magnesium. Samples of the dry forage of each variety for each treatment in the series were analyzed spectographically by the Lundegardh flame method and the results of these analyses, calculated as percentage of dry matter, are presented in Table 6.* In order to evaluate the effects of potassium on the composition of the forage more completely, the actual amounts of potassium, calcium, and magnesium removed by the plants have also been calculated and are presented in Table 7 in terms of milligrams per culture. Graphic illustrations of the effect of potassium in the nutrient solution upon the percentage of potassium, calcium, and magnesium in the plant material are given in Figures 7, 8, and 9 respectively, and the quantities present in milligrams of the same elements per culture are shown in Figures 10, 11, and 12.

TABLE 6. EFFECT OF POTASSIUM CONCENTRATION IN THE NUTRIENT SOLUTION UPON THE PERCENTAGES OF POTASSIUM, CALCIUM, AND MAGNESIUM IN SOYBEAN FORAGE

Millimoles of Potassium	Potassium %		Calcium %		Magnesium %	
	Morse	Virginia	Morse	Virginia	Morse	Virginia
.00	.81	.30	1.34	1.58	1.13	1.49
.12	1.41	1.02	1.34	1.50	.91	1.28
.25	1.53	1.49	1.19	1.40	.90	1.26
.50	2.03	1.96	1.07	1.46	.90	1.14
1.00	2.39	2.28	1.09	1.38	.56	.92
2.00	2.60	2.72	1.01	1.39	.48	.81
4.00	2.95	2.94	.93	1.35	.49	.56
8.00	3.67	4.69	.83	1.06	.43	.52
10.00	3.89	4.81	.74	.85	.36	.40

TABLE 7. EFFECT OF POTASSIUM CONCENTRATION IN THE NUTRIENT SOLUTION UPON THE AMOUNT OF POTASSIUM, CALCIUM, AND MAGNESIUM CONTAINED IN PLANT MATERIAL PER CULTURE

Millimoles of Potassium	Potassium mgm.		Calcium mgm.		Magnesium mgm.	
	Morse	Virginia	Morse	Virginia	Morse	Virginia
.00	7.8	2.2	13.0	11.8	11.0	11.2
.12	28.0	15.7	26.7	23.1	18.1	19.7
.25	32.7	28.1	25.5	26.5	19.5	23.8
.50	58.9	45.1	31.0	33.6	26.1	26.2
1.00	119.5	74.3	54.5	45.0	28.0	30.0
2.00	145.3	113.1	56.5	57.8	26.8	33.7
4.00	221.5	125.2	69.8	57.5	36.8	23.9
8.00	290.3	200.7	65.7	45.4	34.0	22.3
10.00	288.6	208.3	54.9	36.8	26.7	17.3

As would be expected, the potassium content of the plant material increased proportionately with the increase of potassium in the nutrient solution. This effect with potassium fertilization has been

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*Credit is due Dr. V. R. Ells of the Agricultural Chemistry Department for the spectographic analyses.

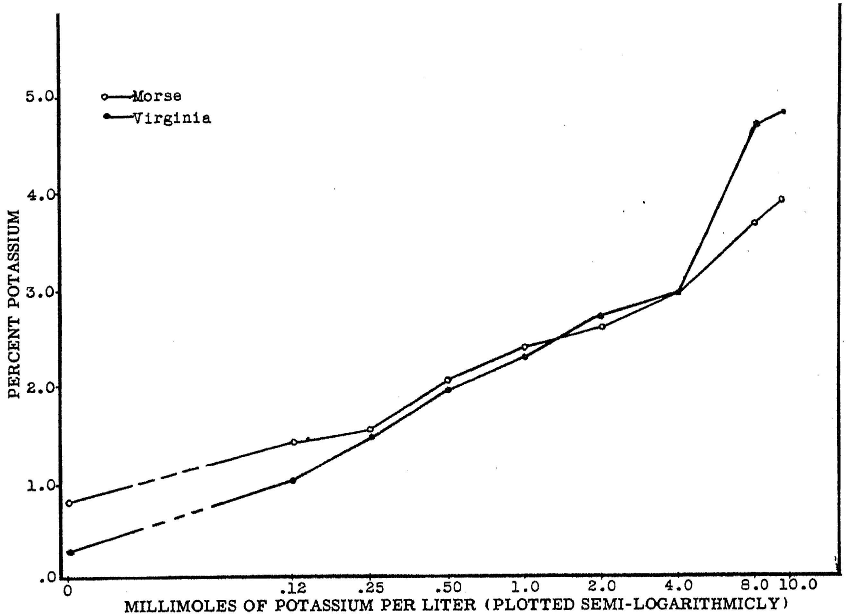

Fig. 7.—Effect of potassium concentration in the nutrient solution upon the percentage of potassium in the dry plant material.

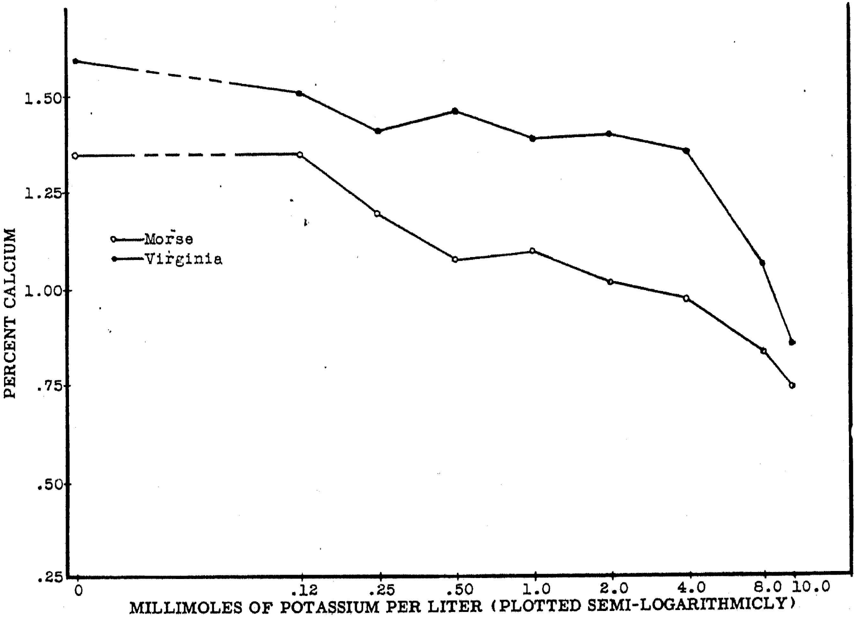

Fig. 8.—Effect of potassium in the nutrient solution upon the percentage of calcium in the dry plant material.

