INFLUENCE OF SOIL AND TREATMENT UPON GROWTH AND CATION UPTAKE OF CORN

by

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INTRODUCTION

In certain areas of Kansas where soils are alkaline in reaction and high in base saturation, corn production has not been satisfactory. Presence of excessive Na and the interrelationships of other cations may have considerable bearing on crop production under such conditions.

The Decatur County, Kansas soils used in this study were observed to be unproductive during the 1956 crop season. Despite application of irrigation water and use of nitrogenous fertilizer, growth of corn was not satisfactory. Furthermore, soil test results indicated that none of the usual fertility deficiencies prevailed.

This combination of greenhouse study and laboratory investigation was conducted during the 1956-57 seasons to ascertain:

(a) whether or not Zn deficiency was the primary cause of poor corn growth,

(b) what effect, if any, may have been attributable to excessive concentrations of Na and/or other cations,

(c) what effects addition of $(NH_4)_2HPO_4$ fertilizer, $Zn\ SO_4 \cdot 7H_2O$, and "Nu Zim"[1] had upon growth and cation accumulation of corn.

REVIEW OF LITERATURE

If there is an excessive concentration of any ion in the soil solution, such may be toxic to plant growth. This sometimes has

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[1] "Nu Zim" is a commercial product of the Tennessee Corporation. It contains 7 percent Zn, 21 percent Fe, and 7 percent Mn.

been explained as being due to "ion antagonism." It is believed by some that addition of certain other ions may cause suppression of the toxic ion.

Considerable work has been done relative to the effect of soil and soil treatments on the growth of plants and uptake of ions by plants. The problem is quite complicated. Conflicting views have been expressed by various workers about effects and interactions of different ions. Close correlation between cations originally present in soil, and those taken up by plants was reported by various workers (7, 12, 13, 15).

Influence of Na on K Absorption and Vice Versa

Although Na is not considered to be an essential element for plant growth, it has been found to be a common constituent of almost all plants. This lends support to the belief that the Na ion, directly or indirectly, might be interrelated to some other ions in plants. The ability to exercise selective absorption and accumulation of cations varies with plant species. This ability may help plants either to absorb or to exclude Na or other ions.

Ratner (25) found that if exchangeable Na was present in appreciable quantity, it depressed absorption of K by plants. Van Itallie (12), working with rye grass, found that an appreciable increase in Na saturation of a soil reduced K absorption and increased Na content in plants.

Larson and Pierre (14), working with beets, flax, oats, and corn on two different soils which had received three levels of Na and K, concluded that capacity to absorb Na differed with different crops and they classified those crops as to their response in the following order: beets > flax > oats > corn. They found that beets responded to Na only when K was present in a large amount; flax responded to Na only when K was limiting; but corn did not respond to Na under any conditions. According to these investigators, these additions of Na to soil generally depressed the uptake of K by plants and vice versa. In some cases, however, this generalization did not hold. They further suggested that results would depend on levels of Na and K applied to plants and upon kind of plant.

Marshall (17) and Harmer and Benne (10) reported that application of Na increased K uptake by various crops other than corn. Wallace et al. (33) worked with alfalfa grown in sand culture. They reported that application of Na usually increased K content of plants otherwise low in K content and did not retard luxury consumption of K.

Cope et al. (6) reported increases in yields of corn, sudan grass, and alfalfa due to Na fertilization. They found that plants did not absorb Na and suggested that high yields might have been due to increased uptake of K on account of application of Na which effected a release of K from the soil to the plants. Corn plants harvested at tasseling time did not reflect an increase in Na content. Sodium content was constant at about 0.2 me./100 grams.

Bower and Wadleigh (4) found that as higher proportions of exchangeable Na were supplied, absorption of Ca, Mg, and K generally decreased as a whole. They studied garden beets, beans, Rhodes grass, and Dallis grass and stated that exchangeable Na did not affect accumulation of Ca and Mg by these plants. They reported the substitution order to be Na $>$ K $>$ Mg $>$ Ca.

McLean (18) reported that corn with only one-third as much root exchange capacity, had the same amount of Na in roots as lespedeza. He suggested that low concentration of Na in corn tops could not be adequately explained on the basis of the node as a physical barrier to the movement of Na in the cornstalk. He also found that corn roots bonded K three to five times as strongly as Na.

Effect of Ca and Mg on Absorption of K and Vice Versa

Hunter et al. (11) stated that so long as a soil had an adequate amount of K, Ca had no adverse effect upon plant accumulation of K, and a good yield could be obtained despite application of Ca to the soil. Van Itallie (12) also agreed with the above view. He reported that K uptake was dependent primarily on the K concentration in the soil solution. He stated, however, that $MgCO_3$ application to a soil which was acidic in reaction, suppressed K absorption.

Viets (29) reported that an increase in absorption of K by barley was obtained when Ca and Mg were added to the nutrient medium. Moser (19) worked with lespedeza, sorghum, and soybeans in sand cultures and nutrient solutions. He found that additions of K caused depression in the absorption of Ca and vice versa. Similar results were reported by York and Rogers (35) and by Pierre and Bower (21).

Stanford et al. (28) stated that corn grown on high lime soil absorbed relatively greater amounts of Ca and Mg and comparatively less of K.

