Specific effects of resin-adsorbed sodium and magnesium on barley (Hordeum vulgare L.) and tomato (Lycopersicon esculentium Mill.)
by S Sajjad Haider

A thesis submitted to the Graduate Faculty in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE in SOILS
Montana State University

Abstract:
This research problem was undertaken to study the specific effects of exchangeable Na and Mg as resin adsorbed ions, excluding the anion variable, in single and in complementary proportions on the growth and cationic accumulation in barley and tomatoes.

The percent saturation of the resin was maintained at 80, with complementary amounts of Mg and Na as follows: 80% Mg and 0 Na; 60% Mg and 20% Na; 40% Mg and 40% Na; 20% Mg and 60% Na; 0 Mg and 80% Na and control (identified as treatment no. 1, 2, 3, 4, 5 and control respectively.) The exchangeable sodium percentage and exchangeable magnesium percentage ranged from .6% to 27.98% and 14.62% to 41.98% respectively. The effects of treatments were studied 21, 31 and 54 days after seeding barley and trans-planting tomatoes as the first, second and final harvest, respectively.

The important conclusions are: The retardation in plant growth was pronounced after 4 weeks from seeding and the plants developed very clear symptoms of chlorosis and necrosis under treatments no. 4 and 5.

Symptoms associated with high exchangeable Na percentage were late flowering; late, small and poor quality of fruit; reduced plant size and a marked reduction in average production of plants. High percentage of exchangeable Mg in growth media had no adverse effect on the height of plants. Number of ears produced by barley was significantly less and tillering was' decreased from 27 under check to 20 under treatment no. 5. Ear yield of barley was significantly reduced by exchangeable Na values of 60% or more. Mean dry weight of tomato tops and fruit production of tomato plants from treatment no. 5 was greatly reduced. A significant increase in Na absorption by plants was observed under increasing levels of exchangeable Na in the growth media. The ratio of Na in straw to Na in ears gradually increased as more Na was absorbed by the plant. Treatment no. 5 decreased the Ca and K uptake up to 50% that of plants under check. High percentage of Mg (treatment no. 1) did not lower the K uptake by plants. High Na treatment was very effective in limiting Ca accumulation in tomato plants, particularly at earlier stages of growth. An equal combination of Mg and Na results in maximum translocation of absorbed Ca to the fruit.. The yield of Na in tomato was found to be one-third of that in barley when Na was present in the treatment. High exchangeable Mg under treatment no. 1 and 2 did not significantly influence the yield of K in tomatoes. Increasing Na increased exchangeable K in soil following harvest, while Mg had little or no influ-ence.

The marked difference in the effect of exchangeable Na upon the growth response as compared with that of exchangeable Mg is a striking feature of this study. Furthermore, the addition of ion variables through resins provides a means of isolating the specific ionic effects. Osmotic, anion, physical, and other non-specific salt effects are eliminated by this mean.

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ABSTRACT

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The percent saturation of the resin was maintained at 80, with complementary amounts of Mg and Na as follows: 80% Mg and 0 Na; 60% Mg and 20% Na; 40% Mg and 40% Na; 20% Mg and 60% Na; 0 Mg and 80% Na and control (identified as treatment no. 1, 2, 3, 4, 5 and control respectively.) The exchangeable sodium percentage and exchangeable magnesium percentage ranged from .6% to 27.98% and 14.62% to 41.98% respectively. The effects of treatments were studied 21, 31 and 54 days after seeding barley and transplanting tomatoes as the first, second and final harvest, respectively. The important conclusions are:

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The marked difference in the effect of exchangeable Na upon the growth response as compared with that of exchangeable Mg is a striking feature of this study. Furthermore, the addition of ion variables through resins provides a means of isolating the specific ionic effects. Osmotic, anion, physical, and other non-specific salt effects are eliminated by this means.

INTRODUCTION

It is acknowledged by soil scientists and botanists that high concentrations of certain soluble salts impair plant growth because of high osmotic presure and reduction in water availability to plants. The effect of different salts varies with the nature of the salt and plant species. This role of adsorbed ions on plant growth was not emphasized by early soil scientists and considerable uncertainty still exists as to why certain ions in low concentrations or in adsorbed form are toxic to certain plant species.

The literature bearing on effects of Na and Mg on plant development is difficult to coordinate and summarize. The experimental procedures employed both in the field and in the laboratory have been diverse and there is wide variability in the tolerance of different plants to different salts. The media used as cultures, climatic conditions, crops studied, and the technique applied are factors responsible for such a wide diversity.

The abundance of Na in nature, 2.75% in the lithosphere and 1.14% in the hydrosphere, and its presence in available form in many areas and under many farming conditions add importance to the Na problem. Crop species vary greatly in their response to Na. Although Na is not generally considered essential for normal growth and development of plants, many crops are benefited by this element, and some do not reach maximum production without it. Little information is available as to the causes for these extreme differences among crop species. It is known, however, that plants vary greatly in their Na content when grown in the same soil or culture medium.

The occurrence and importance of adsorbed Na in semiarid soils was first recognized during the second decade of the 20th centruy. Exchangeable Na adversely affects the physical properties of soils, leading to problems of aeration, moisture movement, and plant growth. In addition, nutritional problems, often associated with high exchangeable Na, are considered to be related primarily to the relative amounts of Ca and Na absorbed by plants.

Mg is one of the essential elements in the growth of plants. It is the key metallic substance in chlorophyll and seems to occupy a position similar to that of the iron in hemoglobin. It is more abundant in the seed and foliage than in the roots and stem. Therefore, the total amount of Mg in the soil and the amount available to plants under different conditions are of special importance. Adsorbed Mg in the soil may cause physical conditions almost as unfavorable as adsorbed Na.

These facts establish the important role of Na and Mg in soil and plant life. These considerations induced the author to undertake a research problem for a humble contribution of a chapter to the story of salt relations to plants. The objectives of this study were to determine the tolerance of plants for Na and Mg when supplied as resin adsorbed ions, to note if any stimulating effect resulted from low concentrations, to study the harmful effects of higher concentrations, and to discover if plants having a wide difference of sensitivity to salts react differently to the same concentrations of the salts. The treatments were devised to simulate saline soil conditions but anion variables were eliminated through the use of resins. The present work has thus been devoted to a study of the specific effects of Na and Mg adsorbed cations in single and in complementary mixed proportions on the growth and cationic accumulation in barley, a relatively tolerant plant, and in tomatoes, comparatively sensitive to salts.

LITERATURE REVIEW

Mg and Na Effects on Soil Properties

Physical Effects

This study is not concerned with effects of Na or Mg on dispersion or swelling of soil colloidal systems, since they have been eliminated by using coarse-textured soil and ion-exchange resins. However, the few references cited here are presented to establish the general physical effects of Na and Mg which have been implicated as problems associated with saline soils.

Na is notorious for creating dispersed soil condition which is not conducive to vigorous growth of plants. The very poor structural status of the soil due to high percentage of Na prevents a replenishment of the soil moisture reservoir that is essential for plant growth. Relatively little is known regarding the effects of exchangeable sodium on germination other than that the dispersed condition of sodic soils is generally deleterious for seedling emergence because of poor aeration and crusting. Bernstein and Pearsan (7) found that, if a favorable physical condition of the soil was maintained by the use of a soil conditioner, ESP up to 60% had little or no effect on the germination of beets or beans. Magistad, et al. (37) found in sand cultures that were Na constituted 76% of the cations present in terms of me/L, the yields were approximately the same as when the ratio of Na to total cation was 50%. Thus in sand cultures where the physical condition of the substrate is not a problem, Na in high ratios does not appear to be a particularly injurious cation for plant growth. Martin, et al. (38) found that the same amount of Na caused greater decrease in hydraulic conductivity in acid than in neutral or alkaline soil. Sherman (46) has encountered severe physical difficulties in Hawaiian soils containing more than 25% Mg saturation.

Magnesium-saturated soils are said to have some of the physical properties of sodium-saturated soil (28, 41). It is, therefore, possible that if the exchange complex acquires a high proportion of exchangeable Mg, the soil will deflocculate and undergo the same hazards as soil with a high proportion of exchangeable Na.

Chemical Effects with Relationship to other "Cation Regimes"

Exchangeable ions in the soil may greatly alter the chemical and physical environment of plants. Many writers have published results indicating that plant growth is reduced by unfavorable proportions of ions. They have concluded that the percentage of Na that may retard plant growth varies with the nature of the complementary ion and plant species. The well known suggestion of Kelley that the presence of a relatively high proportion of Na on the exchange complex of soils may prevent the plant roots from obtaining an adequate supply of Ca because of "The pronounced avidity of the sodium-exchange complex for calcium." Usually the effect of Na is about equivalent to that of K in decreasing Ca and Mg absorption.

The "contact exchange" theory implies a higher rate of plant root uptake of adsorbed cations than of solution cations occurring in "comparable" solutions. But this became a controversy and the importance of establishing a true equilibrium between adsorbed and solution ions was frequently overlooked. To determine whether adsorbed cations *per se* affect plant growth, Lagerwerff (30) conducted an experiment by growing plants under controlled environmental conditions in two types of cultures: (a) solution, and (b) solution plus cation exchange resin. He observed that while growth and Ca uptake decreased and Na uptake increased as the SAR of the solution was increased, no difference in plant response or composition related to the presence or absence of adsorbed Na or Ca were observed. He thus concluded that under conditions of equilibrium the composition of the solution phase of the growth medium fully characterizes the environment of the plant root, the adsorbed cations having no direct effect.

Bernstein and Pearson (7) and Pearson and Bernstein (42) emphasized that the tolerance of crops is not as closely related to the absolute amounts of exchangeable Na in the soil as to the exchangeable sodium percentage (ESP). Ratner (45) concluded that one of the causes of the death of plants when the soil contains a large amount of exchangeable Na may be lack of Ca to nourish the plants and, in general, the breaking down of the "Ca regime" in the soil which, as is well known, acts as a regulator for a whole series of processes connected with plant nutrition.

Many soil scientists found that Mg uptake by the plants increased with increasing Ca:K ratios in the exchange complex. High accumulations of Mg in the substrate have been found to be especially toxic to plants over and above any inhibition in growth that might be associated with osmotic pressure. Mg injury may be associated with an inadequate supply of calcium within the tissue.

The kind of exchange complex itself may have some effect on Mg uptake according to Brown (10). In his experiment the uptake of Mg was increased by increasing the percentage of montmorillonite or illite with respect to Kaolin in the substrate. Embleton, et al. (16) reported appearence of Mg deficiency in crops with increase in soil acidity in areas of high rainfall. They attributed this to an exchange of Mg in the complex by H ions. Cain (11) found that Mg deficiency is most prevalent on arid sandy soils, naturally low in exchange capacity and subject to extensive leaching.

Joffee and Zimmeramn (27) found that the effects of Mg in high concentrations are harmful and tend in the same direction as Na. Orlovskii and Kuptsova, as cited by Thorne (49) found that without Mg adsorbed on the soil 47 to 60% of exchangeable Na was toxic; with 36% of Mg, 45% of Na was toxic. Bower and Turk (9) found that in some highly alkaline soils excessive Na ions sometimes displaced the Mg ions with resultant plant deficiency. Walsh and O'Donohoe, as cited by Zimmerman (55), noted that where Mg deficiency was apparent in plants an extremely high quantity of exchangeable K was present in the soil. Conclusions drawn from studies of Bear, et al. (5) and Epstein and Leggett (17) are (a) High levels of available soil K tend to limit the uptake of sufficient Mg; (b) A field treated with high calcium limestone or fertilized heavily over long periods of time results in the available Mg being replaced in the soil by Ca, K or H ions, thus released Mg is lost by leaching and its availability to the plant is reduced. Prince, et al (44) concluded that the most important single factor influencing the Mg uptake of plants is the quantity of K in the soil that is available for their use. If an abundance of K is at the plants' disposal, its content of Mg will be relatively low. As the K supply decreases, the Mg content of the plant increases, even when the plant is growing on a soil that is very deficient in Mg.

Supranormal amounts of replaceable Mg leads to unfavorable Ca-Mg relations. Ratner (45) states that with Mg up to 50-60% of the replaceable capacity there is no decrease in yield, but above this there is a sharp decrease in plant growth. He interprets this as high Na or Mg limiting Ca availability and intake by the plant and thus reducing growth. Ratner, as cited by Magistad (36), states that soils containing over 70% replaceable Mg are unfavorable to plant growth, probably because Ca relations are disturbed. McMurtrey (39) ascribed poor crops, especially grasses and small grains, in certain soils to an excess of Mg over Ca in the soil. Wadleigh and Gauch (51) have obtained evidence that plants may not show specific symptoms of Mg toxicity under conditions of accumulated Mg in the soil solution when Ca ions are also present at a relatively high level.

Magistad, _et al_. (37) observed that when Ca, Mg and Na are added singly to an otherwise adequate nutrient solution or sand culture, Mg is more toxic than the other two.

Salt Injury of Barley and Tomato

There is relatively little evidence that indicates positively the specific toxicity of the Na ion to plants growing in saline soils. Injury to crops grown on high Na or Mg soils is caused not only by the high pH, ionic concentration, and unfavorable physical condition of the soil, but also by the unbalanced ratio of exchangeable cations.

Reasons for the toxic effect of adsorbed Na as given by several soil scientists are summarized as (a) the adsorbed Na being absorbed by the plant and in some way interfering with the plant metabolism: (b) the absorption of essential elements such as K and Ca being reduced by the presence of high concentrations of adsorbed Na; (c) soils high in adsorbed Na actually depriving seedlings of necessary elements such as K and Ca initially contained in the seed. Bower and Wadleigh (8) found that tolerance to exchangeable Na tends to be correlated with accumulation of Na by plant tops.

Hayward and Wadleigh (23) narrate "Visible symptoms of salt injury may occur if the salt concentration of the substrate is high. When chlorides are present, characteristic symptoms are incipient chlorosis accompanied by a drying and browning of the apex of the leaf blade. The initial tip burn is usually followed by progressive involvement of additional tissue extending along the margins of the blade until one-half to two-thirds, or in some cases the entire surface, becomes brown and necrotic. In severe cases, abscessian of the leaves occurs, dieback of the terminal axis or small branches is evident, and death may ensue." Stod, as cited by Lomanitz (34), reports that water containing one gram salt per liter is harmful to vegetation. Harris, ibid., considers chloride in soil as the most toxic of the acid radicals and Na as the most toxic of the alkalies.