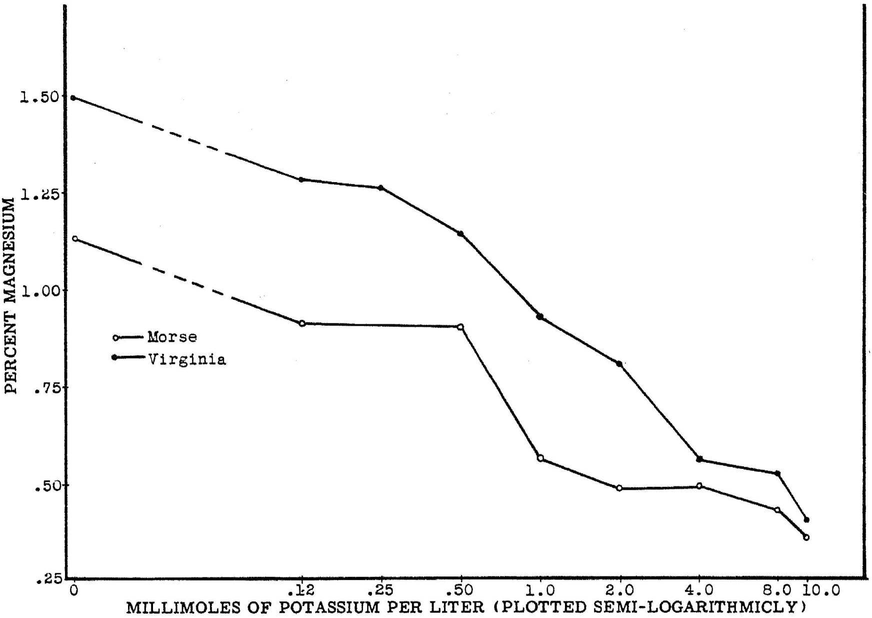

Fig. 9.—Effect of potassium concentration in the nutrient solution upon the percentage of magnesium in the dry plant material.

observed in many other studies among which are those of Ferguson and Albrecht (7), Hartt (12), Johnston and Hoagland (17), and Janssen and Bartholomew (16). Many of these studies have indicated that "luxury" consumption of this element occurs in the higher levels of potassium nutrition. This tendency for luxury consumption of potassium would probably explain the large amounts of potassium taken up by the plants in the higher levels in this experiment.

The depressing effect of potassium upon the uptake of the other cations is also readily noticeable in these results. With increasing potassium in the nutrient solution, and thus increasing percentages of potassium in the plant material, the percentages of magnesium and calcium decrease consistently in both varieties. This effect has also been observed by Drake and Scarseth (5) in experiments with tobacco, and by Ferguson and Albrecht (7) with Virginia soybeans. Fonder (8) reports the same inverse relationship between potassium and calcium in alfalfa plants, and Johnston and Hoagland (17) noted that with low potassium considerably more calcium, magnesium, and phosphorus was absorbed by tomato plants. These are only a few of the instances in which this effect has been observed.

There are also quantitative variations between the Morse and Virginia varieties in composition when grown under varying concentra-

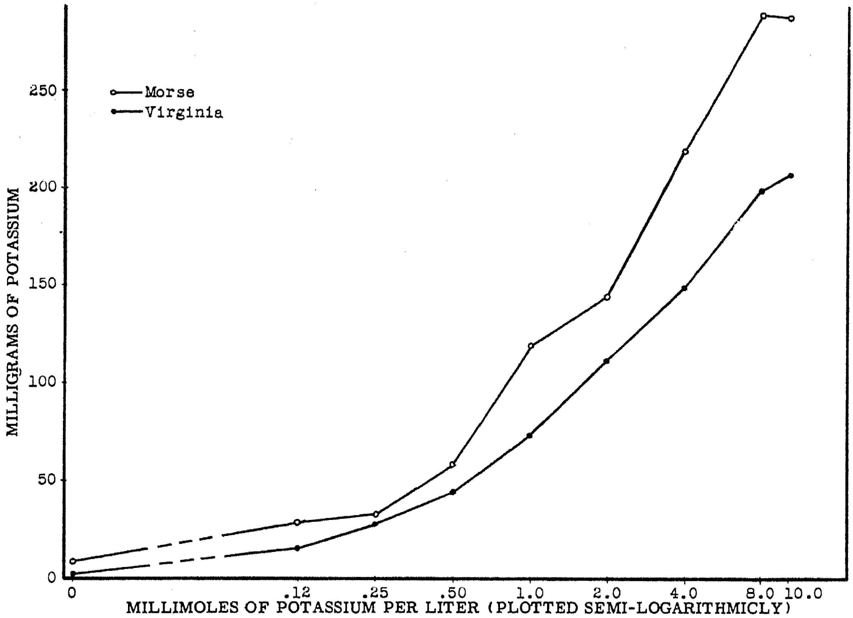

Fig. 10.—Effect of potassium concentration in the nutrient solution upon the potassium content of dry plant material per culture.

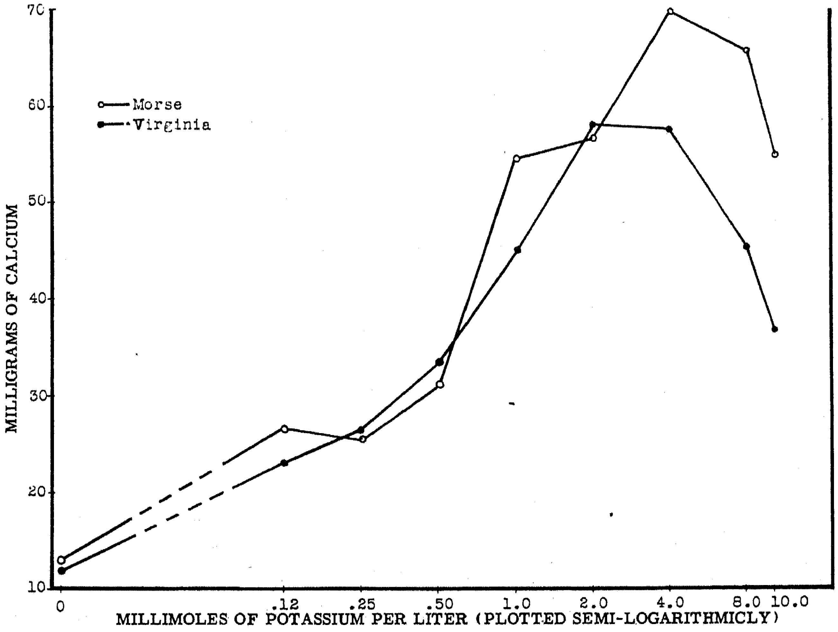

Fig. 11.—Effect of potassium concentration in the nutrient solution upon the calcium content of dry plant material per culture.

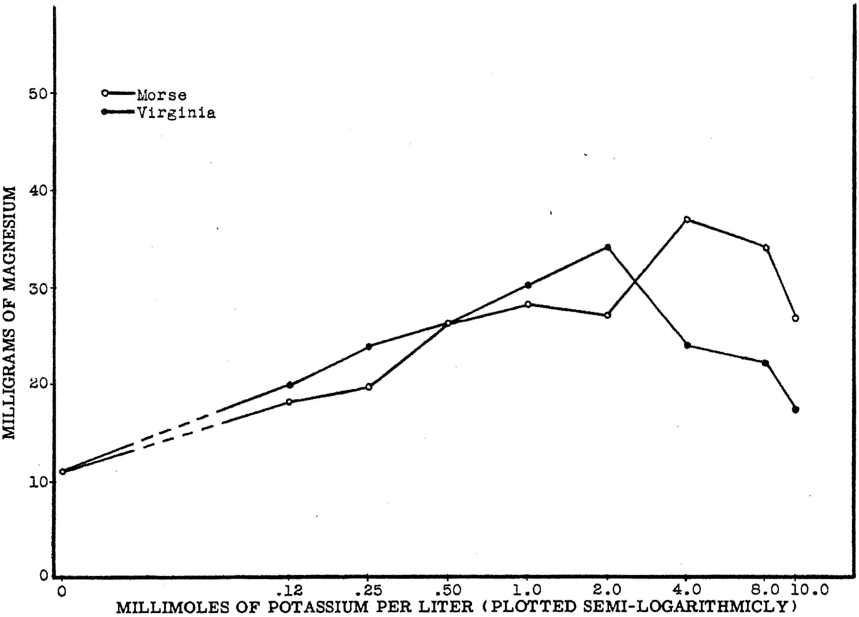

Fig. 12.—Effect of potassium concentration in the nutrient solution upon the magnesium content of dry plant material per culture.

tions of potassium. If taken from the standpoint of percentages, the differences between the two varieties are marked and consistent. In all cases the forage of the Virginia variety contained a higher percentage of both calcium and magnesium than that of the Morse variety. Thus if equal amounts of Virginia and Morse hay were removed from a plot of land, the Virginia hay could be expected to remove a larger amount of calcium and magnesium from the soil. However, this would be true only on the poorer types of soil where Virginia can be expected to yield as much, or even more, than Morse, for on the more fertile soils the larger yield of Morse would increase the total uptake of these elements to more than that of the smaller yield of Virginia. This is shown clearly by the data in Figures 11 and 12. Although the total amounts of calcium and magnesium contained in the forage of the two varieties per culture are not significantly different at the lower and medium levels of potassium nutrition, in the higher levels Morse accumulated considerably more calcium and magnesium than Virginia.