Effect of Other Cations Present

As already stated, the effect of cations has been studied in great length and different results have been reported by various workers. It is, however, established that ions have mutual repressive effect on absorption of one another. This effect depends upon their nature, relative concentration in the nutrient medium, the kind of plant, and other factors. Lundegardh (16) reported that cation antagonism is strongest between the outermost ions in the adsorption series Mn > Ca > Mg > K > Na. Other workers like Carolus (5) and Ratner (25) reported a rather different order of replacement of various cations; K > Na > Mg > Ca. Bower and Wadleigh (4) stated this order to be Na > K > Mg > Ca. Calcium was found to be least competitive while K generally was more competitive. Position of Na differed very much because difference in ability of various plants to absorb this cation from growth medium. Carolus (5), working with the bean, found that presence of large amounts of Na and Ca in the soil actually increased the absorption of K. Van Itallie (13) reported that Ca uptake was dependent upon the ratio of Ca to three other cations present in the soil. He also reported that Mg absorption was adversely affected if other cations were present in large quantities even when Mg was present in sufficient quantity. He found the application of Ca to be favorable to Mg uptake.

Elgabaly(7) grew barley plants in a resin-sand system and studied the effect of Ca, Mg, and Na on the growth and cation accumulation. He concluded that increase of Na in the growth medium increased foliar accumulation of Na, depressed K uptake, and to some extent, suppressed uptake of Ca and Mg. In Ca-Mg combinations, plants absorbed Mg at various degrees of Mg saturation. Potassium absorption was adversely affected to some extent. Other combinations which were tried led him to conclude that the nature of the complementary ion played a great part in the absorption of and depletion of a given nutrient ion.

Wiklander and Elgabaly (34) found with excised barley roots that there was an increase in the absorption of divalent cations due to an increase in the exchange capacity of the growth medium. They grew plants in different combinations of cations in resins, bentonite, and kaolinite.

Effect of N, P, Mn, Zn, and Fe on the Absorption of Cations

Prince (24) reported that application of N on rye grass and crimson clover increased yields, and increased N, P, and K content of forage. Calcium and Mg accumulations were decreased when K was increased in the soil solution. Potassium content of the plants increased but there was no increase in yields. Ellis et al. (8) stated that N application increased uptake of Ca and Mg.

Wallace and Achcroft (32) reported that applied phosphates had no effect on absorption of Mg by either lemon, avocado, barley, or bean plants. Pratt and Thorne (23) concluded that phosphates were more soluble in Na-induced alkalinity than in Ca-induced alkalinity. They stated that phosphate solubility and assimilation increased with an increase in alkalinity from pH 7.0 to pH 9.0. Phosphate addition did not decrease absorption of Zn by corn, according to Boawn et al. (3).

Viets et al. (30) reported that application of $ZnSO_4 \cdot 7H_2O$ at the rate of 11.6 pounds per acre at planting time to bean plants, increased yields of dry beans. Zinc application, however, did not affect plant concentrations of P, K, Mg, and Ca. They stated that applied Mn had no effect on Zn uptake. Banded applications of N increased the uptake of Zn considerably, according to the same workers.

Barnette and Hester (2) concluded that Zn replaces Ca more easily than it does the other cations.

METHODS OF STUDY

Soil Materials Used

Soil materials used in this study were obtained from two different locations at a single farm in Decatur County, Kansas. The materials actually were sub-soils, since such had been exposed at the surface only since 1956 when the fields were leveled for irrigation. Corn was planted and fertilized in 1956. Growth was below normal on Soil I and it was very poor on Soil II in spite of the fact that there was no apparent shortages of N, P, or K.

Laboratory Analyses

Laboratory analyses of both these soils were made so as to determine pH of the saturation paste, total cation exchange capacity, electrical conductivity of the saturation extract, $CaCO_3$ content, organic matter content, and concentrations of various cations present in the exchangeable form and as soluble constituents in the saturation extract.

Plant material was weighed after drying to determine yield, and analyzed to ascertain accumulation of various elements.

The saturation percentage was determined by weighing 500 g. of air-dried and screened soil to which measured amounts of distilled water were added. The soil was stirred thoroughly with a spatula after each addition of water until a uniformly saturated paste was obtained.

The pH of the paste was determined by means of Beckman pH meter equipped with a standard glass electrode. The instrument was first standardized with a buffer solution having a pH of 3.98.

The saturation extracts of these soils were obtained after transferring the pastes to Buechner funnels and applying gentle suction. The extracts were collected in flasks connected to the above described suction apparatus.

Electrical conductivity of saturation extract was determined by means of a standard Wheatstone Bridge at 25° C. It is expressed in millimhos/cm.

The principal water soluble cations were determined in the saturation extract by means of a Beckman flame photometer.

Total cation exchange capacity of soils was determined according to Rendig's method (26) with some modifications. Two g. of air-dried 10-mesh soil was placed in a 100-ml. centrifuge tube and washed four times with 50 ml. of 1 N $NH_4C_2H_3O_2$ solution (adjusted to pH 7.0). The soil was resuspended each time by stirring the mixture for one minute by means of a rubber ball plunger attached to an electric motor. The suspension was centrifuged at 2500 to 3000 rpm. for five minutes. Each washing was discarded. This soil sample, saturated with NH_4^+, was washed with 1 N $Ca(C_2H_3O_2)_2 \cdot H_2O$ solution (adjusted to pH 7.0) by the centrifuge method. The soil was then washed once with $Ca\ Cl_2$ solution. One washing was made with distilled water, which was followed by several washings (Cl^-) with 95 percent ethyl alcohol until washings were free of Cl^-. The soil was then washed with 1 N $NH_4C_2H_3O_2$ (adjusted to pH 7.0) five times to replace Ca^{++}. These washings were collected in a 250-ml. volumetric flask and made to volume with 1 N $NH_4C_2H_3O_2$. After appropriate dilutions, Ca was determined by means of the Beckman flame photometer.

Organic matter was determined according to the method of Peech et al. (20). One g. of soil was placed in a 500-ml. Erlenmeyer flask. Ten ml. of 1 N $K_2Cr_2O_7$ solution and 20 ml. of concentrated H_2SO_4 were added. The suspension was allowed to stand for half an hour. After cooling, approximately 200 ml. of water were added, followed by the addition of concentrated H_3PO_4. One-half ml. of 0.16 percent aqueous solution of barium diphenylsulfonate indicator was added and the contents were titrated with 1 N $FeSO_4 \cdot 7H_2O$ solution. The percentage of organic matter in the soil was calculated.