In about 1800, the German plant physiologist Sachs, or some of his contemporaries, firmly established that Mg was an essential plant nutrient element. Wheeler and Hartwell (53) in 1914 were among the first in the U.S.A. to make scientific observations of increased crop growth with applications of Mg compounds to a soil under field conditions.

Fisher (18) did not observe any abnormal symptoms apparent from the excess of Mg in tomato except a series of light brown pinspots up and down the stem, but these evidently did not interfere with normal plant growth. He observed that roots of tomato appeared somewhat shorter and there were no definite tap roots in the presence of excess Mg.

Effects of Na and Mg salts on Tomato

Kidson (29) noticed that a high level of Na in the culture solution resulted in a high content of Na in the leaves of tomato. An increase in Na uptake was accompanied by a decrease in the K content of the leaves, but had little effect on that of the fruit. Wall and Hartman (52) observed that added Na and Cl ions increased and Ca, Mg and SO_4 ions decreased the absorption of other ions by tomato plants in sand culture. It was also noted by them that the alkaline $NaHCO_3$ solutions are particularly effective in increasing permeability of plant cell membranes and absorption of ions, thus causing more toxicity.

Hayward and Long (21) in their study on responses of tomato to varying concentrations (0.5, 1.5, 3.0, 4.5 and 6.0 atm. of osmotic concentration) of NaCl and Na_2SO_4 in culture solutions, observed a significant reduction in the height of plants and diameter of the stem at the high concentrations. This effect was less in the NaCl than in the Na_2SO_4 series. Greater succulence resulted in the high chloride plants than in the Na_2SO_4 series. They found that in NaCl series there was an increasing accumulation of Na and Cl in the tops of the plants with increasing concentrations of the culture solution but in the Na_2SO_4 series only accumulation of Na increased at the progressively higher concentrations and there was no marked trend with respect to sulfur intake. It was also observed that in solutions with equal concentrations of Na the accumulation of Na was greater in the Na_2SO_4 cultures than in those of the corresponding NaCl series. Observations on comparison of fresh and dry weight, gross morphology, and detailed anatomy indicated that the plants in the high Na_2SO_4 cultures were smaller than those in the corresponding cultures in the NaCl series.

Eaton (14) added 50% Cl and SO_4 ions as Na salts with the remaining 50% divided between Ca and Mg salts, and observed that fruit production by tomatoes was depressed by salt roughly in proportion to the respective reduction in vine growth in the 50%-chloride and 50%-sulfate levels. In the beds maintained with higher salt concentrations blossom-end rot became the dominant factor in yield. He obtained 19% and 96% reductions in the relative dry weight of fruits at the low and high chloride levels respectively, and a 28% and 73% reduction with the corresponding sulfate treatments. He observed that tomato plants showed no burning of the leaves with SO_4 or Cl salts. He further observed that tomato leaves in a field plot experiment showed increased succulence at low and medium salt levels, but at high salt levels there was no change in succulence as compared with leaves of the control plants. He concluded that tomatoes, even though accumulating little Na, were substantially more tolerant to $CaCl_2$ than to NaCl. He tested the growth and yield of stone tomatoes on substrates adjusted to 0.72 (control), 2.5 and 6.0 atm. with NaCl as the added salt. The relative dry weight of the vines including fruit were 100 (control), 77, and 27%, respectively, and those of the fruits were 100 (control), 81 and 4%.

Wall and Hartman (52) observed effects of Na and Mg salts on tomatoes in sand cultures by the reduction in dry weight and the general appearance of the plants. The order of toxicity was $NaHCO_3 > MgCl_2 > CaCl_2 > Na_2SO_4 > MgSO_4$. In their study on effects of Na salts (NaCl and Na_2SO_4 at 40, 80, 120, and 180 me/L) on tomatoes grown in sand culture, Hayward and Long (22) concluded that osmotic concentrations of the substrate was the primary factor in growth inhibition. They observed that the principal effects of high concentrations of Na in the substrate were (a) reduction in height and diameter of stems and fresh and dry weight of vines; (b) reduction in cambial activity, maturation of cells of smaller size, and relatively thicker walls in xylem elements and mechanical cells; (c) inhibited floral development and reduced set of fruit; (d) reduction in total yield of fruit and in size and weight per fruit; and (e) increase in osmotic concentrations of the vegetative and fruit juices. They further observed that the accumulation of Ca, K, Mg and N in the juice of ripe fruit was greater at high osmotic concentrations of the substrate although those elements were supplied in equal amounts for all treatments.

Lyon (35), in his study on responses of tomato to Na_2SO_4 at 80 and 120 me/L levels in the nutrient media, concluded that the presence of high concentrations (120 meq of Na_2SO_4 plus base nutrient) adversely affected the growth, plant height, dry weight of vines and the mean weight of ripe fruit. The smaller stem diameter was caused by an inhibited development of each of the component tissue systems. He observed a reduction of 40% in the fresh weight of fruit produced at the higher salt level. Wall and Hartman (52) found that the harmful effect of $NaHCO_3$ in tomato plant growth is evidenced by reduced plant dry weight and the curtailed absorption of most ions except that of Na. They found that $NaHCO_3$ had reduced availability of many essential nutrients. Mn content was reduced to 1/3, P to 1/2 and Ca and S to 2/3 the normal values, with no significant variation in total ash.

Clay and Hudson (12) observed that the application of excessive amounts of K and Mg salts may have led to luxury uptake of these cations, with consequent depression in Ca uptake. Walsh and Clarke, as cited by Zimmerman (55), noted that K:Mg ratio in the soil determined the degree of Mg uptake in tomatoes. Beeson, <u>et al</u>. (6) concluded that Mg concentration in the tomato plant tissue was positively correlated with Mg supply and negatively correlated with Ca supply in the nutrient medium. Cooper, <u>et al</u>. (13) observed that tomato tops were high in Mg (0.29% and 0.44% dry matter in fruit and vines, respectively) and required an adequate supply of available Mg for optimum growth. In an experiment by Hester (25) the tomato plant was found to absorb 3% of its total Mg during the first month of growth, 20% during the second month, and 77% during the last month.

Effects of Na and Mg salts on Barley

It is generally stated that barley is the cereal crop most likely to succeed in saline soil. Many investigations have been conducted to determine salt effects on barley and to study its apparent salt tolerance.

Ayers, et al. (3) found that barley was one of the most salt-tolerant plants and produced grain satisfactorily at EC_e values of 12-14 mmhos, provided salinity during seedling development was in the range of 1-4 mmhos. They observed that if the salinity level at germination was as high as 9 mmhos, then salinity of 12-14 mmhos in the later stages caused a serious decrease in the yield of grain and that vegetative growth and straw yield were much more sensitive to salinity than was grain production. Ayers and Wadleigh, as cited by Hayward and Wadleigh (23) studied 8 varieties of barley and indicated a high degree of salt tolerance. Relative yields were not reduced when the plots were irrigated with water containing 9000 ppm of added salts. Ayers, et al. (3) in their study on salt tolerance of barley and wheat, found that increased salinization (8,000, 12,000, 16,000 ppm added salts in irrigation water) significantly decreased height of straw but did not decrease yield of grain appreciably.

Hannam, as cited by Lomanitz (34) reported that common salt increased both the quantity and quality of the grain of barley. This was supported by Stewart, as cited by Lomanitz (34), who found that NaCl increased the yield of both straw and grain in barley. A larger amount of potash was taken up by barley in the sand culture experiment of Hoagland and Martin, as cited by Lomanitz (34) when NaCl was applied at the rate of 3000 ppm. There was a somewhat greater yield and also a greater percentage of potash in the plant. Magistad (36) states that $CaCl_2$ was more toxic to barley than NaCl when compared on equal osmotic basis.

Marshal, as cited by Hayward and Bernstein (24), found good stands of barley, although somewhat delayed in maturity, in soil containing 1.6% of mixed Na and Mg sulfates. Pearson and Bernstein (42) in their study on influence of exchangeable Na on 6 crops found that ESP of 48 caused necrosis and eventual death of some of the seedlings of barley. The severity of the injury was more on Chino clay (43 me/100 g. C.E.C.) than on Pachappe loam (C.E.C. of 11 me/100 g.). They also observed that effect of ESP on yield of barley was not consistent for the two soils. The decrease in yield associated with soil of higher C.E.C. with increasing amounts of Na appeared to be related to the ESP rather than to total amount of exchangeable Na present. They found that at equivalent ESPs barley accumulated more Na from Pachappe loam than from Chino clay, although the latter soil contained approximately 4 times as much exchangeable Na. Increasing levels of exchangeable Na in the soil resulted in decreasing K concentrations in barley.

Greenway (19) in his study on barley-plant response to saline substrate (NaCl concentrations of 100, 125 me/L) found that older parts of plants had very high amounts of Cl and Na as compared with the control and thus were severely injured. He concluded that in barley crops the varietal difference in salt tolerance is due to higher chloride and Na and/or lower K concentrations in the sensitive than in the resistant variety. He found that with 125 me/L of NaCl the tiller number was 65 whereas in control it was 168. NaCl reduced growth rate even during grain formation. However, the growth reduction was less during inflorescence formation than during tillering. He inferred that there was no evidence for increased salt tolerance during plant development. Lipman, et al. (33) using culture solution studied effect of different concentrations of NaCl on barley and found that seven days after placing the plants in the solutions, those in concentrations of 18,000 or more ppm NaCl had turned yellow and were making no growth. Plants in concentrations of 21,000 ppm NaCl finally died without making any growth. They found that margin of NaCl tolerance in barley is 9,000 ppm and below that all the plants were generally in a healthy condition. They also noted that the roots were much more depressed in their development at concentrations beyond 5000 ppm NaCl than were the tops, the difference between the 5,000 ppm and 6,000 ppm concentrations being very marked. In concentrations of 13,000 ppm NaCl and above, the roots made practically no increase in length and were markedly discolored.

Moore, et al. (40) found that for excised barley roots, rate of Mg absorption was approximately about half that of Na. Eaton (14) found that barley leaves were burned by chloride and sulfate salts, but no injury was observed on tomato.

Specific Cation Effects on Tomato and Barley

It has been generally observed that yields of crops are related to ESP rather than to the absolute level of exchangeable sodium. Even so, it is difficult to delineate specific cation effects from general salt or anion effects. Results of salt studies have been used to infer certain cation effects.

Bernstein and Pearson (7) found that increasing ESP resulted in increased Na accumulation in the tops. Ca generally decreased but Mg and K increased or decreased, depending upon crop specificity. They noticed that decreasing yields with increasing ESP did not appear to be causally related to altered mineral composition of tops. They suggested that excessive Na accumulation by roots may affect their function, particularly water absorption. Jackson and Adams (26) found in their study on cation-anion balance during K and Na absorption of barley roots that the cation absorption rates were independent of the identities, concentrations, and rates of absorption of the anions of the external solution, including bicarbonate. They concluded that K and Na ions are absorbed independently of the anions of the absorption solution in exchange for H^+, while anions are exchanged for a base. Bain and Fireman (4) concluded that in tomatoes exchangeable Na caused a reduction in the absorption of the micronutrients Mn, Zn, B and Cl. They further inferred that Na caused an increase in absorption of Fe and Cu by tomatoes. They found that a few seeds of tomatoes germinated in low Na treatment (28.5 ESP) and none in the high sodium soil (51.5 ESP). They observed that at the medium ESP level (28.5%) tomatoes made poor growth, particularly in the early stages. They also found that exchangeable Na caused a several-fold increase in the absorption of Na, and a decrease in the absorption of Ca and K by tomato plants. Thorne (49) found that the growth of the tomato plants was not significantly affected by exchangeable Na until it reached a concentration of about 40% of the total exchange capacity. He observed that toxic limit of the tomato plant was reached with Na slightly in excess of 60% of the total capacity. He also found that Na content of the tomato plants increased markedly and the Ca content decreased with increasing proportions of exchangeable Na. He also noted that K absorption was decreased in tomatoes at high Na levels on the clay. Ca content of tomato plants decreased as the proportion of either monovalent complementary ion K or Na increased. Below 50% of Ca saturation, growth of tomato was markedly reduced.

Eaton (14) observed that there is little evidence of interrelations between Na and K accumulation in tomato plants but with barley Na accumulation has been found to depress K accumulation. Shourbagy and Wallace (47) found that average yield increase for all varieties of barley at the 5 and 10 me/L of Na was 28%. The inclusion of 40 me Na/L decreased yield slightly for 4 of the 5 species. The highest decrease in variety Arivat amounted to 24% in the tops and 30% in the roots. This variety which suffered the most had the lowest Ca content of tops and almost the highest Na content of roots. They observed that K content of roots for all varieties was reduced by the highest Na level, but the K content of the tops was not. They found that barley had a low requirement for Ca and Mg, which were decreased by increasing Na but the effect was not consistent.

Ion-Exchange Resins

Studies by a few soil scientists employing ion-exchange resins were somewhat similar to the work undertaken in this study. Specific cation effects were studied by employing ion-exchange resins as the anion.

