STUDIES ON THE EFFECT OF CERTAIN NON-NUTRIENT INORGANIC ELEMENTS ON THE GROWTH OF WHEAT SEEDLINGS IN SAND AND SOIL CULTURES

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Table of Contents

INTRODUCTION

Practically all the work, along the line of plant nutrition, has been done on the essential elements and little attention has been given certain other elements which are found in our soils, irrigation waters and even in the ash of the plants themselves.

It is the purpose of the following experiments to determine the effect of some of these elements, namely:- barium, strontium, manganese, chromium, cobalt and nickel, on wheat seedlings:

REVIEW OF LITERATURE

Experiments with Plant Nutrients

A large number of investigators have worked on this subject of plant nutrition. When we consider all the work done on the essential elements, toxicity of nutrient and non-nutrient bases, effects of certain anions and cations, antagonism, physiologically balanced solutions, physiological role of nutrients, the correction of alkali, and many other lines of investigation; we find the methods almost as numerous and varied as the lines of investigation.

Wheat has been a favorite plant for use in this line of experimentation because of its hardiness, its rapidity of growth in the seedling stage, and its property of being a heavy feeder. Some of the most prominent workers in this field, i.e., Shive (1), Tottingham and Rankin (2), Harter (3), Braezeale (4), and others have used wheat as a criterion of the effect of certain solutions both in sand and solution cultures.

Many investigators have worked on physiologically balanced solutions, and optimum nutrient solutions. Tottingham (5), in his classical paper on nutrient solutions, divides the employment of water cultures into three rather distinct periods:-

"(1) The optimum total salt concentration of the nutrient solution was found to be 0.3 per cent or lower, if the solution were renewed frequently. (2) Differentiation of the essential from the non-essential nutrient elements was accomplished as far as this has been attained up to the present time. The essential elements were found to be nitrogen, sulphur, phosphorus, calcium, potassium, magnesium and iron, while chlorine and silicon were classed as probably only supplemental nutrient substances. (3) Standard formulae for nutrient solutions were proposed, that of Knop being most generally recognized. (4) It was found that the composition of the nutrient solutions could vary widely without apparent detriment to the plant; hence it was considered that there was no single optimum nutrient solution. (5) Quantitative studies, especially those of Knop, indicated that the plant is able both to excrete and to absorb salts selectively, under different conditions. (6) It was generally believed that nutrient salts were absorbed by the plant without dissociation.

"The third and present period of the investigation of water cultures has been characterized by a vigorously renewed activity, in which the method has been applied to current problems in plant nutrition. This activity has resulted in the development of new conceptions regarding the nature of the process of absorption and assimilation from nutrient solutions, and more accurate methods have been developed for following the process of absorbtion in a quantitative way. As a result of thid work, it is now generally believed that the constituent ions rather than the complete salts are selectively absorbed by the plant, and that absorbtion by the latter thus influences both the composition and the chemical reaction of the nutrient solution. It has been shown also that the physiological balance of the nutrient elements in the solution, particularly that of calcium and magnesium, is important, and that this balance varies in a manner dependent both upon the composition and concentration of the solutions and upon the species of the plant. It appears also that the plant takes up an excess of nutrient elements beyond the requisite amount for maximum production, if such excess be present in the medium. Finally, some of the most recent work in this field has indicated that, within certain limits at least, a best or optimum proportion of the nutrient elements in the culture medium can be attained and that it is not absolutely essential for the latter to be absorbed in the form of inorganic compounds."

Along the line of attaining a best or optimum nutrient solution, Tottingham (5) and Shive (6) have made exhaustive studies, Tottingham working out the optimum volume-molecular, partial concentrations of the four salts in Knop's solution, and Shive later working on a simpler three salt solution which would give just as good growth as solutions previously recommended. Shive says of his R 5 C 2 solution, "Judging from the yield of tops and of roots, these solutions are equal to any and superior to most of the nutrient media previously described by other investigators and now in general use for water culture work, at least when these media are prepared with a total concentration of 1.75 atmospheres." Shive found that this solution produced yields 27 per cent better than Knop's while Tottingham's best only improved Knop's 16 per cent.

The method of using these nutrient solutions, in connection with sand cultures, presents quite a problem in itself. McCall (7) devised a method by which seedlings may be grown in sand and the nutrient solution renewed or modified almost as readily as in water cultures. He used graniteware pots provided with a metal outlet at the bottom which was screened on the inside with a plug of glass wool, inserted before the pot is filled. He grew his seedlings according to Tottingham's (5) method. The sand in the pots was flushed with distilled water and allowed to drain out through the outlet at the bottom of the pot. A small clay funnel is placed in the center of the pot and six seedlings planted around it, the top of the grain being just level with the surface of the sand. Surplus water is drawn off by suction and the surface of the sand around the seedlings between the funnel and edge of the pot covered with wax. The wax seal is considered necessary to prevent loss of water by evaporation from the surface of the sand in order that transpiration can be measured and the concentration of the nutrient solution controlled. Nutrient solution is added through the stem of the inverted funnel while the old solution is removed by applying suction to the outlet tube at the bottom. By this method a definite moisture content can be maintained and nutrient solutions renewed as frequently as desired.

Johnson (8), in his studies of the nutrient requirement of the potato plant, has somewhat modified the above method. One-gallon earthenware jars were used instead of metal enamel-ware pots, and no outlet was provided at the bottom. Instead, a small glass tube ran down the inside of the jar to the bottom where it made a right angle and flared out funnel like at the end. A glass wool plug was inserted in the end. Solutions were drawn off by applying suction to the upper end of this tube. Another larger tube ran through the center of the sand to the bottom of the pot. Into this tube fresh solutions were poured. Thus, solutions were added at the bottom and allowed to rise through the sand. Johnson states that the roots are not disturbed by this method.

Davidson (9) in his sand culture experiments used half-gallon pots and kept at 25 per cent moisture content. The seeds were planted in the pots, sixteen to the pot, and then thinned to 5 per pot.

Manganese

Manganese has been considered an essential element so naturally, a great deal of work has been done with manganese.

This element has been found in soil, irrigation water and in the ash of plants. Headden (10) of this station has found the element in soils, and irrigation water.

Occurence in Plants: Rousset (11) citing the work of Heropath states that Heropath found manganese in the ash of raddish, beet and carrot. Liebig (12) reported the presence of manganese in tea. Leclerc (13) concluded from his analyses that manganese occurs in most species of plants, the percentage being rather high in forest trees. Wolf (14) also reports analyses which show that manganese is present in the wood, bark and leaves of various forest trees. The analyses of Prichard (15) likewise reveal a wide distribution of manganese in seed plants. The leaves, actively growing parts, and reproductive organs contain the greatest amount.

Occurence in Soils: As stated above, manganese occurs in various soil types. Fertile soils as a rule contain less than one percent of this element reckoned as oxid. The following table from Wolf (14) is cited in order to show the amounts of manganese and iron found in soils:

Kind of Soil	Percentage of Mn_3O_4	Percentage of Fe_2O_3
Clay - - - - - - - - - - - -	.180	3.173
Loam - - - - - - - - - - - -	.135	2.096
Sand - - - - - - - - - - - -	.080	1.039
Humus - - - - - - - - - - -	.042	0.406

Leclerc (13) found small amounts of this element in the various soils that he studied, and recent work has shown that some types of soil contain unusually large quantities. Kelley (16) working with soils from certain sections of Hawaii found manganese present in as great a quantity as 9.74 per cent. Thomas (17) in his work on the isolation of the rarer elements in a residual soil states, "Manganese is found in most rocks and soils in small amounts in the ferro-magnesian minerals. Through alteration, it appears sometimes on the surfaces of limestones and sandstones". Hillebrand (18) found 0.240 and 0.230 per cent manganese in soils which he examined.

Experiments with Water Cultures: Various investigators have studied the effects of manganese on plants, by growing seedlings in distilled water alone and in distilled water to which nutrient salts were added.

Working with the distilled water cultures, investigators have observed both stimulative and toxic effects. Loew and Sawa (19) found that in the presence of manganese in toxic quantities the leaves lose their turgar and dry up, and no trace of new rootlets is apparent. In a solution containing 1000 parts per million of manganese sulphate, the leaves of barley plants faded to yellow and then turned brown. These investigators found also that barley became chlorotic and the roots turned brown in solutions containing only small quantities of manganese. McCool (20) noted that a solution containing 15 parts per million of manganese in the form of chloride is injurious to field peas, and that a solution containing 30 parts per million prevents root growth entirely. Miss Brenchley (21) found that manganese, when present in strong concentration, exerts a toxic influence on higher plants.

On the other hand, several investigators have obtained plant stimulation in distilled water cultures containing small quantities of manganese. Micheels and DeHeen (22) obtained a pronounced stimulation in colloidal solutions of manganese. McCallum (23) reported an acceleration of tuber formation when potatoes were treated with a solution of manganese chloride. Montemartini (24), although finding marked differences in the sensitiveness of plants, obtained increased growth with all plants used in his experiment. McCool (20) found slight stimulation, as shown by length of the roots of pea seedlings, but the leaves showed no effect.

The effects of manganese in solutions containing nutrient salts are similar to those obtained with distilled water cultures, but experiments show that the nutrients greatly reduce the toxicity of the manganese. McColl (20) found that this reduction of toxicity is proportional to the concentration of the nutrient salts.

According to Miss Brenchley (25), a solution containing 1350 parts per million of nutrient salts and 770 parts per million of manganese in the form of sulphate, reduced the yield 31 per cent. A solution containing but 0.01 of this amount of manganese developed brown roots after four weeks and reduced the yield 3 per cent.

In lower concentrations manganese was decidedly stimulative. Aso (26) found that manganese stimulated the growth of a number of plants. The solutions which he used contained 0.5 per cent of nutrient salts and 0.02 per cent of manganese sulphate in one series and 0.05 per cent of nutruent salts and 0.002 per cent of manganese sulphate in the other series.

Tottingham and Beck (27) reported increased yields of wheat grown in nutrient solutions containing small quantities of manganese chloride. Deatrick (28) working with various manganese compounds, found that both the chloride and sulphate exert of toxic effect when applied to wheat seedlings in high concentrations. In lower concentrations, manganese causes a marked stimulation. Concentrations as high as 100 parts per million showed no toxic effect when used in connection with a complete nutruent solution.

Experiments with Soil Cultures: A large number of experiments are reported in which manganese salts have been applied to soil as a fertilizer. The results are somewhat contradictory.

Sullivan and Robinson (29), after experimenting with various salts and plants, decided that their results were not conclusive. They state that, while increased yields were occasionally obtained, the salts of manganese should not be recommended for general use as a fertilizer. Other workers have also shown that neither a favoring or inhibitory action of manganese compounds on the growth of plants is demonstrable.

Barium

Occurence in Soils and Plants: While manganese has been considered an essential element, little work has been done on the relation of barium to plant growth. Headden (10) in determining the constituents of the ash of certain plants, found alfalfa comparitively rich in barium. Sweet clover surpassed alfalfa while tobacco and corn also contained relatively large amounts. He also analyzed soils and irrigation water and found the element present in both. According to the results obtained by Failyer (30), barium is a widely disseminated element. It is present in most soils of the United States, the larger quantities occuring in soils derived from masses carrying barite deposits. Barium may be expected to be present in small amounts in soil water. Crawford (31) has noted its presence in various plants and has related its occurence to the loco disease. Thomas (17) states that barium is widely distributed in small quantities throughout igneous rocks. Dana (32) states that it has been proven to exist in amounts varying from 0.45 per cent to 2.20 per cent in orthoclase and some acid plagioclases, which are probably the original sources of barium, from which it is dissolved. Hillebrand (18) has found barium in amounts varying from 0.009 per cent to 0.020 per cent.

Several other investigators report the presence of barium in the ash of plants. Marsh, Alsberg and Black (33) found barium in alfalfa, barley, millet and beets collected from various parts of Colorado, Wyoming and Arizona. McHargue (34) discussing the occurence of barium in the tobacco plant and the sycamore tree, concludes that it is present in combination with organic acids and that since it is contained in the live cells of the higher plants, it may function in metabolism. Artis and Maxwell (35) report amounts of barium in the leaves of tobacco, dogwood, cottonwood, cherry leaf, black locust, mulberry, elm, maple, plum, walnut, pear, linden and box-elder varying from 0.005 percent BaO in the cottonwood to 1.07 per cent in the mulberry. Thomas (17) found 0.22 per cent BaO in alfalfa grown on the Pennsylvania State College Farm. Robinson (36) found barium in apples, beets, alfalfa, corn, timothy and wheat.

Since barium occurs in soils and the ash of plants, several investigators have attempted to show what effect it has on plant growth.