$CaCO_3$ was determined by the method given by Piper (22). Two and one-half g. of soil were weighed and transferred to a tall 150-ml. beaker. One hundred ml. of 1 N HCl was added to this. The suspension was stirred vigorously several times during one hour, and allowed to stand until the supernatant liquid became clear. Twenty ml. of supernatant liquid was transferred by means of a pipette to an Erlenmeyer flask. Brom thymol blue indicator was added to it and titrated with 0.1 N NaOH. Percentage of $CaCO_3$ was calculated.

Exchangeable Cations

The exchangeable cations, Ca, Mg, Na, and K in these soils which were high in total salt content were determined according to the following method: Ten g. of air-dried soil were placed in a 125-ml. Erlenmeyer flask and 50 ml. of 1 N $NH_4C_2H_3O_2$ solution were added. The suspension was shaken for 30 minutes on an end-over-end mechanical shaker and then was filtered. The concentrations of cations were determined by means of a Beckman flame photometer. The quantities of cations thus determined, were extractable cations. Calcium, Mg, Na, and K also were determined by means of a Beckman flame photometer in the saturation extract. The values so obtained represented the amounts of water-soluble cations. The difference between the above two values was considered to be the content of exchangeable cations in each instance.

Greenhouse Technique

The soils were air-dried, passed through a one-half-inch mesh screen to reduce the size of aggregates and to remove debris, and finally were mixed well in preparation for potting. Thirty-five hundred g. of soil were placed in each clay pot involved. Twenty-one pots were prepared for Soil I but only 17 were prepared for Soil II. These numbers of pots of each soil represented the entire quantity, except that used in the laboratory, which was available for greenhouse trials. These were distributed among the various treatments as shown in Table 1. In the case of the simple fertilizer treatment (Treatment 2), it may be noted that six replications are reported. Originally, it was planned that three of these would be subjected to a foliar spray treatment involving Zn. However, when it became obvious that Zn deficiency was not a primary cause of poor plant growth, such plans were abandoned.

After the preliminary potting, about one and one-half inches of soil were removed from each pot which received chemical application. The fertilizer treatment then was banded before the one and one-half inches of soil were returned. After this was completed, 850 ml. of distilled H_2O were added to each pot so as to bring the soil approximately to field capacity.

The pots were arranged in a completely randomized design. Five days later, five seeds of Pride of Saline corn were planted in each pot. The soil surface was barely moistened by adding a small amount of distilled H_2O. The upper surface was kept

Table 1. Chemical applications made in greenhouse pot culture tests.

Treatment No.	Treatment	Nutrients applied (lbs./acre)					No. of replications	
		N	P_2O_5	Zn	Fe	Mn	Soil I	Soil II
1	Control	--	--	--	--	--	3	2
2	Fertilizer[a]	200	500	--	--	--	6	6
3	Fertilizer + $ZnSO_4 \cdot 7H_2O$ (1)	200	500	4.55	--	--	3	3
4	Fertilizer + $ZnSO_4 \cdot 7H_2O$ (2)	200	500	9.10	--	--	3	3
5	Fertilizer + Nu Zim (1)[b]	200	500	4	12	4	3	3
6	Fertilizer + Nu Zim (2)[b]	200	500	8	24	8	3	--

[a] Diammonium phosphate (21-53.8-0).

[b] Nu Zim contained 7 percent Zn, 21 percent Fe, and 7 percent Mn.

continuously moistened so as to facilitate germination. The plants received water when required so that there was no shortage at any time during the growth period. The pots were rotated so as to give them equal opportunity at light, and equal exposure to other environmental factors in the greenhouse.

The plants were uprooted after 42 days of growth. Plant material was dried in the oven for 24 hours, cooled, and then roots were separated from tops. Plant material was weighed on an analytical balance so as to determine yields for the various treatments.

Chemical Analyses of Plant Material

Calcium and Magnesium Determination. The plant material was ground in a small Wiley mill. Finely-ground plant tissue was handled according to the method of Gieseking et al. (9) by using HNO_3 and $HClO_4$ to achieve digestion. One g. of ground material was placed in a 150-ml. beaker and 15 ml. of concentrated HNO_3 were added and mixed well. Addition of HNO_3 was followed by the addition of 10 ml. of H_2O and 10 ml. of concentrated $HClO_4$. The mixture was heated on a steam plate for two hours until the plant material was partially oxidized. The mixture was then gently boiled upon a hot plate. After complete oxidation of organic matter, the contents were evaporated to dryness at a low temperature. The residue was then dissolved in 25 ml. of 1 *N* HCl and heated for one-half hour, filtered, and made into 250 ml. volume. Calcium and Mg were determined by means of the Beckman flame photometer.

Potassium and Sodium Determination. Potassium and Na were determined according to the method of Attoe (1). One-half g. of plant tissue was transferred to a 250-ml. Erlenmeyer flask. One hundred ml. of extracting solution which was 2 N with respect to $Mg(C_2H_3O_2)_2 \cdot 4H_2O$ (adjusted to pH 6.9), was added to the plant material. This mixture was shaken on the mechanical shaker for one hour. After filtering the suspension, the filtrate was made to volume in a 100-ml. volumetric flask. Before subjecting this filtrate to passage through the Beckman flame photometer, this extract was refiltered through activated carbon prepared by the Atlas Powder Company, New York, to remove organic matter. It was, however, made certain that no cations were adsorbed by this powder during refiltering during which the extract was decolorized and refined.