The specific effects of adsorbed Na^{+}, Mg^{++}, and Ca^{++} ions on the growth and cationic accumulation by the barley plants were studied in resin (Amberlite 1R-100 H^{+})-sand systems by ElGabaly (15). He observed better growth in systems having a concentration of any two cations, within a given range, than in homoionic or pure sand systems. The range within which stimulation took place varied with the nature of two cations, being narrower for Na-Mg systems, wider for Ca-Mg systems, and intermediate for Na-Ca systems. The length of barley shoot was 12.0 cm, 11.5 cm, 11.4 cm, 10.3 cm, 9.9 cm, and 7.7 cm under 80 Ca:20 Na, 80 Mg:20 Na, 90 Mg:10 Na, 40 Mg:60 Na, 100% Mg and 100% Na systems, respectively. He observed that roots of barley are more sensitive to cations in the environment as shown by differences between maximum and minimum length. Length of roots was 8.8 cm at 80 Ca:20 Na, 8.1 cm at 90 Mg; 10 Na, 7.5 cm at 80 Mg:20 Na, 2.0 cm at 40 Mg:60 Na, 4.4 cm at 100% Mg and 1.0 cm at 100% Na. He further observed that in case of Na + Mg systems the effects were somewhat similar to those where Ca was the complementary ion, except that the maximum stimulation of growth over that in pure sand (control) is lower than Ca + Mg (80:20). He found that roots grown in the system with 100% Mg were thick, short, brown, had very few branches, and were somewhat similar to those of the pure Na system. The yellowing and burning of leaves were more pronounced than in the Na + Ca system at equal degrees of saturation. The plants growing in pure Mg systems showed burning of leaves to a greater degree than did those in pure Ca systems. He observed maximum growth of shoots at Ca:Mg = 70.30. The intensity of chlorosis increased as Mg saturation increased. Na contents in the plant increased as Na saturation increased, attaining a maximum at 60% saturation, then falling at 100% saturation. At 100% Na saturation, all leaves suffered complete burning at the end of the 5-week period. The loss of K increased with the increase in the degree of Na saturation. He found that plants grown in pure Na systems contained almost no K. Ca in plants was lower at all degrees of Na-Mg saturations than in plants grown in pure sand. He inferred that single cations had more deleterious effects than those in combinations. Compared at equal concentrations, Mg and Na have been found to be more harmful than Ca.

Arnon and Grossenbacher (1) studied the comparative growth of tomato plants in four media; (a) sand culture - nutrient solution (control); (b) water culture - nutrient solution; (c) sand culture - all Amberlite-nutrient except K and NO_3; and (d) sand culture - all Amberlite-nutrients. The synthetic resins Amberlite 1R-100 and Amberlite 1R-4 were used as capable of adsorbing cations and anions respectively. They found that average fresh weight of 3-week-old tomato shoots were 25.3, 28.2, 17.2 and 7.1 gm, respectively, indicating a significantly reduced growth in plants in sand-all Amberlite-nutrient media. They observed the same decrease (30% of control) in growth of 20-week-old tomato plants. On comparison between control medium and sand culture-all Amberlite nutrients, the inorganic composition of leaves and stems of 3-week-old tomato plants showed an increase in K from 4.0% to 7.3% dry weight but a fall of Ca, Mg, PO_4, and N from 2.0% to 0.6%, 1.3 to 0.5%, 2.7 to 1.9% and 5.7 to 5.4%, respectively. They inferred that Ca and Mg were unavailable for plant growth in the sand-all Amberlite culture, the cause of unavailability of Ca and Mg was not apparent from the data. The technique they used was not designed to distinguish between absorption from liquid phase and absorption through "contact-exchange" between roots and solid Amberlite particles. Thus, the Ca saturation (and other divalent nutrient ions) was too low to maintain a sufficiently high solution phase concentration of nutrient for normal plant growth.

Arnon and Meagher (2) made an investigation of the chemical properties of a culture medium in which plant nutrients were supplied as adsorbed cations and anions on synthetic resin (Amberlites) and found in leaching experiments with sand mixtures, using H_2O, NaCl or HCl as the leaching agent, that the inclusion of adsorbed K markedly decreased the leachability of Ca and Mg, and the inclusion of adsorbed NO_3-Amberlite decreased the leachability of SO_4 and PO_4. These results demonstrate the realtive difficulty of maintaining adequate solution phase concentration of the divalent nutrients. Employment of the "Donnan Distribution Relationship" for determining resin saturation percentages should obviate these difficulties as demonstrated by Skogley and Dawson (48).

Lehr and Wybenga (32) conducted an experiment on sensitivity of barley to Na, using dusarit/glass-sand mixtures. In order to preclude all influence of anions, cations (Na and K) were supplied in varying composition as adsorbed to the admixed dusarit. They observed that after one month of growth the plants which received no K began to lag behind the others, retardation being more pronounced in those receiving 40% Na than in those receiving 20 or 10% of Na. They found that depressive influence upon the yield is only seen in treatments having more percentage of adsorbed ions occupied by Na than K in the complex. This adverse effect was most pronounced when K was omitted entirely from the complex. Moreover, they also found that Na has no independent function as an essential nutrient.

Bower and Wadleigh (8) employed a mixutre of sand and synthetic cation and anion exchange resins, Amberlite lR-100 and Amberlite lR-4, as cultural media containing the desired amount of ions in adsorbed form with 6 levels of exchangeable Na, viz. 0, 15, 30, 45, 60, and 75% of C.E.C. An amount of K equivalent to 10% of C.E.C. was supplied to all cultures. The remainder of the C.E.C. was satisfied by Ca and Mg in ratio of 3:1 (Ca:Mg). They found that at ESP as low as 15 growth in beans was markedly decreased and almost completely inhibited at the 3 highest levels of Na employed. In sharp contrast with the data for beans, Rhodes grass and garden beets were found to be very Na-tolerant. They observed that accumulation of Ca, Mg, and K by the plants as a whole tended to decrease and that of Na to increase progressively as higher proportions of exchangeable Na were supplied. The magnitude of decrease in accumulation and the extent of Na accumulation varied greatly among the plant species.

MATERIALS AND METHODS

To study the effect of adsorbed cations, Na^+ and Mg^{++}, on barley and tomato plants, cation resin-soil mixture with various intensities of adsorbed cations and in different proportions was used as a medium of growth in greenhouse pot experiments. Specifications and characteristics of the cation resin are as follows:

<u>Amberlite IRC-50</u>, a synthetic cation exchanger, deriving its exchange activity from carboxylic acid groups, is weakly acidic. Its screen grading (wet) is 16 to 50 mesh (U.S. standard) and density is 0.64-0.77 g/ml (0.37 dry gm/wet ml.) H^+ form. Moisture content is 45-55%, average 49%. It exhibits extremely high exchange capacity, that is, 7.8-8.0 me/dry g. or 3.6-3.8 me/ml exchange capacity at pH 7.0. The void volume is 35-40% and effective size is 0.35-0.50 millimeters. Its chemical stability is graded quite high and no disintegration of the exchanger beads has been observed on prolonged contact with certain organic solvents.

Preparation of the resin to represent variables under study consisted of the following steps.

<u>Degassing</u>.

A 250 mm vacuum dessicator was half-filled with the resin and covered with deionized water. Suction was applied to degass the chamber and ultimately the resin. Each batch was treated for 4 hours and degassed resin collected in a big tumbler. Water was kept standing 3-4" above the resin so that air is excluded. The degassing process removes air from the small resin pores and allows solution contact with the exchange sites which would otherwise be blocked by air.

Leaching with HCl.

i) The resin was then leached with 3 batches of 10% HCl.

ii) It was drained and rinsed with deionized water until the effluent indicated pH from 4-5. This process saturated the resin with H^+.

Transfer of treatments to resin beads.

It was decided to employ 6 treatments as detailed below.

Treatment Number	Percentage of saturation of exchange sites of resin		Exchangeable Na * percentage	Exchangeable Mg * percentage
	Mg^{++}	Na^+		
1	80%	0	.61	41.99
2	60%	20%	7.46	35.15
3	40%	40%	14.30	28.92
4	20%	60%	21.14	22.07
5	0	80%	27.98	14.62
6 (check)	0	0	.93	22.22

* The exchangeable Na and Mg percentages were calculated by taking into account the amount of Na and Mg in the soil and the Cation Exchange Capacity of the system (resin + soil).

To arrive at the required level of saturation of the exchange complex in resin, the following calculations are presented as an example.

Treatment No. 1 (80% Mg + 20% H^+)

Requirement by weight of Mg powder, $(MgCO_3)_3 \cdot Mg(OH)_2 \cdot 3H_2O$, to occupy 80% of the exchange sites as adsorbed cation:

(2000 ml. of wet resin x 0.37 dry g/wet ml. = 740 g. of net dry resin in use in a 2 liter jar of wet resin.)

740.0 g. x 7.8 me/g (C.E.C.) = 5,772 me.

5,772 me. x 80% (required value) = 4,618 me. of Mg^{++} (1)

$(MgCO_3)_3 \cdot Mg(OH)_2 \cdot 3H_2O$ = 365.37 g/m. = 4 equivalent of Mg^{++}.

$\frac{365.37}{4}$ = 91.34 g/eq. of Mg = .09134 g/me. of Mg.

.09134 g/me. x 4618 me. (1) = 421.8 g. of Mg powder/2 liters of wet resin will give 80% Mg saturation and 20% H^+ saturation on the exchange complex of the cation resin.

It is assumed that essentialy 100% of the Mg^{++} will be adsorbed from solution as long as only 80% of the resin exchange capacity is satisfied by divalent ions.

Treatment No. 2. (60% Mg + 20% Na + 20% H^+)

For 80% Mg the required weight of Mg powder as derived in calculations of treatment No. 1 is 421.8 g/2 liters of wet resin. Therefore, for 60% Mg (X) the amount of powder is:

$\frac{421.8}{0.80} = \frac{X}{0.60}$. X = 316.4 g. of Mg powder/2 liters of wet resin.

Then, for 20% Na^+ the Donnan distribution system is employed.

____ $(Mg^{++})_{exch}$ = me/amount of H_2O

____ For 100 g. of resin there are about 45 g. of water, therefore, for 100 g. of dry resin there are 182 g. total, or 82 g. of water.

____ For 100 g. dry resin, there are 780 me. of exch. capacity.

____ Therefore, the total concentration in the Donnan exclusion volume can be: 780 me/82 ml. = 9.516 N (constant for all treatments).

____ However, for 60% Mg^{++} saturation; 9.516 N x .6 = 5.71 N.

i)____ Therefore $(Mg^{++})_{exch}$ = 5.71 and $\sqrt{(Mg^{++})_{exch}} = \sqrt{5.71}$ = 2.39.

ii)____ Nest, to obtain $(Na^+)_{exch}$ of 20%; 9.516 x 0.2 = 1.90 N.

iii)____ *Solubility of $MgCO_3 \cdot 3H_2O$ in water at 25^0 and atm. pressure is .142 N.

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* Bradfield (SSSAP 6:8-15, 1941).

Putting the above 3 values into the four component Donnan expressions, the fourth, $(Na^{+})_{Sol.}$, can be derived:

$$\frac{(Na+)_{exch.}}{\sqrt{(Mg^{++})_{exch.}}} = \frac{(Na^{+})_{Sol.}}{\sqrt{(Mg^{++})_{Sol.}}}$$

$$\frac{1.90\ N}{2.39\ N} = \frac{(Na^{+})_{Sol.}}{0.142}$$

$$(Na^{+})_{Sol.} = \frac{1.90 \times 0.142}{2.39} = 0.113\ N.$$

Therefore, to determine amount of NaOh to be added: 5772 me. (exchange capacity per 2 liters of wet resin) x 0.2 = 1154 me/2 liters of resin plüs 113 me. (for each liter of water in the mixutre) x 3.5 (liters of water used in stirring process per 2 liters of wet resin) = 396.

1154 plus 396 = 1550

NaOH = 40 g. eq. = 0.040 g/me.

Weight of NaOH required per 2 liters of resin = 1550 x 0.04 = 62 g.

These same manipulations were followed to find amounts of materials required for the other Mg-Na ratios on the resin.

Specific preparation of cation resin for each treatment.

As indicated above the resin for each treatment was prepared separately. After adding the calculated amount of $MgCO_3$ or NaOH or both in the different required proportions in the resin with the 3.5 liter of deionized water per 2 liters of wet resin, the mixture was thoroughly stirred for 4 hours. Each batch was washed with deionized water by stirring for 30 minutes. Six to eight washes were given as required to adjust the solution pH of the mixture to 7.

The resin of each treatment was air dried separately for 7 days on a laboratory bench.

Soil.

Soil was collected from about 16 miles west of Bozeman, from a field located in the SW $\frac{1}{4}$ of NW $\frac{1}{4}$ of Sec. 21, T 2S, R 3E. It was air dried, passed through a 2 mm. sieve and sterilized in a steam pressure sterilizer. A representative sample of the soil was tested for its chemical characteristics. The analysis and description are given in Tables II and III. The procedures employed are presented in Table I.

Into each pot of 7.5" x 5.75" in dimensions, 3 kilograms of soil and 30 grams of air-dry resin were placed. Thus the C.E.C. of the mixture is:

30 g. of resin/3000 g. of soil = 1 g resin/100 g soil

C.E.C. of soil = 15 me/100 g

C.E.C. of resin = 7.8 me/1 g

Effective C.E.C. of mixture = 22.8 me/100 g.

Layout.

The experimental design employed was a randomized block with 6 treatments and 6 replications conducted in the greenhouse.

Fertilization.

Considering the low fertility status of the soil, the following nutrients were supplied to raise its fertility and to provide the essentials under this subheading:

Table I. Soil analysis procedure employed before sowing.

Name of Analysis	Reference of Procedure
i) Mechanical Analysis	Anderson, J. U. "An Improved Pretreatment for mineralogical Analysis of Samples Containing Organic Matter" Clay and Clay minerals. Vol X. Pergaman Press.
ii) Desorption analysis	Richard, L. A. 1941. A pressure membrane extraction apparatus for soil solutions. Soil Sci. 51:377-386.
iii) pH	Method 21 in Agri. Handbook No. 60, U.S.D.A.
iv) EC of saturation extract	Method 4b in Agri. Handbook No. 60, U.S.D.A.
v) Organic matter	Jackson, M. L. 1958. Soil chemical analysis. pp. 219-221. Prentice Hall.
vi) Available P	Smith, F. W., et al. Soil Sci. Soc. Amer. Proc. 21:400-404.
vii) Lime	Method 23a in Agri. Handbook No. 60, U.S.D.A.
viii) Exchangeable cations	
a) K	Method 18 and 11a in Agri. Handbook No. 60, U.S.D.A.
b) Na	Method 18 and 10a in Agri. Handbook No. 60, U.S.D.A.
c) Mg	Determination in an aliquot of soil extract through Atomic Absorption Spectrophotometer (Jarrell-Ash Model 82-360)
ix) Soluble cations	
a) Ca	Determination in an aliquot of saturation extract through Atomic Absorption Spectrophotometer (Jarrell - Ash Model 82-360)
b) K	Method 11a in Agri. Handbook No. 60, U.S.D.A.