Effect of Barium on Plant Growth: McCool (20) working with Canada field peas, has shown that barium chloride, alone, in distilled water, prevents practically all growth at a concentration of N/1000. In a distilled water check, the length of tops is nearly twice that of tops in a N/4000 solution of barium chloride and roots in distilled water attain a length of 6 inches, while those in N/4000 barium chlorides, make but a feeble growth. Even at a concentration of N/8000, tops make a better growth in distilled water, but roots attain a greater length than the distilled water check.

Through some experiments designed to determine the extent to which barium may replace calcium in the growth of plants, Suzuki (37) found that, although barium is poisonous to plants at relatively dilute concentrations, the poisonous action can be lessened considerably by the presence of calcium salts. McHargue (38) showed that barium compounds are poisonous to plants, but barium carbonate in the presence of calcium carbonate apparently exerts a stimulating influence.

Strontium

Occurence in Soils and Plants: Strontium does not seem to be as widely disseminated as barium and literature on this element is as rare as that on barium. Headden (10) found strontium present in soils, in irrigation water and in the ash of plants. He found alfalfa and corn samples rich in strontium, sweet clover contained less than corn or alfalfa while tobacco showed only traces of the element. Thomas (17) states that strontium is a common ingredient of igneous rocks in small amounts, and has found 0.10 per cent S_2O in alfalfa grown on the Pennsylvania State College Farm. Hillebrand (18) has found the element in soils in amounts varying from 0.010 per cent to 0.033 per cent. Robinson (36) has found strontium in a number of plants among which are apples, beets, alfalfa, corn, timothy and wheat.

Effect of Strontium on Plant Growth: Suzuki (37), while endeavoring to determine whether or not strontium can replace calcium in plants, called attention to the toxicity of this element. Results obtained by McCool (20) show that strontium is not as toxic as barium. A solution of N/50 strontium nitrate prevented the growth of Canada field peas while in condentrations of N/500 and N/1000, green weight of tops, total green weight and average length of tops surpassed the distilled water check.

Haselhoof (39) found that strontium had no injurious action, is absorbed by plants, and the results indicate that it replaces calcium when there is an insufficient supply of that element. McHargue's (38) results, however, show that strontium carbonate cannot be substituted for calcium carbonate.

Chromium

Chromium has probably received less attention than any of the other elements under consideration so naturally very little is known of the effect of chromium. Pfeffer (40) merely states that the poisonous character of chromium has been shown by Knop. Thomas (17) states that chromium is very widely diffused in the form of chromite. Hillebrand (18) has found the element in small quantities in the soil approximating 0.002 per cent.

In his examination of plants, Robinson (36) found chromium present in beets, cabbage, bluegrass and timothy. The amount found ranged from a trace to 0.004 percent of the material.

Cobalt and Nickel

These elements have also received little attention in relation to plant growth.

Duggar (41) says, "The salts of the heavy metals constitute a group of the most toxic agents known". He also states that a concentration of M/51200 nickel nitrate killed the majority of the roots of Zea Mays in twenty-four hours while a concentration of M/6400 cobalt nitrate was necessary to accomplish the same result. Pfeffer (40) states that cobalt and nickel have been detected by Forchhammer in oak wood and that nickel seems to be more poisonous than cobalt. Hawkins (42) found that nickel was only slightly toxic to fungus spores. Thomas (17) found neither of these elements in his soil analysis.

MATERIALS AND METHODS

In selecting a nutrient solution for use in these experiments, it was desired to obtain one which was simple and one in which all the salts could be dissolved at the same time without precipitation so Shive's (6) R5C2 three salt solution, the merits of which have been mentioned above, was selected. This solution contains the salts in the proportions: KH_2PO_4, 0.018m.; $Ca(NO_3)_2$, 0.0052m.; and M SO_4, 0.0154m. and was used in Series II of these experiments. All glassware containers were washed, rinsed, soaked in sulfuric acid-potassium dichromate cleaning solution, washed, rinsed and rinsed again in distilled water. The nutrient solution was made up, as prescribed by Shive, to have a total osmotic concentration of 1.75 atmospheres. A trace of ferrous sulphate was added to provide the necessary iron. The total osmotic concentration of the solution thus made was determined by the "depression of the freezing point" method. For this purpose the Hortvet Cryoscopi was used. This instrument simply consists of a wide mouthed vacuum bottle, into which a little ether is poured. A tube containing the mixture to be frozen, inserted into a larger tube containing alcohol, is lowered into the ether. Two thermometers are used; one is placed in the ether and one, with very large graduations and reading to a thousandth of a degree, is placed in the mixture to be frozen. Air, dried by passing through sulphuric acid, is passed over the ether causing the ether to evaporate and thus lowering the temperature. The total osmotic concentration was found to be 1.88 atmospheres which is well within the limits of experimental error with this instrument and also within the limits of optimum concentration for wheat as determined by Tottingham (5).

Nitrates of all the non-nutrient elements were used, as nitrates are all readily soluble and, as shown by Reed and Haas (43), nitrates are less injurious than either chlorides or sulphates. It is absolutely essential that nitrates of all elements be used, as it is necessary to eleminate as nearly as possible, the effects of any differences in the amon, in judging the effect of the action. All the elements used are bivalent except chromium which is trivalent. Stock solutions of Ba, Sr, Mn, Cr, Co and Ni were made up with a concentration of M/100. All chemicals used were "Baker's Analyzed Chemicals" and were dried at 150° C. before being dissolved in distilled water.

Throughout these experiments, registered Marquis wheat, which was as near a pure line as it was possible to obtain, was used. This wheat contained about one per cent of Fife type and a fraction of a per cent of a red chaffed wheat, but since both these latter types had practically the same growth habits as Marquis, no harm resulted from their presence.

Pure quarz sand composed the substratum for the growth of the seedlings. This sand was washed in distilled water several times before using. Five seeds were planted about one-fourth inch deep, in a common four in flower pot containing 570 grams of the washed quarz sand. Each pot was set in a shallow, white glazed, porcelain sauce dish, 12 c.m.m diameter and 2 c.m deep. This piece of apparatus, the sand being air dry, held 250 c.c. of distilled water, the dish serving as a reservoir for the surplus water and being a constant cource of supply between applications of water. By keeping the water the same height in the dishes, the concentration of the salts remained practically the same throughout the experiments. Besides being extremely simple, inexpensive, and giving as much accuracy as desired, this arrangement provides a means of adding water and solutions without disturbing the seeds before germination or the roots after growth has started. In previous trials without the sauce dish, much trouble was experienced through the washing of the seeds and small plants out of the sand when water or solution was added at thetop of the pot. With this arrangement all distilled water and solutions were poured into the sauce dish and allowed to be drawn up into the moist sand. Distilled water was applied every day.

The plants were watered with distilled water until they were about 2 c.m. high, when the number in each pot was reduced to four, the weakest being removed in each case. By this method, the plants received no setback through transplanting, the roots were well established in the sand, a surprisingly uniform stand was secured and the stored food in the seed was practically exhausted before the solutions were applied.

The total of 684 plants grown in the manner described above, were divided into three series, 228 plants to the series. (Fig. 1) Three concentrations of each salt were used in each series and three pots or twelve plants were treated with each concentration of each six inorganic elements, and three pots or twelve plants were used as a check. Series I, with pure quarz sand as a medium of growth, was treated with solutions of the substances to be tested in distilled water. Each pot contained 250 c.c. of distilled water and 10 cc. of the stock solution were added to each of three pots, making the concentration of the salts M/2600; 20 c.c. of the stock solution were added to each of three more pots, making the concentration in these M/1350; and 30 c.c. were added to each of three more pots, making the concentration in these M/933. Plants in Series II were treated the same as those in Series I, except that the original distilled water was replaced with Shive's three-salt nutrient solution before the

	Series I			Series II			Series III		
	Plot1	Plot2	Plot3	Plot4	Plot5	Plot6	Plot7	Plot8	Plot9
Ba	000	000	000	000	000	000	000	000	000
Sr	000	000	000	000	000	000	000	000	000
Mn	000	000	000	000	000	000	000	000	000
Cr	000	000	000	000	000	000	000	000	000
Co	000	000	000	000	000	000	000	000	000
Ni	000	000	000	000	000	000	000	000	000
Check		000			000			000	

Fig. 1 Showing the arrangement of pots in plots and series.

Series I: quarz sand plus nitrates of metals in distilled water.

Series II: quarz sand plus nutrient solution plus nitrates of metals.

Series III: soil plus nitrates of metals.

Plots 1, 4 and 7 concentration of metalic salts M/2600.

Plots 2, 5 and 8 concentration of metalic salts M/1350.

Plots 3, 6 and 9 concentration of metalic salts M/933.

other solutions were added. Plants in Series III were treated the same as those in Series I except that a light soil very rich in humus was used instead of quarz sand.

The seeds were planted in the pots on January 31, nutrient solution was applied to Series II, February 12, and the non-nutrient solutions were applied to all Series, February 14. The plants were removed from the sand after 24 days, (March 10) from the time the non-nutrient solutions were added. Tops and roots were separated at the point of attachment of the seed. The roots were thoroughly washed in distilled water and both dried for 24 hours at 90° C. The weight of roots in Series III was impossible to obtain with any accuracy, due to the soil adhering to the roots which could not be removed even by washing.

EXPERIMENTAL DATA

Since, as stated above, the elements barium, strontium, manganese, chromium, cobalt and nickel have been found in soils, irrigation water and in the ash of plants, it has been the purpose of these experiments to show whether these elements, individually, have a toxic or stimulative effect on the growth of wheat seedlings. Three concentrations have been considered: M/2600, M/1350 and M/933, and their effect on growth determined.

Series I

The results obtained, when plants grown in quartz sand were treated with the nitrates of these elements dissolved in distilled water, are given in Table I. This series, as

DISTILLED WATER (Series I)

Table I. Dry weight, in grams, of tops and roots of twelve plants grown in sand cultures and treated with nitrates of the metals in solution.

	M/2600 (Plot 1)		M/1350 (Plot 2)		M/933 (Plot 3)	
	T	R	T	R	T	R
Ba	01659	1.841	0.587	1.139	0.705	0.986
Sr	0.672	2.160	0.735	2.005	0.848	1.083
Mn	0.629	1.302	0.735	1.632	0.637	0.877
Cr	0.448	0.885	0.621	1.189	0.580	1.230
Co	0.548	0.521	0.507	0.311	0.371	0.255
Ni	0.491	0.620	0.450	0.418	0.420	0.391
Check	0.450	0.971	0.450	0.971	0.450	0.971

shown in figure I, is divided into three parts according to concentration, plot 1 being treated with a concentration of M/2600, plot 2 with a concentration of M1350 and plot 3 with a concentration of M/933.

Plot I.

In Plot I, strontium nitrate produced the best growth of tops and showed a marked stimulative effect as 0.672 grams of dry tops were produced while in the check, treated with distilled water only, 0.450 grams of tops were produced. After strontium, barium, manganese, cobalt and nickel all show a stimulative effect in the order named. The dry weight of tops, of plants trested with chromium was 0.448 grams while that of the check was 0.450 grams. This difference is not significant, however, and chromium is condidered as showing neither a stimulative or toxic effect in this plot. These results are more clearly demonstrated in figure 2.

Strontium gives the best growth of roots in this Plot and shows a very marked stimulation producing 2.160 grams of dried roots as compared with 0.971 grams produced by the check. Barium and manganese follow strontium in order while chromium is again slightly below the check with 0.885 grams of dried roots. Nickel and cobalt show a marked toxicity toward root growth producing 0.620 and 0.521 grams of roots respectively. Figure 3 shows the relation of these elements to each other and their relation to the check in their action on root growth.

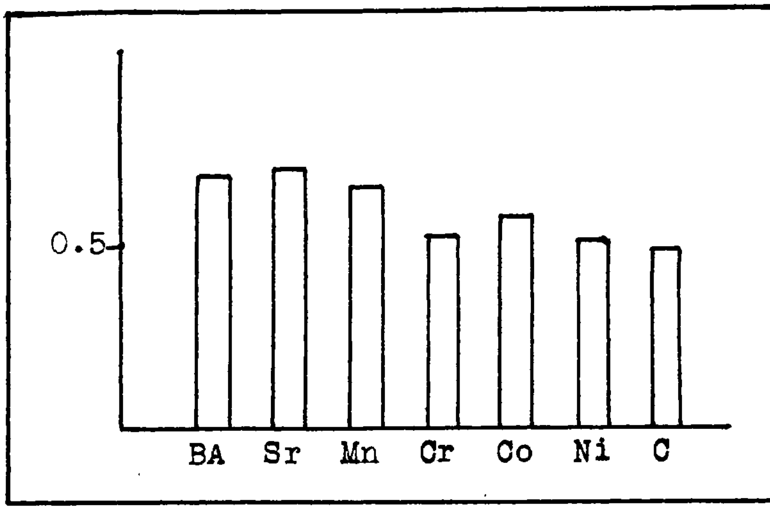

Fig. 2. Relative dry weight of tops of wheat seedlings in Plot 1, Series I.