Chemical Analyses of Root Material

Root material also was finely ground. Since the amount of root material was insufficient to permit individual analyses for each replication, the replications for each treatment were composited. The results shown in Table 5 are based upon these composite determinations.

With root material from Soil I, one g. of the carefully composited sample was digested according to the method of Gieseking et al. (9) in the mixture of HNO_3 and $HClO_4$, as mentioned before under analyses of plant tissue. The final volume was 250 ml. The cations were determined by means of the Beckman flame photometer after appropriate dilutions were made.

With root material from Soil II, 0.5 g. was weighed and the digestion carried out according to the above method. The final volume again was 250 ml. For Ca and Mg determinations, the above procedure was followed. The extracts were analyzed for different cation contents by means of the Beckman flame photometer.

EXPERIMENTAL RESULTS

Soil Analyses

The saturation percentages, pH values of saturation paste, total cation exchange capacities, electrical conductivity of saturation extract, contents of exchangeable cations, calcium carbonate, and organic matter for both soils are given in Table 2.

The results indicated that Soil I had a lower saturation percentage, lower pH, lower electrical conductivity, and lower cation exchange capacity. Percentages of $CaCO_3$ and of organic matter were higher, however, for Soil I than for Soil II. Except with Ca, content of each of the exchangeable cations also was higher in the case of Soil II. When all these factors were considered, it was possible to consider Soil I as being normal or at most, slightly alkaline while Soil II necessarily was characterized as a saline alkali sample, according to Sigmond (27).

The results for Soil I were not as unusual as were those for Soil II. Soil I had a somewhat higher content of exchangeable Na than normally would be expected in most favorable corn producing soils. It was not so high as to exclude the possibility of corn production, however. Other cation concentrations appeared to be

Table 2. Chemical characteristics of soils.

Soil No.	Saturation %	Saturation paste pH	Electrical conductivity of sat.ext. m.mhos/cm.	Cation exchange capacity m.e./100 g.	Exchangeable cations m.e./100 g.				Exchangeable cations, percent of cation exchange capacity				Water soluble cations in saturation extract m.e./100 g. of soil				$CaCO_3$ (%)	Organic matter (%)
					Ca	Mg	K	Na	Ca	Mg	K	Na	Ca	Mg	K	Na		
I	45	7.8	1.0	18.4	12.3	3.0	1.6	0.8	66.7	16.3	8.4	4.3	0.20	0.15	0.04	0.30	2.82	3.0
II	80	8.0	7.3	22.0	9.3	3.5	3.2	4.2	42.1	15.9	14.3	18.8	0.10	0.13	0.06	1.21	3.50	1.9

rather normal.

Soil II had excessive concentration of exchangeable Na. It also had a considerable amount of Na present in the soluble form. It appeared that the excessive amount of Na was present at the expense of exchangeable Ca concentration. While the excessive concentration of Na would be expected to present mainly an undesirable toxic condition for corn, it is possible that such might also compete with Ca for ionic entry into the corn plant. Upon the basis of the soil analyses, it was concluded that the excessive Na concentration present in Soil II was the most evident harmful factor which was present in either soil sample.

General Observations Relative to Plant Growth

After five days' growth, leaf tip burn was noticed on plants growing in pots of Soil II. This had largely disappeared by the time of 10 days of growth, however. Growth always was poorer with plants grown on Soil II than it was for plants grown on Soil I. Infiltration of water was very slow in the case of Soil II. These plants generally showed symptoms of water stress earlier than did those growing on the other soil. Wilting occurred frequently with those plants growing in cultures of Soil II.

In the case of Soil I, plants had either nine or ten leaves at time of harvest but in the case of Soil II, there were only eight or nine. Leaves of plants grown in Soil I were comparatively longer and wider and roots also were well-developed and spread throughout the soil in each pot. In the case of Soil II, the leaves were narrower and smaller in size. Thickened roots were poorly distributed in this soil. These were restricted mainly to the surface layer. The plants grown on Soil I generally showed much better growth than those produced in Soil II.

Effect of Various Treatments on Yield of Corn

Yields of corn plant tops for both soils involving the various chemical treatments are presented in Table 3. Yields of plants were much larger for Soil I than for Soil II, irrespective of chemical treatment. Generally, there was some tendency for yields to be higher in the case of Soil I wherever $(NH_4)\cdot HPO_4$ fertilizer was included as part of the treatment. With this soil there was no suggestion that addition of either Zn or the commercial product, "Nu Zim" had any beneficial effect upon plant growth. In the case of Soil II, no tendency for the fertilizer alone to increase yields was observed. As a matter of fact, all yield values were so low as to suggest that factors other than supplies of the nutrient elements furnished by the various chemical additions, were responsible for the poor results.

Yield variations due to chemical treatment of the soil were not statistically significant in either case.

Effect of Different Treatments on Uptake of Certain Cations by Corn Plant Type

Analytical data for certain cations accumulated by corn plants are given in Table 4. With both soils, the uptake of certain cations varied with the treatments applied. Absorption of Na from each of the soils was higher than what corn plants would

Table 3. Total yield of corn plant tops.

Treatment No.	Treatment	Mean* yield of plant material (gm./pot) Soil I	Soil II
1	Control	5.56	2.33
2	Fertilizer	7.06	2.54
3	Fertilizer + $ZnSO_4 \cdot 7H_2O$ (1)	7.83	3.20
4	Fertilizer + $ZnSO_4 \cdot 7H_2O$ (2)	6.87	3.15
5	Fertilizer + Nu Zim (1)	7.26	2.94
6	Fertilizer + Nu Zim (2)	6.85	--

* Mean of number of replications indicated for each treatment in Table 2. Differences between treatments are not significant for either soil.

Table 4. Cation composition of corn tops.