Table I. (Continued)

Name of Analysis	Reference of Procedure
c) Na	Method 10a in Agri. Handbook No. 60, U.S.D.A.
d) Mg	Determination in an aliquot of saturation extract through Atomic Absorption Spectrophotometer (Jarrell-Ash Model 82-360)
x) Soluble anions	
a) CO_3	Method 12 in Agri. Handbook No. 60, U.S.D.A.
b) HCO_3	
c) Cl	Method 13 in Agri. Handbook No. 60, U.S.D.A.
d) SO_4	Method 14a in Agri. Handbook No. 60, U.S.D.A.
xi) Cation Exchange Capacity	Method 19 in Agri. Handbook No. 60, U.S.D.A.

Table II. Soil Description

Soil Classification	Mechanical Analysis Clay %	Mechanical Analysis Sand %	Mechanical Analysis Silt %	Desorption analysis (15 atm.%) on soil.	pH	EC of saturation extract	O.M. %	N %	Available P
Manhattan very fine sandy loam	13.7	62.8	23.4	9.32	7.8 Mod. Alkaline	1.3 mmhos/cm non-Saline	2.0	0.105	50 lb/A V. low

Table III. Chemical analysis of the soil

Lime	Exchangeable Cations me/100 gm.				Water-soluble Cations me/L					Water-soluble Anions me/L				
	K	Na	Mg	Total	Ca	K	Na	Mg	Total	CO_3	HCO_3	Cl	SO_4	Total
Present	1.29	.12	3.33	4.74	7.75	1.0	.60	1.3	10.65	.12	8.002	1.10	1.40	10.62

Cation Exchange Capacity = 15.0 me/100 gm.

Phosphorus: @ 1.3 g. of $CaH_4(PO_4)_2 \cdot H_2O$/3 kg. of soil (For greenhouse, 4 times the recommended rate of 35 lb. P/acre in the field.)

Nitrogen: @ 2.4 g. of NH_4NO_3/3 kg. of soil (4 times the recommended rate of 90 lb. of N/acre.) One additional application of N at the rate of 100 lb/acre was given to the crops, 24 days after sowing.

Potassium: @ 0.2 g. of K_2SO_4/3 kg. of soil (50 lb. of K_2O/acre).

Preparation of pots.

Each pot was weighed empty and the hole in the bottom was plugged with glass wool. Thirty grams of resin specifically marked for each treatment, 3 kg. of soil and the appropriate amount of P, N and K were thoroughly mixed by hand and transferred to the pots, labelled with treatment and replication, and then laid out on the bench as per design of the experiment.

Sowing.

Twenty-five seeds of barley (Betzes variety) were seeded in each of 36 pots on April 23 (Reps. A-D) and on May 18 (Reps. E-F). Three seedlings of tomato (Fireball variety), 7 days old, were transplanted in each of the remaining 36 pots on April 27 (Reps, A-D) and May 25 (Reps. E-F).

Waterings.

Water-holding capacity of the soil was calculated by adopting the following method.

In a glass cylinder of 1.5" radius 100 cc. of water was added to the soil column of 8.5". After 24 hours the water had percolated in the column to the depth of 4.5" from the top. Calculations:

Weight of cylinder = 300 g.
Weight of cylinder with soil = 1690 g.
Weight of soil = 1390 g.
Water added = 100 cc.
Total height of soil column = 8.5"
Volume of soil = $r^2h = 2.14\ (1.5)^2 \times 8.5 = 40.88$ cubic inches.
Depth of soil wetted from top = 4.5"

$$\frac{8.5''}{1390\text{ g.}} = \frac{4.5''}{X}\ ;\quad 8.5X = 6225\ ;\quad X = 736\text{ g.}$$

Total soil to be used in the pot = 3000 g.
For 736 g. we require 100 cc.
For 3000 g. we require approximately 400 cc.

At the time of sowing 400 cc of water was applied to each pot and then every day each pot was weighed. Loss of water due to evaporation and transpiration was calculated and the loss was made up by addition of measured quantities of water. The surface in each pot was covered by a 1" thick layer of perlite to minimize the loss of water by evaporation. Six pots with equal weight of soil and perlite coverings, but without any crop, were set, one in each replication, to show the approximate amount of water loss by evaporation. This figure was finally calculated and deducted from the total water used to arrive at the figure of water consumption by different plants under different treatments.

It was planned to study the effect of treatments at different stages of growth, viz. 21 days after sowing; 31 days after sowing; and 54 days after sowing as the final date of harvesting the plants. At 1st harvest 25 barley plants were thinned to 20 per pot and 3 tomato plants were thinned to 2 per pot. At the 2nd harvest, barley plants were re-thinned to 15 per pot and of 2 tomato plants one was left till final date of harvesting. The cut plants at the 1st and 2nd harvest were weighed oven dry and analyzed in the laboratory as detailed later.

Data on the performance and any visually noticeable differences in response to various treatments were recorded. Average plant height measurements were made at several intervals during the growth cycle. Data on advancement of maturity and pictures were taken to record visual differences. The plants were occasionally sprayed with insecticides. At the time of harvesting barley plants the ears were removed and counted to show the tillering differences and appraisal of yield components under the different treatments. The remaining plant material was clipped. Tomato fruit was harvested separately, counted and weighed and the remaining plant was clipped. The harvested plant material was dried at 70°C for 24 hours and weighed to determine the total dry weight. The soil from each pot was again air dried and a representative sample was taken for analysis in the Lab. Soil in one replication was sacrificed for observation of root development under different treatments.

Laboratory technique employed.

Air dried soil samples from each pot were analyzed for soluble and exchangeable Ca, Mg, K, and Na. The pH and EC values of each sample were also determined. The methods applied are given below.

Exchangeable Ca, Mg and K: For extraction of soil samples by sodium acetate-acetic acid extracting solution, the procedure was adopted as narrated by Greweling (20) on page 12 of Bulletin 960 of Cornell University Expt. Sta. An aliquot of soil extract was used for determination of exchangeable Ca and Mg through the Atomic Absorption Spectrophotometer

(Jarrell-Ash Model 82-360) and K was determined by employing a flame photometer. For Exchangeable Na, ammonium acetate solution was used and the procedure was followed as detailed on page 8 of Circular No. 757 of U.S.D.A. (43). Na concentration in the aliquot of soil extract was determined by flame photometer.

Soluble cations, pH and EC: Chemical analysis of soil samples for soluble Na, Ca, K and Mg was taken by employing saturation extract technique as detailed in Method 2, 3(a) U.S.D.A. Handbook No. 60 ( ). Ca and Mg concentrations were determined by Atomic Absorption Spectrophotometry. Na and K concentrations in the extract were determined by Flame Photometry. Soil pH and EC of each sample was determined by methods given on page 29 and page 38, respectively, of Bulletin 960 of Cornell Univ. Agri. Expt. Station (20).

Plant analysis:

The fruit and vegetative part of the oven dry plant material was powdered separately in the crushing machine and chemical methods were used for determination of Ca, Mg, K and Na absorbed by different parts of the plant[1/]. Dry ashing procedure as given on page 3 of the bulletin cited was adapted and is summaraized below.

2.0 g dried and powdered plant material in 50 ml. borosilicate beaker was placed in a cool muffle furnace and ashed 4-5 hours by slowly raising

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1/ Grewelling, Thomas. Director of Laboratories, Agronomy Department, Cornell University, Ithaca, New York. 1960.

the temperature to 500 ± 50° C. Cooled ash was evaporated to dryness with 3 ml. of 5N HNO_3 and again placed in the cool furnace and heated to 400° C for about 15 minutes. Again the ash was cooled and moistened and 3 ml. of concentrated HCl was added and allowed to bake on a hotplate for one hour. After removing from the hotplate, 5 ml. of 2N HNO_3 was added. With the aid of hot distilled water it was transferred to 50 ml. volumetric flask and after cooling, made to volume. Ca and Mg were determined through atomic absorption and Na and K by flame photometry.

Statistical procedures:

The data collected from this experiment was analyzed statistically as described by LeClerg, et al. ( ) for randomized complete block designs. The Duncan Multiple Range test was used for mean separation. All statistical calculations were computed on the IBM 1620 Model II at the Montana State University Computing Center.

RESULTS

Growth and Development of Plants

Observations and Growth Data.

The results of this study indicate that plants showed a considerable variation in growth and development in response to various levels of Na and Mg supplied as adsorbed cations in the growth media.

In the first three weeks of growth no appreciable differences were observed in development of the plants. Observations in the fourth week of growth revealed symptoms of deleterious effects under high levels of exchangeable sodium in the growth media. The symptoms increased in severity with increases in Na supply. Retardation in plant growth was more pronounced under treatments No. 4 and 5, receiving 60% and 80% Na, respectively, than in those receiving low levels. After 4 weeks from seeding the plants developed very clear symptoms of chlorosis and necrosis. These symptoms were manifested by lower and older leaves on the plants. Necrosis on lower leaves was more pronounced in barley than in tomatoes.

Younger leaves of tomato plants under high Na supply treatment showed patches of faded green color between the veins instead of a uniform dark green color of leaves receiving high percentage of exchangeable Mg in the growth media. High Na also caused necrosis in the older leaves of tomato plants. Flowering and fruit formation occurred earlier on plants under check and treatments No. 1, 2, and 3 than under treatments No. 4 and 5.

In general, tomato symptoms associated with high exchangeable Na percentage were late flowering; late, small and poor quality of fruit; reduced plant size and a marked reduction in average production of plants.

High Mg was not harmful to plants. In fact, vegetative and reproductive growth were maximum under check and treatment No. 1, 80% Mg, with no Na.

Data on height of plants showing difference in growth associated with various treatments are given in Table IV. The data manifest harmful effects of high exchangeable Na, treatment No. 5. There was a significant difference of 4 and 3.3 inches in height at the time of final harvest between treatment No. 5 and check for tomato and barley plants, respectively.

High percentage of exchangeable Mg in growth media had no adverse effect on the height of plants. Maximum height was attained by both barley and tomato plants under check and treatment No. 1.

Growth rate of barley was not significantly influenced by different levels of Na and Mg during the first 3 weeks after seeding, Figure 1. Between the third and fourth weeks plants without Na treatment (control and 80% Mg) gained in rate of growth more rapidly than plants growing under treatments No. 2, 3, 4, and 5. Increasing Na concentrations in the growth media resulted in a delay in maximum rate of growth as well as less total growth.

Growth rate presented in Figure 2 shows that tomato plants increased in height throughout the growth period. During the first 3 weeks after seeding different levels of exchangeable Na and Mg in the growth media had no influence on rate of plant growth. Between the third and fifth weeks of development exchangeable Na above 20% in the growth media decreased the rate of plant growth. During the late stages of plant development growth rate was not significantly different until the level of exchangeable Na reached 80%. Exchangeable Na supplied to the growth media did not delay

Table IV. Height of barley and tomatoes as influenced by various sodium and magnesium treatments.

Treatment No.	Treatment	Crop	Average Height (days after seeding) 21	28	36	52
	Mg:Na					
Check	0:0	Barley	6.33	13.67	18.92	21.00
1	80:0		6.25	12.62	18.25	20.25
2	60:20		6.19	12.00	18.02	20.19
3	40:40		6.42	12.17	18.00	19.67
4	20:60		5.92	10.83	16.83	19.00
5	0:80		6.00	10.67	17.17	17.67
Check	0:0	Tomato	4.56	7.81	13.25	21.75
1	80:0		4.38	7.31	12.38	21.50
2	60:20		4.12	7.00	12.50	20.75
3	40:40		4.25	6.81	11.88	20.50
4	20:60		4.06	6.62	10.94	19.25
5	0:80		4.38	6.69	11.25	17.75

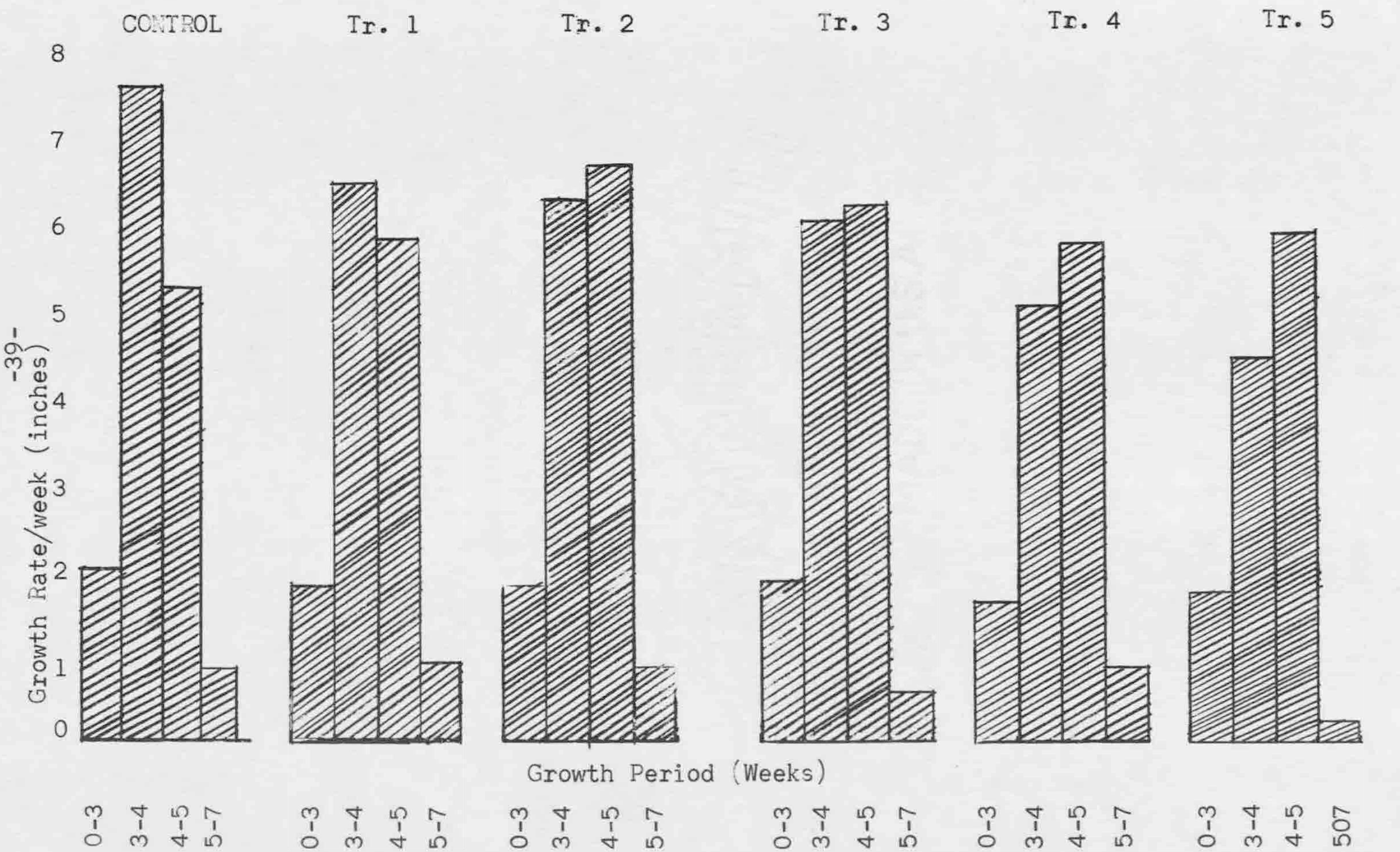

Figure 1. Growth Rate of Barley Plants as Influenced by Different Levles of Exchangeable Na and Mg in soil.