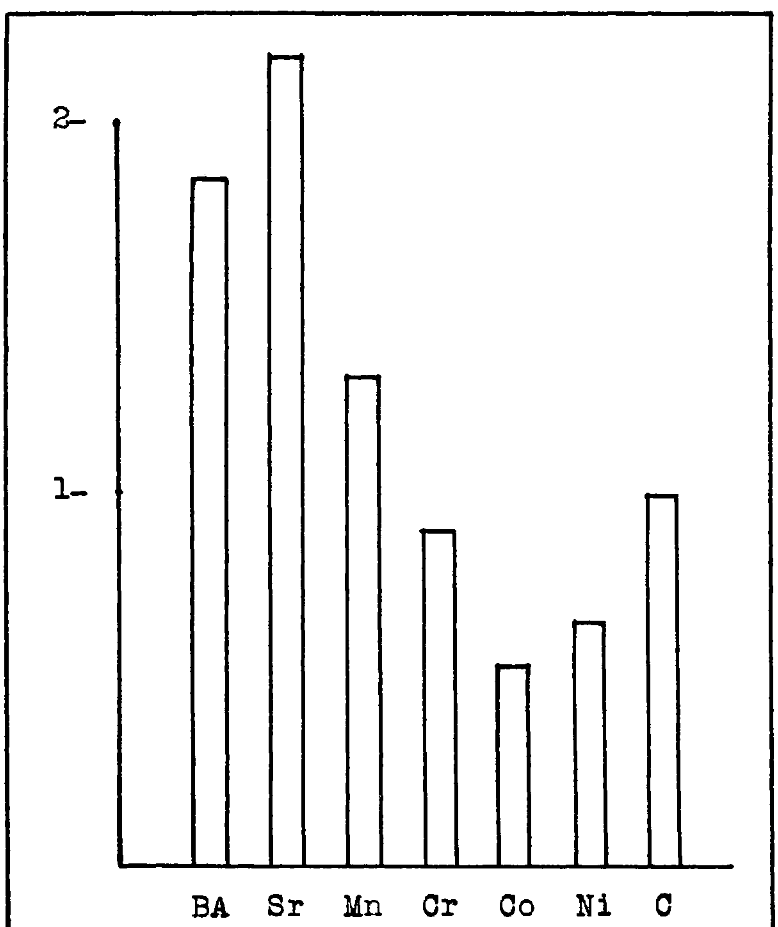

Fig. 3. Relative dry weight of roots of wheat seedlings in Plot 1, Series I.

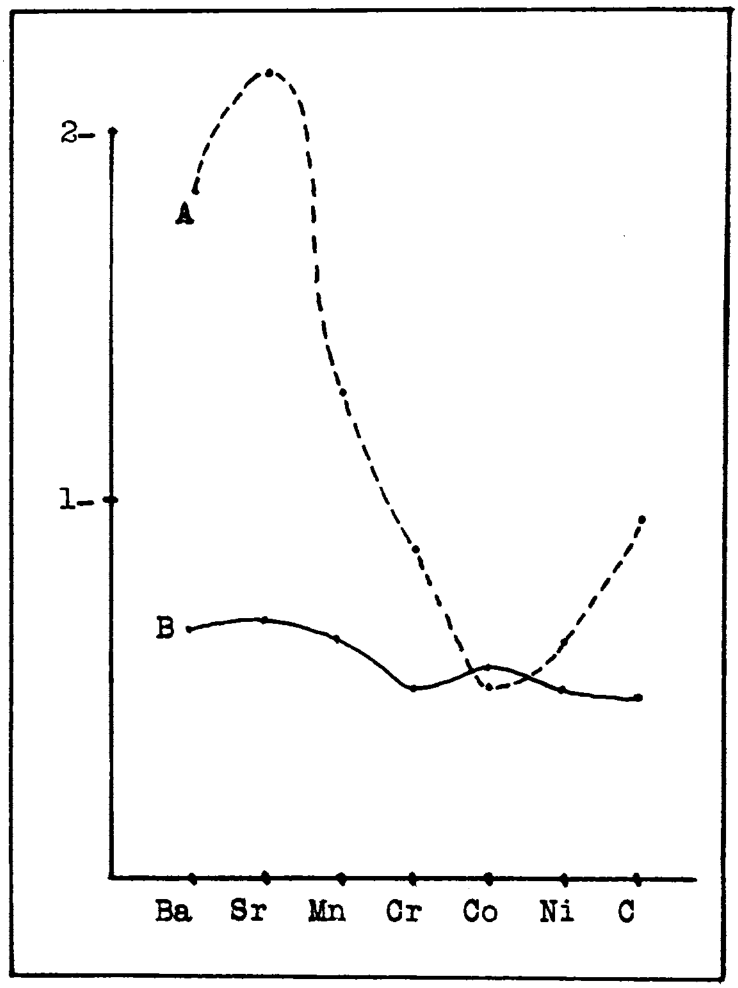

Fig. 4. Relative growth of roots and tops of wheat seedlings in Plot 1, Series I. A-Roots, B-Tops.

A comparison of top and root growth shows that there is no correlation in the effects produced by these elements on the growth of tops and roots, as is demonstrated in figure 4. In top growth we have the following descending series: strontium, barium, manganese, cobalt, nickel, check and chromium while in root growth the series is: strontium, barium, manganese, check, chromium, nickel and cobalt. From figure 4, it may be seen that strontium shows a more marked stimulation of top growth than of root growth, while manganese, chromium and cobalt show the reverse effect.

Plot 2.

In a more concentrated solution, strontium also gives the highest yield of tops, followed in order by: manganese, chromium, barium and cobalt showing stimulative effects while nickel shows neither a stimulative or toxic effect. This is represented in figure 5 which gives the relative dry weights of tops in this plot.

Stimulation of root growth is shown by strontium, manganese, chromium and barium in the order named, while a very marked toxicity is shown by both cobalt and nickel. As shown in figure 6, the weight of roots of the plants treated with strontium was over twice as great as those produced by the check while the roots of plants treated with nickel weighed only half as much as the check and those of cobalt only one third as much as the check.

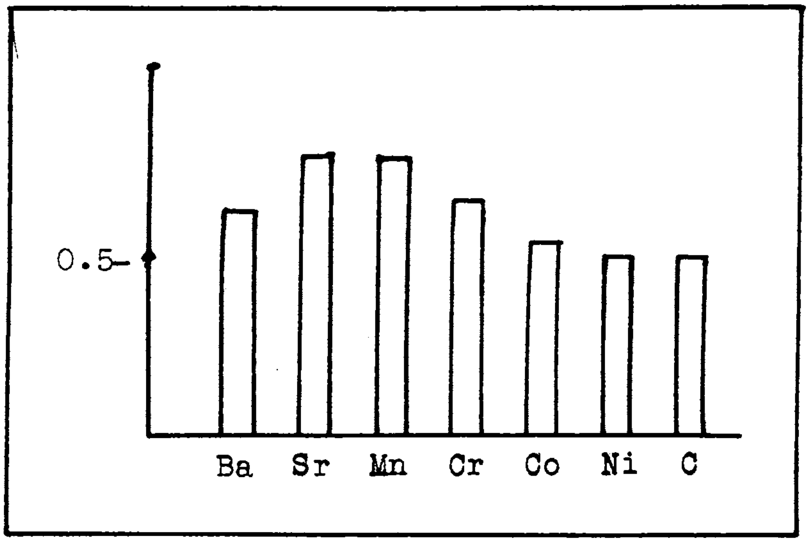

Fig. 5. Relative dry weight of tops of wheat seedlings in Plot 2, Series I.

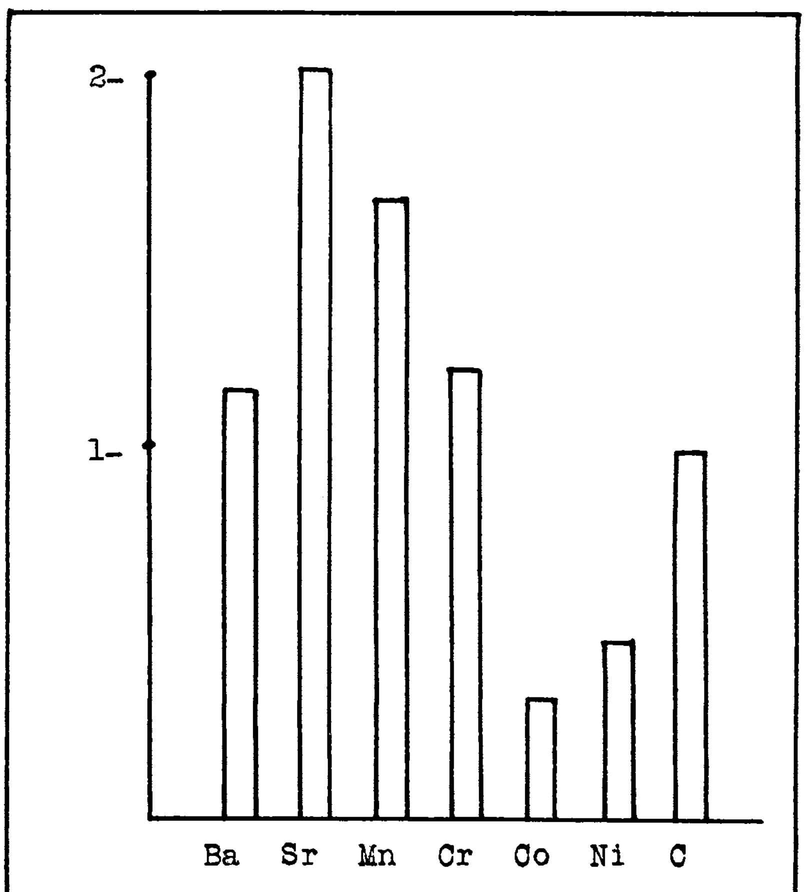

Fig. 6. Relative dry weight of roots of wheat seedlings in Plot 2, Series I.

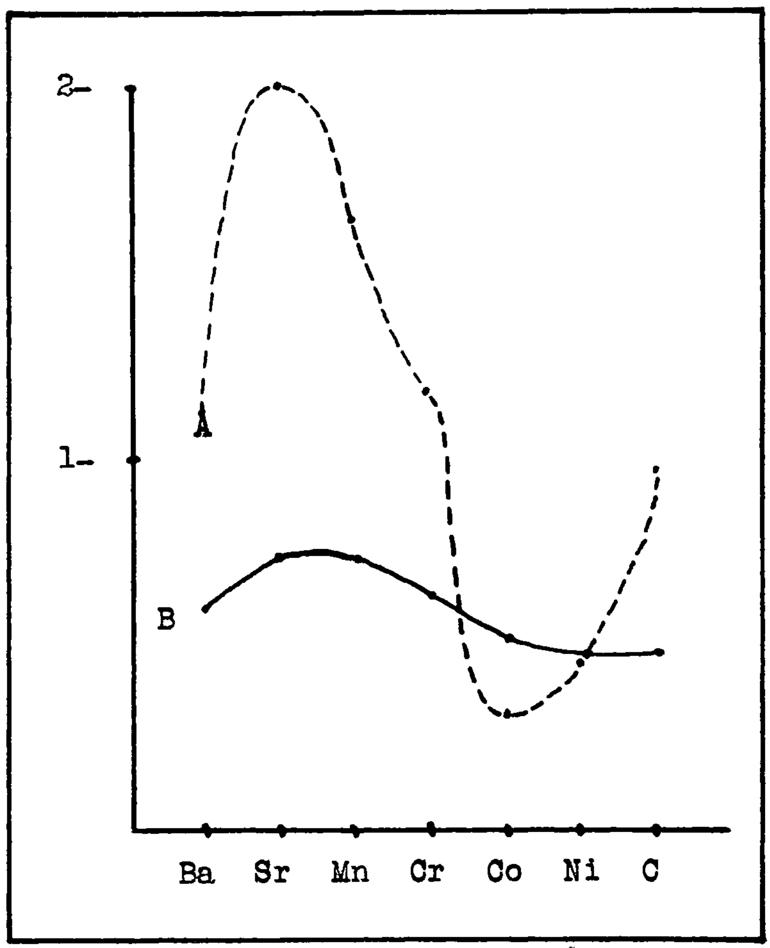

Fig. 7. Relative growth of roots and tops of wheat seedlings in Plot 2, Series I. A-Roots, B-Tops.

