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THE EFFECT OF SOIL SALINITY ON ZINC UTILIZATION BY WHEAT AND BLACK BEANS

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MUNEER HASHIM SADDIQ

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ABSTRACT

The effect of adding manganese and zinc to wheat and black beans grown in salt-affected soils was studied under growth chamber conditions.

Increasing soil salinity by mixing various proportions of saline and nonsaline soil decreased the yield of wheat and black beans significantly with all micronutrient treatments. Adding zinc alone or with manganese had no significant effect on wheat yields at all salinity levels. However, black bean yields on nonsaline soils and at low salinity levels were increased significantly by zinc application. Zinc content and zinc uptake by wheat decreased with increasing salinity, whereas salinity had no significant effect on zinc content of black beans. Zinc uptake by black beans, however, decreased with increases in soil salinity.

The effectiveness of two zinc fertilizers, $ZnSO_4$ and ZnEDTA, in salt-affected soils was also studied. Zinc sulfate was more effective in increasing yield and zinc content at high salinity levels than was ZnEDTA. However, ZnEDTA on nonsaline and slightly saline soils was more effective than $ZnSO_4$ when added at equal concentrations.

Addition of various salts to a nonsaline soil decreased the yield of wheat with or without added zinc. The effectiveness of different salts in depressing yield was similar with and without zinc and followed the order NaCl (10.1 mmhos/cm) $>$ $MgCl_2$ (8.9 mmhos/cm) $>$ $CaCl_2$ (8.8 mmhos/cm) $>$ $MgSO_4$ (B) (8.7 mmhos/cm) $>$ $MgSO_4$ (A) (5.5 mmhos/cm). The chloride salts were more toxic to the plants than sulfate salts. Zinc content of plants decreased when the soil was treated with $MgCl_2$, $CaCl_2$ or $CaSO_4$ and increased when the soil was treated with NaCl or $MgSO_4$. However, the greatest increases occurred when $MgSO_4$ was added. Adding

zinc increased zinc content at all salinity levels. Zinc uptake decreased when salts were added except with $MgSO_4$ where the zinc uptake increased.

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INTRODUCTION

Numerous studies have been conducted to determine the uptake of macronutrients by field crops from soils adjusted to varying levels of salinity. In contrast, studies on the influence of soil salts on micronutrient uptake and the extent to which growth can be improved by adding various kinds of micronutrient fertilizers are limited. Soil salinity greatly affects plant growth by its effect on increasing the osmotic pressure of the soil solution causing a water stress. Excess soil salts may also interfere with nutrient uptake. High salt concentrations may produce nutritional imbalances by decreasing or increasing the uptake of essential nutrients as well as causing specific ion toxicities.

Zinc deficiencies have been noted in both saline and nonsaline soils. Several soils in many parts of the world are both saline and zinc deficient. Thus, in order to obtain a better understanding of zinc deficiency in saline soils, studies were conducted to determine:

1. The effect of soil salinity on the utilization of native and applied zinc.
2. The extent to which zinc fertilizer may improve plant growth under saline conditions.
3. The efficiency of $ZnSO_4$ and ZnEDTA as zinc fertilizers on saline and nonsaline soils.
4. The cations or anions responsible for altering zinc utilization on saline soils.

LITERATURE REVIEW

I. Soil Zinc

The total zinc content of soils varies from 10 to 300 ppm (Lindsay 1972). Hodgson *et al.* (1965) found the concentration of zinc in soil solution to vary from 10^{-6} to 10^{-8} *M* of which 30 to 70% was present as inorganic ions. Exchangeable zinc is usually less than 1.0 ppm (Lindsay 1972).

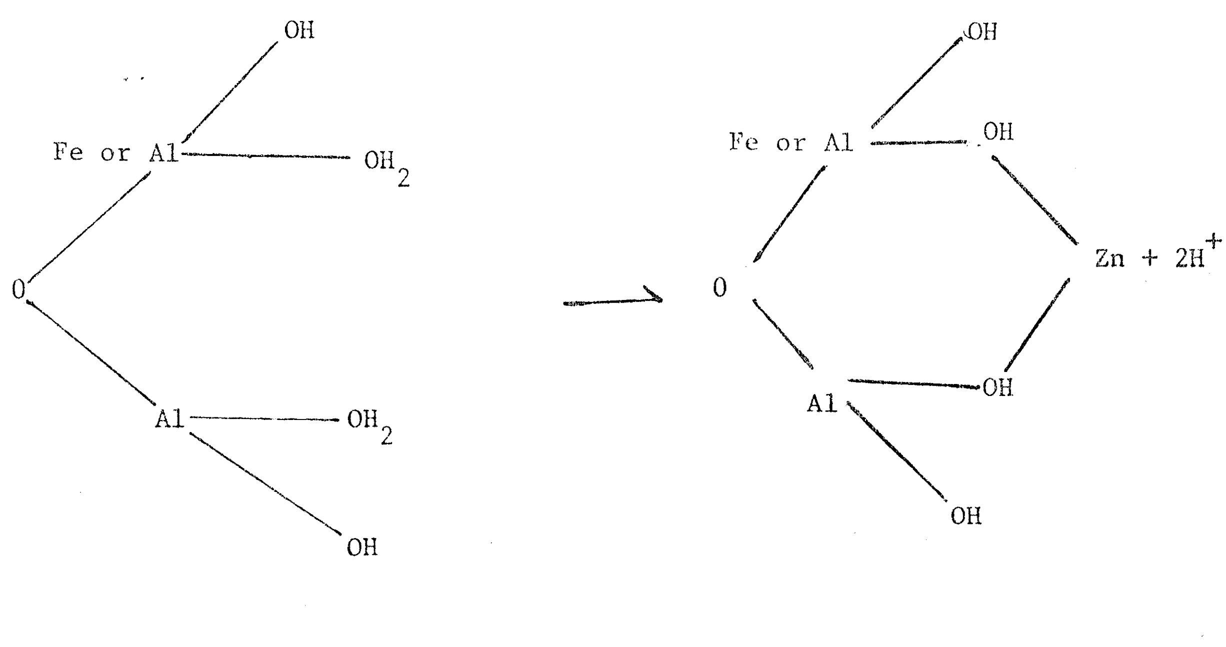
Total zinc content of surface soils is greater than for subsoils (Hibbard 1940; Thorne *et al.* 1942; Wright et al. 1955: Lindsay 1972; Swaine and Mitchell 1960; Follett and Lindsay 1970). Total zinc concentration is greatest in soils that have accumulated organic matter from leaf fall and other plant residues for long periods (Hibbard 1940; Wright *et al.* 1955). Zinc is enriched in the surface soil by vegetative residues and this may be a major factor in zinc deficiencies of deep-rooted plants. In general, zinc is not leached and soil accumulations are closely associated with residues of organic materials.

Zinc in soil is held by exchangeable sites and adsorbed to solid surfaces. Zinc in an active state in soil occurs either as the simple divalent cation (Zn^{2+}) or possibly as the monovalent $Zn(OH)^{+}$ ion (Russell 1973). Separation of zinc reactions into those of precipitation or adsorption is most difficult, and very few studies permit a clear conclusion on this point. One of the major problems in studying adsorption reactions of zinc has been the failure to consider which of the various hydrolysis and complex species of zinc in solution are adsorbed. Some workers have conjectured that retention of zinc in excess of the exchange capacity of soils may be due to precipitation of $Zn(OH)_2$, but the possibility of its precipitation has not been critically examined (DeMumbrum and Jackson 1956; Binghan and Sims 1964).

Most of the simple zinc compounds such as ZnO (zincite), $ZnCO_3$ (Smithsonite) are too soluble to persist in soils. Under reducing conditions where H_2S is produced, ZnS (Sphalerite) can form; but under normal oxidizing conditions the concentrations of $S^{=}$ is too low for this mineral to be stable (Lindsay 1972). Kittrick (1976) examined the solubility of ZnS in the presence of H_2S and found the concentrations of H_2S actually found in the atmosphere are high enough to engender control of zinc in the soil solution of aerated soils by ZnS. However, these results contradict findings of McGregor (1972) who reported that adding ZnS maintained a higher zinc concentration in soil solution than for untreated soils. He concluded that ZnS did not control zinc concentration in soil solution. Kalbasi (1977) found that the zinc concentration in soil solution increased with time when ZnS was banded. In contrast, the zinc concentration in soil solution decreased with time when the soil was treated with $ZnSO_4$ and ZnEDTA. He attributed this difference to the partial oxidation of ZnS to less sparingly soluble compounds. He also found that the concentrations of zinc in extracts of soils treated with ZnEDTA were much higher than concentrations of zinc in extracts of soils treated with $ZnSO_4$. Zinc concentrations in soil solution were much lower when the soils were treated with ZnS than when they were treated with $ZnSO_4$ or ZnEDTA. His results indicated that when non-calcareous soils were treated with $ZnSO_4$, the reaction product was $Zn(OH)_2$ which persisted for only a few weeks. $ZnSO_4$ was precipitated as $ZnCO_3$ or $Zn_5(CO_3)_2(OH)_6$ in calcareous soils which persisted for 32 weeks or more. No solid-phase reaction products were found when ZnEDTA was banded in the soil. He suggested that this may be caused by zinc persisting in the soil as ZnEDTA resulting in low concentrations of ionic zinc in soil solution and therefore little or no precipitation of zinc compounds near the ZnEDTA band. He also found that ZnS dissolved very slowly such that ZnS persisted in the soils at all sampling dates. He concluded that when very large amounts of zinc were applied to soil or when microregions in soil were saturated with zinc, such as a band or point source of application, the formation of new zinc solid phases, in addition to adsorption and fixation were very likely.

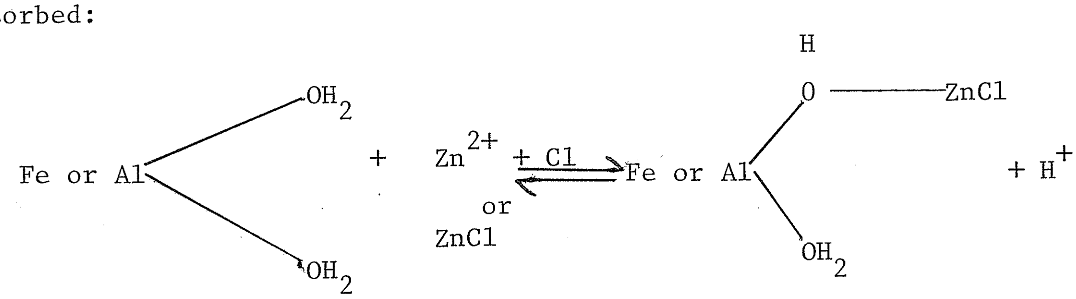
Jenne (1968) proposed that zinc, along with several other heavy metal ions, may be occluded and coprecipitated with hydrous oxides of manganese and iron and that these oxides form the principal matrix in which the less abundant heavy metals are held. Tillar (1967) concluded that the interaction between zinc and silicic acid is probably due to adsorption rather than formation of a separate zinc silicate phase. Nelson and Malsted (1955) studied the reaction of zinc with montmorillonite and concluded that strongly bound zinc was desorbed according to first-order chemical kinetics. Kalbasi (1977) postulated two mechanisms for zinc adsorption by oxides of Fe and Al (Fe_2O_3 and Al_2O_3):

1 - Specific zinc adsorption which involved adsorption of Zn^{2+} and the release of two H^+ ions for each mole of zinc adsorbed:



Adsorption by this mechanism accounted for 60 to 90% of zinc absorbed by Fe and Al oxides (Kalbasi 1977).

2 - Nonspecific zinc adsorption which involved adsorption of $ZnCl^{+}$ or Zn^{2+} plus Cl^{-}, and the release of one H^{+} ion for each mole of zinc adsorbed:



Adsorption of zinc by this mechanism accounted for 10 to 40% of total zinc adsorbed and decreased markedly with increasing pH.

Udo et al.(1970) found that the adsorption of zinc by calcareous soils could be explained by the Langmuir adsorption equation and the solubility of zinc in calcareous soils corresponded to the solubility of zinc hydroxide or carbonate when the amount of added zinc exceeded the adsorption maximum. Algabaly and Jenny (1943) concluded that some adsorbed zinc becomes non-extractable by entering the octahedral layer of montmorillonite. Later, Elgabaly (1950) suggested that zinc might be fixed in holes normally occupied by Al^{3+} in the octahadral layer. Zn^{2+} with an ionic radius of (0.83Å)was found to substitute to some extent for Mg^{2+}(0.78Å) and Fe^{2+} (0.83Å) due to their ionic radii similarity (Goldschmidt 1954). Thorne (1957) indicated that zinc was adsorbed on the crystal surfaces of dolomite and magnesite at sites in the lattice that were normally occupied by Mg^{2+}. Zinc formed a silicate mineral (Souconite) when zinc substituted for Mg in montmorillonite (Lindsay 1972).

High levels of organic matter in the upper horizon of soil are believed to be important in keeping zinc more available in the surface horizon of soil. Numerous studies have demonstrated a high correlation between organic matter and chemically extractable or plant available zinc (Follett and Lindsay 1970; Martens et al. 1966). Apparently organic matter can interact with zinc in three important ways: -

1. Organic zinc can be mineralized and made available to plant.
2. Organic matter constituents can form mobile and labile complexes with zinc.
3. Zinc can be bound into organic constituents that are immobile in soils and constitute a fixation mechanism by which zinc is not readily released.

The presence of soluble zinc-organic complexes in soils was demonstrated by Hodgson et al. (1966). They concluded that on the average about 60% of the soluble zinc in soils was complexed with organic matter. The degree of complexing of zinc was correlated with soluble organic matter ($r = 0.88$). Stevenson and Ardakani (1972) reviewed the reactions of organic matter with micronutrients. They concluded that insoluble metal combinations were most likely bound to the humic fraction, particularly humic acid, while soluble metal complexes were mainly associated with individual biochemical molecules such as organic acids and amino acids. Metal complexes with fulvic acid were found to have high water solubilities.

Randhawa (1965a,b) studies the adsorption of zinc by humic acid. The least stable fraction that accounted for most of the zinc was believed to be associated with phenolic-OH and weakly acidic-COOH groups. The more stable fraction of zinc was bound by stronly acid-COOH groups. In his studies, strongly bound zinc represented less than 1% of the total zinc retained.