The Morse forage also contained a larger total amount of potassium per culture than that of Virginia, again because of its ability to yield more at the higher levels of potassium, since the percentages of potassium in Virginia forage grown at the 8.0 and 10.0 millimole levels were actually greater than those of Morse.

Calcium Series

Forage yields.—The results of this series are presented in Table 8 and Figure 13. While both varieties showed large increases in yield with the first few increments of calcium above the deficiency level, yields decreased uniformly at all levels of more than 2.5 millimoles of calcium per liter. A very sharp drop in yields occurred with the 20.0 millimole level and toxicity symptoms in cultures at this level indicated that an unbalanced condition resulted from the extremely high concentration of the calcium ion.

TABLE 8. EFFECT OF CALCIUM CONCENTRATION IN THE NUTRIENT SOLUTION UPON AVERAGE HEIGHT, FRESH WEIGHT, AND DRY WEIGHT OF PLANTS PER CULTURE

Millimoles of Calcium	Height cms.		Fresh Weight grams		Dry Weight grams	
	Morse	Virginia	Morse	Virginia	Morse	Virginia
.00	17	14	...	...	1.05	.85
.16	40	32	35.4	15.9	5.60	2.58
.31	43	38	39.3	23.3	5.85	3.52
.62	43	45	40.6	31.6	6.16	4.55
1.25	45	44	33.4	27.7	5.39	4.05
2.50	48	50	36.7	32.0	6.00	5.04
5.00	45	46	30.7	31.4	5.19	4.75
10.00	39	41	26.2	28.0	4.68	4.23
20.00	31	27	15.7	10.8	2.94	2.01

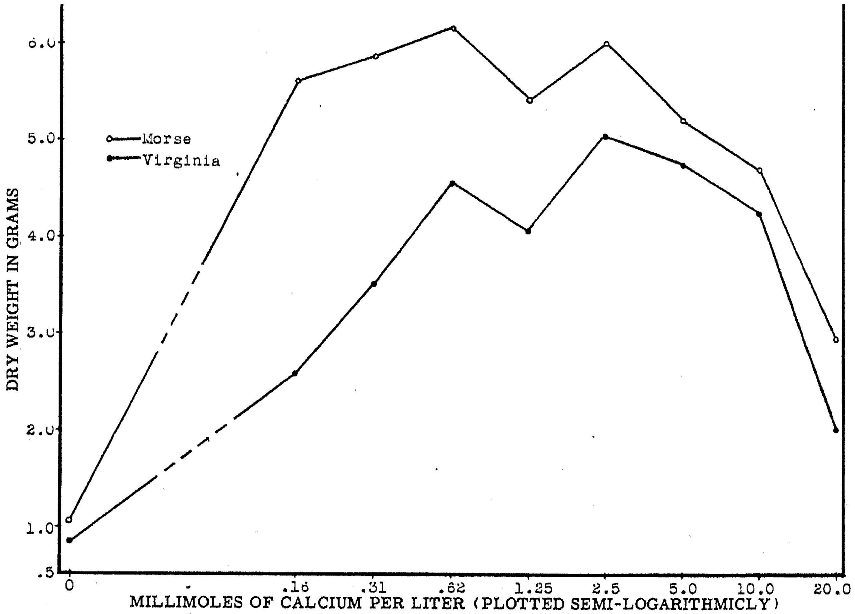

Fig. 13.—Effect of calcium concentration in the nutrient solution upon the dry weight of plants per culture.

There was some evidence of a differential behavior between the two varieties in the calcium levels of 0.16 to 2.5 millimoles per liter. It appeared that the Morse variety was probably superior to Virginia at these levels of calcium in the presence of ample quantities of other essential elements when judged by the production of forage.

Analytical results.—As in the Potassium and Magnesium Series, the composition of the forage with respect to calcium, potassium, and magnesium content was determined spectographically. Results expressed as percentage of dry weight are presented in Table 9, and Figures 14, 15, and 16, and as total milligrams per culture in Table 10, and Figures 17, 18, and 19.

TABLE 9. EFFECT OF CALCIUM CONCENTRATION IN THE NUTRIENT SOLUTION UPON THE PERCENTAGE OF CALCIUM, POTASSIUM, AND MAGNESIUM IN SOYBEAN FORAGE

Millimoles of Calcium	Calcium %		Potassium %		Magnesium %	
	Morse	Virginia	Morse	Virginia	Morse	Virginia
.00	.09	.09	4.96	5.01	.82	.89
.16	.10	.11	4.41	4.07	.66	.88
.31	.18	.16	3.96	3.52	.67	.89
.62	.27	.24	3.10	3.54	.67	.85
1.25	.38	.36	2.60	3.22	.63	.84
2.50	.61	.64	2.06	2.42	.51	.72
5.00	.82	.87	1.92	2.20	.42	.59
10.00	1.04	1.26	1.09	2.37	.37	.52
20.00	1.56	1.79	.78	.68	.30	.37

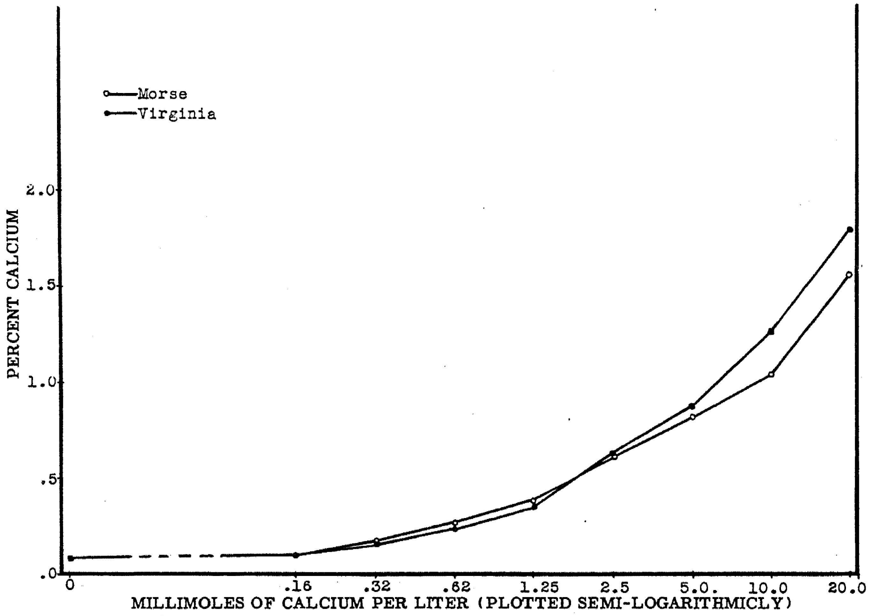

Fig. 14.—Effect of calcium concentration in the nutrient solution upon the percentage of calcium in the dry plant material.