A comparison of top and root growth as shown in figure 7 demonstrates that here, there is a little correlation, barium and chromium showing practically equal stimulation, barium and chromium showing practically equal stimulation of roots and tops but strontium and manganese are more stimulative toward roots than toward tops. Strontium, manganese, chromium and barium produce increased growth in both roots and tops in the order named as shown in figures 5 and 6, but in varying degrees in relation to each other. Tops show a slightly increased growth when treated with cobalt but root growth is seriously impaired. Nickel is neutral on top growth but almost as toxic as cobalt on growth of roots.

Plot 3.

The best growth of tops in this plot was obtained with those plants treated with strontium nitrate, the dry weight being nearly twice that of the check (figure 8), barium, manganese and chromium follow in order. Nickel and cobalt are both toxic in this higher concentration, cobalt showing more toxicity than nickel.

Chromium, strontium and barium are stimulative in their action on root growth in the order names, while manganese is slightly toxic, nickel more so, and cobalt so much so that scarcely any roots whatever were produced. These results are represented graphically in figure 9.

Root and top growth show no correlation in this plot. Chromium shows better root growth than top growth, while all

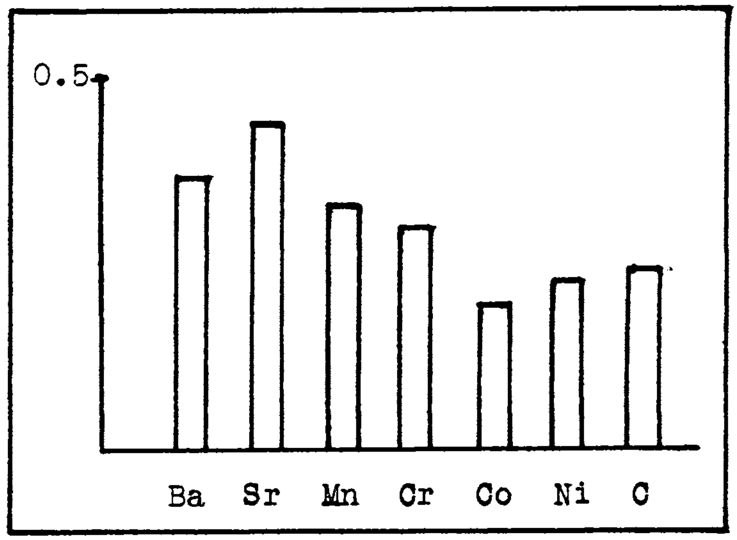

Fig. 8. Relative dry weight of tops of wheat seedlings in Plot 3, Series I.

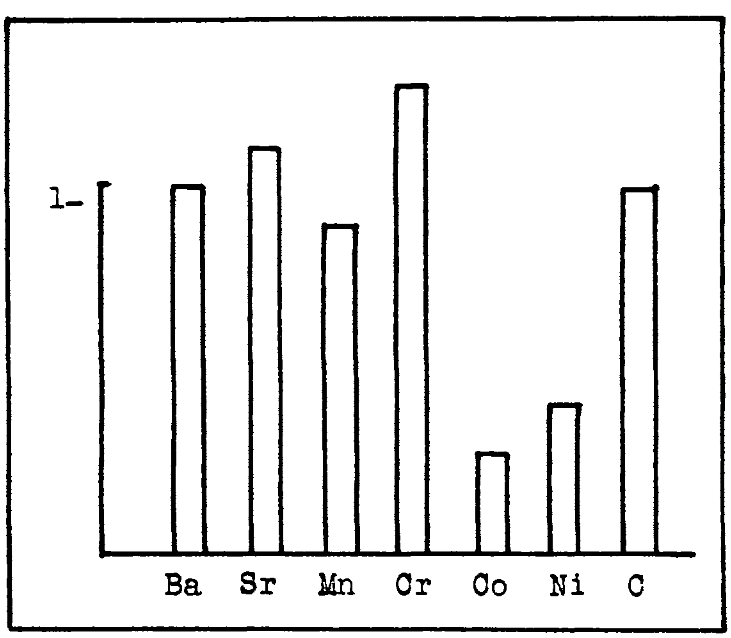

Fig. 9. Relative dry weight of roots of wheat seedlings in Plot 3, Series I.

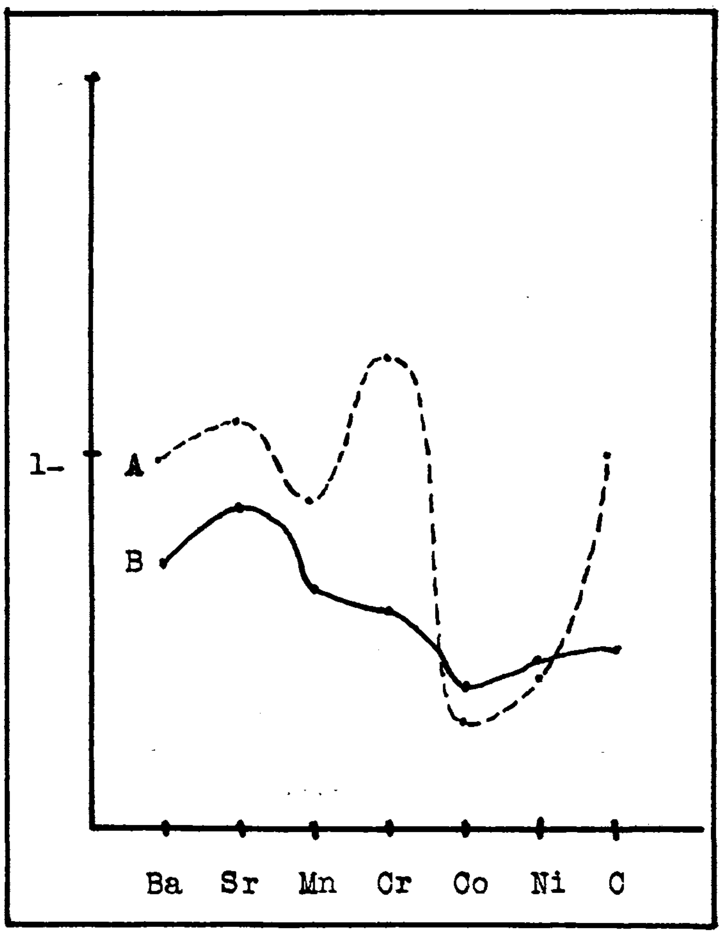

Fig. 10. Relative growth of roots and tops in Plot 3, Series I. A-Roots, B-Tops.

the others show better top growth than root growth. It may be seen from figure 10 that the action of some of these elements was different on the growth of tops than on the growth of roots. According to dry weight of tops a descending series is found: Sr., Ba., Mn., Cr., Check, Ni. and Co. while according to dry weight of roots the series is: Cr., Sr., Ba., check, Mn., Ni., and Co.

Effect of Concentration

By consulting Table I and comparing figures 2, 5, and 8, it may readily be seen that these various concentrations did not produce the same effect with the different elements. In the case of barium, a concentration of M/1350 gave a smaller dry weight of tops than a concentration of M/2600 while a concentration of M/933 gave a greater dry weight of tops than either of the former. Strontium shows a perfect ascending stimulation of top growth with increased concentration. In a concentration of M/1350 manganese nitrate, tops made a better growth than in either the stronger or weaker concentration, indicating that the optimum concentration for manganese nitrate for growth of tops lies somewhere between the limits of M/2600 and M/933. Chromium is somewhat similar to manganese, the optimum concentration of chromium lying somewhere between the concentrations M/2600 and M/933. A study of the graphs shows that nickel changes from stimulative to toxic as the concentration increases, being slightly stimulative at a concentration of M/2600, neither toxic nor stimulative at M/1350 and slightly toxic at a concentration of M/933.

Cobalt acts somewhat similarly to nickel except that it shows stimulation in both weaker concentrations and toxicity in the higher concentration.

As can be seen from Table I and figures 3, 6, and 9, the effects of these elements in the different concentrations are altogether different in the case of roots than in the case of tops. The stimulative action of barium decreases as the concentration increases. Strontium is like barium in this respect, except that in all three concentrations strontium gave better root growth than barium. The optimum concentration for manganese is somewhere between M/2600 and M/933 as a greater weight of roots was produced in a concentration of M/1350 than either of the former. Chromium changes from slightly toxic at M/2600 to slightly stimulative at M/1350 showing increased stimulation with increased concentration. Cobalt and nickel both show increased toxicity with increased concentration.

Series II

Plants in this series were treated the same as those in Series I, except that they were grown in nutrient solution instead of distilled water. Results in this series are given in Table II.

Plot 4

The plants in this plot were treated with nitrates of the metals in the same concentration as Plot 1 of the preceeding series, M/2600. A study of figure 11 shows that manganese produced the greatest stimulative effect on top growth with barium, chromium and strontium following in the order named. Cobalt and nickel are both toxic, cobalt showing more toxicity than nickel.

In root growth, chromium produced a very marked stimulation, with barium and manganese following in order. From figure 12 it will be noticed that for the first time strontium shows a slight toxic effect. This, in all probability is due to some error as there are only two cases in these experiments, in which strontium shows any toxicity and in these cases the toxicity is only slight. Cobalt and nickel were again toxic in the same order as in the other cases.

From figure 13, it will be seen that little correlation exists between top and root growth. Although the same element may produce a stimulation or a diminution of growth upon both tops and roots this effect is not proportional between the different elements in the same plot nor the same element in different plots. Manganese produced the highest yield of tops while chromium produced the highest yield of roots. Barium was second in both, while manganese was third in yield of roots and chromium third in yield of tops. Strontium showed a slight stimulation of top growth and a slight toxicity toward root growth as was the case in the preceeding plot. Nickel and cobalt produced a diminution in yield of both tops

NUTRIENT SOLUTION (SERIES II)

Table II. Dry weight, in grams, of tops and roots of twelve plants, grown in sand cultures and treated with Shive's R5C2 nutrient solution and nitrates of the metals in solution.

	$\frac{M}{2600}$ (Plot 4)		$\frac{M}{1350}$ (Plot 5)		$\frac{M}{933}$ (Plot 6)	
	T	R	T	R	T	R
Ba	2.078	2.520	1.972	2.286	1.881	2.051
Sr	1.901	2.101	1.838	2.130	1.786	2.407
Mn	2.265	2.480	1.834	1.938	1.719	1.805
Cr	2.049	4.221	1.892	1.993	1.820	1.815
Ni	0.925	1.022	0.541	0.550	0.501	0.405
Co	0.983	1.454	0.271	0.337	0.315	0.270
Check						

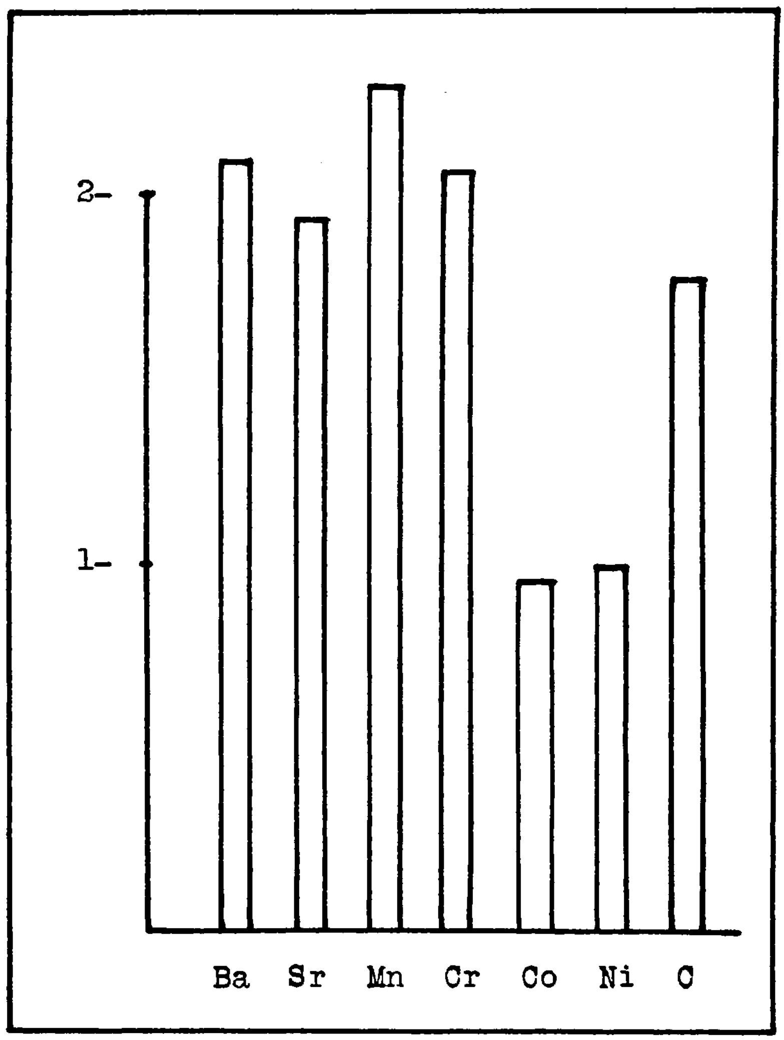

Fig. 11. Relative dry weight of tops of wheat seedlings in Plot 4, Series II.