Treatment No.	Treatment	Mean* cation composition of corn plant tops (m.e./100 g. of plant material)									
		Soil I					Soil II				
		Ca^{++}	Mg^{++}	K^+	Na^+	Total	Ca^{++}	Mg^{++}	K^+	Na^+	Total
1	Control	17.5	42.9	142.0	1.03	203.43	13.4	48.1	125.0	42.8	229.3
2	Fertilizer	19.9	32.4	147.8	5.80	205.90	15.8	34.0	108.8	70.6	229.2
3	Fertilizer + $ZnSO_4 \cdot 7H_2O$(1)	20.5	45.4	151.0	1.20	218.10	21.3	49.1	128.5	42.7	241.6
4	Fertilizer + $ZnSO_4 \cdot 7H_2O$(2)	24.1	45.7	160.0	1.50	231.30	23.3	35.8	119.7	58.9	237.7
5	Fertilizer + Zu Zim (1)	12.5	45.5	146.4	5.10	209.50	20.4	45.3	104.7	77.8	248.2
6	Fertilizer + Zu Zim (2)	17.5	34.3	153.1	7.50	212.40	--	--	--	--	--
Least significant differences	(.05	4.4	NS	NS	2.82		3.8	NS	16.7	20.2	
	(.01	6.2	NS	NS	3.99		5.6	NS	NS	NS	

* Mean of number of replications indicated for each treatment in Table 2.

normally accumulate from a productive soil. This was especially true for Soil II which produced corn plant tops which contained more Na upon an equivalent basis than it contained of either Ca or Mg. Potassium was the most abundant cation present in the case of plant material grown on either soil. It probably was present in amounts that were larger than normally could be expected. Calcium was present in what appeared to be abnormally low amounts. Total cation concentration of plant tissue was especially high in the case of Soil II.

Treatment 2. Application of $(NH4)2\ HPO4$ seemed to increase plant uptake of Ca and Na from each soil. The tendency for such treatment to increase plant uptake of Na was especially significant. This effect apparently was more significant with Soil II than with Soil I. This same treatment decreased K uptake in the case of plants grown on Soil II but it did not materially influence K uptake from Soil I. Magnesium uptake was not influenced significantly in either case.

Treatment 3. Inclusion of the lower rate of application of $ZnSO_4 \cdot 7H_2O$ along with $(NH_4)_2HPO_4$ fertilizer suppressed the uptake of Na which was enhanced by application of the fertilizer alone. This effect was accompanied by significant increases in the uptake of both Ca and K in the case of Soil II. There was some tendency for the same to occur with Soil I but the effects were not significant, probably because the previously noted effect upon Na accumulation was comparatively small in magnitude.

Treatment 4. This treatment produced significant increases in Ca uptake by plants grown on each soil. Inclusion of the

Table 5. Cation composition of corn roots.

Treatment No.	Treatment	Cation composition* of corn plant roots (m.e./100 g. of plant material)									
		Soil I					Soil II				
		Ca^{++}	Mg^{++}	K^{+}	Na^{+}	Total	Ca^{++}	Mg^{++}	K^{+}	Na^{+}	Total
1	Control	18.1	25.0	70.5	16.3	129.94	14.5	20.0	35.3	39.0	108.75
2	Fertilizer	15.6	25.0	76.9	53.3	170.80	10.5	18.3	35.3	41.5	105.55
3	Fertilizer + $ZnSO_4 \cdot 7H_2O$(1)	27.5	33.3	92.4	12.0	165.74	18.5	20.8	44.9	40.0	124.21
4	Fertilizer + $ZnSO_4 \cdot 7H_2O$(2)	29.4	34.4	99.4	15.2	178.32	15.5	15.8	35.3	36.0	102.59
5	Fertilizer + Nu Zim (1)	15.0	28.1	73.7	50.0	166.84	9.0	13.3	35.3	42.0	99.59
6	Fertilizer + Nu Zim (2)	24.4	30.2	76.9	42.4	173.89	--	--	--	--	--

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* Analyses performed upon composite samples.

larger amount of Zn did not further suppress Na accumulation, however. In general, the effects of this inclusion of Zn were not greatly different than those observed for the lesser addition.

Treatment 5. "Nu Zim", in combination with $(NH_4)_2$ HPO_4, apparently did not suppress the uptake of Na as did Zn when it was used at either level of application. The most significant effect of the addition of "Nu Zim" was its tendency to suppress Ca accumulation by plants grown in Soil I. Somewhat the same tendency was noted for plants grown in Soil II but the effect was not statistically significant.

Treatment 6. Diammonium Phosphate, in combination with the double application of "Nu Zim" was applied to Soil I only. The additional quantity of "Nu Zim" encouraged considerably the uptake of Na. Inclusion of this larger amount of "Nu Zim" tended to decrease the uptake of Mg and likewise tended to increase the uptake of K, but these effects were not significant. Calcium uptake, in the presence of this amount of "Nu Zim", was significantly greater than where only the small quantity of this commercial product was applied. In this case, Ca uptake was at the same level as it was on the control cultures.

Influence of Soil and Treatments on Cation Accumulation of Corn Plant Roots

Because of the comparatively small quantity of corn root material produced, it was necessary to composite individual replications in order to provide large enough samples for chemical analyses. The results presented in Table 5 are upon this basis and consequently, no statistical analysis was possible.

Apparently, corn accumulated about the same quantity of Ca in roots as it did in the plant tops. This held for each soil. Sodium was accumulated in much greater quantity by the roots of plants grown in Soil I than it was in the tops of plants grown in the same soil. Sodium was nearly as abundant in the roots of corn plants grown in Soil II as it was in the tops of plants produced upon this soil. Magnesium and K were accumulated in much smaller amounts in the roots grown in both soils than was true for the tops of the plants.