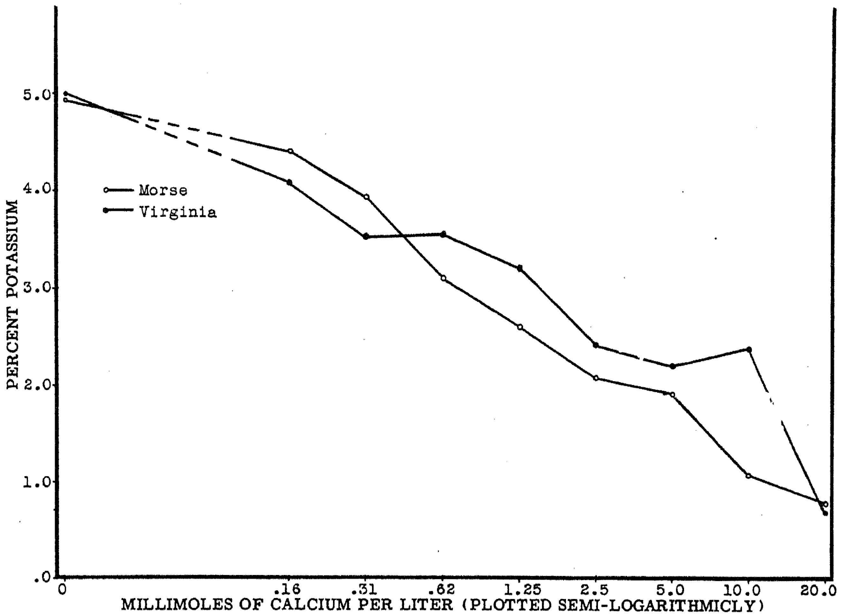

Fig. 15.—Effect of calcium concentration in the nutrient solution upon the percentage of potassium in the dry plant material.

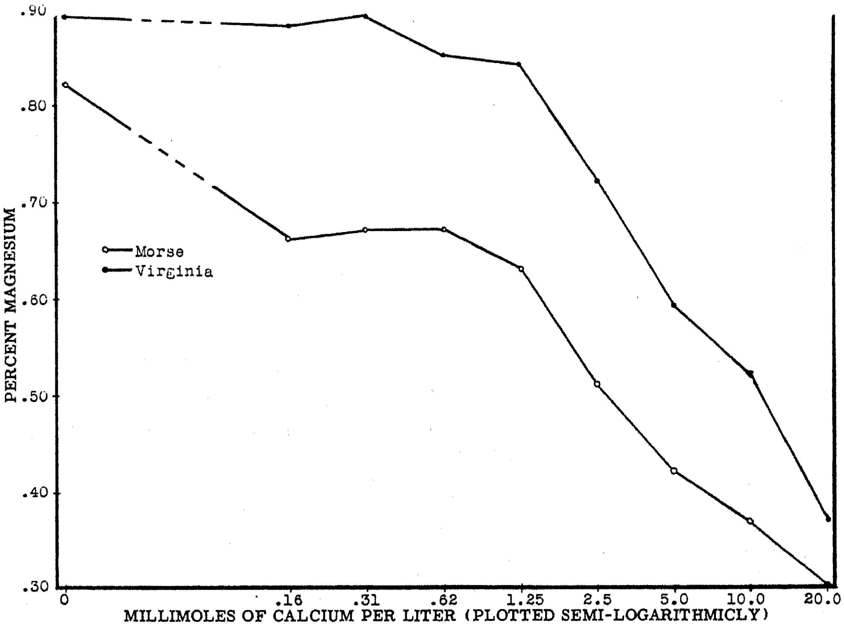

Fig. 16.—Effect of calcium concentration in the nutrient solution upon the percentage of magnesium in the dry plant material.

TABLE 10. EFFECT OF CALCIUM CONCENTRATION IN THE NUTRIENT SOLUTION UPON THE AMOUNT OF CALCIUM, POTASSIUM, AND MAGNESIUM CONTAINED IN PLANT MATERIAL PER CULTURE

Millimoles of Calcium	Calcium mgm.		Potassium mgm.		Magnesium mgm.	
	Morse	Virginia	Morse	Virginia	Morse	Virginia
.00	.9	.8	52.1	42.6	8.6	7.8
.16	5.6	2.8	247.0	105.0	37.0	22.7
.31	10.5	5.6	231.7	123.9	39.2	31.3
.62	16.6	10.9	191.0	161.1	41.3	38.7
1.25	20.5	14.6	140.1	130.4	34.0	34.0
2.50	36.6	32.3	123.6	122.0	30.6	36.3
5.00	42.6	41.3	99.6	104.5	21.8	28.0
10.00	48.7	53.3	51.0	100.3	17.3	22.0
20.00	45.9	36.0	22.9	13.7	8.8	7.4

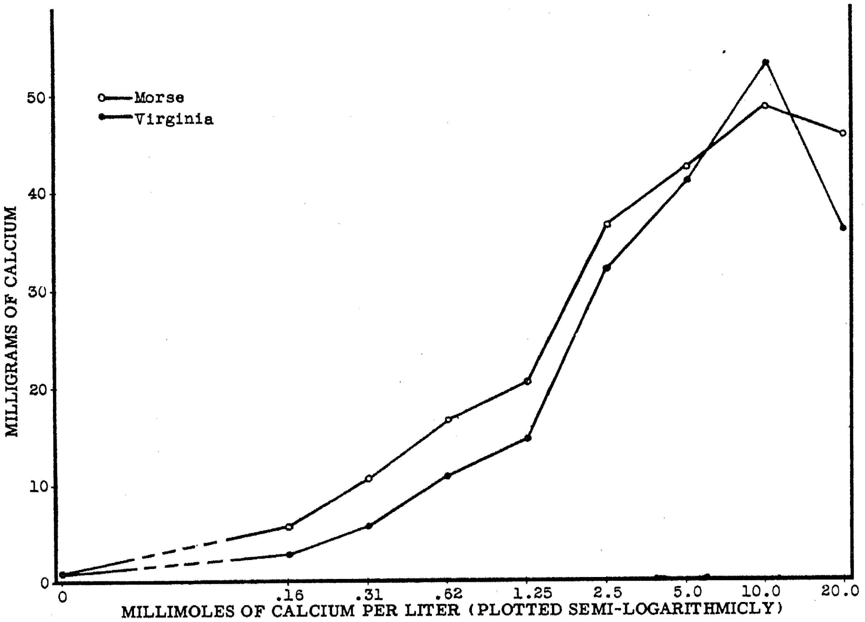

Fig. 17.—Effect of calcium concentration in the nutrient solution upon the calcium content of dry plant material per culture.

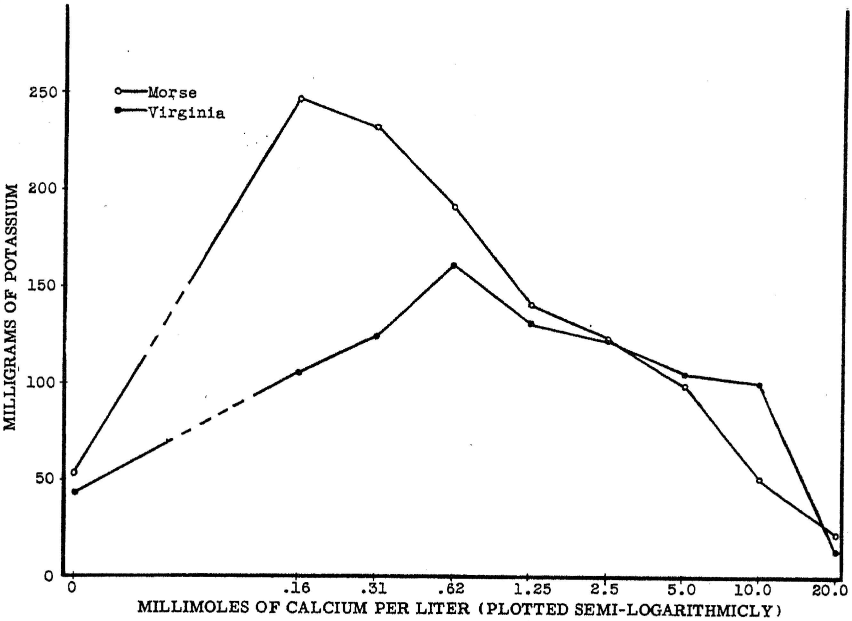

Fig. 18.—Effect of calcium concentration in the nutrient solution upon the potassium content of dry plant material per culture.