II. Zinc in the Plant

Lack of zinc in plants results in distinctive plant symptoms associated with retardation of normal growth and a lack of chlorophyll. An abnormal shape of palisade cells and an almost complete absence of chloroplast and starch were also observed in zinc-deficient plants such as corn, tomato, buckwheat and mustard (Thorne 1957). Zinc plays an important role in auxin formation and in other enzyme systems. Zinc is recognized as an essential component in several dehydrogenases, proteinases, and peptidases (Vallee and Walker 1970).

Skoog (1940) investigated the relationship between Zn deficiency and auxin production. He could find no auxin activity in stems of zinc deficient tomato and sunflower plants and a very reduced activity in the leaves. When zinc was added to severely affected plants, auxin content increased greatly in one to a few days. He postulated that auxin destruction in deficient plants resulted from an increase in peroxidase activity. The role of zinc in auxin production of plants has been further clarified by Tsui (1948a). He confirmed the findings of Skoog with respect to the reduction in auxin content of zinc-deficient plants and further showed that the decrease in auxin applied to bound auxin as well as to free auxin. Tsui (1948b) found that within two days after zinc was added to deficient plants, the water content of the plants increased and growth resumed. The osmotic pressure of the sap of the tops of zinc-deficient plants ranged from 5 to 9 atmospheres, whereas that of the controls varied from 5 to 6 atmospheres. The changes in water content were directly related in time to changes in auxin content. These findings are consistent with the report of Skoog et al.(1939). He found the application of indoleacetic acid (auxin) to decapitated stems increased uptake of water and salt. Van Overbeek (1944) also showed that auxin increased the uptake of distilled water by potato discs. Apparently the increased water in tissues in the presence of auxin did not result from water moving against a concentration gradient, but resulted from the action of auxin under aerobic conditions in causing a loosening of the cell wall which allowed the cell to absorb water and expand osmotically (Orden *et al*. 1956; Cleland and Bonner 1956).

Kessler and Monselise (1959); Brown and Hayward (1966); and Prask and Plocke (1971) found that RNA and ribosome levels decreased in zinc deficient plants.

The findings noted above show that zinc plays a role in production or functioning of several enzyme systems. However, the interrelationships involved have not been clarified.

III Factors Which Affect the Availability of Zinc in Soil

1. Soil pH

Plant uptake of zinc decreases as pH increases (Thorne 1957; Lindsay 1972). Lindsay (1972) found the solubility of zinc decreased 100-fold for each unit increase in pH. Lott (1938) showed that zinc toxicity was eliminated by the addition of $CaCO_3$ to a soil when the pH was increased to 6.0 or above. He found the mininum uptake of zinc by oat seedlings occurred at a pH of 6.5. Peech (1941) found Zn extracted with one normal NaCl increased with decreasing soil pH. Sharpless *et al*. (1969) suggested the decrease in availability of zinc with increasing pH was due in part to formation of Zn-hydroxide and Ca-zincate which have low solubility. Kalbasi (1977) felt that the decreasing availability of zinc with increasing pH was due to the adsorption of zinc by iron and aluminum oxides which increased with increasing pH. At low pH values, some Zn^{2+} may be present on the exchange complex of soils, but at high pH values the level of Zn^{2+} in solution is so low that very little Zn^{2+} is held on the exchange complex (Lindsay 1972).

2. Soil Texture

Soils with a high proportion of clay retain or contain more zinc than soils with a high proportion of sand. Sandy soils are often deficient in available zinc since quartz is generally low in total zinc (Lucas and Kneezek 1972). Martens *et al.*(1966) found the amount of zinc extracted by 0.2 *M* $MgSO_4$ varied inversely with clay content.

Udo *et al.* (1970) found a good correlation between zinc content and organic matter and clay contents, suggesting that these two soil components are primarily responsible for retention of native zinc in some Arizone calcareous soils. The fixation of zinc in clay lattices was reported by Nelson and Melsted (1955). Zn^{65} was added to soils and clays with different exchangeable cations and measured zinc adsorption. The data indicated that zinc retention by soils in relation to other cations followed the order:

$$H > Zn > Ca > Mg > K$$

The low availability of zinc in soils with a high clay content may be due to two processes:

1. Adsorption on clay particles as Zn^{2+} or $Zn(OH)^+$
2. Precipitation of zinc as zinc hydroxide

It has been found that the strongest adsorption of zinc on crystal lattices was associated with surfaces that contain the Mg^{2+} ion (Thorne 1957).

3. $CaCO_3$ Content

The amount of $CaCO_3$ in the soil has an important effect on the availability of soil zinc to plants and zinc deficiencies are common on calcareous soils (Thorne 1957). Calcareous soils have pH values of 7.4 or higher; the high pH values lower the availability of zinc; thus, zinc deficiencies would be expected on calcareous soils.

Leeper (1952) postulated that $CaCO_3$ may act as a strong adsorbent for heavy metals. Ravikovitch et al. (1968) found the zinc content of six crops grown on highly calcareous soils with a mildly alkaline reaction to be low; the zinc content of plants decreased with increases in the $CaCO_3$ level in the soil. Navrot and Ravikovitch (1969) used twenty-one calcareous soils and found an inverse relationship between native zinc absorption (content and uptake) by tomato plants and soil $CaCO_3$ content.

4. Organic Matter

Soil organic matter forms very stable complexes with zinc (Ellis and Kneezek 1972). Thorne (1957 and Baughman (1956) reported that zinc retained by organic matter was in two forms, chelated zinc and complexed zinc. Chelated zinc was defined as the portion of zinc that was extractable with copper acetate, whereas complexed zinc was designated as that portion which was not extractable by either copper or ammonium acetate, but which was released by oxidation of the organic matter with hydrogen peroxide. Thorne (1957) suggested that chelation and complexing of zinc by organic matter may be a significant factor in reducing zinc availability in soil. Several workers found that the Zn-organic matter complex supplied zinc in plant available form after it decomposed. Follet and Lindsay (1970) found a high correlation between organic matter content and DTPA extractable zinc. Martens et al. (1966) found that an increase in organic matter content at a constant level of clay increased the amount of zinc bound by the organo-clay complex, thereby resulting in increased extractability of soil zinc by 0.1 N HCl.

5. Available Phosphorus

An abnormally high content of soluble phosphate in soil can cause zinc deficiencies (Thorne 1957). In a study of zinc deficiency in tung trees in Florida, Mowry and Camp (1934) found that high phosphate in the soil was an important factor in reducing the availability of zinc. Ellis and Thurlow (1964) found a negative correlation between zinc and phosphorous concentration in corn tissue. Martin et al. (1965) found that phosphorus application reduced zinc concentration in potato tissue while zinc application tended to reduce phosphorus concentration in the tissue. Stukenholtz et al. (1966) suggested that the depressive action of phosphorus on zinc nutrition of corn was physiological in nature expressed at the root surface and/or in root cells, and not the result of chemical inactivation of zinc in the soil. The actual cause of phosphorus induced zinc deficiency is still unknown. Haluschak (1971) found that the zinc content of wheat and flax decreased with increasing amounts of added phosphorus and concluded ion antagonism was responsible for reduced zinc uptake in a high phosphorus medium. In contrast to the above findings, Boawn (1954) found the application of superphosphate to soils in the Columbia Basin area of Washington did not effect uptake of either applied or native zinc by beans.

6. Soil Temperature

Zinc deficiencies are usually found in field crops during the early part of the growing season and may disappear by midseason (Pumphrey and Koehler 1959; Lindsay 1972). Bauer and Lindsay (1965) found that soil incubated at $43^{o}C$ for 163 weeks released available zinc to corn plants. Martin et al. (1965) found that high P application induced zinc deficiency in tomato at a low temperature, but this effect was eliminated by increasing the temperature. On the other hand, Rudgers et al. (1970) found the zinc concentration in corn grown at a high temperature lower than the zinc concentration in corn grown at a lower temperature. Lindsay (1972) suggested two means by which zinc availability to plants was reduced by cool temperatures: (1) the plant root system was not well established in cool soils and thus their feeding zone was restricted; (2) release of plant available zinc from organic matter was decreased due to decreased microbiological activity.

7. Effect of Ions

Lindsay (1972) indicated that alkaline earth cations strongly depressed zinc uptake by wheat over a wide range of concentrations. The order of effectiveness in depressing zinc uptake was $Mg^{2+} > Ca^{2+} = Ba^{2+} = Sr^{2+}$. Of the cations studied, magnesium was the most effective in depressing zinc uptake by plants. In contrast, Merril *et al.* (1953) found that leaves of tung plants grown in soil treated with magnesium had a high zinc content, whereas soil treated with zinc increased the uptake of magnesium. This was in agreement with the results of Jurinak and Bauer (1956) who found a close relation between the adsorption of zinc and magnesium. They postulated that zinc adsorbed on the crystal surface at sites normally occupied by magnesium and this was due to similarity in the ionic radii of zinc and magnesium, which are 0.83Å and 0.78Å, respectively. Seatz (1960) found the use of a liming material containing some $MgCO_3$ decreased the severity of zinc deficiency in flax and sorghum. In other studies, Seatz (1960) observed an increase in zinc availability when soils were treated with $MgSO_4$. He suggested that increase in zinc availability was due to the Mg^{2+} per se and not to any zinc impurities that may be associated with liming materials.

Bowen (1969) and Schmid *et al.* (1965) found the addition of copper depressed the uptake of zinc. They suggested that both zinc and copper may be absorbed at the same uptake site.

IV. Saline Soils and Effect of Alinity on Plant Growth

Soils are classified as saline when they contain an excess of soluble salts; the electrical conductivity of a saturated paste extract is more than 4 mmhos/cm at 25^{o}C, and the exchangeable-sodium percentage is less than 15. Ordinarily the pH is less than 8.5 (U.S.D.A. Handbook 60). A saturation extract with a specific conductivity of 4 mmhos/cm corresponds to a salt concentration of 45 me/liter ($10.37 \times 4^{1.065}$); to a solute suction of 1.46 atm (4×0.365) and to a percent salt in the saturation extract of $4 \times 0.064 \times$ saturation percentage (U.S.D.A. Handbook 60).

Plants grown on saline soil tend to be relatively small in size and have a dark bluish-green color. Occasionally, symptoms such as browning of the tip, marginal or interior portions of leaves, leaf mottling, leaf curling and incipient chlorosis are exhibited (Black, 1968).

Three theories have been advanced to account for the detrimental effects of soil salinity on plant growth: -

1. Water Availability Theory

Soluble salts in saline soils increase the solute suction of the soil water, thereby decreasing availability of water to plants (Eaton 1941; Hayward and Spurr 1944; Hayward and Wadleigh 1949: Gauch and Wadleigh 1944; Wadleigh and Ayers 1945). Eaton (1941) showed that the rate of entry of water into roots was inversely proportional to the physiological availability of the water as measured by the osmotic pressure of the nutrient solution. Magistad et al. (1943) studied the growth response of numerous crops in sand cultures in which relatively large quantities of chloride and sulfate were added to nutrient solutions.

Growth inhibitions accompanying increasing concentration of added salts was virtually linear with increases in osmotic pressure and was largely independent of whether the added salts were choride or sulfate. Gauch and Wadleight (1944) found the effect of NaCl, $CaCl_2$, Na_2SO_4 on bean plants to be similar at equal osmotic pressures. However, he obtained more severe growth inhibition with $MgCl_2$ and $MgSO_4$ than with the other salts at the same osmotic pressures. He suggested this may have been due to a toxic effect ot Mg^{2+} on the bean plant. Hayward and Spurr (1943) also noted a toxicity of Mg using corn as a test crop.

2. Osmotic - Inhibition Theory

This theory suggests that plant growth is inhibited by the excess of solutes taken up from a saline medium. This theory postulates that the excess salts absorbed by the plant decreases the free energy of a unit mass of water even though the absolute mass of water in the plant may not be reduced after the plant has adjusted to the excess of salts present externally (Bernstein 1961; Slayter 1961).

Slatyer (1961) studied osmotic adjustment in young tomato plants subjected to osmotic pressure increases of 5 and 10 atm by addition of KNO_3, NaCl, mannitol, or sucrose to the nutrient solution. Initial wilting was followed by rapid recovery in all treatments except with mannitol. Recovery was associated with solute uptake; chloride and sucrose, for example, rapidly reached the same concentration in the plant as in the medium. He suggested the depression in plant growth was due to osmotic adjustment by the plant rather than to the reduction of water uptake. He assumed that osmotic adjustment by plants grown in a saline medium may have decreased the cell turgor pressure and reduced the cell water potential. Bernstein (1961) found the leaves, stems and roots of pepper and cotton plants increased in osmotic pressure by approximately the same amount as the osmotic pressure of the medium increased. It was concluded, therefore, that a decreased osmotic gradient for water uptake such as might occur in plants not adjusted to the increased osmotic pressure of the medium, could not be responsible for impaired growth of these adjusted plants on the saline media. He suggested many possible mechanisms for osmotic growth inhibition in plants, despite the osmotic adjustemnt mechanisms. These included a possible inability of subcellular osmotic units (mitochondria and plastids) to adjust to the higher osmotic pressure, and the possibility that osmotic adjustment in itself may limit growth by requiring all cells to develop and maintain higher concentrations of solutes, and the possibility that increased osmotic pressure of the cell or increased concentrations of specific ions may affect anzymes, many of which have been shown to be sensitive to osmotic pressure, salt concentration, or specific ions (Miller and Evans 1956: Honda and Muenster 1961).

3. Specific - Toxicity Theory

This theory suggests soil salinity exerts a detrimental effect on plants through the toxicity of one or more specific ions in the salts present in excess (Black 1968). Ions that are frequently found in excess in saline soil include chloride, sulfate, bicarbonate, sodium, calcium, and magnesium. Ions less frequently encountered in excessive amounts in saline soils are potassium and nitrate (Hayward and Wadleigh (1949). Species and even varietal differences among plants make it difficult to generalize regarding the toxicity of various salts or ions (U.S.D.A. Handbook 60). However, differences in plant tolerance to excessive concentration of ions in the substrate are related, to some degree, to specific selectivity in ion absorption and nutrient requirements of the plants (Hayward and Wadleigh 1949; Bernstein and Ayers 1953; Brown and Hayward 1956; Abel and Mackenzie 1964; Francois and Bernstein 1964; Bernal and Oertli 1974).

The effects of specific ions which may be accumulated in saline soils are discussed in the next few paragraphs.