Treatment 2. Application of $(NH_4)_2$ HPO_4 alone increased considerably the accumulation of Na by roots grown in Soil I. Thiswas not true for Soil II where Na accumulation was great in the roots of every culture. This fertilizer decreased slightly the root uptake of Mg in the case of Soil II. In the case of Soil I, apparently it increased the root uptake of K.

Treatment 3. Root accumulation of Ca was increased as a result of application of $ZnSO_4 \cdot 7H_2O$ in combination with the fertilizer. Similarly, root uptake of K from both soils was increased. There was no increase of root Mg uptake from Soil II, but it was slightly increased at a comparatively low level on Soil I, but it was not so effective in this regard with Soil II.

Treatment 4. When $ZnSO_4 \cdot 7H_2O$ application was doubled, it increased root uptake of both K and Ca in case of Soil I, but accumulation of each of these cations was reduced with Soil II. Sodium and Mg accumulation by roots grown in Soil I were more than for treatment 3, but on Soil II, the absorption of each of these was slightly less than was true for treatment 3.

Treatment 5. Addition of the low rate of "Nu Zim", in combination with $(NH_4)_2\ HPO_4$ applied to Soil I resulted in very high root uptake of Na as compared with treatments 3 and 4. This addition decreased the uptake of each of the other cations. With Soil II, this treatment also produced high Na uptake in the roots. It produced very low accumulation of Ca and Mg by roots grown in Soil II. Potassium accumulation with this treatment was less than where $ZnSO_4 \cdot 7H_2O(1)$ was applied but it equalled that which occurred when $ZnSO_4 \cdot 7H_2O(2)$ was furnished.

Treatment 6. Increased application of "Nu Zim" resulted in increased accumulations by roots of Ca, Mg, and K as compared to the preceding treatment. These accumulations were less than for treatments 3 and 4, however. Sodium accumulations by roots grown in Soil I was less than for the roots grown in the same soil with the lower level of "Nu Zim." It was much higher than that accumulated when treatments 3 and 4 were involved.

Influence of Soil and Treatments on Accumulation of Zn by Corn Plants

Quantities of Zn in composite samples of the corn plant tops were determined in the Chemical Service Laboratory of the Department of Chemistry, Kansas State College. Results of these analyses are presented in Table 6. Calculated average contents of Zn in plants grown on various cultures are presented in Table 7.

The quantities of Zn which were present in plants grown upon control cultures of each soil material, were comparatively large.

Table 6. Zinc composition of corn plant tops.

Treatment No.	Treatment	Zinc content*, ppm. Soil I	Zinc content*, ppm. Soil II
1	Control	55	75
2	Fertilizer	60	62
3	Fertilizer + $ZnSO_4 \cdot 7H_2O$ (1)	69	59
4	Fertilizer + $ZnSO_4 \cdot 7H_2O$ (2)	96	69
5	Fertilizer + Nu Zim (1)	69	71
6	Fertilizer + Nu Zim (2)	60	--

* Analyses performed upon composite samples.

Table 7. Zinc accumulation by corn plant tops.

Treatment No.	Treatment	Zinc contained in plant tops (mg./pot) Soil I	Zinc contained in plant tops (mg./pot) Soil II
1	Control	.306	.174
2	Fertilizer	.423	.157
3	Fertilizer + $ZnSO_4 \cdot 7H_2O$ (1)	.540	.189
4	Fertilizer + $ZnSO_4 \cdot 7H_2O$ (2)	.659	.217
5	Fertilizer + Nu Zim (1)	.501	.208
6	Fertilizer + Nu Zim (2)	.411	--

These amounts, 55 ppm. for plant material grown upon untreated Soil I and 75 ppm. for plant material grown upon untreated Soil II were well above those reported as being efficient by other investigators (31). Furthermore, the plant material grown on Soil II which was the least productive, contained the most Zn. This certainly did not suggest a deficiency of Zn in this soil.

Application of $ZnSO_4 \cdot 7H_2O$ seemed to result in a definite increase in the accumulation of Zn in corn plant material produced on Soil I. This was especially evident where the greatest amount of Zn was furnished (treatment 4). Application of the smaller quantity of "Nu Zim" produced plant material with the same amount of Zn as did application of the small quantity of $ZnSO_4 \cdot 7H_2O$. Application of the larger amount of "Nu Zim" to Soil I did not result in more Zn being present in the corn plant tissue than did treatment with $(NH_4)_2HPO_4$ alone.

Results of analyses for Zn content of plants grown on Soil II apparently were more erratic with this material than was true for Soil I. In no instance was there indication that applied Zn, either that furnished as $ZnSO_4 \cdot 7H_2O$ or that furnished as a constituent of "Nu Zim," caused an increase in the Zn content of corn plant tops.

DISCUSSION

No chlorosis or abnormality of any kind was noticed during the growth period, except the leaf tip burn as noted previously for the early stages of corn plants grown in Soil II. Lack of chlorosis suggested that Zn deficiency did not prevail in this soil since other investigators (30, 31) have reported definite symptoms of chlorosis for deficiencies of this particular element. Presence of leaf tip burn for plants grown in Soil II was more suggestive of salt or alkali interference than it was of nutrient element deficiency.

Lack of significant yield responses to applications of nitrogen and phosphorus contained in $(NH_4)_2HPO_4$, to Zn and S contained in $ZnSO_4 \cdot 7H_2O$ and to Zn, Fe, and Mn as well as other unidentified elements contained in "Nu Zim" certainly did not suggest that any of these nutrient elements was present in deficient supply. Furthermore, the presence of very large amounts of K in plant tissue grown in each soil seemed to eliminate the possibility of that element being deficient. Likewise, Mg seemed to be present in adequate supply in plant tissue produced by each soil. It appeared that the causes of poor plant growth were of some other nature.