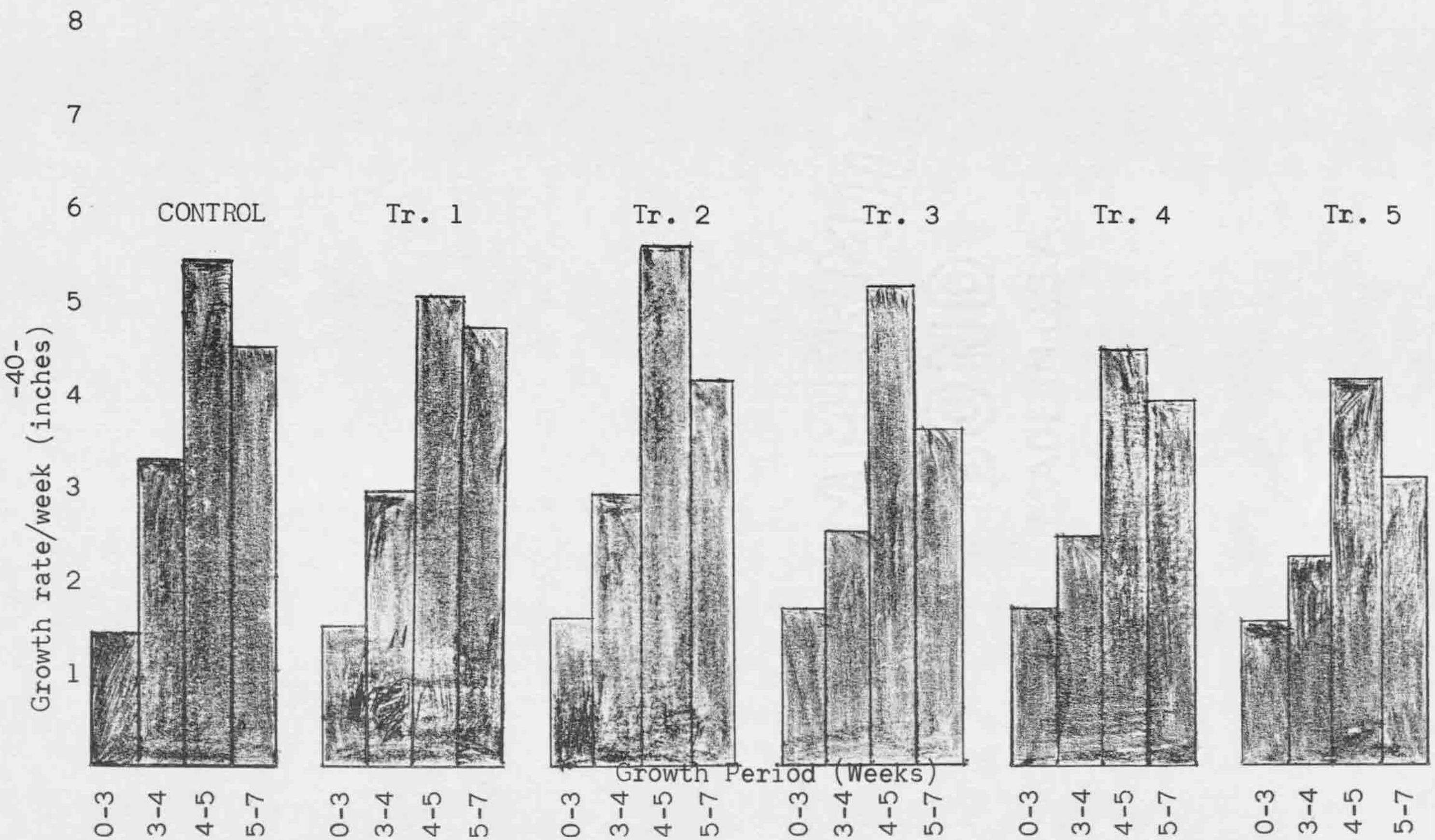

Figure 2. Growth rate of Tomato Plants as Influenced by Different Levels of Exchangeable Na and Mg in Soil.

the period for maximum growth rate of tomatoes as was the case with barley.

Exchangeable Mg without Na increased the rate of plant growth during the last two weeks in tomato plants. This appears to be a result of a slight delay in rate of growth. However, final plant height under this treatment (Mg 80%:0 Na) was not significantly greater than the control.

Dry matter yields of barley and tomato plants 21 days and 31 days after seeding are presented in Table V. The data substantiate that there was no significant effect of various levels of exchangeable Na and Mg in the growth media on barley and tomatoes during the first 3 weeks as well as during the first 31 days of growth. However, it may be pointed out that sampling of smaller plants and leaving the larger ones for final harvest has introduced a bias in measurement.

Final Harvest Data.

Barley yield (tops, ears and roots) and numbers of ears, showing tillering capacity, as influenced by various levels of exchangeable Na and Mg in the growth media are presented in Table VI.

High values of exchangeable Na under treatments No. 4 and 5 resulted in significantly less straw production than occurred under the check treatment. Forty percent or less exchangeable Na did not have significantly adverse effects on straw production.

Number of ears produced by barley was less when exchangeable Na was present in the growth media. However, significant differences were not measured until the exchangeable Na concentration attained 80% level in the exchange capacity of the resin. Tillering was decreased from 27 under the

Table V. Dry weight of barley and tomato plants as influenced by various Na and Mg treatments during early growth period.

Treatment No.	Treatment	Crop	Average dry weight of plant (days after seeding)	
			21 days	31 days
	Mg:Na			
Check	0:0	Barley	1.33	2.50
1	80:0		1.45	2.33
2	60:20		1.45	2.56
3	40:40		1.30	2.43
4	20:60		1.33	2.50
5	0:80		1.25	2.35
Check	0:0	Tomato	0.93	3.50
1	80:0		0.82	3.50
2	60:20		1.20	3.40
3	40:40		1.00	3.50
4	20:60		0.65	3.42
5	0:80		1.00	4.00

Table VI. Barley yield (tops, ears, and roots) and number of ears at 54 days after seeding as influenced by varying levels of exchangeable Na and Mg in growth media.

Treatment No.	Treatment Mg:Na	Vegetative part Mean dry weight		Fruit		Total dry weight of plant, including ear.
		Straw	Roots*	No. of ears	mean dry weight	
Check	0:0	18.40 a	25.0	27 a	9.6 ab	28.09
1	80:0	17.27 ab	13.5	25 ab	9.8 ab	27.12 a
2	60:20	16.80 ab	20.0	22 ab	10.2 a	27.03 a
3	40:40	17.35 ab	19.0	23 ab	9.1 abc	26.47 a
4	20:60	16.69 b	17.4	22 ab	8.7 bc	25.43 b
5	0:80	16.87 b	19.0	20 b	7.9 c	24.78 b

Means followed by the same letters are not significantly different at the 5% probability level by Duncan's multiple range test.

* One replication data only.

check to 20 under treatment No. 5.

Grain yield of barley was significantly reduced by exchangeable Na values of 60% or more. Measureable differences were not obtained between the control and exchangeable Na treatments with values less than 60% in the exchange complex of the resin. High Mg did not appear to be detrimental to barley.

Root yield (data of one replication only) indicated maximum development under check treatment while yield was lowest under treatment No. 1 which received the highest value of Mg. In the other treatments the difference in yield is slight. However, the measurements of one replication cannot be relied upon.

Yield data of tomatoes (top, fruit and roots) are presented in Table VII. Mean dry weight of tops under different treatments indicated the lowest yield under treatment 5, 14.55 gm., which is significantly less than yield from any other treatment. The highest value of adsorbed Mg under treatment No. 1 resulted in maximum yield, 23.99 g., but not significantly different from yields of treatments No. 2 and 3.

Fruit production of plants from treatment No. 5 was greatly reduced, both in number and weight, as compared to check or high Mg. No significant difference was observed in effects of low concentrations of Na or Mg or in close proportionate combinations with each other.

The comparative data of total production (tops and fruit) elucidate the detrimental effect of high Na percentage in growth media. The mean total dry weight of plants under treatment 5 was 60% of total dry weight

Table VII. Tomato yield (tops, fruit and roots) as influenced by various levels of exchangeable Na and Mg in growth media.

Treatment No.	Treatment Mg:Na	Vegetative Part Mean Dry Weight(gms) Tops	Vegetative Part Mean Dry Weight(gms) Roots*	No. of fruit	Fruit Fresh Wt. (grams)	Fruit Dry Wt. (grams)	Total dry weight, tops and fruit
Check	0:0	20.49 bc	5.6	4.8	41.41	8.28	28.77 bc
1	80:0	23.99a	5.7	5.2	36.81	7.38	31.27a
2	60:20	22.70ab	8.0	5.7	35.95	7.86	30.56ab
3	40:40	20.54abc	4.9	4.2	33.72	5.12	25.66 c
4	20:60	17.87 c	4.5	4.3	28.71	6.74	24.66 c
5	0:80	14.55	4.3	3.3	25.58	4.25	19.80

Means followed by the same letters are not significantly different at the 5% probability level by the Duncan multiple range test.

* One replication data only

under check. It is significantly less than the yield from other treatments. Highest total dry weight was measured under treatment 1 (80% Mg:0 Na).

Root yield did not indicate an observable difference between treatments except that it was comparatively low under treatments 4 and 5 and unexpectedly very high under treatment 2. The data, from one replication only, cannot be relied upon, but may indicate the general effects.

In general, there was considerable evidence of deleterious effects of high exchangeable Na percentage in soil on growth and development of barley and tomato plants.

Plant Analysis Following Harvest

The effects of varying levels of exchangeable Na and Mg in the growth media on absoprtion of cations by barley plants have been shown by analytical data presented in Table VIII. Because the yields were about equal regardless of treatment, the % concentration data can be used as an estimate of uptake during early growth.

Data on uptake of Mg by the plants indicate that during the first 3 weeks of growth the maximum absorption of Mg took place under treatments No. 1 and 2 (80% Mg:0 Na and 60% Mg:20% Na). There was minimum absorption of Mg by plants under treatments No. 4 and 5 and check. Thirty-one days after seeding, pattern of Mg uptake by plants under different treatments was almost the same as in early growth period. except concentration of Mg in plants under treatment 1 was greater at this stage of growth. At final harvest, the analytical data revealed a greater percent accumulation of Mg

Table VIII. Chemical composition of barley plants at different stages of growth as affected by various levels of exchangeable Na and Mg in the growth media.

Treatment No.	Treatment Mg:Na	Crop	Mean percentage expressed on dry basis (Days after Seeding)							
			21		31		54			
		Barley	Mg	Na	Mg	Na	Mg	Na	Ca	K
Check	0:0	Top	.197 bc	.00016a	.161a	.00008a	.314 bc	.00010a	1.126a	2.881a
		Ear					.198ab	.00005 b	.550a	.951ab
1	80:0	Top	.343a	.00014a	.524	.00008a	.694	.00009a	.754 b	2.417ab
		Ear					.322a	.00006 b	.346ab	.997a
2	60:20	Top	.346a	.00122	.330 b	.00092	.454a	.00100	.871ab	2.260 b
		Ear					.306a	.00008	.294 b	.867ab
3	40:40	Top	.253 b	.00268	.201ab	.00164	.376ab	.00219	.443 c	1.355 c
		Ear					.175ab	.00014	.295b	.913ab
4	20:60	Top	.162 c	.00383	.157a	.00245	.229 c	.00302	.686 bc	1.284 c
		Ear					.104 b	.00018a	.267 b	.903ab
5	0:80	Top	.133 c	.00511	.133a	.00333	.212 c	.00440	.564 bc	1.112 c
		Ear					.116 b	.00019a	.268 b	.818 b

Means followed by the same letter are not significantly different at the 5% probability level by the Duncan multiple range test.

under all treatments, but the same general effect of treatment as during earlier sampling dates.

Analytical data on percent Mg in the barley ears indicated that treatment effects were not as pronounced as was the case in barley straw. There was no significant difference between treatments No. 1, 2, 3, and check. Treatments No. 3, 4, and 5 with 40% Mg, 20% Mg, and 0% Mg, respectively, were significantly lower in Mg than the other four treatments.

The data indicated a significant increase in Na absorption by plants under increasing levels of exchangeable Na in the growth media. Only treatment No. 1 and Check, with no Na supply in the growth media, are the same. The same ratios in uptake of Na under increasing supply of exchangeable Na were observed at the second sampling, 31 days after seeding. The percent Na of plants was somewhat less at this stage of development than it was at 3 weeks.

The analysis of final harvest indicated almost the same percentage of Na and in the similar order of significance in barley straw as was noted at the second sampling date. Sodium concentration of barley ears leveled off at the 60% Na treatment whereas the straw percentage Na was proportional to the amount present in the media. It is interesting to note that the ratio of Na in straw to Na in ears gradually increased as more Na was absorbed by the plant. Concentration of Na in straw was about twice that in ears under check and Treatment No. 1 but with increasing levels of exchangeable Na in the soil the ratio widened, ranging from 12.5:1 under treatment No. 2 to 23:1 under treatment No. 5.