1 - Na^+

Relatively little evidence was found in the literature indicating specific toxicity of sodium to plants growing in saline soils. Many plant species tend to exclude sodium absorption (Collander 1941; Hayward and Wadleigh 1949). Hayward and Wadleigh (1949) suggested that a specific toxic effect of sodium could arise from the exclusion of sodium along with an accumulation of accompanying anions from the substrate. However, Hayward and Long (1941) found there was an accumulation of sodium in tomato plants when grown in a soil containing excessive amounts of NaCl and Na_2SO_4. Ehlig (1964) obtained similar results with raspberries, blackberries and boysenberries.

2 - Mg^{2+}

High concentrations of Mg^{2+} in the substrate have been found to be far more toxic to plants than would result from inhibition in growth associated with osmotic pressure effects (Wadleigh and Gauch 1944).

Gauch (1940) and Wadleigh and Gauch (1944) suggested that Mg^{2+} injury may be associated with an inadequate supply of Ca^{2+} within the tissue and the plant may recover from Mg^{2+} toxicity symptoms when Ca^{2+} is also present at a relatively high level.

3 - Ca^{2+}

The specific effects of high concentrations of Ca^{2+} vary with plant species. Some plant species such as guayule were more tolerant to saline substrates dominated by $CaCl_2$ than to those dominated by other neutral salts (Wadleigh and Gauch 1944). Wadleight _et al_. (1951) reported a specific toxicity of Ca^{2+} to orchard grass grown in soil cultures treated with various salts.

4 - Cl^{-}

For many species of plants, chloride salts are no more inhibitory to growth than isosmotic concentrations of sulfate salts (Hayward and Long 1941; Magistad _et al_. 1943). However, Brown and Hayward (1953) found chloride salts to be toxic to peaches and other stone fruits. Ehlig (1964) found foliar symptoms of excess salinity were associated with a high concentration of Cl^{-} in blackberries, boysenberries and raspberries.

5 - SO_4^{2-}

There are numerous reports concerning the specific toxicity of high concentrations of sulfate for crops such as beans (Gauch and Wadleigh 1945); cotton and orchard grass (Hayward and Wadleigh 1949). The reports show that high concentrations of sulfate in the substrate definitely limit the activity of the calcium ion and thereby condition cationic intake by plants. Analyses of leaves of beans (Gauch and Wadleigh 1945) showed that the tissues contained an appreciably lower content of calcium and higher contents of sodium and potassium when sulfate was the predominant anion in the substrate as compared to similar cultural conditions in which chloride was the predominant anion. Hayward and Wadleigh (1949) indicated that toxicity of sulfate may be caused, at least in part, through effects on the uptake or metabolism of essential nutrients.

V. The Effect of Soil Salinity on Uptake of Macronutrients

1. Nitrogen

Haas and Reed (1926) found in short-term absorption experiments with citrus seedlings that nitrate absorption was depressed by the addition of eight millequivalents of chloride per liter. Chapman et al. (1940) found increases of both anions and cations depressed absorption of nitrate. Using citrus as a test crop, they showed that a balance between calcium and potassium favorable for potassium absorption exerted a favorable influence on nitrate absorption. Gauch and Eaton (1942) showed the nitrogen content of barley increased with increasing salinity. Comparable results were obtained with kidney beans by Wadleigh and Ayers (1945). Lunin and Gallatin (1965a) found salinity had little effect on the nitrogen content of bean leaves, whereas there was a pronounced increase in the nitrogen content of the stems. In contrast to the above findings, Ravikovitch and Porath (1967) found plant nitrogen content decreased with increased salinity in most crops (cowpeas, tomato, corn, vetch). Khalil et al. (1967), in their experiment with cotton, found that salinity had no marked effect on nitrogen uptake. results were similar to those of Langdale and Thomas (1971), who found that relatively high levels of soil salinity did not inhibit nitrogen absorption by coastal bermudagrass, but appeared to block metabolic pathways for protein synthesis. Ravikovitch and Yales (1971) found increasing salinity resulted in reduced yields, and increased nitrogen content of millet plants.

The effect of soil salinity on uptake of nitrogen appears to be variable depending upon plant species and availability of nitrogen from the soil under saline conditions.

2. Phosphorus

Chapman et al. (1940) found no evidence that high chloride or sulfate depressed phosphate absorption. Bernstein and Hayward (1958) indicated that Relfenberg and Rosovsky (1947) found little or no effect of chloride at concentrations up to 3000 ppm on the absorption of phosphate by barley seedlings. However, an increase in phosphate concentration in the growth media depressed chloride absorption. Gauch and Eaton (1942) also found that salinity had no effect on the phosphorus content of barley. However, Lunin and Gallatin (1965b) found that salinization of the soil by seawater containing NaCl, $MgCl_2$, $CaSO_4$, K_2SO_4 tended to decrease the phophorus content in both leaves and stems of bean plants. This was also observed when varying amounts of phosphorus were added, even though phosphorus fertilization generally tended to increase the phosphorus content of the plant at a specific salinity level. They suggested the decrease in phosphorus content with increasing salinity may have been due in part to the precipitation of phosphorus as insoluble compounds of calcium and magnesium. Ravikovitch and Porath (1967) also found a trend toward decreasing phosphorus uptake by cowpeas and tomato with increasing salinity. However, adding large amounts of phosphorus to the saline soil led to an increase in phosphorus content in the plant tissues as compared to the nonphosphated soil at the same salinity level. Khalil _et al_. (1967) found phosphorus uptake by cotton and corn decreased with increasing salinity and the decrease was proportional to reduction in root growth. Their work was supported by Hassan _et al_. (1970a), who found that extractable phosphorus in the soil increased slightly with increasing salinity, but the uptake and concentration of phosphorus in the vegetative parts and grain heads of barley were depressed by increasing salinity. They suggested that since phosphorus was not highly mobile in the soil the depression in uptake of phosphorus may have been related to a reduction in root growth caused by soil salinity and an associated decrease in the surface area of roots in contact with phosphorus in the soil.

Most reports indicated that salinity decreased phosphorus uptake by crops. In some cases, little or no effect of salinity on phosphorus uptake was observed. Although investigators did not agree on the effect of salinity on phosphorus uptake, all investigators agreed that adding phosphorus to the soil increased the phosphorus content of plant tissue and improved the plant growth under saline soil conditions (Ravikovitch and Y ales 1971; Lunin and Gallatin 1965b; Ravikovitch and Porath 1967; Peter 1963).

Potassium

Chapman et al. (1940) found that increasing the concentration of both calcium and potassium in the nutrient solution decreased the absorption of calcium but increased absorption of potassium. In contrast, Khalil et al. (1967) found that soil salinity achieved by the addition of $CaCl_2$, $MgCl_2$ and NaCl caused the potassium content of cotton to decrease. They suggested that salinity presumably depressed potassium absorption and may have increased the absorption of Ca^{2+}, Mg^{2+}, and Na^{+}. Decreases in potassium content with increases in salinity have also been reported by Francois and Bernstein (1964) with safflower; by Hassan et al. (1970a,b) with barley and corn; by Ravikovitch and Yales (1971) with clover; and by Torres and Bingham (1973) with wheat. The decrease in uptake of potassium by the stems and leaves of plants may have been related to attendant increase in the uptake of sodium (Bange 1959). Ravikovitch and Yales (1971) using millet as a test crop, found that as soil salinity increased, there was an increase in plant potassium content and a decrease in the K/Na ratio in the plant. Bernstein et al. (1974) found that the potassium content of barley, lettuce and carrot leaves decreased with increasing leaf sodium and calcium content, but in wheat, a large increase in leaf calcium content had little effect on leaf potassium content.

Chapman et al. (1940) indicated that Burstrom (1934) had shown that there was antagonistic effects between calcium and potassium and that this effect was more pronounced when the two ions were present in about equivalent quantities. A relatively small change in the concentration of either ion produced greater antogonism than when the amount of the two ions were greatly out of balance. Chapman et al. (1940) found in experiments with citrus, that increases in the concentrations of both ions resulted in decreased calcium and increased potassium absorption, and they emphasized the importance of mass-action effects in the phenomena of antagonism.

VI. Effect of Soil Salinity on Uptake of Zinc and Manganese

Manganese toxicity has been recognized as an important factor affecting the production of crops under a number of different conditions. The increase in the solubility of manganese associated with decreases in soil pH and the increase in divalent maganese associated with reducing conditions, have long been recognized as factors affecting the amount of manganese available to plants (Conner 1918; Piper 1931). Availability of manganese has been found to increase with salt addition to the soil (Foy 1964; York et al. (1954). Manganese content of alfalfa and corn increased with NaCl and KCl addition to the soil (York et al. 1954). They suggested the addition of these salts decreased soil pH and increased the availability of manganese. Jackson et al. (1966) suggested that the increase in manganese availability was due to the prescence of the Cl^- ion rather than to the decrease in soil pH. They found the addition of K_2SO_4 and K_2CO_3 did not affect manganese uptake by bushbean, whereas the addition of KCl increased manganese in the plant to toxic levels. Addition of $CaCl_2$ to the soil had effects similar to that of KCl.

Hassan et al. (1970a) suggested that the increase in manganese uptake by barley with increasing soil salinity was due to a reduction in soil pH (from 6.7 to 6.0) when salts were added to the soil. In contrast to the findings with barley, Hassan et al. (1970b) found the uptake of manganese by component parts of corn decreased with increased salinity, even though the manganese concentration in component parts of corn increased with salinity. Thus, the reduction in manganese uptake with increased salinity was due to a greater reduction in vegetative yield than increase in manganese concentration. Maas et al. (1972) found the manganese concentration in tomato and soybean tops increased with increasing soil salinity when soils were salinized by adding a solution containing NaCl. In contrast, they found the manganese concentration in squash tops decreased with increasing salinity. Thus, the NaCl had a specific inhibitory effect on manganese uptake by squash. Raviovitch and Navrot (1976) found that manganese uptake by tomato and millet increased with increased soil salinity (0.5 to 13 mmhos/cm) when NaCl was added. They suggested three possible reasons why this occurred.

1. Decreased soil pH with the addition of salts.
2. The effect of the chloride ion on the oxidation-reduction reactions of manganese in soil.
3. The replacement of manganese by sodium on the soil-exchange sites.

They also found that application of $MnSO_4$ to the soil increased the uptake of maganese by tomato and millet at all salinity levels. Application of $MnSO_4$ to the saline soil counteracted to some degree the depression in growth caused by salinity. The $MnSO_4$ fertilizer was more effective in increasing growth at high salinity than at low salinity.

Addition of salts to soils increases zinc uptake by plants; this may be due to the reduction in soil pH caused by soil salts. Altering the pH of soils alters zinc availability in soil (Hassen et al. (1970a). Increase in zinc availability by salinization of the soil may also be related to the replacement of exchangeable zinc. Zinc in the soil can be partially extracted by neutral salts (Ravikovitch et al. 1968; Stewart and Berger 1965; Martens et al. 1966). Stewart and Berger (1965) used 2 N $McGl_2$ solution as an extractant for available zinc in soil. They suggested that Mg^{+2} ion being alike in charge and ionic radius to the zinc ion, could readily displace the available zinc from the soil. Also, an excess of chloride would form a stable complex with zinc and would tend to derive the reaction to completion. Magnesium chloride was also used as an extractant for available zinc by Matt (1971). Ravikovitch et al. (1968) indicated that Bergh (1947) had used $MgSO_4$ as an extractant for available soil zinc. Martens et al. (1966) also used $MgSO_4$ as an extract of soil available zinc but suggested that only the zinc in soil solution and readily exchangeable zinc was extracted by 0.2 M $MgSO_4$. Other salts such as NH_4NO_3, KCl, $CaCl_2$ have been used to measure soil available zinc (Navrot and Ravikovitch 1968; 1969; Ravikovitch et al. 1968). Thus, adding neutral salts to the soil likely displaces zinc from the soil solid surfaces and adding salts to the soil would tend to increase zinc uptake by plants. Ravikovitch and Navrot (1976) found the availability of zinc to increase when a NaCl solution was added to soil to create saline soils in the range of 0.5 to 13 mmhos/cm electrical conductivity. They suggested that salinizing soil with NaCl may well cause replacement of the exchangeable zinc which then becomes more readily plant available. They found that adding NaCl increased zinc uptake by tomato plants grown in a loam soil which was zinc deficient. Zinc uptake by berseem grown in a clay soil which was high in natural zinc was also increased by salinity. However, zinc uptake by tomato grown in the clay soil did not change with increasing salinity. Adding zinc fertilizer increased the zinc uptake by both tomato and berseem grown in both the clay and loam soils. They also found that $ZnSO_4$ may be a more efficient zinc fertilizer than ZnEDTA on a saline soil. Hassan et al. (1970a) found the concentration of zinc in barley tissue increased with increasing salinity caused by adding Na_2SO_4 and $CaCl_2$. They suggested the salts used in salinizing the soil decreased the pH of the soil and enhanced acid-soluble zinc. In other experiments (1970b) they found that the zinc concentration in component parts of corn increased with increasing salinity but zinc uptake decreased with increasing salinity. They suggested that this was due to the reduction in vegetative growth with salinity. Maas et al. (1972) found the zinc content of tops and roots of tomato, soybean and squash increased with increasing salinity when NaCl was added to basal nutrient solution. The concentration of NaCl solution added ranged from 25 to 100meq/liter. The zinc concentration of squash increased very little with salinity. They suggested that the increased zinc concentration in plants with increased salinity was due to the restricted growth of the tops. Bernstein (1964) noted similar consequence of salinity treatments on the content of other elements.

Nitrogen fertilizer was found to increase availability of applied and native Zn (Viets et al. 1957; Singh and Franklin 1974). Singh and Franklin (1974) used different combinations of zinc and nitrogen fertilizers. Urea, NH_4NO_3, $Ca(NO_3)_2$, $NaNO_3$, $(NH_4)_2SO_4$ at 25 ppm N were added to saline and non-saline soils. Singh (1974) found the highest uptake of native and applied zinc by corn in nonsaline soil occurred when NH_4NO_3 was mixed with the zinc fertilizer. In saline soils, $NaNO_3$ induced a greater uptake of native and applied zinc by corn when compared to other nitrogen fertilizers. With alfalfa, $NaNO_3$ increased native zinc uptake to a greater extent than other nitrogen fertilizers on nonsaline soils, but $(NH_4)_2SO_4$ was more effective than other nitrogen fertilizers in increasing native zinc uptake by alfalfa in saline soils. Viets et al. (1957) also observed that application of nitrogen fertilizer affected the availability of zinc in the soil and suggested that this effect was dependent on the pH change that can occur by adding nitrogen fertilizer to the soil.