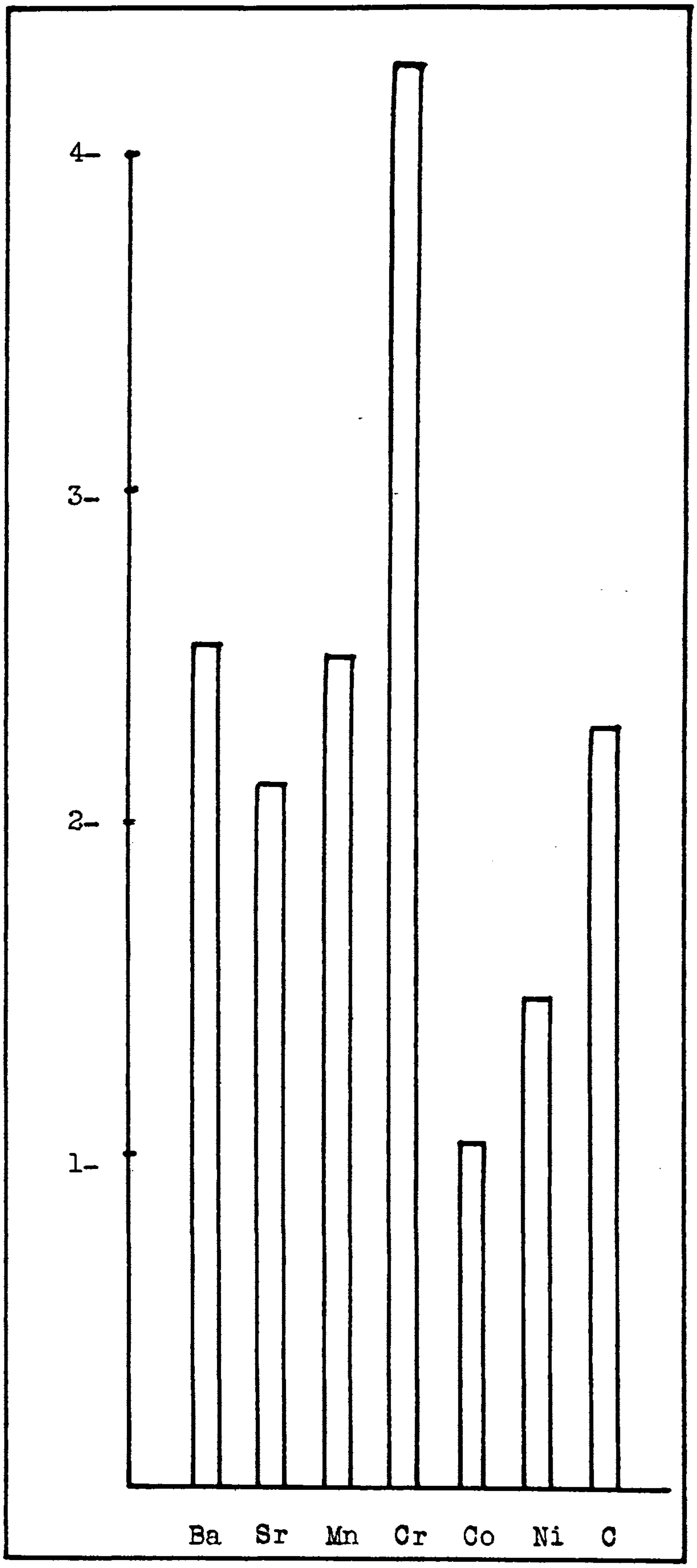

Fig. 12. Relative dry weight of roots of wheat seedlings in Plot 4, Series II.

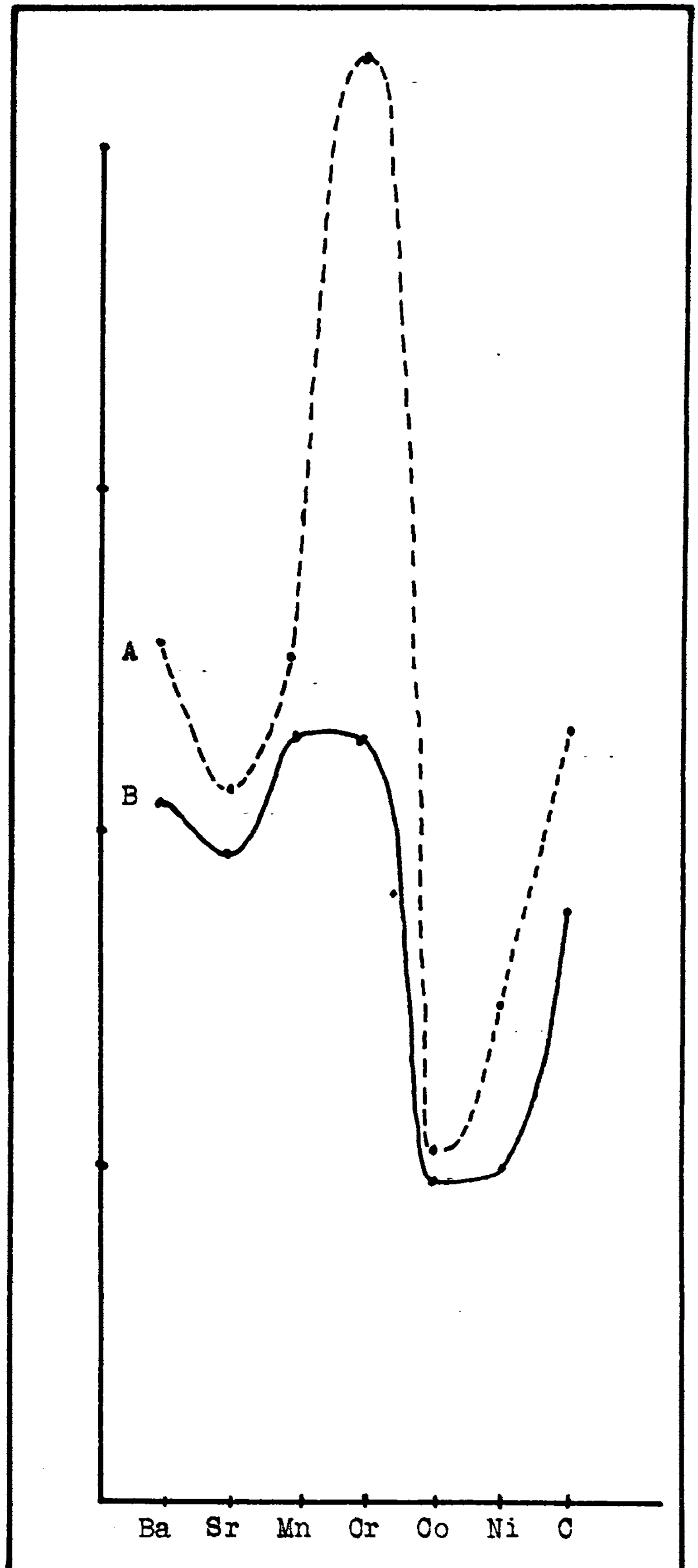

Fig. 13. Relative growth of tops and roots of wheat seedlings in Plot 4, Series II. A-Roots, B-Tops.

and roots, the former being less toxic in both cases than the latter.

Plot 5

A concentration of M/1350 of each metal was used here the same as in Plot 2 of the preceeding series. Barium gave the highest yield of tops as shown in figure 14. Chromium, strontium, and manganese follow barium in producing a stimulation of top growth. Cobalt and nickel are toxic but their positions are now reversed, nickel being the more toxic of the two.

The effect upon root growth in this plot is rather peculiar, barium being the only element to produce any stimulation. Strontium produced 0.140 grams of roots less than the check which is probably not significant in these experiments. Chromium, manganese, cobalt and nickel follow strontium in the order named. The effect of these elements on root growth is graphically shown in figure 15.

From figure 16, it would appear that the elements in this plot produced somewhat similar effects on top and root growth, but an analysis of the curves and an examination of the figures in Table 2 discloses the fact that little correlation exists. Barium gives the most marked stimulation of both root and top growth, but chromium produces a stimulation of top growth and is toxic to roots. The same is true of

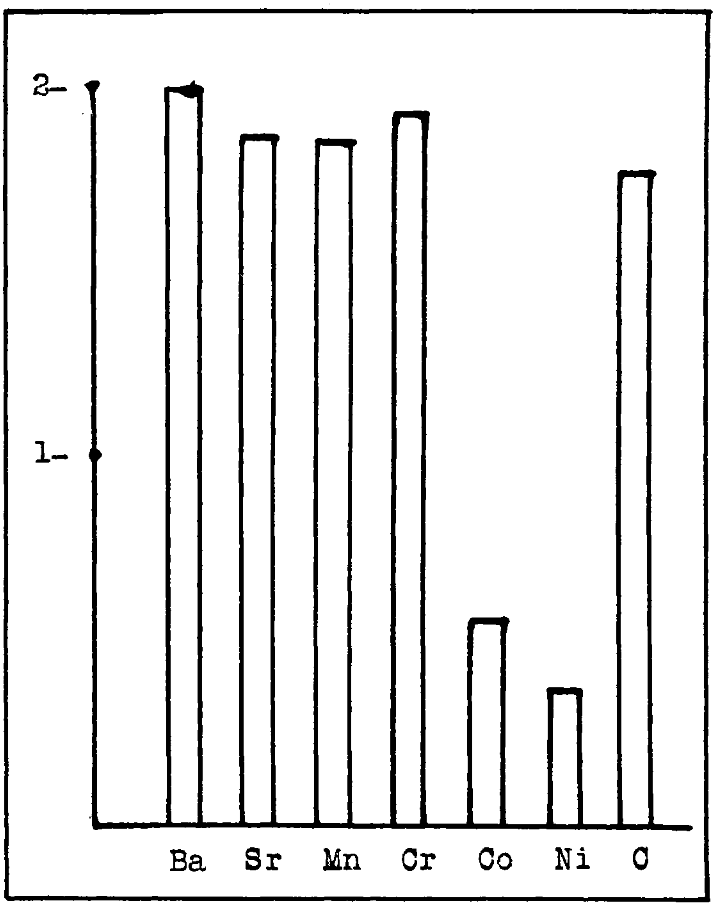

Fig. 14. Relative dry weight of tops of wheat seedlings in Plot 5, Series II.

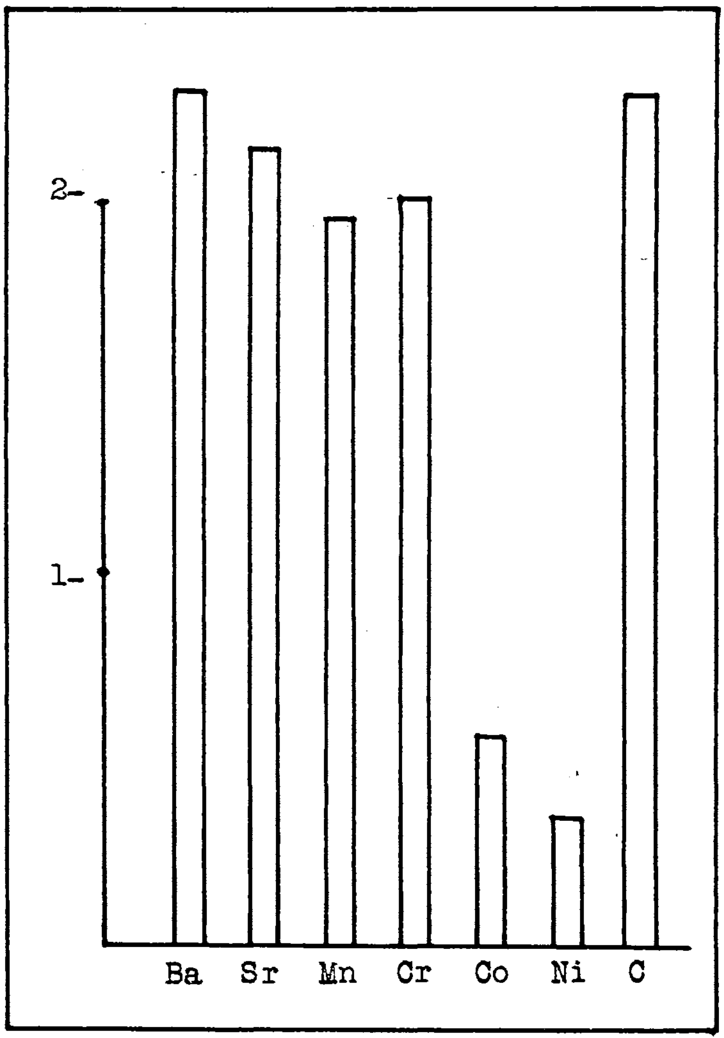

Fig. 15. Relative dry weight of roots of wheat seedlings in Plot 5, Series II.