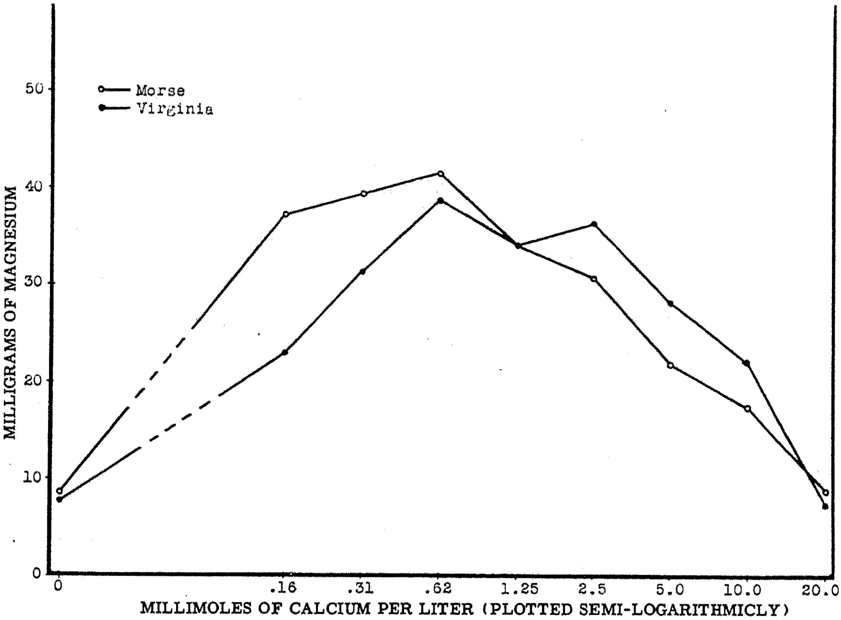

Fig. 19.—Effect of calcium concentration in the nutrient solution upon the magnesium content of dry plant material per culture.

Both varieties show a direct relationship between the percentage of calcium in the forage and the level of calcium in the nutrient solution. Likewise, as was observed in the Potassium Series, the percentages of the cations which were held constant in the nutrient solution, potassium and magnesium in this case, were inversely proportional to the amounts of calcium added in the nutrient solution.

Taking the results from the standpoint of total amounts of calcium, potassium, and magnesium contained in the forage at the different levels of calcium, such uniform trends or relationships were not obtained as is shown graphically in the Figures 17, 18, and 19 inclusively. In terms of milligrams, the amounts of potassium and magnesium removed by the plants per culture increased with increasing calcium up to a level of about 0.62 millimoles of calcium per liter, and gradually decreased with additional increments of calcium. The total calcium, on the other hand, increased uniformly with each increment of calcium in the nutrient solution reaching a peak at the 10.0 millimoles level and declining slightly at the 20.0 millimoles level.

Results similar to those have been secured by other workers. Horner (14) found that Virginia soybeans absorbed greater quantities of calcium and smaller quantities of magnesium and potassium with increasing amounts of calcium in the nutrient media. He used sand and colloidal clay culture media with the calcium adsorbed on the clay, but the results are similar to those in this experiment where nutrient solutions were added to sand cultures. Hutchings (15), also working with Virginia soybeans and colloidal clay culture media, likewise observed a direct relationship between potassium content as percentage of dry weight and level of calcium in the culture medium. He also secured increasing calcium content, both as percentage of dry weight, and in total amount contained in the plant material per culture, with increasing calcium in the nutrient medium.

Thus there seems to be no doubt that with increasing calcium in the nutrient medium, increasing percentages of calcium and decreasing percentages of potassium and magnesium can be expected in soybean plants. Likewise, the total amount of calcium removed by the plants increases with increasing calcium in the nutrient solution.

Not so much evidence of varietal variation was obtained in this series. Probably the only significant variation was in the case of magnesium on a percentage basis in the forage of the two varieties. Regardless of the calcium concentration in the nutrient solution, the forage of the Virginia variety always contained considerably higher percentages of magnesium than forage of the Morse variety.

Magnesium Series

Forage yields.—Further evidence of varietal variation in the response to an essential nutrient element is shown by the forage yields in the Magnesium Series. The yields of the two varieties were very similar in the deficiency and in the 0.16 millimole levels, but with all higher levels of magnesium Morse was far superior to Virginia in utilizing the available magnesium for the production of forage, as shown by the results in Table 11 and Figure 20. In

TABLE 11. EFFECT OF MAGNESIUM CONCENTRATION IN THE NUTRIENT SOLUTION UPON AVERAGE HEIGHT, FRESH WEIGHT, AND DRY WEIGHT OF PLANTS PER CULTURE

Millimoles of Magnesium	Height cms.		Fresh Weight grams		Dry Weight grams	
	Morse	Virginia	Morse	Virginia	Morse	Virginia
.00	18	16	5.7	4.6	1.20	1.02
.16	31	32	21.1	22.2	3.36	3.17
.31	49	44	54.9	31.8	7.04	3.92
.62	53	49	64.2	37.2	8.55	4.28
1.25	51	43	71.2	29.2	9.98	3.64
2.50	50	44	57.5	35.2	7.73	4.39
5.00	49	44	52.8	33.8	7.78	4.11
10.00	54	51	64.8	38.0	9.30	4.76
20.00	49	46	57.7	30.0	8.46	3.94

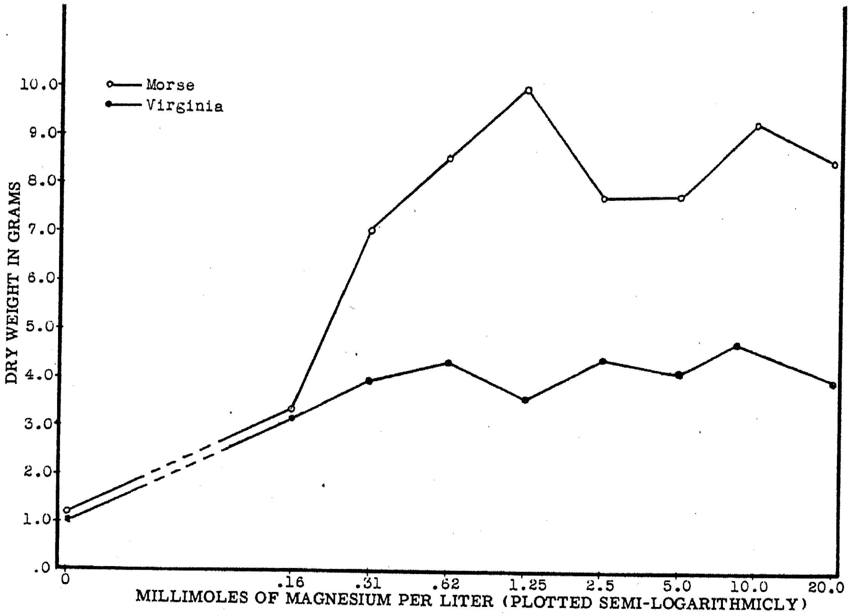

Fig. 20.—Effect of magnesium concentration in the nutrient solution upon the dry weight of plants per culture.

fact, the Virginia variety showed little ability to utilize the magnesium at concentrations of more than 0.31 millimoles per liter of nutrient solution, if yield of forage is used as a criterion in measuring such ability, since all yields at levels of magnesium above this were approximately the same. The Morse variety, on the other hand, grew rapidly with additions of magnesium above the 0.16 millimole per liter level, and yields approximately double those of Virginia were produced. Judging from these results it would seem reasonable to conclude that Morse can be expected to utilize larger quantities of magnesium in the production of forage than Virginia when all other essential elements are present in sufficient quantities.