Information on the effect of zinc application on plant growth under saline conditions is limited. Ravikovitch and Navrot (1976) conducted an experiment to determine the effect of zinc application on tomato, millet and berseem growth. They found that growth of tomato in a nonsaline clay soil and at salinity levels up to 7 mmhos/cm was unaffected by zinc application both as ZnEDTA and $ZnSO_4$. When salinity increased to 9 mmhos/cm a yield increase of 18% was obtained with both zinc fertilizer. The increase in yield was even more pronounced at a salinity level of 11 mmhos/cm. Yield increased by 58% and 38% with 0.5 ppm zinc as ZnEDTA and 5 ppm as $ZnSO_4$, respectively. Tomato grown on a loam soil responded to zinc fertilization at all salinity levels and the yield increase was similar for both saline and nonsaline soils. Zinc sulfate was more effective than ZnEDTA in increasing yields on saline soil. Yield of berseem straw and seed obtained on the nonsaline clay soil decreased with added zinc (12.5 ppm as $ZnSO_4$), whereas in the salinized soil, addition of the same amount of $ZnSO_4$ increased seed yield by 21%.

The studies reported indicate that the nutrition of plants under saline conditions varies from that under nonsaline conditions. Ravikovitch and Navrot (1976) suggested that by adapting the nutritional regime to the specific requirements of the plant grown in salt-affected soils, yields could be significantly increased.

METHODS AND MATERIALS

The experimental methods used for the individual studies reported in this manuscript are described with the results obtained in the appropriate subsection. The analytical procedures employed in the investigations and in characterizing the soils are outlined below.

(A) Description of Soils

Saline and non-saline soils of the Tarno association, a carbonated Rego Humic Gleysol, were selected for study. The soils used in experiments 1 and 2 were obtained in 1976. Soils used in experiments 3 and 4 were obtained in 1977 at sites near those selected for experiments 1 and 2. The soils were obtained from the Ap horizons of cultivated soils. The soils selected all effervesced when treated with dilute HCl. Some chemical and physical properties of these soils are presented in the appropriate subsections.

(B) Soil Analysis

1) Soil pH

Soil pH was determined by measuring the pH of an extract from a water-saturated soil paste using glass and colomel electroder.

2) Electric conductivity (EC)

The level of salinity in the soils was estimated by measuring the electrical conductivity of a water saturated-soil extract using a conductivity meter (Campbell 1948).

3) Determination of water content at field capacity

Soil, ground and sieved through a two mm sieve, was placed into a 400 ml beaker. Sufficient water was added to wet the top one-half of the soil. The samples were enclosed in a polyethylene bag and allowed to equilibrate for four days. Soil samples were taken above the wetting front and dried at $105^{\circ}C$ for 24 hours. The loss in weight of the samples was measured and the moisture content of the soil calculated.

4) Major cations

Exchangeable K, Na, Ca and Mg were determined by the ammonium acetate saturation method. Exchange sites of a 5.0 g soil sample were saturated with ammonium by shaking for one hour in 100 ml of 1.0 N NH_4OAc solution containing 250 ppm lithium and adjusted to pH 7.0. The suspension was filtered, and the Na, K, Ca and Mg concentrations in the extractant measured using a Perkin Elmer Model 303 atomic absorption spectrophotometer.

5) Determination of DTPA-extractable zinc in soil

Zinc was extracted from soil using a DTPA (diethylenetriamine pentaacetic acid) extracting solution which was 0.005 M in DTPA, 0.01 M in $CaCl_2$ and 0.1 M in TEA (triethanolamine). The pH of the extracting solution was adjusted to 7.3. Air dry soil (12.5 g) was shaken with 25 ml DTPA extractant for two hours. The suspensions were filtered and the zinc concentrations of the filtrates determined using a Perkin Elmer Model 303 atomic absorption spectrophotometer.

6) Available phosphorus determination

Soil available phosphorus was extracted by shaking 5 g of soil in 100 ml of 0.5 N $NaHCO_3$ for a half hour (Olson *et al*. 1954). The suspension was filtered. An aliquot of 25 ml was treated with H_2SO_4 to reduce the pH, then mixed with ammonium molybdate and ascorbic acid as described by Murphy and Riley (1962). The color intensity of the solution was measured using a spectrophotometer set at a wavelength of 885 mu. The phosphorus concentration was determined by comparison of these readings with those obtained for a standard curve.

7) Chloride determination

Chloride was determined on extracts obtained from saturated soil-water paste. Two ml of soil extract was titrated with 0.05 M $AgNO_3$ and the chloride concentration calculated (Reitemeier 1943).

8) Sulfate determination

Sulfate was extracted by shaking 50 g-2 mm soil with 100 ml distilled water for a half hour. The suspensions were filtered. The soluble SO_4^{2-} in a 25 ml aliquot was precipitated as $BaSO_4$ by the addition of BaCl; the solution was constantly stirred during the addition of BaCl. The turbidity of the solution was measured and the concentration of SO_4 determined by comparison of the sample readings to those obtained for a standard curve.

(C) Plant Analysis

Minor Element Determination

Oven-dried plant samples (80°C) were finely ground using a small steel mill. A 1.0 g sample was placed into a micro-Kjeldahl flask and five ml of concentrated HNO_3 added. After one hour of predigestion, two ml of 70% $HClO_4$ were added and the mixture digested on a micro-Kjeldahl heating unit until the solution became colourless. The clear solution was diluted to 25 ml with deionized water. The zinc, manganese and copper concentrations were measured using a Perkin Elmer Model 303 atomic absorption spectrophotometer.

Growth Chamber Experimental Methods

The soil samples were air dried and thoroughly mixed to eliminate variability during field sampling. A portion of the soil was crushed using a porcelain mortar and pestle and passed through a 2 mm sieve. The sieved portion was used for characterizing the soil.

Two and one-half kilograms of crushed soil were placed into 18 cm by 17 cm plastic pots. All pots were washed with 0.1 M EDTA (ethylene diaminetetra acetic acid) then with 10% HNO_3 solution and rinsed with deionized water prior to use.

All the experiments were split block designs with three replicates. Two way analysis of variance was used to analyze the data.

All plant material obtained at time of harvest was washed in 0.15 M HCl then washed with deionized water. The plant material was dried at 80C for 24 hours, weighed and retained for analysis.

The temperature of the growth chamber with blackbeans was maintained at 20C for the light period and 15C for the dark period. The relative humidity was 40% and 80% for the light and dark periods, respectively. The light period was 15 hours and dark period was 9 hours.

The temperature of the growth chamber for wheat was 25C and 18C for light and dark periods, respectively. The relative humidity was 80% and 50% for dark and light periods, respectively. The length of the light period was 16 hours and the dark period was 8 hours. Lighting was provided with Sylvania (Grow-Lux) fluorescent lamps and incandescent bulbs which together resulted in a light intensity of approximately 30,000 lux at the tops of the plants.

The soil was watered daily to field capcity with deionized water.

RESULTS AND DISCUSSION

Experiment 1
Effect of Soil Salinity on Dry Matter Yield and Zinc Utilization by Wheat

Saline and nonsaline soils were mixed in various proportions so that soil mixtures with six salinity levels were obtained. The salinity levels obtained and other soil characteristics are shown in Table 1. Salinity levels ranged from 1.1 to 12.3 mmhos/cm. After potting the soils, nitrogen at 100 ppm N was added to all pots as NH_4NO_3. Phosphorus was added to all pots as KH_2PO_4 at 50 ppm P. The P and N were added as a solution and well mixed with the soil. Four micronutrient treatments were used for every salinity level. These treatments were:

1. control (no micronutrients)
2. 2 ppm Zn as ZnEDTA
3. 10 ppm Mn as $MnSO_4 \cdot H_2O$
4. 2 ppm Zn as ZnEDTA + 10 ppm Mn as $MnSO_4 \cdot H_2O$

The Zn and Mn were added in solution and well mixed with the entire volume of soil in each pot. Twenty wheat seeds were planted 2 cm below the soil surface in each pot. Plants were thinned to eight plants per pot after ten days. The wheat was grown for 47 days and then harvested.

The results of this experiment are given in Tables 2 to 4 and Figures 1 and 2. Addition of Zn and Zn + Mn had no significant effect on yield at any salinity level (Table 2 and Figure 1). The DPTA-extractable Zn ranged from 0.75 ppm for the nonsaline soil to 0.82 ppm for the highly saline soil (Table 1). Addition of Mn also had no significant effect on yield except at a salinity level of 4.8 mmhos/cm where the yield significantly decreased when Mn was added (Table 2). These results are in contrast to those obtained by McGregor (1972) who reported that wheat responded to Zn fertilizer when the DPTA-extractable soil zinc was less than 1.3 ppm.

Increasing salinity decreased yield with or without micronutrients. Many of these decreases between salinity levels were statistically significant.

The zinc content in plants with and without added zinc decreased with increasing salinity (Table 3 and Figure 2). However, significant decreases in zinc content from that obtained for the soil with an E. C. of 1. 1 mmhos/cm usually occurred only when zinc was added and only when salinity increased to very high levels. The data indicates that salinity had a negative effect on zinc utilization by plants. There were no significant differences in zinc content between the plants treated with Zn and Zn + Mn. Adding zinc to the soil significantly increased the concentration of zinc in plants at most salinity levels. These results are in good agreement with the findings of Ravikovitch (1976) who reported that zinc applications increased the zinc content of tomato and berseem in nonsaline as well as saline soils. Adding Zn + Mn also increased zinc concentration at all salinity levels. However, the increase in zinc concentration was significant only at salinity levels of 1.1 mmhos/cm and 6.5 mmhos/cm. Adding Mn had no significant effect on zinc concentration.

The zinc uptake by wheat plants with and without added zinc decreased with increasing salinity (Table 4). The decrease in zinc uptake was significant only when salinity levels were 4.8 mmhos/cm or more and when zinc was added. The significant decrease in zinc uptake occurred at a higher salinity level (EC = 6.5 mmhos/cm) when zinc was not added. Adding zinc fertilizer increased the zinc uptake significantly at low salinity levels (EC = 1.1 and 4.8 mmhos/cm). However, the increase in zinc uptake was not significant at high salinity levels (EC = 8.2, 10.5 and 12.3

mmhos/cm). Adding Mn had no significant effect on zinc uptake.

The decrease in zinc uptake with increased salinity for the control and Mn only treatments was mainly due to a restriction of growth as the zinc concentration in the plants for these treatments did not change significantly with increasing salinity. Increases in salinity decreased zinc uptake when zinc was added and the decrease in zinc uptake was significant at most salinity levels. This was due to a lowering of zinc concentration in the plants as well as decreased yields. The lowering in zinc concentration indicates that the applied zinc was less available to plants under saline than under nonsaline soil conditions. Excess of cations, especially Mg^{2+} may have restricted the uptake of zinc from the ZnEDTA. An excess of cations such as Mg^{2+} or Ca^{2+} may have displaced the Zn from the EDTA ligand. The Zn displaced from the EDTA ligand would then be fixed by the soil in a relatively plant unavailable form. It is also possible that excesses of cations such as Mg^{2+} or Ca^{2+} competed with zinc at root adsorption sites, thus limiting the uptake of zinc.

Table 1. Physical and Chemical Properties of Soil Used for Experiments 1 and 2.

Sample No.	E.C. (mmhos/cm)	pH	Field Capacity (%)	DPTA-Extractable Zn (ppm)
1	1.1	8.1	41.0	0.75
2	4.8	7.8	40.0	0.79
3	6.5	7.9	40.0	0.79
4	10.5	7.9	40.5	0.81
5	10.5	7.9	40.5	0.81
6	12.3	8.1	40.7	0.82

Sample No.	DTPA-Extractable Mn (ppm)	NH_4OAC-Extractable Ca (ppm)	NH_4OAC-Extractable Mg (ppm)	NH_4OAC-Extractable Na (ppm)
1	7.4	4549	2127	161
2	7.9	4581	2765	616
3	8.1	4537	3351	1093
4	9.0	4422	4070	1555
5	9.5	4441	4840	1958
6	9.8	446 6	5583	2358

Sample No.	NH_4OAC-Extractable K (ppm)	$NaHCO_3$-Extractable P (ppm)	H_2O-Extractable SO_4 (ppm)	H_2O-Extractable Cl (meq/L)
1	621	12.1	23	not detected
2	572	11.5	795	not detected
3	482	11.2	1645	not detected
4	433	11.4	2362	not detected
5	396	10.7	3100	not detected
6	365	11.2	4175	27.1

Table 2. Effect of Soil Salinity and Micronutrients on Yield of Wheat (g).

Micronutrients Added (ppm)	Salinity Level (mmhos/cm)					
	1.1	4.8	6.5	8.2	10.5	12.3
0	$^{A}15.6^{a*}$	$^{A}14.7^{a}$	$^{B}8.6^{a}$	$^{BC}6.9^{a}$	$^{CD}5.4^{a}$	$^{D}3.8^{a}$
(2) Zn	$^{A}14.8^{a}$	$^{A}13.6^{ab}$	$^{B}9.3^{a}$	$^{C}6.9^{a}$	$^{CD}5.3^{a}$	$^{D}3.8^{a}$
(10) Mn	$^{A}15.0^{a}$	$^{B}12.6^{b}$	$^{C}8.7^{a}$	$^{CD}7.0^{a}$	$^{DE}5.2^{a}$	$^{E}4.1^{a}$
(2) Zn + (10) Mn	$^{A}16.3^{a}$	$^{B}13.0^{b}$	$^{C}9.1^{a}$	$^{D}6.4^{a}$	$^{DE}4.6^{a}$	$^{E}3.6^{a}$

* Tukey's test. Treatment means followed by the same letters are not statistically significant at the 5% probability level. Lower case letters are for comparisons of micronutrient treatments within a salinity level. Upper case letters are for comparisons of salinity treatments within a micronutrient level.