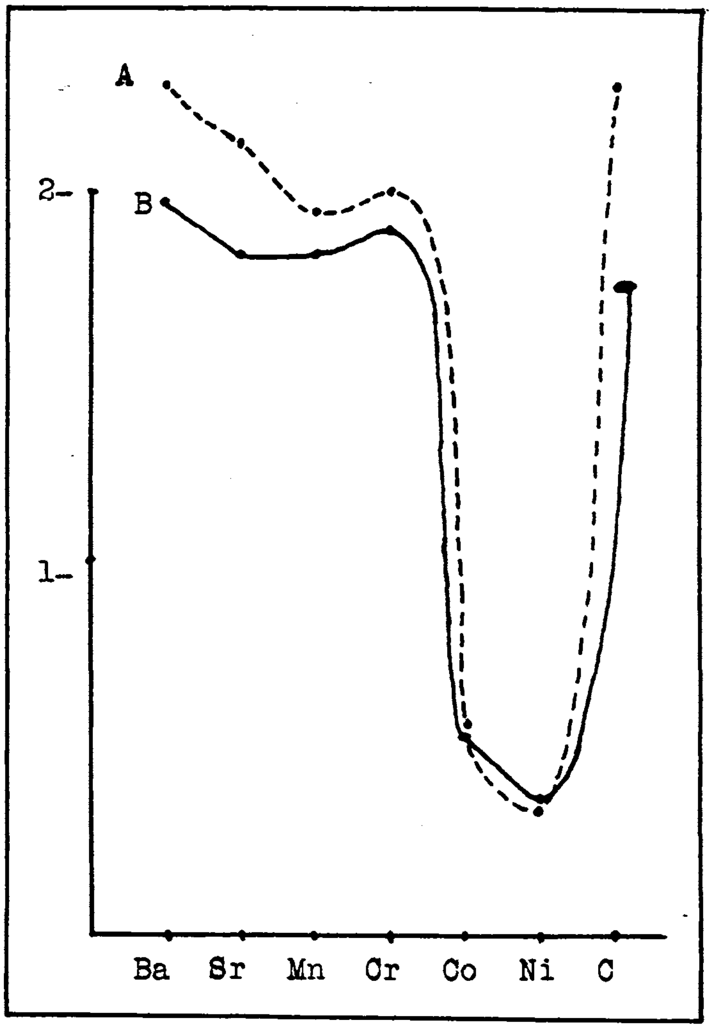

Fig. 16. Relative growth of tops and roots of wheat seedlings in Plot 5, Series II. A-Roots, B-Tops.

strontium and manganese and although they stand in the same order in dry weight of tops and roots produced, they are stimulative on the one hand and toxic on the other. Cobalt and nickel show like effects on both top and root growth being toxic in the same order in both cases.

Plot 6

With an increase in concentration, effects are almost identical with the preceeding plot except that yields are somewhat reduced. Barium, chromium and strontium produce an increased yield of tops over the check, while manganese is not significantly toxic, differing from the check by only 0.043 grams. Figure 17 shows these relations and also that cobalt produced only one-fourth the tops that the check did and nickel only one-sixth the weight of the check.

Root growth is also similar to that in Plot 3, except that strontium and barium have reversed places, strontium showing stimulation in this case and barium showing a slight toxicity. Chromium, manganese, cobalt and nickel follow barium in the order named. These relations are more clearly demonstrated in figure 18.

No correlation exists between root growth and top growth as is demonstrated in figure 19. Strontium gives stimulation of both tops and roots, barium is stimulative toward tops, but slightly toxic toward roots, and the same is true for chromium only the toxicity toward roots is more marked. Manganese produces no significant effect on tops but is markedly toxic

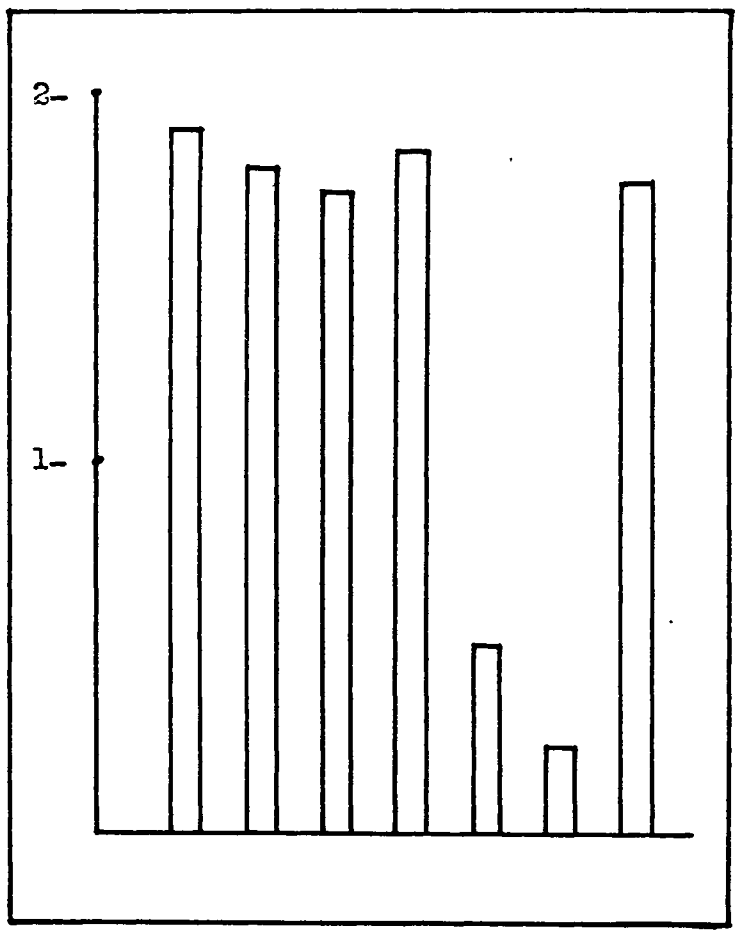

Fig. 17. Relative dry weight of tops of wheat seedlings in Plot 6, Series II.

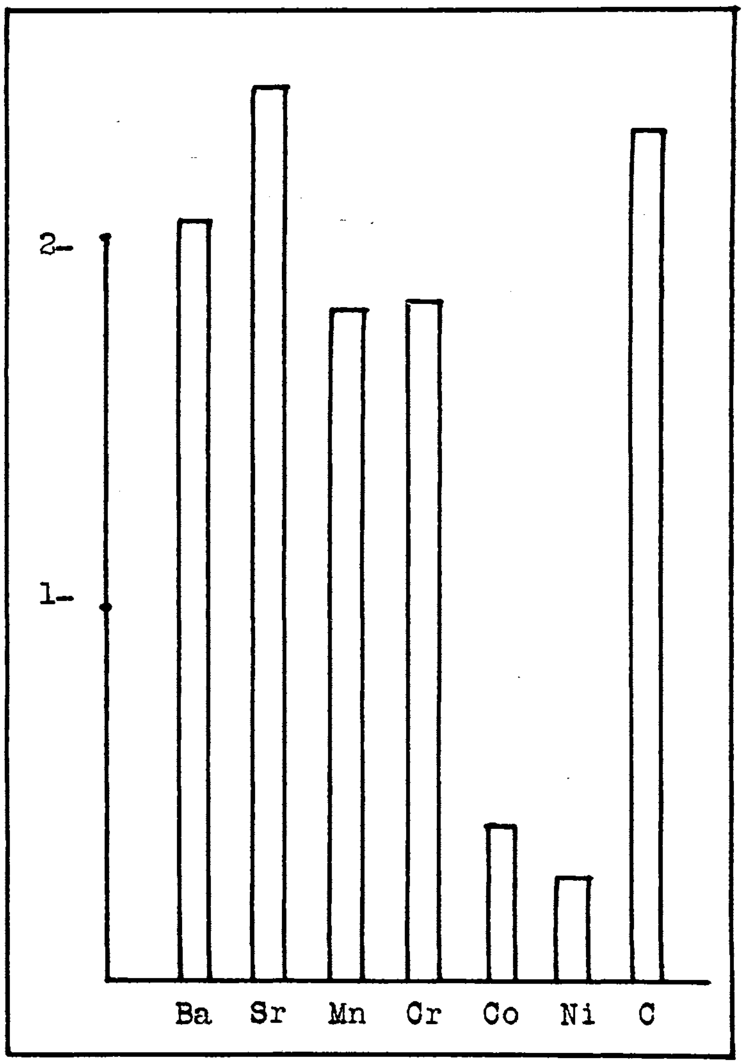

Fig. 18. Relative dry weight of roots of wheat seedlings in Plot 6, Series II.

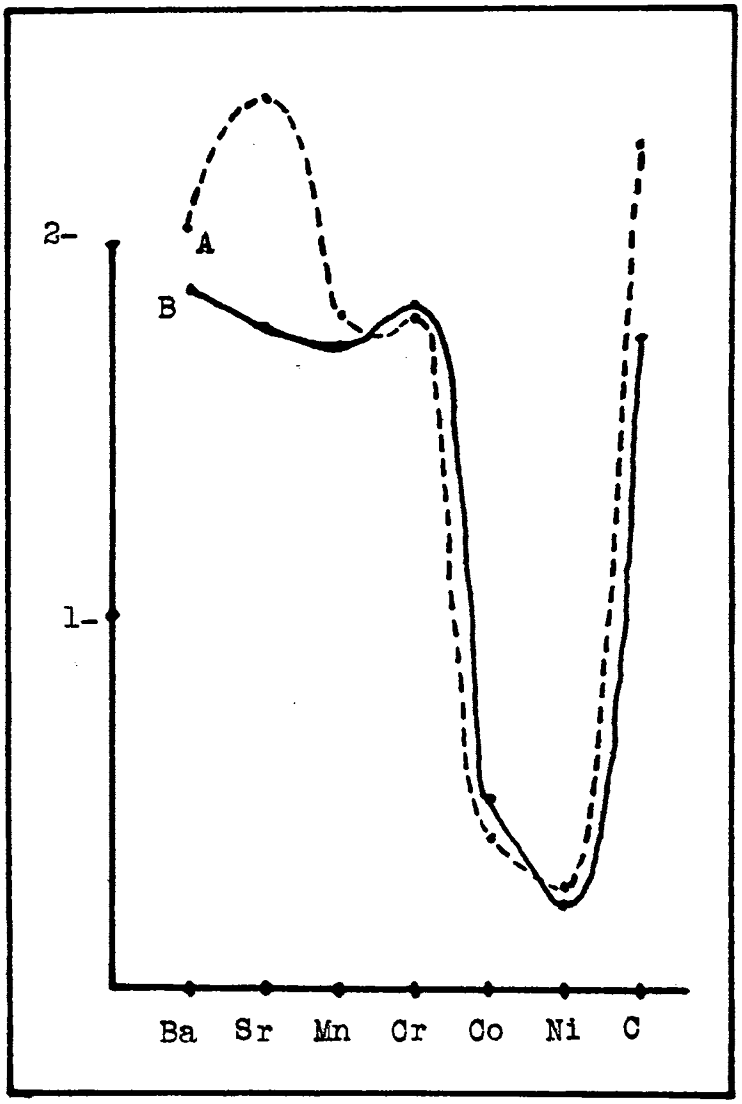

Fig. 19. Relative growth of roots and tops in Plot 6, Series II. A-Roots, B-Tops.

toward roots. Cobalt and nickel are extremely toxic toward both roots and tops.

Effect of Concentration

Table II and figures 11, 14 and 17 show that concentration had a much more uniform effect on growth in this series than in the preceeding series. In the case of tops the effect was the same for all elements. Yields decreased as concentration increased. Manganese is the most striking example, producing the highest yield of tops in the entire series at a concentration of M/2600 and being neutral or slightly toxic at a concentration of M/933.

The effect on roots is identical with the effect on tops except in the case of strontium which has the reverse effect, the yield of roots increasing as the concentration increased. Chromium produced a somewhat abnormal growth of roots in Plot 4 of this series.

Series III.

The effect of these non-nutrient elements in sand cultures, both in distilled water and in nutrient solution has already been considered and it now remains to determine their effect in soil cultures. The plants in Series III were treated in the same manner as the plants in Series I, except that soil provided the substratum for growth instead of quarz sand.

Plot 7 is peculiar and different from all other plots in the series in that all the elements produced a stimulation of top growth in the following order: chromium, manganese, cobalt, barium, strontium and nickel. The dry weight of tops is given in Table III and graphically represented in figure 20.