Analytical results.—Data on the composition of forage expressed as percentages of dry weight are presented in Table 12 and Figures 21, 22, and 23, and as total milligrams per culture in Table 13 and Figures 24, 25, and 26.

TABLE 12. EFFECT OF MAGNESIUM CONCENTRATION IN THE NUTRIENT SOLUTION UPON THE PERCENTAGE OF MAGNESIUM, POTASSIUM, AND CALCIUM IN SOYBEAN FORAGE

Millimoles of	Magnesium %		Potassium %		Calcium %	
Magnesium	Morse	Virginia	Morse	Virginia	Morse	Virginia
.00	.07	.07	3.88	5.35	.11	.11
.16	.10	.10	2.84	3.03	.12	.10
.31	.19	.18	2.90	3.72	.13	.12
.62	.27	.38	2.39	3.55	.13	.11
1.25	.31	.47	3.11	4.15	.12	.11
2.50	.42	.47	2.17	2.87	.11	.10
5.00	.50	.60	2.53	3.40	.10	.09
10.00	.64	.67	2.82	2.55	.09	.08
20.00	.76	.89	1.96	1.72	.07	.07

TABLE 13. EFFECT OF MAGNESIUM CONCENTRATION IN THE NUTRIENT SOLUTION UPON THE AMOUNT OF MAGNESIUM, POTASSIUM, AND CALCIUM CONTAINED IN PLANT MATERIAL PER CULTURE

Millimoles of	Magnesium mgms.		Potassium mgms.		Calcium mgms.	
Magnesium	Morse	Virginia	Morse	Virginia	Morse	Virginia
.00	.8	.7	46.6	54.6	1.3	1.1
.16	3.4	3.2	95.4	96.0	4.0	3.2
.31	13.4	7.1	204.2	145.8	9.2	4.7
.62	23.1	16.3	204.3	151.9	11.1	4.7
1.25	30.9	17.1	310.4	151.0	12.0	4.0
2.50	32.5	20.6	167.7	126.0	8.5	4.4
5.00	38.9	24.7	196.8	139.7	7.8	3.7
10.00	59.5	31.9	262.3	121.4	8.4	3.8
20.00	64.3	35.1	165.8	67.8	5.9	2.8

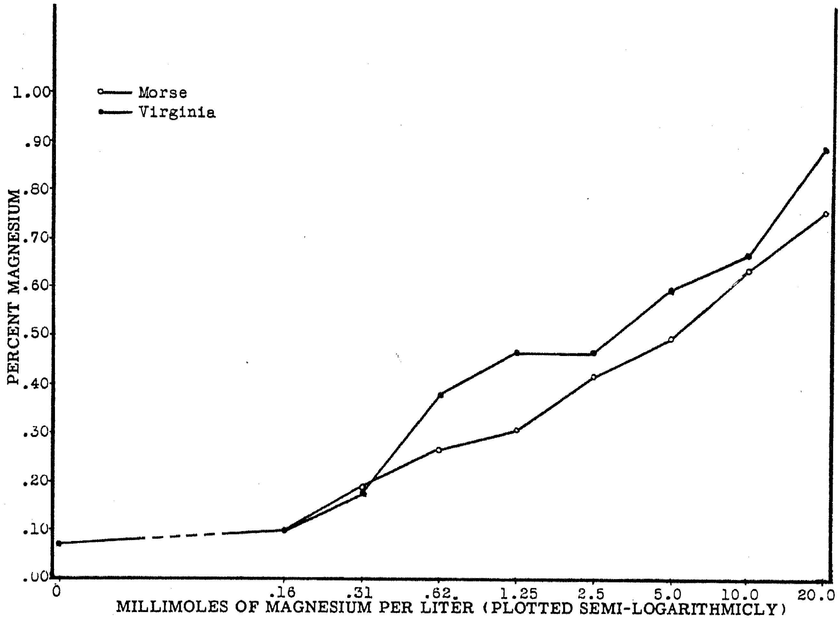

Fig. 21.—Effect of magnesium concentration in the nutrient solution upon the percentage of magnesium in the dry plant material.

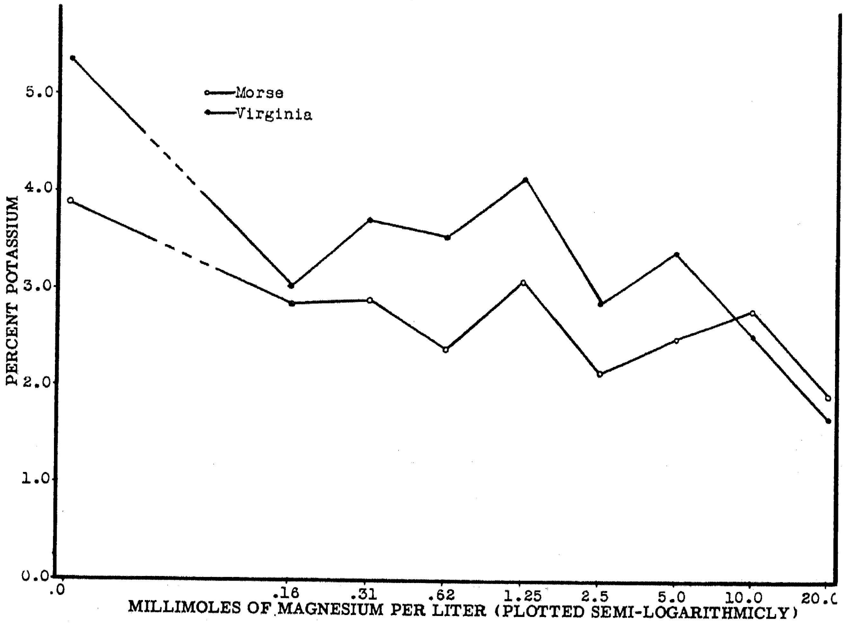

Fig. 22.—Effect of magnesium concentration in the nutrient solution upon the percentage of potassium in the dry plant material.

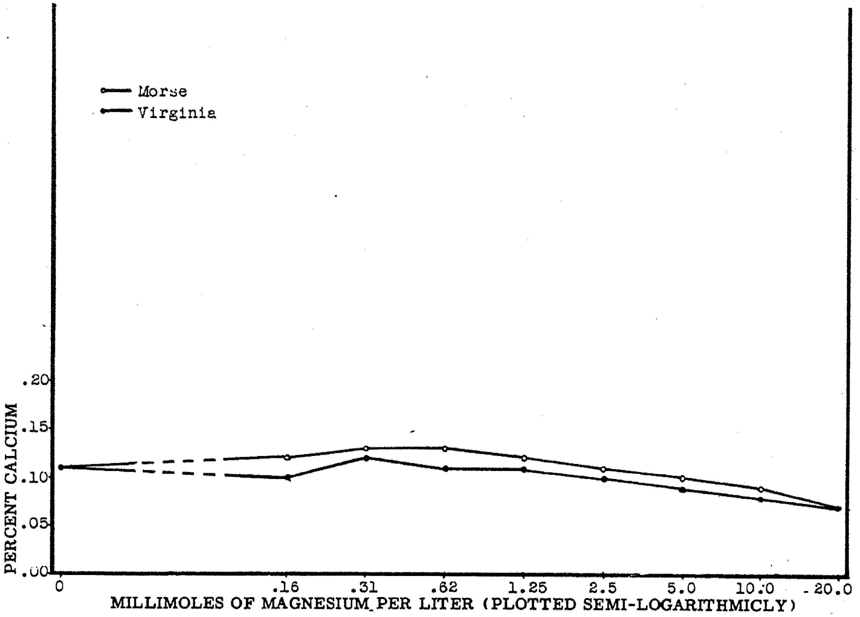

Fig. 23.—Effect of magnesium concentration in the nutrient solution upon the percentage of calcium in the dry plant material.