Total cation uptake by corn plants seemed to be higher than normally could be expected. Total cation accumulation, expressed on an equivalent basis, was greater in the case of Soil II than for Soil I. Growth was especially poor in the case of Soil II. Perhaps the total accumulation of cations by plants grown in Soil II was partly a result of an unusual build-up of such in otherwise stunted plants. Actually, the excess accumulations of cations in plants produced by Soil II could be accounted for mainly by the excessively high concentration of Na. Thus, it appeared that Na concentrations of both roots and tops grown on the soil were so high as to be responsible for most of the poor plant development. Excessive amount of exchangeable Na in Soil II undoubtedly contributed to this unfavorable condition. Furthermore, it appeared that the undesirable effects of Na were direct in effect. That is to say, excessive Na had mainly a toxic effect upon the corn plants and did not cause poor growth of such by causing a lack of some other cation concentration in the plants. It was apparent that Ca, Mg, and K accumulations by plants grown on Soil II were generally about like those in plants grown on Soil I. If Na had any undesirable effect upon cation accumulation by corn plants, it was in the case of K accumulation by the roots. Root accumulation of K by plants grown in Soil II was only about half that of plants grown in Soil I. This lack of accumulation of K in such may, in some manner, have been associated with the observed very poor development of the same.

Total cation accumulation by plant tops, expressed upon an equivalent basis, was relatively constant for a given soil irrespective of chemical soil treatment. Much more variation in this regard prevailed in the cases of root tissues of each soil. Also, there was much greater difference in the total cation accumulations of roots and tops in the case of Soil II than there was in the case of Soil I. This again might suggest that root development was especially affected by the toxic proportions of Na which were present in Soil II. That Na was present in toxic amounts was strongly suggested by root cation data for plants grown on Soil II. Sodium actually accounted for one-third or more of the equivalents of cations present in plant material grown on each soil. In the case of the more productive soil (Soil I), K generally accounted for about one-half or more of the equivalents of cations present in the corn roots. In the case of the very unproductive soil (Soil II), it accounted for only about one-third of the total equivalents of cations present in the corn roots.

Potassium accumulation, except as noted for roots produced in Soil II, generally was the greatest of the cations. Furthermore, it appeared that K absorption was least affected by application of the various chemical treatments. The greater accumulation of K undoubtedly was due to its greater competitive ability and greater mobility in the ionic state. Such possibility has been suggested by various workers (5, 25). This might also have been due to the fact that K is very strongly bonded to corn roots as observed by McLean (18).

Nitrogen and P, applied as $(NH_4)_2$ HPO_4 behaved in a variable but interesting manner, depending upon how used. This treatment invariably seemed to cause a marked increase in the accumulation of Na when applied alone or with "Nu Zim." This sort of increase was especially obvious in the corn tops produced by Soil II and in the roots produced by Soil I. This same treatment had only a small effect on the accumulation of Ca, causing a slight increase in its accumulation by tops and effecting a slight decrease in its accumulation by roots. Magnesium accumulation was noticeably reduced in tops but little affected in the roots. Potassium accumulation was reduced in the case of corn tops produced in Soil II. This appeared as a result of the marked increase in Na absorption which occurred in the same plant tops. Thus, it appeared that this fertilizer treatment alone was at best, only very slightly beneficial. Actually, it seemed to promote Na accumulation by plants growing in the presence of high Na concentration in the soil. This apparently was more harmful than beneficial.

Inclusion of $ZnSO_4 \cdot 7H_2O$ along with the $(NH_4)_2HPO_4$ fertilizer treatment invariably seemed to have beneficial effects insofar as nutrient cation accumulation was concerned. This inclusion generally increased the accumulations of Ca, Mg, and K at least slightly. Furthermore, it helped to keep Na accumulation at a comparatively low level, at least compared to the effects which occurred when fertilizer alone was added. Doubling the rate of application of Zn seemed to further increase the uptake of Ca by corn tops but did not cause any appreciable additional effect on either K or Mg accumulations in the tops. This treatment seemed to have facilitated the release of Ca from the soil or at least to have facilitated its mobility into the plant. At the same time, it restricted the uptake of the undesirable Na by the corn plants.

Use of the commercial preparation "Nu Zim" which supplied Zn and also Fe and Mn, as well as other elements, did not produce the same desirable nutrient cation relationship as did application of somewhat similar quantities of Zn when applied merely as a constituent of $ZnSO_4 \cdot 7H_2O$. Wherever this constituent was included with $(NH_4)_2HPO_4$ fertilizer, the ultimate levels of cation accumulation were about like those which prevailed where the $(NH_4)_2HPO_4$ fertilizer alone was applied. Apparently, the presence of either Mn and/or Fe served to nullify the beneficial effects previously observed for Zn. This was especially true insofar as Na relationships were concerned.

Any beneficial effect of application of $ZnSO_4 \cdot 7H_2O$ seemingly was not due to its contribution as a nutrient element. Plant analyses generally suggested an adequacy of Zn in the corn plant tissue produced upon control pots. It may have been true that the addition of $ZnSO_4 \cdot 7H_2O$ had favorable effects upon the availability of Ca and at the same time, such served to curtail the mobility of Na. At least it seemed that the favorable effects of the extra Zn resulted more from occurrences in the soil than from physiological happenings within the plant.

SUMMARY AND CONCLUSIONS

1. Poor growth of corn on these soil materials was not due to Zn deficiency in the growth media. Zinc accumulation apparently was adequate in plants grown in control cultures of both soil materials.

2. Poor growth of corn, especially in the case of Soil II, was due primarily to excessive quantities of both soluble and exchangeable Na being present in the soil. These excessive quantities of Na were reflected in both plant tops and roots in the case of corn grown on Soil II. Sodium was less of a problem on Soil I than on Soil II, but nevertheless it still occurred at a rather high level in the plants, especially in the roots. It may have interfered somewhat with the normal accumulation of Ca by plants grown on each soil.