High values of exchangeable Na under treatment 5 decreased % Ca up to 50% of % Ca in plants under check. The same was true in the case of % K, which was 50% less in plants under treatment 5 than under the check. High percentage of Mg (treatment No. 1) did not lower % K in plants but lower levels of Mg in combination with Na, more than 20%, under other treatments significantly lowered the % K in plants.

Ca and K concentration of barley ears was close to half that of the straw. The effects of different treatments on Ca and K percentage in ears were similar to the effects observed under straw. In general, Na concentration in the plants was much lower than those of Ca, Mg and K. Mg concentration was found to be approximately 150 times more than Na; about 33% and 70% of Ca concentrations under check and other treatments, respectively; and about 20% of K concentration with little difference under various treatments.

The analytical data presented in Table IX show the effects of varying levels of exchangeable Na and Mg on concentration of cations by tomato plants at three harvest dates. 21 days after seeding Mg absorption by plants was found to be 3 times more under maximum supply of Mg than under check, considering about equal plant growth (Table 5) and greater concentration (Table 9). The concentration of Mg in plants under different treatments corresponded to the level of supply in growth media, ranging from 1.145% under treatment No. 1 to 0.232% under treatment No. 5. Treatment No. 1 was found to be significantly greater than all other treatments. There was no significant difference between treatments No. 2 and 3 (60% Mg:20% Na and 40% Mg:40% Na). Similarly, check treatment and treatment No. 5 were

Table IX. Chemical composition of tomato plants as affected by various levels of exchangeable Na and Mg in the growth media at different stages of growth.

Treatment No.	Treatment Mg:Na	Plant Part	Mean percentage expressed on dry basis — Days After Seeding: 21		31				54			
			Mg	Na	Mg	Na	Ca	K	Mg	Na	Ca	K
Check	0:0	Vine	.385cd	.00018b	.594ab	.00011b	3.323ab	2.885ab	.328c	.00011a	3.309a	2.175a
		Fruit							.247	.000065	.539	1.95
1	80:0	Vine	1.145	.00023b	1.677	.00007b	2.363c	2.136b	.890	.00010a	2.203b	1.827a
		Fruit							.486	.000074	.395	1.76
2	60:20	Vine	.774a	.00046b	8.70a	.00012b	3.438a	2.791ab	.673a	.00016a	2.875ab	1.998a
		Fruit							.407	.000112	.574	1.77
3	40:40	Vine	.585ab	.00175	.645ab	.00138	2.675bc	2.639b	.562ab	.00106	2.856ab	1.999a
		Fruit							.349	.000141	.614	2.02
4	20:60	Vine	.424bc	.00348a	.544ab	.00203a	2.745abc	3.614a	.413bc	.00127	2.554ab	1.928a
		Fruit							.216	.000195	.221	1.29
5	0:80	Vine	.232d	.00339a	.332b	.00245a	1.608	2.418b	.341c	.00161	2.276ab	1.970a
		Fruit							.113	.00177	.140	1.89

Means followed by the same letter are not significantly different at the 5% level.

not significantly different from each other. Similar treatment effects were found on Mg% at 31 and 54 days, but the plants were higher in Mg at 31 days and lower at 54 days than they were at 21 days after seeding.

Mg concentration in tomato fruit was also influenced by varying levels of exchangeable Mg in the soil. Under treatment No. 1 Mg in tomato fruit was found to be two and four times more than under check and treatment No. 5, respectively. The same ratio of Mg in vine to Mg in fruit was maintained as long as Mg was present in the treatment (No. 1, 2, 3 or 4). In the check treatment there was a greater proportion of the total plant Mg accumulated in the fruit, and in treatment No. 5 this proportion was considerably lower than in treatments No. 1-4.

Na concentration in the plants throughout the growing period increased with increasing exchangeable Na values in the soil over the entire range investigated. In the early harvest, plants were highest in Na concentration and its concentration decreased as the season progressed. Concentration of Na was 50% less at the time of maturity than in the first 3 weeks.

At the final harvest maximum % Ca occurred with the check treatment. The highest level of adsorbed Mg (treatment No. 1) resulted in significantly lower % Ca than in the check plants but not significantly less than in the other treatments. It appears also that high Na treatment is very effective in limiting Ca accumulation, particularly at earlier stages of growth. High Na (treatment No. 5) resulted in lower % Ca in plants than did high Mg (treatment No. 1).

The distribution of Ca between vines and fruit appears to be greatly influenced by both Mg and Na. The ratio of Ca in vines to Ca in fruit is 6.1:1 in check plants. This ratio is 5.6, 5.0, 4.6, 11.6 and 16.3 for treatments 1-5, respectively. It appears that an equal combination of Mg and Na results in maximum translocation of Ca to the fruit. Mg also enhances Ca translocation to fruit, but Na alone is very inhibitory in this function.

No significant influence of any treatment on % K of tomato plants was observed at final harvest, although maximum K concentration was measured under the check treatment. Difference in K concentration in tomato fruit under various treatments was not consistent.

In general, the ratio of concentration of various cations in tomato plants was found to be different than in barley. Ca had the 'lion's share', next in order were K and Mg. (In the case of barley, K concentration was at maximum, then came Ca and next in order was Mg.) Na concentration was very low, almost unmeasureable, ranging from 0.00011 to 0.00161% under the check and treatment No. 5, respectively. This amounts to approximately one four-hundredth that of Mg in the plant. On an average, Mg was found to be about 20% of Ca and 33% of K in tomato plants, but in fruit Mg was almost equal to Ca except under treatments No. 4 and 5 where Mg was about 50% of Ca. In general, Mg in tomato fruit was about 25% of K.

Yield data of various cations in barley and tomato plants are presented in Table X. Addition of exchangeable Mg in the growth media increased Mg yield in barley plants at lower concentrations of exchangeable Na. High levels of exchangeable Na in the media (treatments No. 4 and 5)

Table X. Yield of cations in barley and tomato plants at the time of final harvest, 54 days after seeding, as influenced by varying levels of exchangeable Na and Mg in growth media.

Treat-ment No.	Treat-ment Mg:Na	Mg Yield	Mg % of check	Na Yield	Na % of check	Ca Yield	Ca % of check	K Yield	K % of check
			Barley (straw + ear), Yield in me						
Check	0:0	.664	100	.0011	100	1.314	100	1.533	100
1	80:0	1.253	185	.0012	109	0.834	63	1.326	86
2	60:20	.816	123	.0077	700	0.894	68	1.197	78
3	40:40	.688	103	.0170	1500	0.527	40	0.823	53
4	20:60	.395	60	.023	2090	0.677	51	0.724	47
5	0:80	.378	57	.033	3000	0.578	44	0.644	42
			Tomato (vine + fruit), Yield in me						
Check	0:0	.735	100	.0013	100	5.615	100	1.550	100
1	80:0	2.077	282	.0013	100	4.109	73	1.455	94
2	60:20	1.625	221	.0021	161	5.498	97	1.510	99
3	40:40	1.091	148	.0097	746	4.511	80	1.306	83
4	20:60	.754	102	.0100	769	2.856	50	1.159	75
5	0:80	.445	60	.0120	923	1.924	34	0.936	60

NOTE: 100% based on control treatment.

significantly decreased Mg yield. Similar effects were noticed in the case of tomato plants except that the increase in yield under treatment No. 1 was 282% of check as compared to 185% of check by barley. Tomato plants, in general, yielded more Mg than barley plants under comparable treatments.

Na yield in barley was quite low under control. However, addition of Na irrespective of Mg level very significatnly increased Na uptake. The higher the supply of exchangeable Na in the growth media, the higher the yield, almost proportionate to Na supply. The increase in Na yield of tomatoes was associated with increase in supply of exchangeable Na in the growth media, but comparatively the yield of Na in tomato was found to be one-third of that in barley when Na was present in the treatment.

The interference of exchangeable Mg and Na on Ca yield was significant. Under the control treatment maximum Ca yield was obtained by both barley and tomatoes. High Mg (treatment No. 1) decreased yield of Ca by barley plants 37%. The same treatment reduced Ca yield by tomatoes 27%. By altering the balance of Mg to Na (60%:20%), Ca yield by barley was decreased 32% and only 3% by tomatoes. By decreasing the Mg:Na ratio Ca yielded by both crops decreased.

K yield in barley plants was more significantly influenced by exchangeable Na than by exchangeable Mg. A significant decrease in yield of K was observed with increasing supply of exchangeable Na in the growth media, reaching a low of 42% of check under treatment No. 5. Similar effects of increasing Na were noticed in K yielded by tomato plants except that the effects were not as pronounced as in barley. High exchangeable Mg under treatments No. 1 and 2 did not significantly influence the yield of K in tomatoes.

Soil Analysis Following Harvest

Chemical data of soil after harvest of barley and tomato crops have been presented in Table XI. EC values in all the treatments supplied with exchangeable Na and Mg were found to be significantly greater than the check. Generally, EC increased as the supply of exchangeable Na increased in the growth media.

pH values ranged from 7.68 to 8.42 with increasing Na in the treatment. It was significantly higher under treatments No. 4 and 5 than under other treatments.

SAR values ranged from 0.36 to 4.13 and 0.43 to 3.62 in soil under barley and tomato, respectively. It increased with increasing supply of exchangeable Na in the soil over the entire range investigated. Treatment No. 5 resulted in significantly greater SAR values than the other treatments. There was no significant difference in SAR values under 40% and 60% supply levels of exchangeable Na.

The exchangeable Na percentage in the soil following harvest ranged from 1.0 to 20.96 from check to treatment No. 5, respectively.

In general there was no observable difference in values of EC, pH, SAR and ESP in soil under barley and those values in soil under tomatoes.

Analytical data showing exchangeable cations in soil following harvest of barley and tomato have been given in Table XII. Exchangeable Mg in soil increased with increasing supply of exchangeable Mg in the growth media.

Table XI. Chemical characterization of soils following harvest of barley and tomato crops as influenced by various levels of exchangeable Na and Mg in the growth media.

Treatment No.	Treatment Mg:Na	EC mmhos/cm	pH	SAR	Exchangeable Sodium percentage	Exchangeable Magnesium percentage
Barley						
Check	0:0	0.952	7.68c	0.36b	1.00	15.11
1	80:0	1.408c	7.74c	0.49b	0.78	33.07
2	60:20	1.664bc	7.80c	1.33	4.79	28.13
3	40:40	1.952ab	8.12b	3.15a	13.05	23.23
4	20:60	1.728b	8.34ab	3.31a	17.11	12.81
5	0:80	2.096a	8.42a	4.13	20.96	10.34
Tomato						
Check	0:0	0.944c	7.74c	0.43b	1.24	15.75
1	80:0	0.936c	7.80c	0.37b	1.02	31.70
2	60:20	1.128c	7.78c	1.41	4.77	27.22
3	40:40	1.560b	8.14b	2.74a	11.46	23.38
4	20:60	1.872a	8.20ab	2.85a	18.33	12.06
5	0:80	1.776ab	8.40a	3.62	19.56	9.12

Table XII. Exchangeable cation analyses in soils following harvest of barley and tomato crops as influenced by varying levels of exchangeable Na and Mg.

Treatment No.	Treatment Mg:Na	Crop	Exchangeable Cation in meq/100 g. soil Mg	Na	Ca*	K
Check	0:0	Barley	2.266 b	0.1a	87.5	.734 e
1	80:0		7.540	0.1a	62.5 a	.765 de
2	60:20		6.415	1.0	58.75a	.837 cd
3	40:40		5.299	2.9	60.0 a	.901 bc
4	20:60		2.920a	3.9	60.0 a	.960ab
5	0:80		2.358ab	4.7	60.0 a	1.021a
Check	0:0	Tomato	2.361ab	0.1a	81.75	.701 c
1	80:0		7.227	0.2a	57.5 a	.689 c
2	60:20		6.207	1.0	57.5 a	.676 c
3	40:40		5.332	2.6	56.25a	.748 bc
4	20:60		2.749a	4.1 b	57.5 a	.806ab
5	0:80		2.078 b	4.4 b	58.75a	.858a

Means followed by the same letter are not significantly different at the 5% level by Duncan's multiple range test.

* Presence of lime in the soil invalidates these values as exchangeable Ca.

The 20% Mg supply under treatment No. 4 was not significantly different from treatment No. 5 (0 Mg) but it was significantly different from the check.

Exchangeable Na in the soil was proportional to its supply in the growth media. With barley treatment No. 4 and 5 were found to be significantly different while with tomatoes there was no significant difference between these treatments.

The soil employed was very rich in lime, therefore the Ca data do not reflect a true value for exchangeable Ca.

The general effects of Mg and Na on exchangeable K remaining in the soil following harvest were that Mg had little or no influence, while increasing amounts of Na increased exchangeable K. There was more exchangeable K in soil under barley in treatments No. 4 and 5 than in soil under tomatoes.

Analytical data of soluble cations in soil following harvest of barley and tomatoes have been presented in Table XIII. Soluble Mg in soil under barley was significantly higher under treatments No. 1 and 2 than under all other treatments. There was no significant difference in check and treatments No. 3, 4, and 5. Mg in soil under tomatoes was significantly higher under treatment No. 1 than all other treatments but treatment No. 2 was not significantly different from check.

There was a consistent increase in soluble Na with increasing supply of exchangeable Na in the growth media. Check and treatment No. 1 (which received no Na) were not significantly different. Treatment No. 5, in the soil under barley, resulted in significantly higher concentrations of

Table XIII. Soluble cation analyses in soils following harvest of barley and tomato crops as influenced by varying levels of exchangeable Na and Mg in the growth media.