Results are somewhat different in Plot 8, where a more concentrated solution of the elements is applied. Strontium produces a very marked stimulation of top growth and is followed in order by nickel, chromium, barium, and cobalt. Manganese shows a toxic effect in this concentration as may be seen in figure 21.

In a concentration of M/933 strontium again produces the highest yield of tops and is followed by chromium and cobalt. Nickel shows a slight toxic effect as do barium and manganese, the latter producing practically an equal yield of tops as may be seen in Table III and being more toxic than nickel. These relations are graphically represented in figure 22.

SOIL (SERIES III)

Table III. Dry weight, in grams, of tops and roots of twelve plants, grown in soil cultures and treated with nitrates of the metals in solution.

	$\frac{M}{2600}$ (Plot 7)		$\frac{M}{1350}$ (Plot 8)		$\frac{M}{933}$ (Plot 9)	
	T	R	T	R	T	R
Ba	2.555	---	2.840	---	2.069	---
Sr	2.540	---	3.460	---	2.685	---
Mn	2.826	---	2.085	---	2.068	---
Cr	2.895	---	2.852	---	2.460	---
Co	2.690	---	2.840	---	2.445	---
Ni	2.455	---	3.120	---	2.370	---
Check	2.430	---	2.430	---	2.430	---

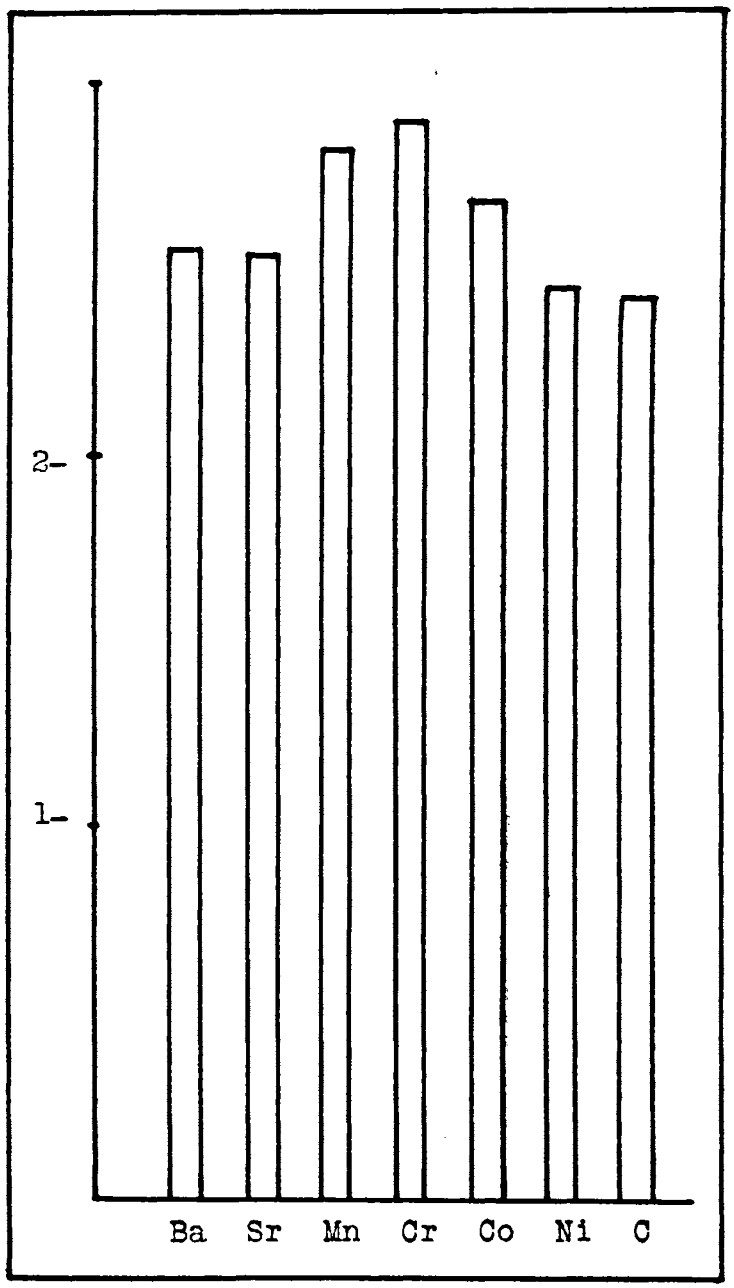

Fig. 20. Relative dry weight of tops of wheat seedlings in Plot 7, Series III.

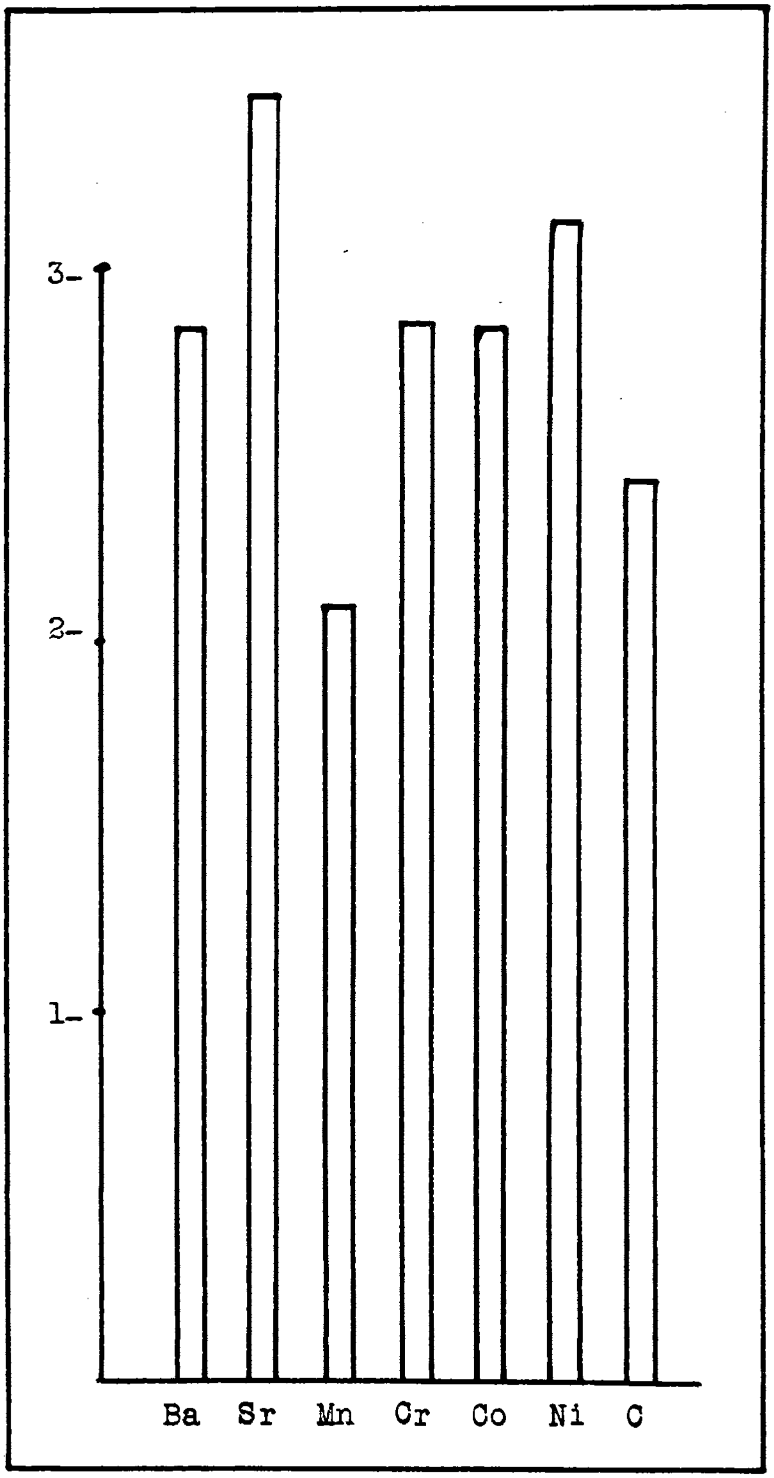

Fig. 21. Relative dry weight of tops of wheat seedlings in Plot 8, Series III.

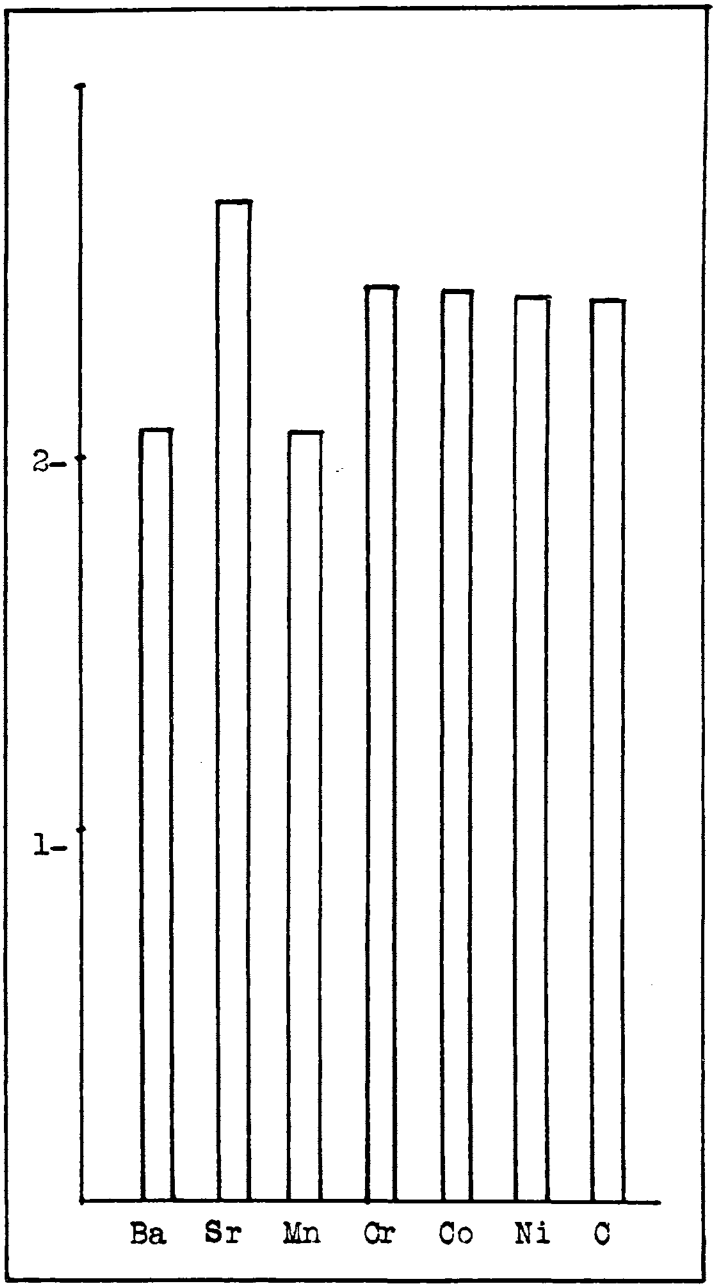

Fig. 22. Relative dry weight of tops of wheat seedlings in Plot 9, Series III.

Effect on Total Growth of Plants

The effect of the various elements on top growth and on root growth has already been determined and this leads to a consideration of the effect of these elements on the total growth of the plant. These results are given in Table IV.

Series I

From the Table IV it may be seen that strontium produces the greatest stimulation of growth on wheat seedlings in Plot 1. Barium and manganese in the order named, also produce a stimulation of plant growth while chromium is slightly toxic. Nickel and cobalt were slightly stimulative to tops in this plot but toxic enough to roots to make the total effect on the plant toxic. In general, then, strongium, barium, and manganese produced a stimulation of growth on plants in this plot, chromium was slightly toxic throughout, cobalt stimulated top growth but was detrimental to the growth of roots and nickel, like chromium, gave a slight increase in yield of tops but a slight decrease in yield of roots.

In Plot 2, strontium, manganese, chromium and barium are stimulative in the order named while nickel and cobalt are toxic. In this plot strontium, manganese, chromium and barium are stimulative to the growth of the wheat seedlings, chromium gives an increased yield of tops but is toxic on roots and nickel is toxic throughout.

DISTILLED WATER (SERIES I)

Table IV. Total dry weight, in grams, of twelve plants grown in sand cultures and treated with nitrates of metals in solution.

	$\frac{M}{2600}$ (Plot 1)	$\frac{M}{1350}$ (Plot 2)	$\frac{M}{933}$ (Plot 3)
Ba	2.500	1.726	1.691
Sr	2.832	2.740	1.931
Mn	1.931	2.367	1.514
Cr	1.333	1.810	1.810
Co	1.069	0.818	0.596
Ni	1.111	0.918	0.811
Check	1.421	1.421	1.421

Strontium again produces the greatest dry weight of plants in Plot 3 and chromium, barium, and manganese follow strontium in the order named. Nickel and cobalt are both toxic, cobalt being more toxic than nickel. Stimulation, in this plot, is produced by strontium, barium and chromium, manganese is stimulative on top growth but slightly toxic toward growth of roots, while nickel and cobalt are both toxic.