3. Excessive Na seemed to have contributed to management problems in the case of Soil II. Infiltration of water into this soil, its absorption by plants (as indicated by a tendency for wilting to occur during the day), and the development of roots were very poor.

4. Chemical fertilization, including the addition of several trace and secondary elements, did not improve the growth of corn on either soil.

5. Addition of $ZnSO_4 \cdot 7H_2O$ had a favorable effect upon cation accumulations by the corn plants. This beneficial effect of $ZnSO_4 \cdot 7H_2O$ seemed to be independent of its supplying additional Zn as a nutrient element.

6. Addition of somewhat similar quantities of Zn as a constituent of the commercial product "Nu Zim" was without benefit. Seemingly, the presence of Fe and/or Mn served to counteract almost completely the beneficial effects observed when $ZnSO_4 \cdot 7H_2O$ was added alone.

7. Chemical treatment of the soil was not suggested as a remedy for the problem which existed on a Decatur County, Kansas farm.

8. Since addition of $ZnSO_4 \cdot 7H_2O$ alone had some beneficial effect, while addition of the commercial mixture supplying not only Zn but also Fe and Mn did not, it was suggested that trace element problems should be considered as individual nutrient problems which may not necessarily be remedied by application of a general trace element mixture.

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INFLUENCE OF SOIL AND TREATMENT UPON GROWTH AND CATION UPTAKE OF CORN

by

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Subsoil materials from two different Decatur County, Kansas locations were used in this study. The fields from which these were collected were leveled for irrigation in 1956. Growth of corn was poor on Soil I and very poor on Soil II in spite of the fact that there was no evidence of deficiency of N, P, or K.

A greenhouse experiment was conducted so as to determine: (1) whether or not Zn deficiency was a primary cause of poor growth, (2) what effects, if any, excessive concentration of Na and/or other cations had upon corn development, and (3) what effects additions of $(NH_4)_2HPO_4$ fertilizer, $ZnSO_4 \cdot 7H_2O$, and "Nu Zim" (a commercial soil amendment) had upon corn growth and development.

Glazed earthenware pots, filled with 3500 g. each of the soil materials, were used in a completely randomized experiment. Chemical amendments were added in bands about one and one-half inches below the soil surface. Equal amounts of water were added to each pot. Pride of Saline corn was harvested after being allowed to grow for 42 days. Five chemical treatments, plus control cultures, were employed with Soil I but only four treatments, plus the control, were involved with Soil II.

Laboratory determinations of saturation percentage, pH of saturation paste, total cation exchange capacity, electrical conductivity of soil saturation extract, $CaCO_3$ content, organic matter content, and concentrations of different cations were made for each soil. Upon the basis of laboratory results, Soil I was classified as normal to slightly alkaline while Soil II was classified as being a saline alkali sample.

Application of chemical treatment did not produce significant variations in plant yields on either soil. Total uptake of cations appeared to be high for corn.

In the case of Soil I, total Ca absorption by roots and tops were alike on control cultures. Application of $(NH_4)_2HPO_4$ increased Ca uptake in foliar tissue but reduced it in root tissue. Application of $ZnSO_4 \cdot 7H_2O$ in either quantity, and heavy application of "Nu Zim" increased Ca absorption in tops.

Magnesium accumulation in roots was increased considerably by application of each treatment containing Zn except that involving the largest dosage of "Nu Zim".

Uptake of K by roots and tops produced on Soil I was increased by each treatment except that involving fertilizer alone.

Application of $(NH_4)_2HPO_4$ and "Nu Zim" increased Na content of tops and roots. On the other hand, addition of $ZnSO_4 \cdot 7H_2O$ to $(NH_4)_2HPO_4$ treatment caused a reduction in Na uptake by roots.

In the case of Soil II, Ca absorption in tops increased for each treatment applied, whereas, in roots, Ca uptake was decreased by application of either $(NH_4)_2HPO_4$ alone or in combination with "Nu Zim." Magnesium uptake by roots and tops was reduced where $(NH_4)_2HPO_4$ was used alone and in combination with either "Nu Zim" or the heavy application of $ZnSO_4 \cdot 7H_2O$.

Potassium absorption by either tops or roots produced in Soil II was not increased by any treatment except that involving the lighter application of $ZnSO_4 \cdot 7H_2O$. In the tops, uptake of K was considerably decreased by application of $(NH_4)_2HPO_4$ alone and in combination with the highest rate of "Nu Zim."

Plant material from both Soils I and II contained similar quantities of Ca and Mg but plants grown on Soil I had greater amounts of K than plants grown on Soil II. Total quantities of Na present in plant material produced upon Soil II were considerably larger than for Soil I.

Plant tops contained greater amounts of total cations than did the roots.

In the case of Soil I, total uptake of Zn by plant tops was increased by $(NH_4)_2HPO_4$ application alone as well as in combination with $ZnSO_4 \cdot 7H_2O$ and "Nu Zim." Application of $ZnSO_4 \cdot 7H_2O$ caused a greater increase in Zn uptake than did use of "Nu Zim." In case of Soil II, use of $ZnSO_4 \cdot 7H_2O$ and "Nu Zim" caused an increase in Zn uptake by plant tops, but this was only one-half to one-third as great as for Soil I. Application of $(NH_4)_2HPO_4$ alone reduced Zn uptake by plants grown on Soil II.

Poor growth of corn on Soil II apparently was not due to Zn deficiency, but seemingly it was due to high exchangeable Na percentage. Results indicated that applications of "Nu Zim" and $(NH_4)_2HPO_4$ actually increased the uptake of Na. On the other hand, use of $ZnSO_4 \cdot 7H_2O$ suppressed Na absorption somewhat which, in turn, increased plant growth to a small extent.