Treatment No.	Treatment Mg:Na	Crop	Soluble Cations in meq/L of Saturation Extract			
			Mg	Na	Ca	K
Check	0:0	Barley	1.17 b	1.23 b	11.20a	.35 b
1	80:0		2.42a	1.57 b	8.55abc	.34 b
2	60:20		2.38a	4.49	9.40ab	.48a
3	40:40		0.99 b	7.76a	5.85 c	.40ab
4	20:60		0.73 b	8.15a	5.30	.30 b
5	0:80		0.74 b	10.80	6.15 bc	.36 b
Check	0:0	Tomato	0.90ab	1.26 c	8.05a	.24a
1	80:0		1.69	1.15 c	8.20a	.25a
2	60:20		1.05a	3.50	5.25 b	.18ab
3	40:40		0.70 bc	6.15 b	4.55 b	.16 b
4	20:60		0.74 bc	7.15ab	5.75 b	.16 b
5	0:80		0.62 c	8.04a	4.55 b	.21ab

Means followed by same letter are not significantly different at the 5% probability level by Duncan's multiple range test.

soluble Na than all other treatments.

The soil under tomatoes in treatment No. 5 was not significantly different from treatment No. 4, and treatments No. 3 and 4 were also not significantly different from each other.

Soluble Ca in the check soil under barley was found to be almost double the amount in soil under treatments No. 3, 4, and 5. There was no significant difference in check and treatments No. 1 and 2. In general, soluble Ca in soil under tomato was lower than in soil under barley. The overall difference was about 20%. Treatments No. 2, 3, 4, and 5 were not significantly different from each other.

In soil under barley soluble K was not significantly different as a result of any treatment except treatment No. 2, which resulted in more soluble K. However, soluble K in soil of treatment No. 2 was not significantly greater than that of treatment No. 3.

Soluble K under all treatments with tomato was lower in concentration than in soil under barley. The decrease was more pronounced, about 50%, in treatments No. 2, 3, and 4 than in other treatments, where it was about 30%. High Mg did not alter the amount of soluble K in tomato soils as compared to that in the check treatment. High Na tended to decrease soluble K, and the influence was not consistent as evidenced by similar amounts of soluble K in check and treatment No. 5.

DISCUSSION

The results of this investigation indicated that, in terms of the objective sought, an affirmative answer could be given to the question about specific action of adsorbed cations on the growth of plants. The marked difference in the effect of exchangeable sodium upon the growth response as compared with that of exchangeable magnesium is the striking feature of this study. Increasing levels of exchangeable Na had deleterious effects on growth and development of plants even though the range of Na was quite low. In the field this might be attributed in large part to the adverse physical condition of the soil. The results of this study indicate that growth was reduced even when steps were taken to prevent the adverse physical conditions. It seems reasonable to assume, therefore, that physiological and/or chemical effects are involved.

The data presented do not bear directly on the nature of mechanism by which ions adsorbed on the Amberlite were taken up by the roots. The interpretation of the data is to be sought, not in terms of the synthetic resin-soil system used, but in terms of adsorbed-ion effects, characteristic of well-known soil colloids.

The soil used was rich in lime which was not washed out. This prevents interpretations of the effects of adsorbed Na and Mg on the "Adsorbed Calcium regime" in this study. However, the importance of Na is regarded from a broader point of view, namely, in relation to the equilibrium of the cations in the growth media and in their absorption by growing plants. In the equilibrium of cations, the decisive factor is the exact proportion rather than the absolute quantities.

The relevant literature bears evidence about fatal effects of very high percentage of exchangeable Na on crops. Under such conditions most popular crops in agricultural economy fail to germinate or the seedlings die before harvest. Bain and Fireman (4) found that few seeds of tomato germinated in low Na treatment (28.5 ESP) and none in the high Na soil (51.5 ESP). This was the main reason for providing a relatively low ESP for this study (ranging from ESP 0.6 to 27.98). Range of exchangeable magnesium percentage under study was from 14.62% to 41.98%.

Effects on Growth and Development of Plants.

Saline soils may affect plant growth in two distinct ways: (a) the increased osmotic pressure of the soil solution affects an accompanying decrease in the physiological availability of water to the plant; and (b) the concentrated soil solution may be conducive to the accumulation of toxic quantities of various ions within the plant. Also, monovalent cations, especially Na^+, have such a dispersive effect upon protoplasmic colloids that they may induce complete disorganization and death unless balanced by a divalent cation, especially Ca. On the other hand, the divalent ions tend to have a coagulative effect and may seriously inhibit permeability of the membrane.

In general, the physiological observations and the yield data on the effects of resin-adsorbed ions bear similarity to a number of studies. Absence of any significant difference in the early stages of growth under different treatments establishes the fact that exchangeable sodium percentage and exchangeable magnesium percentage up to the levels of 27.98 and

41.98, respectively, had no apparent adverse effect on barley and tomato plants in early stages of growth. The presence of excess lime in the soil may tend to ameliorate the adverse effects of Mg^{++} and Na^{+}. Secondly, the ESP values under study did not affect either crop in germination and establishment of plants in their first 3 weeks. Once the plants were established a general supression of growth from the third week to maturity was the most common plant response of barley and tomatoes to high levels of exchangeable Na in the growth medium. A characteristic of barley is its very high resistance to injury from salts, but results of this study suggest that barley may be more sensitive to Na than it is to salinity, per se.

The toxic effects of high levels of exchangeable Na, when they set in, manifested themselves with a fair degree of sharpness. Higher concentrations of Na caused pronounced marginal and tip burns, resulting in brown necrotic tips and margins. Pearson and Bernstein (42) found that ESP of 48 caused necrosis and eventual death of some of the seedlings of barley. All the visual symptoms of diagnostic significance were quite observable in the late stage of growth, close to maturity, depicting harmful effects of adsorbed Na from the highest ESP values employed in this study. The yellow-green color frequently occurring in isolated patches on the primary leaves and slight curling at the tip of primary leaves of tomatoes suggested symptoms of inadequate Mg supply caused by excess of exchangeable Na under treatment No. 5.

Comparatively, the effect of high exchangeable Na percentage on the height of barley plants was about the same as its effect on dry weight. Under treatment No. 5 there was a decrease in height of 16% and a decrease in dry weight of 12% compared to check plants. For tomatoes, however, the dry weight was decreased by 31% from treatment No. 5 while the plant height was reduced only 18%. These results do not bear out those of Pearson and Bernstein (42) who found that ESP had a greater effect on weight of straw or on total weight of tops than on height of grain crops.

Ayers, *et al*. (3) observed that vegetative growth and straw yield were much more sensitive to salinity than was grain production. Contrary to their data, the deleterious effects of high exchangeable Na under the condition of this study appeared to be marked reduction in the number of ears of barley, and weight of the ears. A decrease of 26% and 18% in number of barley ears and dry weight of ears, respectively, under treatment No. 5 as compared to the check was evidence for potential reduction in grain yield. These plants were not carried to maturity, so no direct grain yield was obtained. In 40% Na:40% Mg the yield was only 6% below that of the check. Similarly, Elgabaly (15) obtained approximately normal growth of barley seedlings in sand cultures containing 40% Na-saturated Amberlite.

A slight increase in dry weight of ears only, 102% and 106% of check, under treatments No. 1 and 2, indicated slightly beneficial effects of 80% Mg:0 Na and 60% Mg:20% Na in the growth media. But statistically, there was no significant difference in dry weight of ears under check, treatment No. 1 and treatment No. 2. The effects of Na as a single cation were in agreement with findings of Elgabaly (15) who inferred that single cations had more deleterious effects than those in combination. But results from treatment No. 1 where Mg was added singly did not agree with his findings. This discrepancy may be due to high Ca in the soil employed in this study.

The harmful effects of exchangeable Na on fruit of plants were more pronounced in the case of tomatoes than barley. A yield of 68%, 61% and 51% of the check in number of fruit, fresh weight of fruit and dry weight of fruit of tomatoes respectively, was associated with the highest value of ESP (27.98) in this study. Similar results were reported by Hayward and Lang (22).

The beneficial effects of Mg, as shown by significant increase in total dry weight of tomato plant to 108% of check under treatment No. 1 (80% Mg:0 Na), again indicated exchangeable magnesium was useful even up to the highest level employed (41.98 percent).

Potential yield depression from high Mg application was probably alleviated by the presence of lime in the soil. Wadleigh and Gauch (5) have obtained evidence that plants may not show specific symptoms of Mg toxicity under conditions of high Mg in the soil when Ca ions are also present at a relatively high level. Ratner's statement, cited by Magistad (36) that soil containing over 70% replaceable Mg was unfavorable to plant growth, probably because Ca relations were disturbed, could not be investigated because the Mg levels were lower and the soil was high in Ca. However, Ratner's (45) findings that high Na limits Ca availability to plants were borne out in this study, especially in the case of tomatoes where Ca plays a critical role in the health and development of the plant.

The physiological basis for such pronounced difference in salt tolerance by different species is not clear. In this study an exchangeable Na percentage of 27.98 caused soil pH to increase from 7.68 to 8.40 and might have brought about chemical changes which were not favorable for the availability of micronutrients other than molybdenum. Under these alkaline conditions, iron, copper and zinc are presumed to precipitate as hydroxides and Mn to be oxidized to inert MnO_2 which may be less available to plants. Probably the increased uptake of Na itself contributed to the suppressed absorption of some of the micronutrients. This hypothesis is in agreement with Bain and Fireman (4) who found an increase of pH from 7.35 to 8.5 with 28.5 ESP and attributed decrease in growth and development of plants to effects of high ESP upon the availability of micronutrients. Another assumption is that the decreases in yield of crops with increasing ESP may be caused by deranging the mineral composition of tops or roots, thus affecting their normal functions, particularly as related to water absorption.

Effect of Exchangeable Mg and Na on Chemical Composition of Plants.

The factors determining cation uptake are not fully elucidated. Certainly the process is a complex one. The concentration of any given element in plant tissue was in many instances not only correlated, up to physiological limitations, with the supply of that element alone in the growth medium, but also with the supply of other ions. Variations in the relative proportions of exchangeable cations in the growth medium resulted in large differences in mineral composition of both fruit and vegetative part.

Uptake of Mg by plants depends on the exchangeable K, Na, Ca and NH_4

contents and on soil pH, as well as the exchangeable Mg. Cation activity ratios, at a given temperature, have a characteristic value for a given soil with a particular complement of exchangeable cations. Bower and Turk (9) found that in some of the highly alkaline soils excessive Na ions sometimes displaced the Mg ions with resultant plant Mg deficiency. In this study similar effects were noticed with treatment No. 5 (80% Na:0 Mg) where the uptake of Mg was 58% and 45% of check for barley ears and tomato fruit, respectively. The effects of Na in lowering the uptake of Mg was more pronounced in reproductive parts than in vegetative parts of the plant. High Mg in the growth media, treatment No. 1, did not suppress Na uptake.

Application of greater amounts of Mg may have led to luxury uptake of the cation with consequent greater depression in Ca uptake. Under treatment No. 1, Mg uptake by barley and tomatoes was 185% and 282% of check, respectively, while Ca uptake was depressed 37% and 27% under the same treatment.

In general, with an increase in exchangeable Mg in the growth medium, there was an increased uptake of Mg and a significant decrease in Ca uptake by both plants. Similar results were reported from a study conducted by Clay and Hudson (12).

The effect of high exchangeable Mg under treatment No. 1 was not antagonistic to K uptake by plants. The decrease in K uptake was 14% and 6% of check for barley and tomato, respectively, and the differences were not statistically significant.

Bernstein and Pearson (7) reported that increasing ESP resulted in increased Na accumulation in the tops and that Ca generally decreased while Mg and K increased or decreased depending upon crop specificity. The analytical data of tables 5 and 6 in this study represent similar effects. Results of the studies by Bower and Wadleigh (8), Bains (4), and Thorne (44) were also in agreement, indicating that high exchangeable Na caused a several-fold increase in the absorption of Na and a decrease in the absorption of Ca and K.

The accumulation of Na by barley, as reported in the literature, varies considerably, with particularly wide deviations being reported for the Na content of straw. Elgabaly (15) found that Na contents in the barley seedlings increased as Na saturation increased, attaining a maximum at 60% saturation, then falling at 100% saturation. Likewise, in the present study, increasing amounts of exchangeable Na resulted in a marked progressive increase in the Na uptake by plants. The findings of Bower and Wadleigh (8) are in essential agreement with these results. The accumulation of Ca, Mg and K by the plants as a whole tended to decrease and that of Na to increase progressively as higher proportions of exchangeable Na were supplied. Eaton's (14) results also agreed with those of the author; that Na accumulation in barley had been found to depress K accumulation. On sampling barley at the stage close to maturity the author found the largest concentration of K in the ears, whereas the highest content of Na was found in the vegetative parts of the plants. It was also observed that crops accumulated more K at low levels of exchangeable Na. Decreasing K accumulation with increasing ESP values cannot be explained on the basis of a lower K level in the soil. As shown in table 9, there was more K remaining in the soil under high Na than under check or high Mg. Elgabaly (15) found loss of K increased with the increase in the degree of Na saturation and that plants in pure Na system contained almost no K. In the present study the decrease in K accumulation was shown as 58% and 40% of check in barley and tomato, respectively, under treatment No. 5. Thus, the effect of high ESP on suppressing the uptake of K was more pronounced in barley than in tomatoes. In barley, it appeared that in the event of a decrease in K absorption (K = 44% and 38% of check in barley straw under treatments No. 4 and 5, respectively) most of the Na went to the foliage, where it set free a certain quantity of K for translocation and accumulation in the grain of barley (K = 95% and 86% of check in barley straw under treatments No. 4 and 5, respectively). This may suggest an independent "sparing" function of Na in barley plants.

Plant species differences and K level in the growth media have generally been considered the major factors, other than Na level, influencing Na absorption by plants. There was a large difference in the abilities of barley and tomatoes to absorb Na. It was found that even where large amounts of Na were added (treatment No. 5) barley tops contained 3 times more Na than tomato tops. The differential responses of these species are attributed to variations in their inherent abilities to absorb selectively the cations involved.

The Ca content of tomato plants decreased as the proportion of added

Na increased. As compared with the vegetative tissues, the accumulation of Ca, Mg, Na and K in the tomato fruit was low, and differences due to treatment were small (table 6). These observations were similar to those of Hayward and Lang (22).

There was essential similarity in the results of this study to those of Eaton (14). Both results indicated little evidence of interrelations between Na and K accumulations in tomato plants but with barley Na accumulation had been found to depress K accumulation. Similar results were found by Pearson (42).

Cation Regime in the Growth Medium.