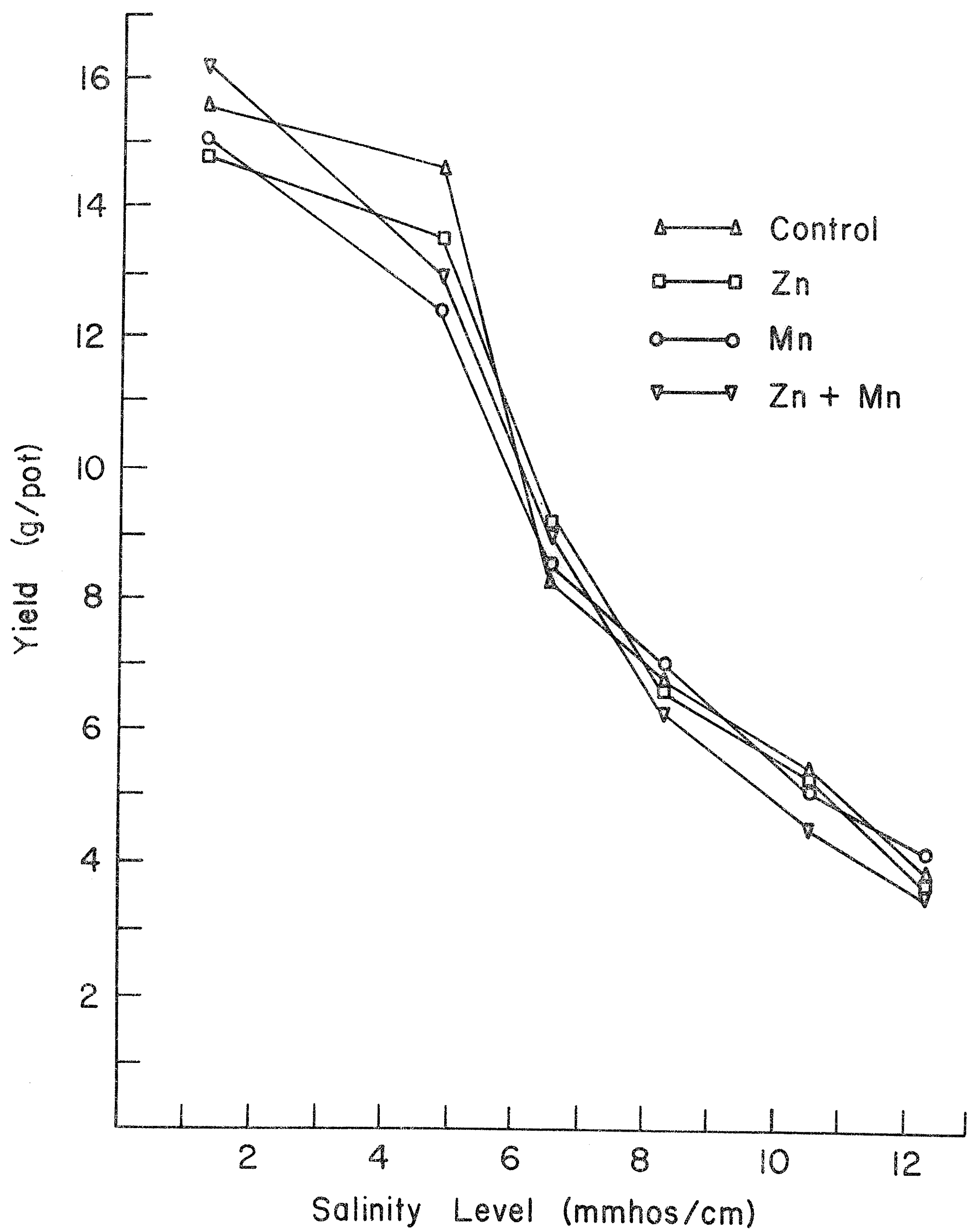


Fig. I Effect of soil salinity and micronutrients on yield of wheat.

Table 3. Effect of Soil Salinity and Micronutrients on Zinc Content of Wheat (ppm).

Micronutrients Added (ppm)	Salinity Level (mmhos/cm)					
	1.1	4.8	6.5	8.2	10.5	12.3
0	$^{A}11.3^{b*}$	$^{AB}9.6^{b}$	$^{AB}10.1^{b}$	$^{AB}9.0^{b}$	$^{B}7.6^{a}$	$^{AB}7.9^{b}$
(2) Zn	$^{A}16.1^{a}$	$^{AB}12.8^{a}$	$^{BC}12.3^{ab}$	$^{BC}10.8^{ab}$	$^{C}9.2^{a}$	$^{BC}10.8^{a}$
(10) Mn	$^{A}10.8^{b}$	$^{A}10.8^{ab}$	$^{A}10.b^{b}$	$^{A}8.4^{b}$	$^{A}8.3^{a}$	$^{A}7.5^{b}$
(2) Zn + (10) Mn	$^{A}15.8^{a}$	$^{BC}11.6^{ab}$	$^{AB}13.8^{a}$	$^{ABC}12.8^{a}$	$^{C}10.0^{a}$	$^{BC}11.3^{a}$

* Tukey's test. Treatment means followed by the same letters are not statistically significant at the 5% probability level. Lower case letters are for comparisons of micronutrient treatments within a salinity level. Upper case letters are for comparisons of salinity treatments within a micronutrient level.

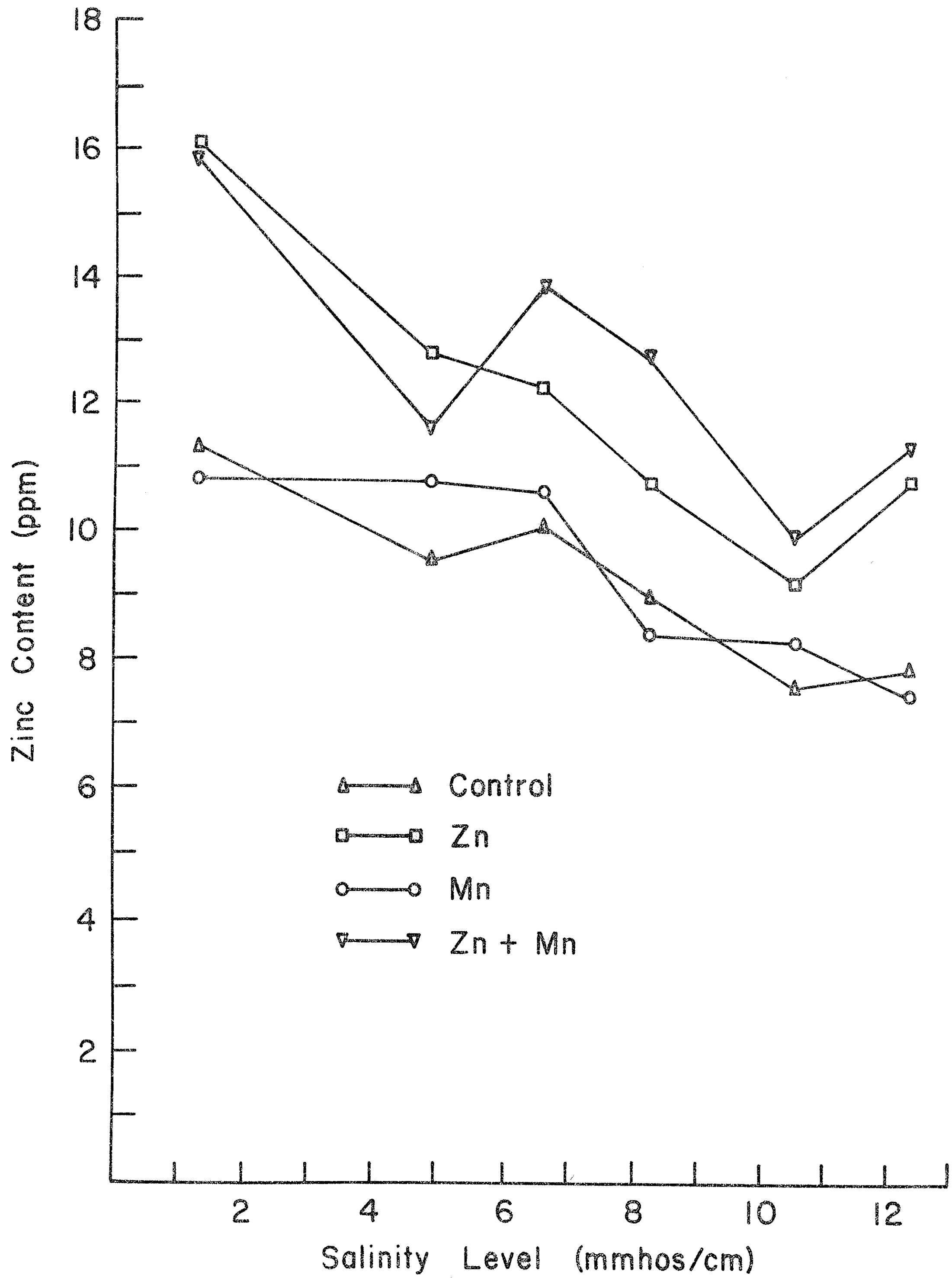


Fig. 2 Effect of soil salinity and micronutrients on zinc content of wheat.

Table 4. Effect of Soil Salinity and Micronutrients on Zinc Uptake by Wheat (µg/pot).

Micronutrients Added (ppm)	Salinity Level (mmhos/cm)					
	1.1	4.8	6.5	8.2	10.5	12.3
0	$^{A}175^{b*}$	$^{A}141^{b}$	$^{B}87^{b}$	$^{BC}62^{a}$	$^{C}40^{a}$	$^{C}29^{a}$
(2) Zn	$^{A}235^{a}$	$^{B}174^{a}$	$^{C}113^{ab}$	$^{D}73^{a}$	$^{D}48^{a}$	$^{D}40^{a}$
(10) Mn	$^{A}161^{b}$	$^{A}135^{b}$	$^{B}92^{b}$	$^{BC}58^{a}$	$^{C}43^{a}$	$^{C}30^{a}$
(2) Zn + (10) Mn	$^{A}256^{a}$	$^{B}150^{ab}$	$^{B}126^{a}$	$^{C}81^{a}$	$^{CD}44^{a}$	$^{D}40^{a}$

* Tukey's test. Treatment means followed by the same letters are not statistically significant at the 5% probability level. Lower case letters are for comparisons of micronutrient treatments within a salinity level. Upper case letters are for comparisons of salinity treatments within a micronutrient level.

Experiment 2
The Effect of Soil Salinity on Dry Matter Yield and Zinc Utilization by Black Beans

Black beans, classified as sensitive to both salinity and low levels of soil zinc were grown on the same soils used in the experiment with wheat. This experiment was conducted to study the effect of added zinc and manganese on zinc uptake and dry matter yield of black beans under saline and nonsaline soil conditions.

Soils used in the experiment with wheat were air dried, crushed and repotted. Phosphorus fertilizer was added for all treatments as KH_2PO_4 at 50 ppm P. It was added as a solution and well mixed with soil. For every salinity level, micronutrients were added as described for the experiment with wheat.

Six black bean seeds were inoculated with a proper nitrogen inoculum and planted 2.0 cm below the soil surface. After two weeks, the plants were thinned to two plants per pot. The plants were grown for 51 days and then harvested.

The results of this experiment are given in Tables 5 to 8 and Figures 3 and 4. The black bean plants did not grow when soil salinity was higher than 6.5 mmhos/cm and plant yields were not obtained.

The addition of Zn or Zn + Mn significantly increased yield on the nonsaline soil (EC of 1.1 mmhos/cm)(Table 5.). The response to zinc decreased with increasing soil salinity (Table 5 and Figure 3). Effectiveness of adding zinc in increasing yield decreased from 108% on the nonsaline soil to 32% on the highly saline soil when zinc alone was added (Table 8). Percent yield increases were 117% on the nonsaline soil and 13% on the highly saline soil when both zinc and manganese were added. Although added zinc increased yield at a salinity level of 6.5 mmhos/cm, the increase was nonsignificant. The increase in yield with

Table 5. Effect of Soil Salinity and Micronutrients on Yield of Black Beans (g).

Micronutrients Added (ppm)	Salinity Level (mmhos/cm)		
	1.1	4.8	6.5
0	$^{A}3.1^{b*}$	$^{B}1.3^{b}$	$^{B}0.6^{a}$
(2) Zn	$^{A}6.5^{a}$	$^{B}2.8^{a}$	$^{C}0.8^{a}$
(10) Mn	$^{A}2.5^{b}$	$^{AB}1.2^{b}$	$^{B}0.5^{a}$
(2) Zn + (10) Mn	$^{A}6.8^{a}$	$^{B}2.3^{ab}$	$^{C}0.7^{a}$

* Tukey's test. Treatment means followed by the same letters are not statistically significant at the 5% probability level. Lower case letters are for comparisons of micronutrient treatments within a salinity level. Upper case letters are for comparisons of salinity treatments within a micronutrient level.

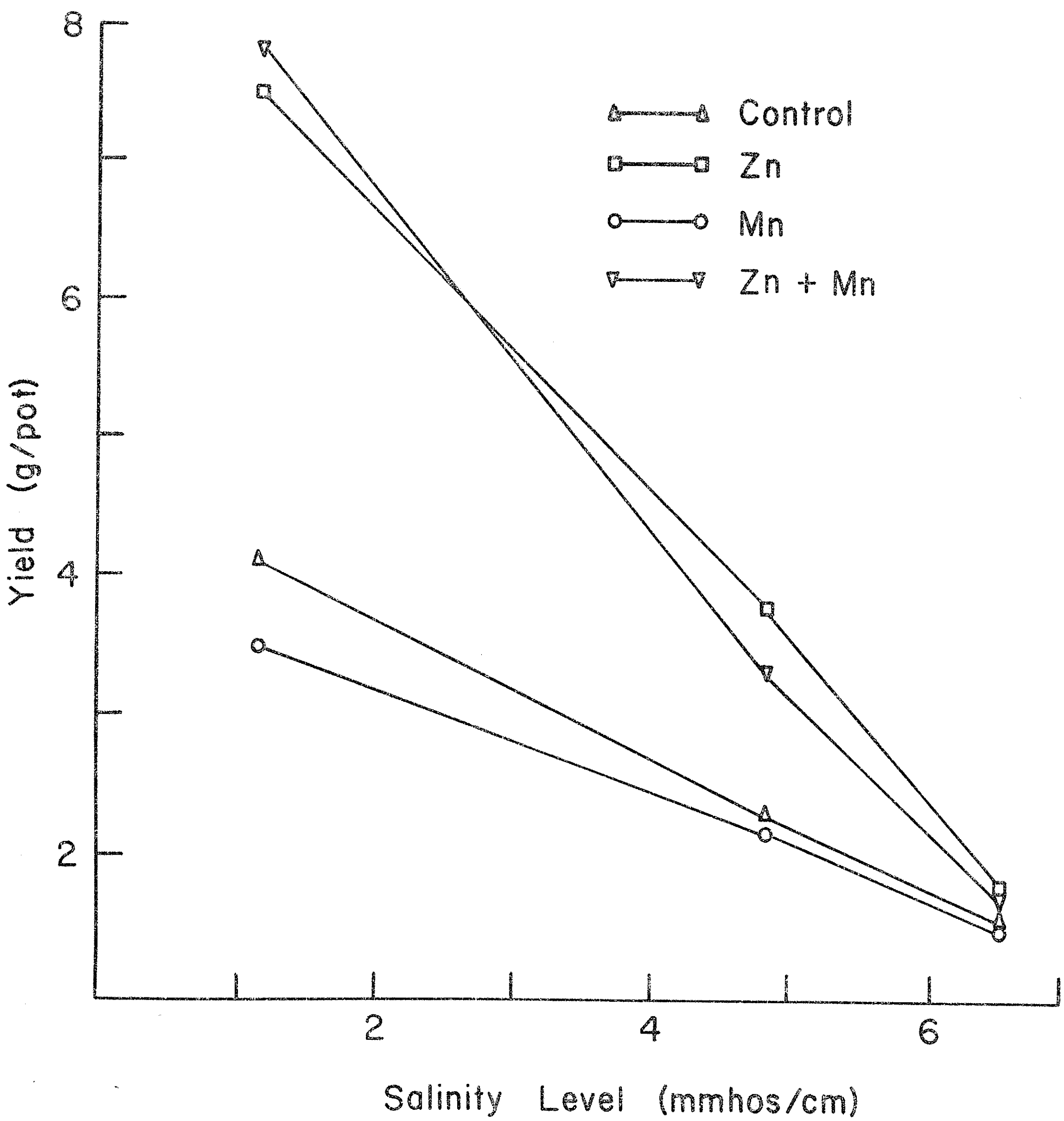


Fig. 3 Effect of soil salinity and micronutrients on yield of Black beans.