Series II

From Table V, it may be seen that in Plot 4 the elements produce a stimulative effect in the following order: chromium, manganese and barium. Strontium shows a slight toxicity but not enough to be significant and may be considered neutral in its effect on total plant growth. Nickel and cobalt are both toxic. A consideration of growth in this plot shows that chromium, manganese and barium are stimulative; strontium stimulates top growth, but is toxic toward roots; nickel is toxic and so is cobalt.

In Plot 5, barium alone shows stimulation, strontium, however, is not significantly toxic, differing from the check only by 0.062 grams. Chromium and manganese are slightly toxic while cobalt and nickel are very markedly toxic. A general consideration of growth in this plot shows that barium is stimulative on total growth, strongium stimulates top growth but shows a slight toxicity toward root growth, chromium and manganese are similar to strontium while cobalt and nickel are in the reverse order from the preceeding plots but are both markedly toxic.

NUTRIENT SOLUTION (SERIES II)

Table V. Total dry weight, in grams, of twelve plants grown in sand cultures treated with Shive's R5C2 nutrient solution and nitrates of metals in solution.

	$\frac{M}{2600}$ (Plot 4)	$\frac{M}{1350}$ (Plot 5)	$\frac{M}{933}$ (Plot 6)
Ba	4.598	4.258	3.932
Sr	4.002	3.968	4.193
Mn	4.745	3.772	3.524
Cr	6.270	3.885	3.635
Co	1.947	1.091	0.906
Ni	2.437	0.608	0.585
Check	4.032	4.032	4.032

The positions of strontium and barium in Plot 6 are the reverse of what they were in Plot 5, strontium being the only element producing stimulation and barium showing a slight toxicity. Otherwise, the relation of the elements is the same as in the preceeding plot. Strontium is stimulative throughout, barium and chromium stimulate top growth but are detrimental to root growth; manganese shows little effect on top growth but is significantly toxic on root growth; cobalt and nickel are both toxic.

GENERAL DISCUSSION

The above data has shown that some of these elements exert a toxic effect, some a stimulative effect and some show both a stimulative effect and a toxic effect, depending on the concentration and the medium of growth.

Strontium.

Strontium has been shown in these experiments, to produce a very marked stimulation on top growth in Series I. This stimulation is not so marked in Series II but is again clearly demonstrated in Series III.

The effect of strontium on root growth, however, is somewhat different. Marked stimulation is produced in Series I but a somewhat poisonous effect in Plots 4 and 5, and a stimulation in Plot 6 are produced in Series II.

On total growth, strontium shows a very marked stimulation in Series I. In Series II, however, a slight poisonous action is shown which, as has been stated above, is not enough to be significant.

Practically these same effects have been shown by McCool (20) with Canada Field Peas. He has shown that strontium nitrate is stimulative on top growth up to a concentration of N/500, above which, however, toxic effects are produced. Toxic effects were shown on roots in all concentrations used. In total green weight, stimulation corresponded to top growth.

Barium.

Barium produces an increased growth of tops in both Series I and II, but has a poisonous action at a concentration of M/933 in Series III.

This element shows greater stimulation of root growth than does strontium producing increased growth throughout Series I, but being toxic at a concentration of M/933 in Series II.

In total growth, it also surpasses strontium, being stimulative in all plots except Plot 6 where a slight poisonous effect is shown corresponding to the poisonous action on root growth in this plot.

McCool (20) obtained somewhat similar results but with very different concentrations and with the chloride instead of the nitrate. In a concentration of N/1000, $BaCl_2$, Canada Field Peas made practically no growth during twenty-four days. In a concentration of N/5000 a little better growth was obtained but the element was still very toxic, and marked stimulation of growth of both roots and tops and total growth was obtained at a concentration of N/10,000.

Chromium.

The effect of chromium on top growth is practically the same as the effect produced by barium. Chromium stimulates top growth in all cases except in Plot 1, Series I, where it differs from the check by only 0.002 grams, which is not significant, so it may be said that chromium is equal to or even surpasses barium im stimulating top growth.

In Series I, chromium is toxic at a concentration of M/2600 but becomes stimulative and more stimulative on the growth of roots at the higher concentrations. The reverse effect occurs in Series II, the element being stimulative at M/2600 and toxic in the other two concentrations.

Chromium is not as beneficial to total growth as strontium, barium or manganese, the effects being similar to those on root growth.

Manganese:

A very clear diminution in stimulative influence is shown by the effect of manganese on tops. In Series I the element is stimulative in all three concentrations. When a nutrient solution is present, it becomes toxic at a concentration of M/933 and in soil is toxic at concentrations of M/1350 and M/933. This same effect of the influence of the medium of growth has already been shown by both McCool (20) and Deatrick (28).

This element is stimulative on root growth in Series I, except at a concentration of M/933. In Series II it is toxic at both the higher concentrations.

Manganese is about equal to strontium in its effect on total growth, proving stimulative in Series I, but quite toxic in Plots 5 and 6 of Series II.

Deatrick (28) found that Manganese caused marked stimulation in lower concentrations but was toxic at higher concentrations. McCool (20), later obtained the same results.

Cobalt.

In the case of cobalt, some peculiar and rather unexpected results were obtained. On top growth, stimulation was obtained at concentrations of M/2600 and M/1350 in Series I, but toxicity was shown throughout Series II. Stimulation was shown throughout Series III. These results are the more striking since the toxicity of the salts of the heavy metals, has been so thoroughly emphasized.

Very marked toxicity was displayed, both towards root growth and toward total growth. Four days after the solutions of this element were applied, toxic effects were apparent on the plants. The leaves became lighter in color and somewhat wilted. Longitudinal stripes, alternate green and yellow, appeared later and remained throughout the experiment.

The roots were brown in color, very short and thick. Some of the leaves died and all plants were extremely small at harvest.

<u>Nickel</u>.

In pure solutions, nickel stimulated top growth at a concentration of M/2600 but was toxic through the rest of Series I and in Series II. It was stimulative in concentrations of M/2600 and M/1350 in Series III, but toxic at M/933.

Root growth and total growth are very much reduced by the presence of nickel. One day after application of this element, the leaves of the plants wilted and turned yellow. Later many of the leaves, though still alive, assumed a brownish red color. The plants seemed to recover somewhat after this remaining alive but making very little growth. This indicates that nickel is more toxic than cobalt, although higher yields were obtained with nickel in some cases. These higher yields were probably due to a better recovery of some plants from the effects of the nickel.

SUMMARY OF RESULTS

Strontium seems to be stimulative on top growth in the concentrations used in these experiments. It is also stimulative on root growth but this stimulation is somewhat reduced in the presence of a nutrient solution.

Barium produces an increase in top growth, but this stimulation is not so marked in a soil culture where it becomes toxic at a concentration of M/933. Stimulation is also produced on root growth but the presence of a nutrient solution somewhat reduces this stimulation.

Chromium also stimulates top growth and is equal to or better than barium in this respect. Chromium is toxic on root growth in weak concentrations with only distilled water present and is stimulative in higher concentrations. The reverse effect is obtained when a nutrient solution is present, stimulation being shown in weak concentrations and toxic effects in higher concentrations.

Manganese stimulates top growth but the stimulation is reduced in the presence of a nutrient solution and still more reduced in soil. The element stimulates root growth in weaker concentrations but is toxic at higher concentrations. Stimulation is modified by the presence of a nutrient solution.

In a pure solution, cobalt stimulates top growth in weak concentrations; in the presence of a nutrient solution it is highly toxic and this toxicity is so modified in a soil culture that the element is again stimulative. It is extremely toxic to root growth.

Nickel, in a pure solution is stimulative in very weak concentrations but is toxic in the presence of a nutrient solution, this toxicity being so modified in soil that stimulation is produced in the two weaker concentrations. Roots make very little growth in the presence of nickel.

The degree of stimulation or toxicity is modified by the medium of growth. The amount of this modification depends on the complexity of the growth medium, the modifying effect of a full nutrient solution not being as great as a soil culture.

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Plate I. Showing stimulation produced by barium nitrate at a concentration of M/1350 in a sand culture treated with Shive's R5C2 nutrient solution.
A-check
B-treated with $Ba(NO_3)_2$

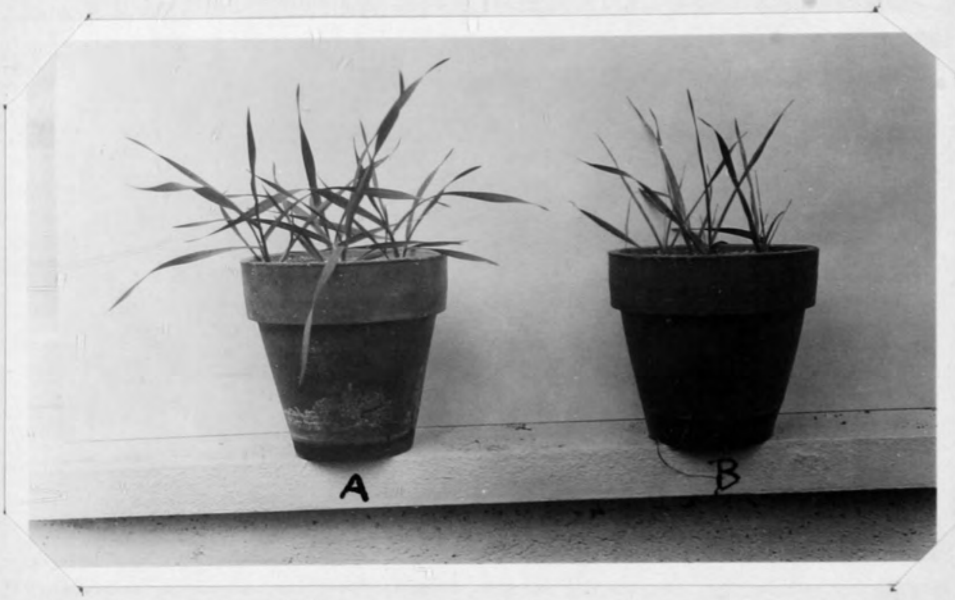

Plate II. Showing toxic effect of cobalt nitrate at a concentration of M/2600 in a sand culture treated with Shive's R5C2 nutrient solution.
A-Check
B-Treated with $Co(NO_3)_2$

Plate III. Showing increase of toxicity with increased concentration, in the case of cobalt nitrate. Concentration M/933 in sand culture treated with Shive's R5C2 nutrient solution.
A-Check
B-Treated with $Co(NO_3)_2$

Plate IV. Showing toxicity of nickel nitrate at a concentration of M/2600 in sand culture treated with Shive's R5C2 nutrient solution.
A-Check.
B-Treated with $Ni(NO_3)_2$

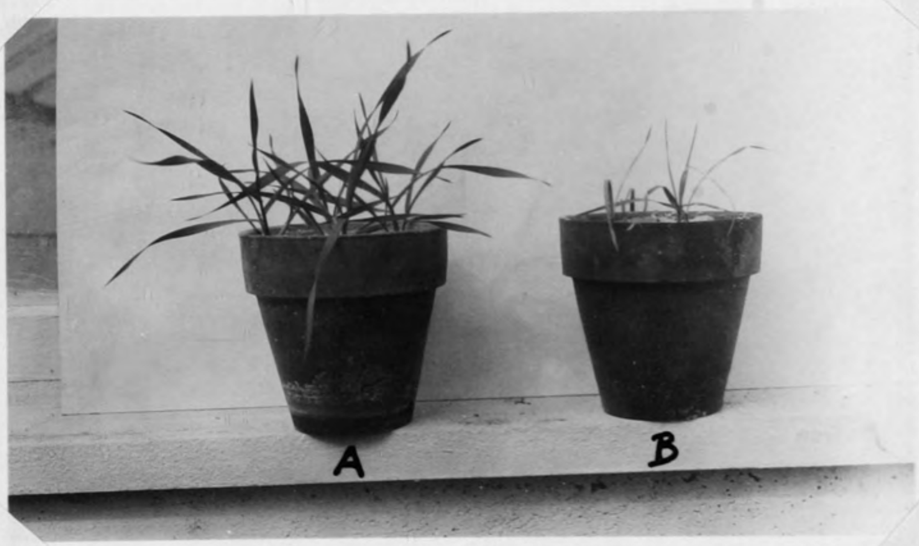

Plate V. Showing increased toxicity with increased concentration in the case of nickel nitrate. Concentration M/933, in sand culture treated with Shive's R5C2 nutrient solution.
A-Check
B-Treated with Ni $(NO_3)_2$

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