Fig. 24.—Effect of magnesium concentration in the nutrient solution upon the magnesium content of dry plant material per culture.

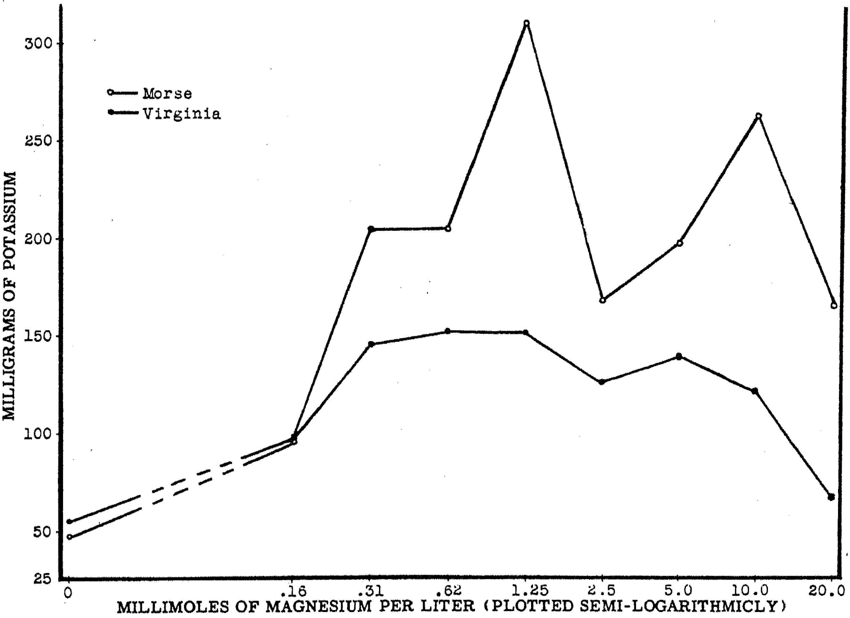

Fig. 25.—Effect of magnesium concentration in the nutrient solution upon the potassium content of dry plant material per culture.

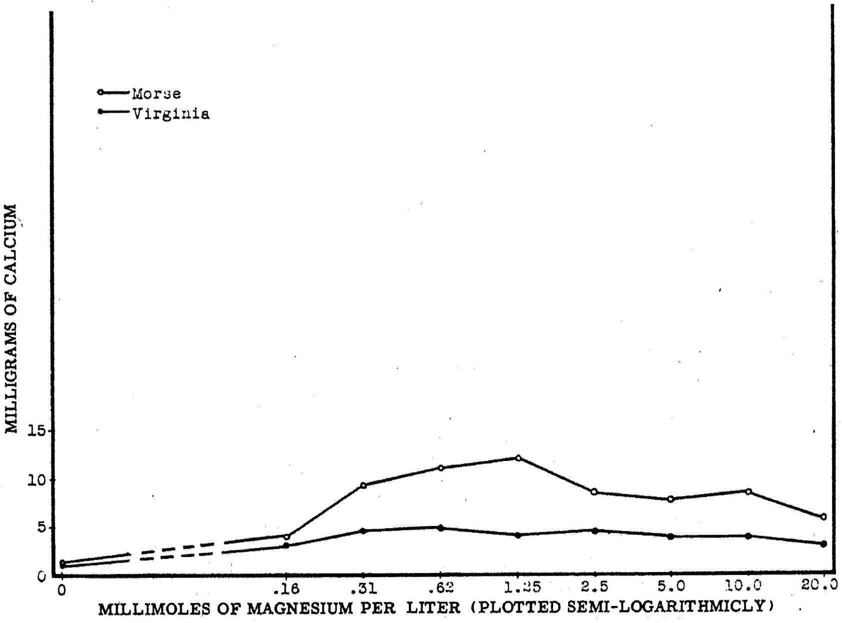

Fig. 26.—Effect of magnesium concentration in the nutrient solution upon the calcium content of dry plant material per culture.

Judging from the results of the Potassium and Calcium Series, it would be logical to expect that the percentage of the variable cation of this series, Magnesium, would increase in the forage proportionately with the amount supplied to the plants and that the other two cations would decrease consistently in percentage at the same time. However, this is only partially true. While the magnesium content of the forage does show a direct relationship to the amount of magnesium supplied, and the potassium an inverse relationship, the calcium content remains practically constant throughout the entire range of magnesium treatments. Evidence similar to this was secured by Graham (10) working with the Virginia variety of soybeans and colloidal clay media. He found that with increasing magnesium the percentage of calcium remained practically constant, and the percentage of magnesium increased rapidly. Moreover, when his results are considered from the standpoint of total milligrams in the forage per culture, the total calcium increased slightly and the total magnesium increased very rapidly with increasing magnesium in the nutrient medium.

These results when considered from the standpoint of percentage composition show no significant difference between varieties with respect to potassium or calcium content and only a slight difference in magnesium content in favor of the Virginia variety. This is rather surprising, since in both the other cation series there was a large difference between varieties in the percentage of magnesium contained in the forage in most cases. Thus, at first glance this would seem to be in contrast to the results from the other series; but it probably is not. For instance, in both the Potassium and Calcium Series where there were very large differences in magnesium composition of the varieties, these differences were obtained at the deficiency or low concentrations of the variable ion. In both cases, when the higher levels of the ion being tested were reached, the magnesium contents of the two varieties were more nearly the same, and the differences were probably no more significant than they are in this series. Thus it appears that when calcium and potassium are present in the nutrient medium in sufficient quantity, and particularly in extremely large quantities, the tendency for Virginia to accumulate more magnesium than Morse is not so marked.

If the results are considered in terms of actual milligrams of the cations removed by the two varieties per culture, evidence of varietal variation appears in all cases as was shown in Figures 24, 25, and 26. At all levels of magnesium nutrition above 0.16 millimoles per liter there were significant differences in the amounts of magnesium, potassium, and calcium contained in the forage per culture in favor of Morse. Thus it seems that the Morse variety could again be expected to remove larger quantities of these cations from the soil than Virginia, if the differences in yield should be as great as they were in this series.

DISCUSSION

The objective of this study, as stated before, was to determine whether a differential growth response to variable mineral nutrient conditions could be expected from the Morse and Virginia varieties of soybeans. Such a response was found in the experiments reported in this paper. Not only did differential growth response occur with respect to variable supply of certain of the essential nutrient elements, but differences were also found in the accumulation of the nutrient ions by the forage of the two varieties, both in percentage and total composition. It is reasonable to expect that other varieties of soybeans will exhibit still different responses if grown under these same nutrient conditions. In fact, the present results would suggest that differences between varieties in this respect may be as distinct as some of the differences which are known to occur between species. Moreover, if climatic conditions were also to be varied the resulting varietal response might be as great as those caused by variations in the level of nutrition.

The most apparent evidence, in the present study, of differential response to various levels of a particular nutrient element was obtained in the Potassium and Magnesium Series with forage yields. The Morse variety was far superior to the Virginia variety in forage yields at the higher concentrations of the variable ion in these series. Somewhat less conclusive but still apparent evidence was obtained in the yields of the two varieties at certain levels of nitrogen, phosphate, and calcium, with Morse still superior to Virginia at the higher concentrations. The results obtained with variable sulfate supply were so irregular that any conclusions as to varietal behavior would be open to serious question.