Table 6. Effect of Soil Salinity and Micronutrients on Zinc Content of Black Beans (ppm).

Micronutrients Added (ppm)	Salinity Level (mmhos/cm)		
	1.1	4.8	6.5
0	$^{A}8.7^{b*}$	$^{A}10.5^{b}$	$^{A}14.6^{b}$
(2) Zn	$^{A}22.1^{a}$	$^{A}19.3^{a}$	$^{A}21.3^{a}$
(10) Mn	$^{A}8.9^{b}$	$^{A}12.0^{b}$	$^{A}12.9^{b}$
(2) Zn + (10) Mn	$^{A}25.7^{a}$	$^{A}22.1^{a}$	$^{A}23.9^{a}$

* Tukey's test. Treatment means followed by the same letters are not statistically significant at the 5% probability level. Lower case letters are for comparisons of micronutrient treatments within a salinity level. Upper case letters are for comparisions of salinity treatments within a micronutrient level.

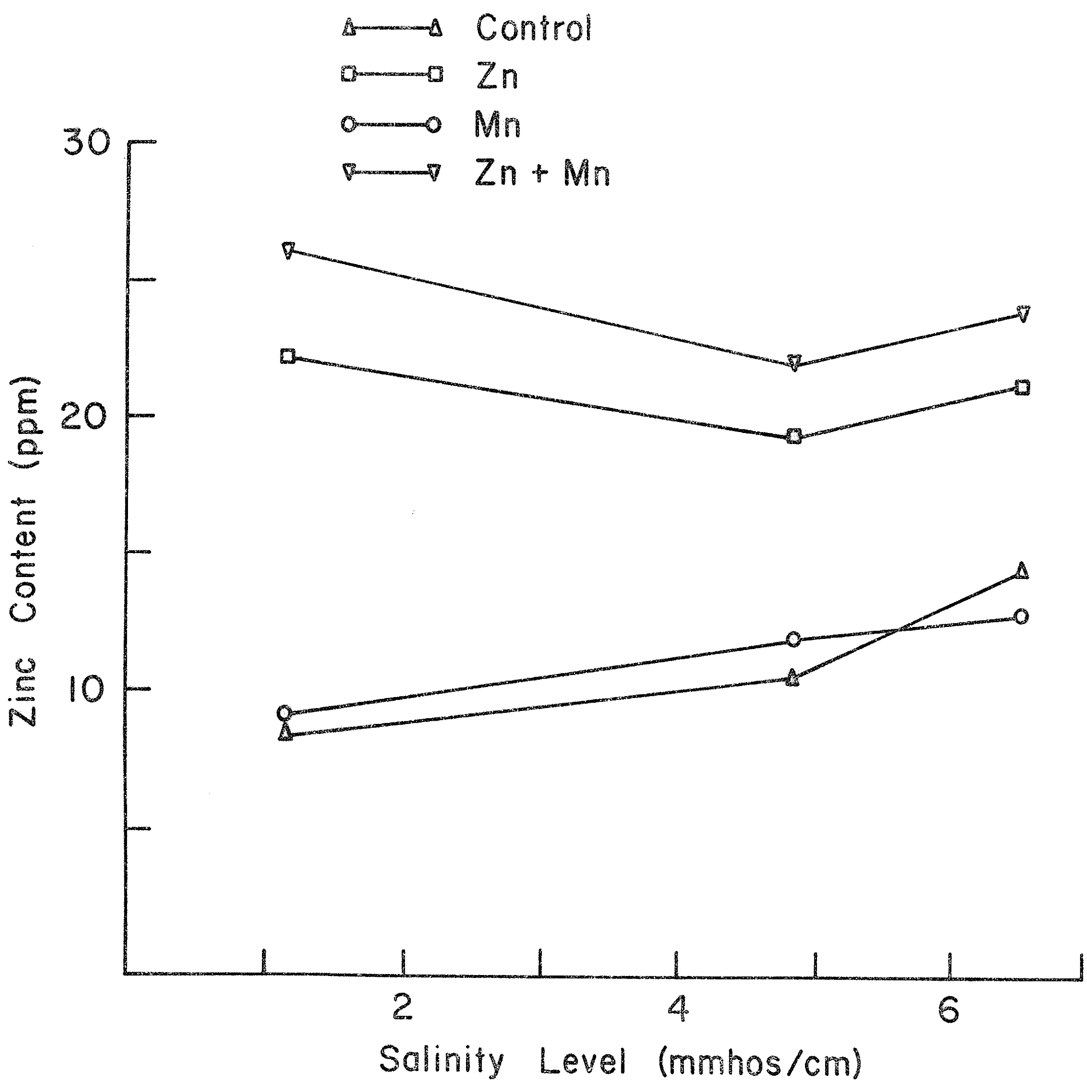


Fig. 4 Effect of soil salinity and micronutrients on zinc content of Black beans.

Table 7. Effect of Soil Salinity and Micronutrients on Zinc Uptake by Black Beans (µg/pot).

Micronutrients Added (ppm)	Salinity Level (mmhos/cm)		
	1.1	4.8	6.5
0	$^{A}27^{b*}$	$^{A}13^{b}$	$^{A}8^{a}$
(2) Zn	$^{A}145^{a}$	$^{B}54^{a}$	$^{C}16^{a}$
(10) Mn	$^{A}21^{b}$	$^{A}14^{b}$	$^{A}6^{a}$
(2) Zn + (10) Mn	$^{A}174^{a}$	$^{B}50^{a}$	$^{C}15^{a}$

* Tukey's test. Treatment means followed by the same letters are not statistically significant at the 5% probability level. Lower case letters are for comparisons of micronutrient treatments within a salinity level. Upper case letters are for comparisions of salinity treatments within a micronutrient level.

Table 8. Percent Increase (+) or Decrease (-) in Yield, Zinc Content and Zinc Uptake as Affected by Salinity Level and Micronutrient Addition.

Salinity Level mmhos/cm	Micronutrients Added	Yield	Zinc Content	Zinc Uptake
1.1	Zn	108	154	425
	Mn	-22	2	-21
	Zn + Mn	117	195	531
4.8	Zn	114	84	296
	Mn	-7	14	19
	Zn + Mn	77	110	267
6.5	Zn	32	46	45
	Mn	-16	-12	-36
	Zn + Mn	13	64	67

added zinc fertilizer is in good agreement with the findings of Hedayat (1978) for nonsaline soils. Ravikovitch and Navrot (1976) obtained response to zinc on saline soils.

Adding Mn to the saline and nonsaline soils decreased yield slighlty. This decrease was not significant. Adding Mn to the soil may have increased available Mn to slightly toxic levels. Many investigators found the Mn content of plants increased with increasing soil salinity (Maas et al. 1972;Hassan et al. 1970 a, b; Jackson et al. 1966; Ravikovitch and Navrot 1976). These findings are in good agreement with results of this experiment. Data (not shown) indicated that Mn content of the plants increased with increasing salinity with all treatments.

Yield decreased more rapidly with increasing soil salinity for black beans than for wheat. Black bean plants did not grow at all at salinity levels greater than 6.5 mmhos/cm, whereas wheat grew even at salinity levels of 12.3 mmhos/cm. This was a result of black beans being much more sensitive to salinity than wheat.

Adding Zn or Zn + Mn increased zinc content significantly at all salinity levels (Table 6 and Figure 4). Adding Mn had no significant effect on zinc content. Increasing salinity increased zinc content of plants grown without applied zinc. However, the increase was not significant. Increasing salinity had no significant effect on zinc content when Zn or Zn + Mn were added. These results are in contrast to those obtained by Ravikovitch and Navrot (1976) who reported that zinc content increased with increasing salinity. The reason for the difference in findings may be a result of Ravikovitch and Navrot (1976) adding NaCl to nonsaline soils to create different salinity levels. Adding the salt may have reduced the pH of soil, thus making zinc more available to the plant. The effectiveness of adding zinc fertilizer in increasing zinc content decreased with increases in salinity. Effectiveness decreased from 154% with the nonsaline soil to 46% with the highly saline soil when only Zn was added (Table 8). Effectiveness decreased from 195% with the nonsaline soil to 64% with highly saline soil when Zn and Mn were added.

Adding Zn or Zn + Mn increased zinc uptake significantly in the nonsaline soil and at salinity levels of 1.1 and 4.8 mmhos/cm (Table 7). Adding Zn or Zn + Mn had no significant effect on zinc uptake at a salinity level of 6.5 mmhos/cm. Adding Mn had no significant effect on zinc uptake by plants at all salinity levels.

Increasing salinity had a negative effect on zinc uptake with all treatments. However, zinc uptake decreased significantly with increasing salinity when Zn or Zn + Mn were added. The decrease in zinc uptake was not significant when zinc was not added. The nonsignificant change in zinc content with increasing salinity indicates that zinc uptake decreased with increasing salinity as a result of a reduction in vegetative yield. The effectiveness of added zinc in increasing zinc uptake decreased with increasing salinity (Table 8). The increases in zinc uptake were 424% and 45% with nonsaline and highly saline soils, respectively, when Zn was added. These results are in good agreement with the findings of Ravikovitch and Navrot (1976) who reported that zinc uptake by tomato and berseem plants increased when zinc fertilizer was added to nonsaline as well as saline soils.

Experiment 3
The Effect of Soil Salinity and Zinc Fertilizer Upon Dry Matter Yield and Zinc Utilization by Black Beans

The second experiment showed that zinc fertilizer had a positive effect on increasing yield of black beans. The yield was increased by 108% and 32% on nonsaline and saline soils, respectively when zinc was added as ZnEDTA. Thus, the effectiveness of ZnEDTA in increasing yield decreased with increasing soil salinity. The third experiment was conducted to study the effectiveness of ZnEDTA and $ZnSO_4$ in increasing yield, zinc content and zinc uptake by black bean plants under various soil salinity levels.

Saline and nonsaline soils were mixed in various proportions so that soil mixtures with four salinity levels were obtained. The salinity levels obtained and other soil characteristics are shown in Table 9. The salinity levels ranged from 1.1 to 6.4 mmhos/cm. After potting the soil, nitrogen at 100 ppm N was added to all pots as NH_4NO_3. Phosphorus was added to all pots as KH_2PO_4 at 50 ppm P. The P and N were added as a solution and well mixed with the soil. During the growth period of 53 days, 100 ppm N as NH_4NO_3 was added to each pot at different stages of growth. Thus, the plants were supplied with 300 ppm N during the growth period. Six zinc treatments were used for every salinity level. These treatments were:

1 - Control

2 - 2 ppm Zn as ZnEDTA

3 - 4 ppm Zn as ZnEDTA

4 - 4 ppm Zn as $ZnSO_4$

5 - 8 ppm Zn as $ZnSO_4$

6 - 16 ppm Zn as $ZnSO_4$

Table 9. Physical and Chemical Properties of Soil Used for Experiment 3.

Sample No.	E.C. (mmhos/cm)	pH	Field Capacity (%)	DPTA-Extractable Zn (ppm)
1	1.1	8.2	29.8	0.77
2	3.9	8.0	31.0	0.70
3	5.8	7.9	33.7	0.71
4	6.4	7.9	33.6	0.66

Sample No.	DPTA-Extractable Mn (ppm)	NH_4OAC-Extractable Ca (ppm)	NH_4AOC-Extractable Mg (ppm)	NH_4OAC-Extractable Na (ppm)
1	5.1	5141	3671	369
2	4.7	5678	3918	477
3	4.3	6545	4290	634
4	4.2	7178	4688	769

Sample No.	NH_4OAC-Extractable K (ppm)	$NaHCO_3$-Extractable P (ppm)	H_2O-Extractable SO_4 (ppm)	H_2O-Extractable Cl (meq/L)
1	308	11.0	55	not detected
2	315	10.4	445	not detected
3	322	9.6	1138	not detected
4	327	9.0	1675	not detected

The zinc fertilizers were added in solution and well mixed with the entire volume of soil in each pot. Six black bean seeds were planted 2 cm below the soil surface in each pot. Plants were thinned to two plants per pot after two weeks. The black beans were grown for 53 days and then harvested.