Soil scientsits have demonstrated experimentally the importance of the degree of cation saturation on soil colloids to plant nutrition. In the light of such experimentation it is significant that in most soils the total exchangeable bases consist chiefly of Ca, Mg, Na and K.

Composition of the soil solution may not directly control the availability of cations to plants. Different activity ratios in solution may explain more clearly the effect of different complementary cations. Even to a greater extent, the degree of colloid saturation does not directly control ion availability. All cations are fixed, the degree of fixation depending on the effective radius and valence of the ion in question. Exchangeability of a given adsorbed cation varies in accordance with the extent to which the cation saturates the exchange material and with the kind of complementary cations present. The exchangeability of Ca and Mg decreases markedly as the degree of Na saturation is increased.

Increasing levels of exchangeable Na in the soil were associated with increasing concentration of Na and decreasing concentration of Mg and Ca in the soil solution. Under treatment No. 5 of the barley soil the decrease was 38% and 46% of the check for Mg and Ca, respectively. Potassium was least affected as it was 102% of check under treatment No. 5. These findings were in full agreement with those of Bernstein and Pearson (7) and Bower and Wadleigh (8).

Concerning the effect of high exchangeable Mg in the soil, there was a difference in response by Ca and K in soils under barley and tomatoes. Treatment No. 1 resulted in a decrease of Ca in soil solution to 76% of the check, but in the case of tomatoes, Ca in solution under Treatments No. 1 was 102% of check. Again there was no significant difference in the effect of different values of exchangeable Mg on K going into soil solution.

Comparable effects of adsorbed cations under study and salt effects as cited in the literature.

The view has sometimes been expressed that plants are injured by salts because of the high osmotic pressure in soil solution and the consequent limitation to water uptake. Magistad, et al. (37) found that total salt concentration expressed in atmospheres was a greater factor in determining the amount of growth reduction than affects caused by specific ions. Growth reduction was in most cases linear with increasing osmotic concentration of substrate. Chloride and sulfate salts when compared on an equal osmotic basis, depressed growth to an equal extent with a number of crops. In case of other crops, chloride salts were slightly more toxic than the sulfates at equal osmotic concentration.

In view of diverse reactions and the specificity shown in toxic uptake by different plants, it seems improbable that chloride and sulfate toxicity can be evaluated on a simple physical or chemical basis. Eaton (14) noticed that toxicity of chloride and sulfate cannot be expected to be independent of the kind and proportions of the bases with which they are associated in culture or soil solution. The tips of older leaves of barley plants under both the chloride and sulfate treatments were burned considerably, and this burning was more pronounced with the higher concentration (14). Almost similar effects were observed by the author in case of barley under treatment nos. 4 and 5. Eaton (14) also noticed that both chloride and sulfate salts decreased the succulence of barley but different values of exchangeable Na in the present study did not produce any observable effect on succulence of barley or tomato plants.

Ayers (3) found that when the irrigation water contained 5000 PP of added salt, emergence of seedling of barley was delayed 2-3 days. When 10,000 PP salts were added to the water, there was an additional delay of 1-2 days. No such adverse effects on germination of barley or tomato were observed under high values of ESP in this study. At the end of the second period of growth Ayers (3) observed marked difference between treatments. The control plot had produced by far the greatest amount of growth and the herbage was lighter green in color than that of any of the saline treatments. Similar results were not found in this study. There was no observable difference in color of foliage under control and high ESP treatment.

However, tip burn, necrosis and chlorosis occurred in older leaves under treatment No. 5. Ayer (3) also found that the decrease in plant height and weight of straw as a result of salinity was greater by far than the yield decrement of threshed grain. The adverse effects of ESP on barley plant height, on dry weight of straw and on dry weight of ears also were found to be of different magnitude in this study. The height was 84% of check, dry weight of straw was 91% of check and dry weight of ears was 82% of check under treatment No. 5.

Hayward and Long (21) observed that the leaves of tomato plants at the high salt concentrations were significantly thicker in the NaCl and Na_2SO_4 series than in the base nutrient culture. The leaves of plants grown in high NaCl solution were more succulent than those of the base nutrient and Na_2SO_4 series (21, 22). In contrast, no such effects on leaves of tomato plants were observed under high ESP treatments of this study except the symptoms already mentioned.

The osmotic concentration of the substrate appeared to be a primary factor in growth inhilition, although secondary effects of the Cl^- and $SO_4^=$ were noted (22). Hayward and Long (21) found a progressive growth depression with increasing concentration in the NaCl and Na_2SO_4 series. A significant reduction in the diameter of first internode of stem of tomato plant was observed at the high concentration 48 days after planting. This was least in the NaCl and greatest in the Na_2SO_4 series. Hayward and Long (21) found that percentage of dry matter increased with increasing concentration in the Na_2SO_4 and remained practically unchanged in the NaCl series.

This indicated greater succulence in the high chloride plants than in those of the Na_2SO_4 series. Although no direct comparisons were made, no such effects of different values of ESP were observed by the author on tomato plant.

Evidence of a substantial benefit to tomatoes from chloride concentration as high as 10 me/L was observed by Eaton (14). In sulfate concentration of 2.5, 5.0 and 10 me/L the tomato plants were of approximately equal weight. Growth was slightly depressed in the solution with only 1 me/L of sulfate and in solutions with more than 10 me/L of sulfate successive reductions in growth occurred. Symptoms of injury other than decrease in size were not in evidence. Average green weight of tops per plant was 3.0 gm and 13.0 gm under 100 me/L and 10 me/L of chloride concentration respectively. Tomato plants accumulated far more Ca from solution high in sulfate. Calcium accumulation is thus not independent of the complementary ion with which it is supplied. However, as demonstrated by data from this study (Tables 8, 9 and 10), the uptake and accumulation of Ca is highly influenced by adsorbed cations even in a soil rich in lime.

Physiological Ca deficiency may be a factor contributing to the detrimental effect of high concentration of cations in the growth media whether they are present as salt or adsorbed ions. Similar effects may occur with other nutrient ions as well. These effects may be very important aspects of high Mg or Na in saline soils in addition to the non-specific salt effect on water availability.

SUMMARY AND CONCLUSIONS

The role of adsorbed ions on plant growth was not emphasized by early soil scientists and considerable uncertainty still exists about the varying effects of exchangeable ions on plant development. Little information is available as to the causes for these extreme differences among crop species.

This study was undertaken to determine the tolerance of plants for exchangeable Na and Mg as resin adsorbed ions, to study the harmful effects of higher concentrations, to note if any stimulating effect resulted from low concentration, and to observe the specific effects of Na and Mg adsorbed cations in single and in complementary proportions on the growth and cationic accumulation in barley and tomatoes.

The deleterious effects of Na or Mg on dispersion or swelling of soil colloidal systems was essentially eliminated by using coarse-textured soil and ion-exchange resins to provide the Na and Mg variables. The use of resins also eliminated the anion variable which accompanies ordinary salt studies.

Amberlite IRC-50, a synthetic cation exchanger, and soil (Manhattan very fine sandy loam) mixture was used as a medium of growth in greenhouse-pot experiment. Six treatments were employed with 6 replications under randomized block design. The percent saturation of the resin was maintained at 80, with complementary amounts of Mg and Na as follows: 80% Mg and 0% Na; 60% Mg and 20% Na; 40% Mg and 40% Na; 20% Mg and 60% Na; 0% Mg and 80% Na and control (identified as treatment Nos. 1, 2, 3, 4, 5, and control, respectively). Taking into account the amounts of Na and Mg in the soil and the CEC of the system, the exchangeable sodium percentage and exchangeable magnesium percentage ranged from .6% to 27.98% and 14.62% to 41.98% respectively. Resins for each treatment were prepared separately.

The analysis describes soil as nonsaline, mildly alkaline, rich in lime with pH of 7.8, EC of 1.3 mmhos/cm, low in organic matter and very low in available P. Phosphorous, nitrogen, and potassium were supplied at rates of 140, 360 and 50 lbs/2,000,000 lbs. of soil, respectively.

25 seeds of barley (Betzes variety) were seeded in each of 36 pots and 3 seedlings of tomato (Fireball variety) were transplanted in each of the remaining 36 pots. At the time of sowing 400 cc. of water was applied to satisfy the water holding capacity of the soil. Loss of water due to evaporation and transpiration was made up every day by addition of a measured quantity of water.

The effects of treatments were studied at 21, 31 and 54 days after seeding as the first, second and final harvest respectively. At first harvest five barley plants and one tomato plant were removed for analysis. At the second harvest five additional barley plants and one tomato plant were harvested. The plants from each harvest were dried, weighed and analyzed in the laboratory for Mg, Na, Ca and K. Data on the performance, advancement of maturity and any visually noticeable differences in response to various treatments were recorded.

After final harvest air dried soil samples from each pot were analyzed for soluble and exchangeable Ca, Mg, K and Na. pH and EC values of each sample were also determined.

The results of this study indicate that plants showed a considerable variation in growth and development in response to various levels of Na and Mg supplied as adsorbed cations in the growth media.

The following observations and conclusions were recorded.

1) In the first 3 weeks of growth no appreciable differences were observed in development of the plants in response to variables under study.

2) After 4 weeks from seeding the retardation in plant growth was pronounced and the plants developed very clear symptoms of chlorosis and necrosis under treatments no. 4 and 5. These symptoms were manifested by older leaves on the plants.

3) Necrosis on older leaves was more pronounced in barley than in tomatoes. Younger leaves of tomato plants under higher Na supply treatment showed patches of faded green color between the veins instead of uniform dark green color of leaves receiving high percentage of exchangeable Mg in the growth media.

4) Symptoms associated with high exchangeable Na percentage were late flowering; late, small and poor quality of fruit; reduced plant size and a marked reduction in average production of plants.

5) There was a significant difference of 4 and 3.3 inches in height at the time of final harvest between treatment no. 5 and check for tomato and barley plants, respectively.

6) High percentage of exchangeable Mg in growth media had no adverse effect on the height of plants.

7) Increasing Na concentration in the growth media resulted in a delay in maximum rate of growth as well as less total growth.

8) High values of exchangeable Na under treatment nos. 4 and 5 resulted in significantly less straw production than occurred under the check treatment. 40% or less exchangeable Na did not have significant adverse effects on straw production.

9) Number of ears produced by barley was significantly less and tillering was decreased from 27 under check to 20 under treatment no. 5.

10) Ear yield of barley was significantly reduced by exchangeable Na values of 60% or more.

11) Mean dry weight of tomato tops under treatment no. 5 was significantly less (60% of check) than yield from any other treatment.

12) Fruit production of tomato plants from treatment no. 5 was greatly reduced, both in number and weight, as compared to check or higher Mg.

13) The highest value of adsorbed Mg under treatment no. 1 resulted in maximum yield of tomato tops.

14) Pattern of Mg uptake by plants during different stages of growth was uniform, i.e., maximum absorption under treatments no. 1 and 2 minimum absorption under treatment no. 4, 5 and check.

15) Treatment effects on percent Mg in barley straw were more pronounced than in barley ears.

16) A significant increase in Na absorption by plants was observed during 3 stages of growth under increasing levels of exchangeable Na in the growth media.

17) The ratio of Na in straw to Na in ears gradually increased as more Na was absorbed by the plant. Concentration of Na in straw was about twice that in ears under check and treatment no. 1 but with increasing levels of exchangeable Na in the soil the ratio widened, ranging from 12.5:1 under treatment no. 2 to 23:1 under treatment no. 5.

18) High value of exchangeable Na under treatment no. 5 decreased the Ca and K uptake up to 50% of Ca and K absorption by plants under check.

19) High percentage of Mg (treatment no. 1) did not lower the K uptake by plants but lower levels of Mg in combination with Na, more than 20%, under other treatments significantly lowered the K absorption by plants.

20) Ca and K concentration of barley ear was close to half that of the straw.

21) Mg concentration in barley plants was found to be approximately 150 times more than Na; about 33% and 70% of Ca concentration under check and other treatments respectively; and about 20% of K concentration with little difference under various treatments.

22) Similar treatment effects were found on Mg % in tomato plants at 31 and 54 days but the plants were higher in Mg at 31 days and lower at 54 days than they were at 21 days after seeding. Percent of Mg under treatment no. 1 was found to be significantly greater than all other treatments, two and four times more than under check and treatment no. 5, respectively.

23) Concentration of Na was 50% less at the time of maturity than in the first 3 weeks.

24) High Na treatment was very effective in limiting Ca accumulation in tomato plants, particularly at earlier stages of growth.

25) An equal combination of Mg and Na results in maximum translocation of absorbed Ca to the fruit.

26) Mg concentration in tomato plant was found to be about 20% of Ca and 33% of K in tomato plants, but in fruit Mg was almost equal to Ca except under treatment no. 4 and 5 where Mg was about 50% of Ca.

27) The yield of Na in tomato was found to be one-third of that in barley when Na was present in the treatment.

28) Interference of exchangeable Mg and Na in Ca yield in barley and tomatoes was significant.

29) K yield in barley plant was more significantly decreased by exchangeable Na than by exchangeable Mg. It was 42% of check under treatment no. 5.

30) High exchangeable Mg under treatment no. 1 and 2 did not significantly influence the yield of K in tomatoes.

31) Generally EC increased as the supply exchangeable Na increased in the growth media.

32) Exchangeable Mg and Na in the soil were proportionate to their supply in the growth media.

33) The general effects of Mg and Na on exchangeable K remaining in the soil following harvest were that Mg had little or no influence, while increasing Na increased exchangeable K in soil.

34) Soluble Ca in the check soil under barley was found to be almost double

the amount in soil under treatment no. 3, 4, and 5. In general, soluble Ca in soil under tomato was lower than in soil under barley.

35) Soluble K under all treatments with tomato was lower in concentration than in soil under barley.

These results present several answers to the question about specific action of adsorbed Mg and Na on the growth of plants. The marked difference in the effect of exchangeable Na upon the growth response as compared with that of exchangeable Mg is a striking feature of this study. Comparison of results from this type of investigation with those of salt studies allows isolation of specific cation effects from non-specific salt or anion effects. It is apparent that salts at high concentrations may retard plant growth through specific cation effects as well as osmotic or other salt effects. Direct comparison of salt and adsorbed ion effects would be necessary to delineate the contribution of both types of effect under specific conditions.

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