Thus, in all series except one, there was some indication that these two varieties of soybeans did not exhibit the same type of growth response. As a rule, the Virginia yields were more nearly normal and, likewise, more nearly equal to the Morse yields at the lower concentrations of the nutrient elements; and they did not show much increase with an increase in the concentration of these elements. In other words, the Virginia variety evidently is able to utilize the nutrients from a medium such as could be expected of a soil of low fertility. The Morse variety, on the other hand, while making rather low yields at the lower levels of nutrition, showed very rapid increases in the production of forage with increasing concentrations of the nutrient elements and usually gave maximum forage yields with rather high levels of nutrition. Since these higher concentrations of nutrient elements in sand cultures probably provide as much available nutrients as would soils of fairly high fertility, it seems that the Morse could be expected to give maximum hay yields on soils that are comparatively fertile. This has been found to be true in field experiments.

Other evidence of differential behavior was secured in the percentages of potassium, calcium, and magnesium contained in the forage when the plants were grown at different levels of potassium, calcium, and magnesium nutrition. These percentages were in most cases, higher in the Virginia variety. For a broadly generalized comparison of these data with respect to variety, a simplified tabular arrangement is presented in Table 14.

TABLE 14. A SIMPLIFIED COMPARISON OF THE PERCENTAGES OF POTASSIUM, CALCIUM, AND MAGNESIUM CONTAINED IN FORAGE OF MORSE AND VIRGINIA SOYBEANS GROWN UNDER VARIABLE SUPPLIES OF THESE THREE CATIONS

Series (ion varied)	comparison of varieties in percentage of:		
	Potassium	Calcium	Magnesium
K	Similar in both varieties	Much higher in Virginia	Much higher in Virginia
Ca	Slightly higher in Virginia	Similar in both varieties	Much higher in Virginia
Mg	Similar in both varieties	Similar in both varieties	Slightly higher in Virginia

This summary of percentage results indicates that the Virginia forage was always richer in magnesium and equal to, or exceeded Morse forage in calcium and potassium. These results are potentially important to the livestock feeder, who would certainly prefer a hay which contained more minerals. Thus the Virginia forage would have a greater feed value because of its higher content of these elements.

A quantitative difference between the two varieties likewise occurred with respect to actual milligrams of potassium, calcium, and magnesium contained in the dry forage per culture of three plants. Almost without exception the Morse forage contained larger quantities of potassium, and in general approximately equal or larger quantities of calcium and magnesium than did the Virginia forage when the varieties were compared on an absolute basis. In other words, the Morse variety, as a rule, removed larger quantities per plant of these elements from the nutrient media than did the Virginia variety and thus can be said to be a heavier feeder of potassium, calcium, and magnesium than the Virginia variety.

Summarizing the differences between varieties, Morse was found to be superior in yield and total accumulation of potassium, calcium, and magnesium in the forage, but Virginia was superior in percentage content of these same elements. Thus the farmer who wanted to sell his hay would prefer Morse because he could expect to secure higher yields of hay and a larger total quantity of these elements in the hay from an acre of land. On the other hand, the livestock feeder who bought hay would prefer to buy Virginia because it could be expected to be richer in potassium, calcium, and magnesium on a percentage basis, and would thus have a greater value as a feed for each pound fed.

In his experiments with these same varieties of soybeans, Poehlman (20) was able to secure yields of Virginia significantly higher than those of Morse on soils of extremely low fertility, but on all soils of a higher fertility level, the Morse was superior to Virginia from the standpoint of hay yields. Results of his field experiments are given in Table 15.

TABLE 15. COMPARATIVE HAY YIELDS IN FIELD PLOT EXPERIMENTS

Soil type	Yields of hay in pounds per acre Morse	 Virginia
Lebanon silt loam	1834	2192
Oswego silt loam	3205	2804
Putnam silt loam	5506	4322
Summit silt loam	4520	4184
Wabash clay	5285	4742

When the same varieties were tested on these same soils in pot experiments at Columbia the following results were secured:

TABLE 16. YIELDS OF FORAGE WITH DIFFERENT SOIL TYPES IN POT EXPERIMENTS

Soil type	Average yield in grams per pot Morse	 Virginia
Lebanon silt loam	28.2	23.9
Oswego silt loam	58.7	57.9
Putnam silt loam	64.4	61.7
Summit silt loam	79.2	71.0
Wabash clay	54.6	53.2

In these pot experiments Virginia was inferior to Morse in yield regardless of soil type. Now these pot experiments and the field experiments seemingly gave entirely different results, particularly in the case of the Lebanon silt loam. However, if the techniques used in these experiments are taken into consideration, the explanation of this discrepancy seems to be obvious. In his field experiments Poehlman used 15 grams of seed for each 16½-foot row, while in the pot experiments an equal number of plants (six) of each variety were grown per pot. Actual counts of five samples of seed of each variety from three different sources reveals that the average number of Morse seeds per 15 grams is 87 and for Virginia,

132. Thus in the field experiments about one-third more Virginia seed were grown per unit area than Morse. If this ratio had been maintained in the pot experiments it is probable that several of the resulting yields would have been in favor of the Virginia variety instead of the Morse, and he would have secured varietal variation in the pot experiments as well as in the field experiments.

This seems to explain the difference in results obtained in field and pot experiments with these two varieties in the preceding investigation. Poehlman, in using equal weights of seed in his field experiments followed the practice of farmers in seeding equal amounts of seed per acre regardless of variety, a practice which most investigators would not follow in pot experiments.

SUMMARY

A study was made of the effect of varying concentrations in the nutrient medium of major nutrient elements upon the forage yields of the Morse and Virginia soybean varieties. This was accomplished by raising the concentration of the element to be studied from a complete deficiency to an extremely high level with other ions kept constant at ample levels for the normal growth of these varieties. The effect of each of the cations upon the calcium, potassium, and magnesium composition of the forage of these varieties was also determined.

In this study the following facts seemed to be of importance:

1. Low concentrations of phosphate in the nutrient solution gave best forage yields with both varieties of soybeans, while high concentrations caused toxicity and reduced yields.
2. A differential response, as measured by forage yields, was exhibited by the two varieties to the amount of potassium supplied in the nutrient medium with Morse yielding almost twice as much as Virginia at the higher levels of potassium. The Virginia variety showed little ability to utilize supplies of potassium above one or two millimoles per liter.
3. The same type of response was exhibited with increasing amounts of magnesium in the nutrient solution. Morse showed a much superior ability to utilize the higher levels of magnesium, while Virginia showed little increase in yield with increasing magnesium above 0.31 millimole per liter of nutrient solution.
4. Less striking but probably significant differential variation between the varieties was also exhibited with respect to concentrations of nitrogen, phosphorus, and calcium in the nutrient solution.
5. Differential behavior was also evident in the percentage composition of the forage. Virginia forage, as a rule, contained higher percentages of the cations than that of Morse, and in almost every case contained more magnesium than Morse.
6. There was a direct relationship between the amount of potassium in the nutrient solution and the percentage of potassium in the forage of both varieties, and an inverse relationship with respect to percentages of calcium and magnesium under these same conditions.
7. With increasing supplies of calcium in the nutrient medium there were increasing percentages of calcium and decreasing percentages of potassium and magnesium in the forage.
8. With increasing supplies of magnesium the percentage of magnesium increased in the forage, and potassium percentages decreased, but there was little change in the calcium composition.
9. In most series, forage yield had a greater effect in determining the total milligrams per culture of any element removed by the plants than percentage of that element contained in the plants. Consequently, Morse removed larger quantities of potassium, calcium, and magnesium from the nutrient media; particularly at the higher levels of these elements in the nutrient solutions.

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