The results of this experiment are given in Tables 10 to 13 and Figures 5 and 6. Addition of zinc fertilizer had a positive effect on increasing yield at all salinity levels (Table 10 and Figure 5). However, on the nonsaline soil and at a low salinity level of 3.9 mmhos/cm, adding 2 ppm Zn as ZnEDTA and 8 ppm Zn as $ZnSO_4$ had no significant effect on yield. In contrast, adding 4 ppm Zn as ZnEDTA and 16 ppm Zn as $ZnSO_4$ increased yields significantly. Addition of 4 ppm Zn as $ZnSO_4$ significantly increased yield at a salinity level of 3.9 mmhos/cm. Addition of 4 ppm Zn as $ZnSO_4$ did not affect yields on the nonsaline soil. There were no significant increases in yield when zinc was added to soils with salinity levels of 5.8 and 6.4 mmhos/cm (Table 10 and Figure 5). Yields on the nonsaline soil were increased 59.9% and 35.9% when 4 ppm as ZnEDTA and $ZnSO_4$, respectively, were added (Table 13). The yield increases were 65.4% and 102.8% when 4 ppm Zn as ZnEDTA and $ZnSO_4$, respectively, were added to the soil with a salinity level of 3.9 mmhos/cm. The increases in yield were also higher with $ZnSO_4$ than with ZnEDTA at equal concentrations in the highly saline soils (EC = 5.8 and 6.4 mmhos/cm) (Table 13). Thus the relative effectiveness of ZnEDTA and $ZnSO_4$ varied with soil salinity. At equal concentrations, ZnEDTA was more effective than $ZnSO_4$ in increasing yields at low salinity, whereas $ZnSO_4$ was more effective than ZnEDTA in increasing yields on saline soils.

Addition of zinc fertilizer as $ZnSO_4$ and ZnEDTA increased zinc

Table 10. Effect of Zinc Fertilizer and Soil Salinity on Yield of Black Beans (g).

Zinc Added (ppm)	Salinity Level (mmhos/cm)			
	1.1	3.9	5.8	6.4
0	$^{A}3.4^{b*}$	$^{AB}2.2^{c}$	$^{B}2.2^{a}$	$^{B}1.5^{a}$
(2) ZnEDTA	$^{A}4.4^{ab}$	$^{B}3.1^{bc}$	$^{B}2.6^{a}$	$^{B}1.9^{a}$
(4) ZnEDTA	$^{A}5.4^{a}$	$^{B}3.6^{ab}$	$^{B}2.4^{a}$	$^{B}2.5^{a}$
(4) $ZnSO_4$	$^{A}4.6^{ab}$	$^{A}4.4^{a}$	$^{B}2.6^{a}$	$^{B}2.6^{a}$
(8) $ZnSO_4$	$^{A}4.6^{ab}$	$^{B}3.3^{abc}$	$^{B}2.2^{a}$	$^{B}2.3^{a}$
(16) $ZnSO_4$	$^{A}5.5^{a}$	$^{B}3.6^{ab}$	$^{BC}2.5^{a}$	$^{C}2.1^{a}$

* Tukey's test. Treatment means followed by the same letters ar not statistically significant at the 5% probability level. Lower case letters are for comparisons of zinc treatments within salinity levels. Upper case letters are for comparions of salinity treatments within zinc levels.

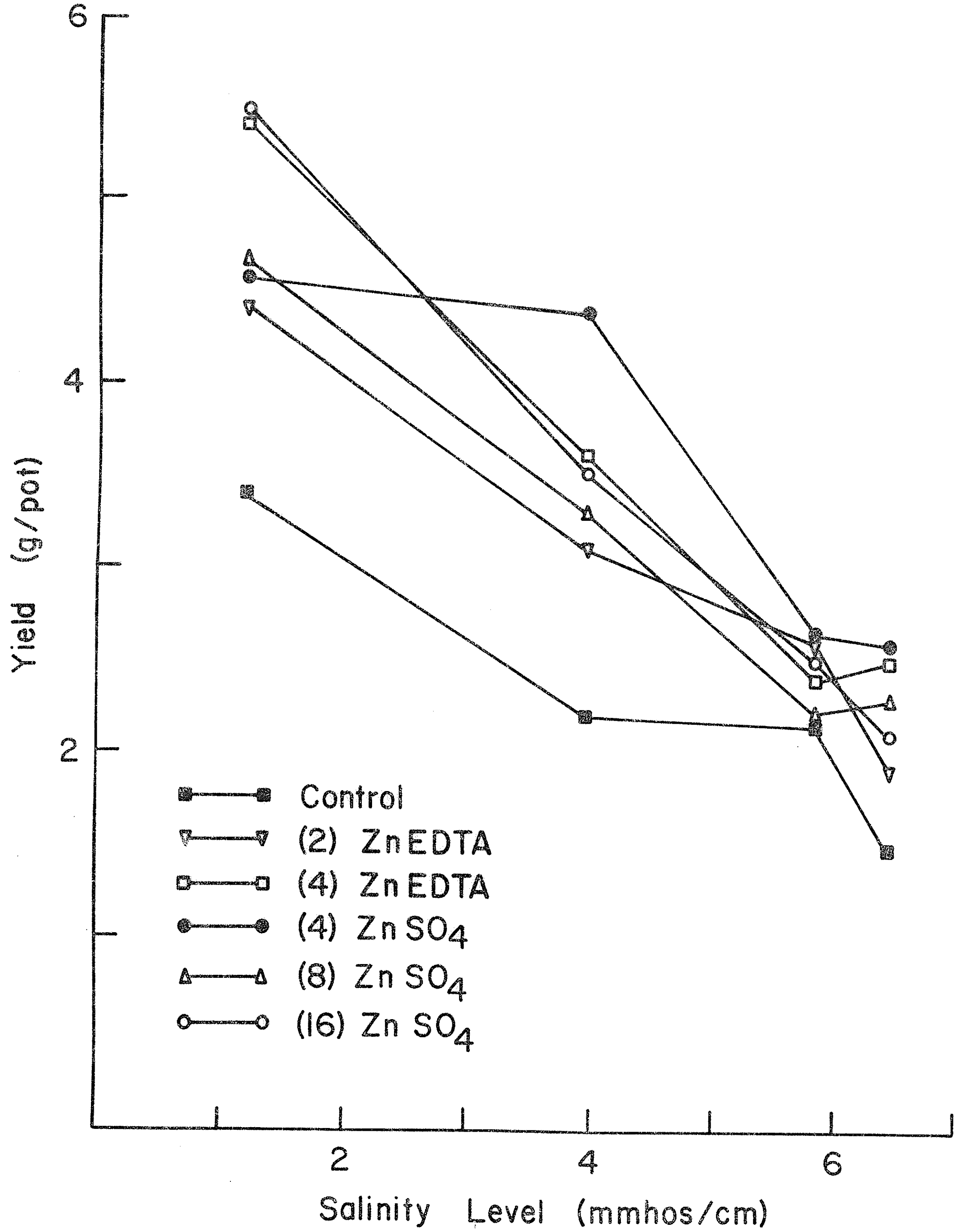


Fig. 5 Effect of soil salinity and zinc fertilizer on yield of Black beans.

Table 11. Effect of Zinc Fertilizer and Soil Salinity on Zinc Content of Black Beans (ppm).

Zinc Added (ppm)	Salinity Level (mmhos/cm)			
	1.1	3.9	5.8	6.4
0	$^{A}3.9^{d*}$	$^{A}5.0^{d}$	$^{A}5.8^{e}$	$^{A}5.6^{d}$
(2) ZnEDTA	$^{A}12.7^{c}$	$^{A}14.0^{c}$	$^{AB}12.3^{d}$	$^{B}9.6^{c}$
(4) ZnEDTA	$^{A}20.7^{b}$	$^{A}22.5^{b}$	$^{B}16.8^{c}$	$^{C}11.8^{c}$
(4) $ZnSO_4$	$^{B}12.1^{C}$	$^{A}15.3^{c}$	$^{A}15.2^{cd}$	$^{AB}12.6^{c}$
(8) $ZnSO_4$	$^{B}18.1^{b}$	$^{A}21.3^{b}$	$^{A}21.6^{b}$	$^{B}16.1^{b}$
(16) $ZnSO_4$	$^{A}29.5^{a}$	$^{A}31.2^{a}$	$^{A}31.4^{a}$	$^{B}26.3^{a}$

* Tukey's test. Treatment means followed by the same letters are not statistically significant at the 5% probability level. Lower case letters are for comparisons of zinc treatments within salinity levels. Upper case letters are for comparisons of salinity treatments within zinc levels.

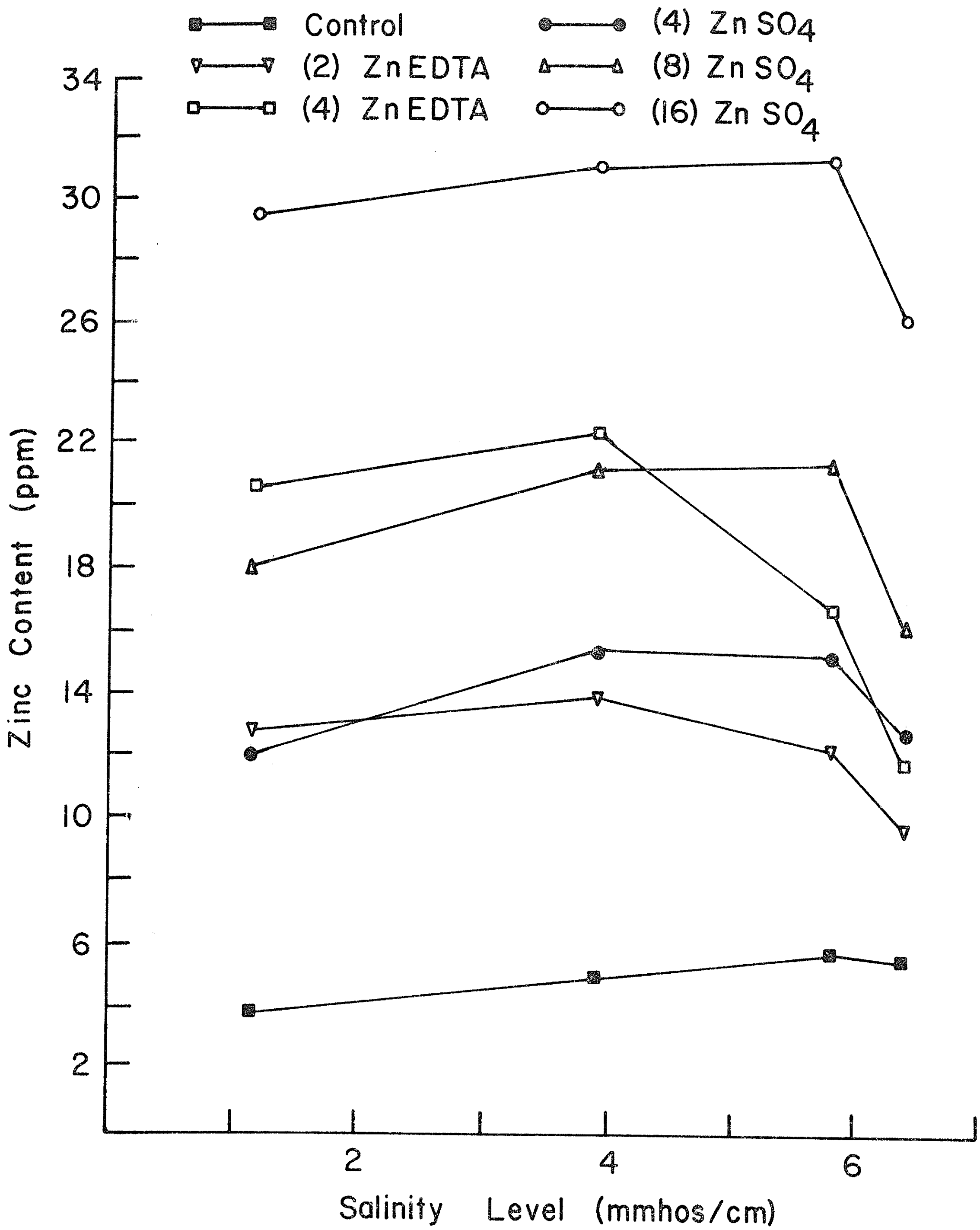


Fig. 6 Effect of soil salinity and zinc fertilizer on zinc content of Black beans.

Table 12. Effect of Zinc Fertilizer and Soil Salinity on Zinc Uptake by Black Beans (µg/pot).

Zinc Added (ppm)	Salinity Level (mmhos/cm)			
	1.1	3.9	5.8	6.4
0	$^{A}13^{e}$	$^{A}11^{d}$	$^{A}13^{c}$	$^{A}8^{c}$
(2) ZnEDTA	$^{A}55^{d}$	$^{AB}43^{c}$	$^{AB}32^{bc}$	$^{B}k8^{bc}$
(4) ZnEDTA	$^{A}111^{b}$	$^{B}81^{b}$	$^{C}40^{b}$	$^{C}29^{abc}$
(4) $ZnSO_4$	$^{AB}55^{d}$	$^{A}67^{bc}$	$^{B}39^{b}$	$^{B}33^{abc}$
(8) $ZnSO_4$	$^{A}83^{c}$	$^{AB}71^{b}$	$^{BC}47^{b}$	$^{C}36^{ab}$
(16) $ZnSO_4$	$^{A}161^{a}$	$^{B}111^{a}$	$^{C}77^{a}$	$^{C}54^{a}$

* Tukey's test. Treatment means followed by the same letters are not statistically significant at the 5% probability level. Lower case letters are for comparisons of zinc treatments within zinc levels.

Table 13. Percent Increase (+) or Decrease (-) in Yield, Zinc Content and Zinc Uptake by Black Beans as Affected by Salinity Level and Zinc Fertilizer.

Salinity Level (mmhos/cm)	Zinc Added (ppm)	Yield (%)	Zinc Content (%)	Zinc Uptake (%)
	(2) ZnEDTA	29.1	223	317
	(4) ZnEDTA	57.9	427	738
1.1	(4) $ZnSO_4$	35.9	208	319
	(8) $ZnSO_4$	36.5	361	527
	(16) $ZnSO_4$	61.7	653	1119
	(2) ZnEDTA	40.6	180	292
	(4) ZnEDTA	65.4	350	649
3.9	(4) $ZnSO_4$	102.8	207	519
	(8) $ZnSO_4$	51.2	327	550
	(16) $ZnSO_4$	65.0	523	923
	(2) ZnEDTA	19.1	112	152
	(4) ZnEDTA	10.2	189	215
5.8	(4) $ZnSO_4$	19.5	160	207
	(8) $ZnSO_4$	0.9	270	269
	(16) $ZnSO_4$	13.9	439	505
	(2) ZnEDTA	20.8	72	119
	(4) ZnEDTA	61.0	112	252
6.4	(4) $ZnSO_4$	68.2	125	292
	(8) $ZnSO_4$	47.4	188	337
	(16) $ZnSO_4$	34.4	372	552

content of plants significantly at all salinity levels (Table 11 and Figure 6). The effectiveness of both ZnEDTA and $ZnSO_4$ in increasing zinc content is shown in Table 13. ZnEDTA was more effective than $ZnSO_4$ in increasing zinc content of plants in the nonsaline soil and at a salinity level of 3.9 and 5.8 mmhos/cm. The effectiveness of 4 ppm Zn in increasing zinc content was 427% and 208% for ZnEDTA and $ZnSO_4$, respectively, on the nonsaline soil (Table 13). In contrast, the effectiveness was 112% and 125% for ZnEDTA and $ZnSO_4$, respectively, on the highly saline soil (EC = 6.4 mmhos/cm). Four ppm Zn as ZnEDTA was more effective in increasing zinc content (427%) than 8 ppm Zn as $ZnSO_4$(361%) on the nonsaline soil. However, at higher salinity levels (5.8 and 6.4 mmhos/cm) adding 8 ppm $ZnSO_4$ was about equal in effectiveness to 4 ppm Zn as ZnEDTA. These results are in good agreement with the findings of Ravikovitch and Navrot (1976) who reported that the relative effectiveness of ZnEDTA and $ZnSO_4$ varies with soil salinity. They found ZnEDTA to be superior to $ZnSO_4$ on nonsaline soils and $ZnSO_4$ to be superior to ZnEDTA on saline soils.

Adding zinc fertilizer as ZnEDTA and $ZnSO_4$ significantly increased zinc uptake by plants at low salinity (EC = 3.9 mmhos/cm) and on the non-saline soil (Table 12). At a higher salinity level (EC = 5.8 mmhos/cm), adding ZnEDTA and $ZnSO_4$ significantly increased zinc uptake except when 2 ppm Zn as ZnEDTA was added. At very high salinity levels only 8 and 16 ppm Zn as $ZnSO_4$ increased the zinc uptake significantly. Thus, increasing soil salinity decreased the effectiveness of all zinc treatments in increasing zinc uptake. The effectiveness of 4 ppm Zn as ZnEDTA and $ZnSO_4$ in increasing zinc uptake were 738% and 319%, respectively, on the nonsaline soil and 252% and 292%, respectively, on the soil with a salinity level of 6.4 mmhos/cm.

These results show that $ZnSO_4$ is a more effective zinc fertilizer than ZnEDTA on saline soils. An excess of cations such as Ca^{2+} or Mg^{2+} in saline soil may displace Zn from the EDTA ligand. The zinc may then be fixed by the soil in a less available form. Increasing soil salinity decreased zinc uptake by plant for all treatments. However, most of these decreases were not significant and it appears the decrease in zinc uptake with increasing salinity was more significant when zinc fertilizer was added. The continuous decreases of zinc uptake with increasing salinity may be due in part to the depression of yield caused by salinity, and may also be due to lower native zinc in saline than in nonsaline soil.

Experiment 4
The Effect of Adding Different Salts and ZnEDTA as Zinc Fertilizer on Dry Matter Yield and Zinc Uptake by Wheat

The previous experiments showed that soil salinity decreased dry matter yields and zinc uptake by plants. Saline soils contain a mixture of different kinds of salts. It is not known if or which cations or anions alter zinc uptake. These experiments were conducted to study which cations and/or anions may be responsible for altering zinc uptake by plants. The nonsaline soil used in experiment 3 was used. Five different kinds of salts were added to the nonsaline soil so that five salinity levels were obtained (Table 14). The effect of Ca, Mg, Na, Cl and SO_4 were investigated. The salts were added in equivalent quantities, i.e., 0.137 eqts. of Cl or SO_4 per 2500 g of soil were added for all salts except with $MgSO_4$. With $MgSO_4$, two treatments, 0.137 and 0.274 eqts. of SO_4 per 2500 g of soil were used. The salts were added in powder form and well mixed with the entire volume of soil. Salinity levels range from 1.1 to 8.9 mmhos/cm (Table 14).

Nitrogen was added to all treatments as NH_4NO_3 at 100 ppm N. Phosphorus fertilizer was added to all treatments as KH_2PO_4 at 50 ppm P. The P and N fertilizers were added as a solution and well mixed with the soil before planting. An additional 100 ppm N was added to treatments during the growth period. Two zinc fertilizer treatments were used for every salinity level. These treatments were:

1 - Control (no micronutrients)

2 - 2 ppm Zn as ZnEDTA

The zinc was added as a solution and well mixed with soil in each pot.

Twenty wheat seeds were planted 2 cm below the soil surface in each pot. Plants were thinned to eight plants after ten days. The

Table 14. pH and Electrical Conductivity of Soil After Adding Different Soils.

Salt Added	E.C. (mmhos/cm)	pH
Control	1.1	8.2
NaCl	10.1	7.9
$MgCl_2$	8.9	7.8
$CaCl_2$	8.8	7.7
$CaSO_4$ $2H_2O$	4.6	7.9
$MgSO_4$ $7H_2O$ (A)	5.5	7.9
$MgSO_4$ $7H_2O$ (B)	8.7	7.8

wheat was grown for 45 days and then harvested.

The results of this experiment are given in Tables 15 to 18. Addition of salts decreased the dry matter production with and without added zinc, except when $CaSO_4$ was added (Table 15). Addition of NaCl (EC = 10.1 mmhos/cm), $MgCl_2$ (EC = 8.9 mmhos/cm) or $CaCl_2$ (EC = 8.8 mmhos/cm) decreased yields significantly when no zinc was added. Addition of $MgSO_4$ (A) (EC = 5.5 mmhos/cm) or $MgSO_4$ (B) (EC = 8.7 mmhos/cm) had no significant effect on yield. Thus, chloride salts depressed yields more than did sulfate salts. These results are in good agreement with the findings of Brown (1953) who reported that chloride salts were toxic to peaches and other stone fruits. Addition of zinc had no significant effect on yield except with $CaCl_2$ (EC = 8.8 mmhos/cm) where the yield increased significantly when zinc was added. The largest decreases in yield occurred when NaCl was added to the soil (Table 18). Yield decreases were 46.9% and 57.5% with and without zinc added, respectively. This may be due to a high osmotic pressure in soil solution as well as to the toxic effects of chloride.

Addition of zinc slightly increased zinc content of plants at most salinity levels (Table 16). However, increases in zinc content were nonsignificant except with $MgCl_2$ and $MgSO_4$ at 0.274 eqts./2500 g of soil. Zinc content increased when NaCl or $MgSO_4$ (A) or $MgSO_4$ (B) were added to the soil without added zinc. Although these increases were relatively large, they were not significant. Zinc content increased when $CaSO_4$ and $MgSO_4$ were added to the soils treated with zinc. Only the $MgSO_4$ at 0.274 eqts. per 2500 g of soil caused a significant increase in zinc content. Thus, addition of $MgSO_4$ had a positive effect on increasing zinc content with both zinc treatments. Zinc content was increased by 62.4% and 33.6% when $MgSO_4$ at 0.137 and 0.274 eqts. per

Table 15. Effect of Various Salts and Zinc Fertilization on Yield of Wheat (g)

Zinc Added (ppm)	Salinity Level (mmhos/cm)						
	1.1	10.1 (NaCl)	8.9 ($MgCl_2$)	8.8 ($CaCl_2$)	4.6 ($CaSO_4$)	5.5 ($MgSO_4$)	8.7 ($MgSO_4$)
0	$^{AB*}15.5^{a}$	$^{E}8.2^{a}$	$^{DE}10.8^{a}$	$^{CD}12.1^{a}$	$^{A}17.4^{a}$	$^{ABC}14.8^{a}$	$^{BCD}13.2^{a}$
2	$^{A}16.0^{a}$	$^{D}6.8^{a}$	$^{C}12.4^{a}$	$^{ABC}14.3^{b}$	$^{A}16.2^{a}$	$^{AB}15.7^{a}$	$^{BC}13.0^{a}$

* Tukey's test. Treatment means followed by the same letters are not statistically significant at the 5% probability level. Lower case letters are for comparisons of zinc treatments within a salinity level. Upper case letters are for comparisons of salinity treatments within a zinc level.

Table 16. Effect of Various Salts and Zinc Fertilization on Zinc Content of Wheat (ppm)

Zinc Added (ppm)	Salinity Level (mmhos/cm) 1.1	10.1 $NaCl$	8.9 $MgCl_2$	8.8 $CaCl_2$	4.6 $CaSO_4$	5.5 $MgSO_4$	8.7 $MgSO_4$
0	$^{AB}7.1^{a*}$	$^{AB}10.2^{a}$	$^{AB}6.7^{a}$	$^{AB}6.8^{a}$	$^{B}5.5^{a}$	$^{A}11.5^{a}$	$^{AB}9.5^{a}$
2	$^{B}8.4^{a}$	$^{B}8.6^{a}$	$^{B}9.8^{b}$	$^{B}8.6^{a}$	$^{AB}12.4^{a}$	$^{AB}13.9^{a}$	$^{A}16.4^{b}$

* Tukey's test. Treatment means followed by the same letters are not statistically significant at the 5% probability level. Lower case letters are for comparisons of zinc treatments within a salinity level. Upper case letters are for comparisons of salinity treatments within a zinc level.

Table 17. Effect of Various Salts and Zinc Fertilization on Zinc Uptake by Wheat (μg/pot)

Zinc Added (ppm)	Salinity Level (mmhos/cm)						
	1.1	10.1 (NaCl)	8.9 ($MgCl_2$)	8.8 ($CaCl_2$)	4.6 ($CaSO_4$)	5.5 ($MgSO_4$)	8.7 ($MgSO_4$)
0	$^{AB}109^{a}$	$^{B}82^{a}$	$^{B}72^{a}$	$^{B}82^{a}$	$^{AB}97^{a}$	$^{A}167^{a}$	$^{AB}125^{a}$
2	$^{BCD}133^{a}$	$^{D}61^{a}$	$^{D}119^{a}$	$^{CD}122^{a}$	$^{ABC}201^{b}$	$^{A}218^{b}$	$^{AB}212^{b}$

* Tukey's test. Treatment means followed by the same letters are not statistically significant at the 5% probability level. Lower case letters are for comparisons of zinc treatments within a salinity level. Upper case letters are for comparisons of salinity treatments within a zinc level.

Table 18. Percent Increase (+) or Decrease (-) in Yield, Zinc Content and Zinc Uptake as Affected by Different Salts and Zinc Addition

Zinc Added (ppm)	Salts Added	Yield (%)	Zinc Content (%)	Zinc Uptake (%)
	NaCl	-46.9	43.9	-23.4
	$MgCl_2$	-30.1	-5.8	-34.1
0	$CaCl_2$	-20.7	-4.7	-25.1
	$CaSO_4$	12.6	-21.8	-11.5
	$MgSO_4$ (A)	-4.2	62.4	52.6
	$MgSO_4$ (B)	-14.9	33.6	14.4
	NaCl	-57.5	2.5	-54.4
	$MgCl_2$	-22.5	16.9	-10.6
2	$CaCl_2$	-10.5	2.0	-8.9
	$CaSO_4$	1.4	47.7	50.4
	$MgSO_4$ (A)	-1.7	65.6	63.6
	$MgSO_4$ (B)	-18.8	95.9	58.9

2500 g soil were added to soils without added zinc. The $MgSO_4$ at 0.137 and 0.274 eqts./2500 g soil increased zinc content by 65% and 95.9%, respectively, when zinc was added. These results are in good agreement with the findings of Merrill <u>et al</u>. (1953) who reported that leaves of tung plants grown in soil treated with Mg salts had a higher zinc content than untreated soils.

Addition of zinc increased zinc uptake for all salt treatments. These increases, however, were significant for only $CaSO_4$ and both $MgSO_4$ treatments (Table 17). Sodium chloride, $MgCl_2$, $CaCl_2$ and $CaSO_4$ decreased zinc uptake by plants when zinc was not added. Both $MgSO_4$ treatments increased zinc uptake when zinc was not applied. These increases and decreases were not statistically significant when compared with the soil without salt. Zinc uptake on soils treated with zinc decreased when Cl salts were added, but increased when SO_4 salts were added. However, these increases and decreases were not significant except with $MgSO_4$ at 0.137 eqts./2500 g soil. Thus, adding $MgSO_4$ to the soil increased the zinc uptake by plants with or without added zinc.

Most of the salts decreased zinc uptake in both zinc treatments, whereas zinc uptake increased 52.6% and 14.4% with $MgSO_4$ at 0.137 and 0.274 eqts./2500 g soil, respectively, when zinc was not added (Table 18). Zinc uptake increased by 63.6% and 58.9% with $MgSO_4$ at 0.137 and 0.274 eqts/2500 g soil, respectively, when zinc was added. This may be due to the replacement of Zn^{2+} by Mg^{2+} on exchange sites. The Zn displacement into soil solution would be available to plants. The ability of Mg^{2+} to replace Zn^{2+} may be due to their ionic radii similarity. Zinc uptake by plants grown on the saline soil with $CaSO_4$ was higher than on the nonsaline soil when zinc was added; zinc uptake increased 50.4% (Table 18).

SUMMARY AND CONCLUSIONS

In many countries, maximizing the productivity of salt affected soils through fertilizer application is a necessity. The literature generally indicates salinity decreases crop yields. However, for a given salinity level, yields can be increased by fertilizer application. Studies reported in the literature on N, P, K nutrition showed that addition of large amounts of P and K enhanced growth on saline soils. In contrast, little or no information on the effect of zinc application on improving plant growth under saline soil conditions was found in the literature. Thus, a series of growth chamber experiments on saline and nonsaline soils was conducted to determine:

1 - The effect of soil salinity on the utilization of native and applied zinc.

2 - The extent to which zinc fertilizer may improve plant growth under saline conditions.

3 - The efficiency of $ZnSO_4$ and ZnEDTA as zinc fertilizers on saline and nonsaline soils.

4 - The cations or anions responsible for altering zinc utilization on saline soils.

The first growth chamber experiment was conducted to study the effect of adding zinc and manganese on dry matter yield and zinc uptake by wheat grown under six salinity levels varying from 1.1 to 12.3 mmhos/cm. The yield of wheat decreased significantly with increasing salinity. Addition of zinc and manganese had no effect on yield at any salinity level. Zinc content of the plants usually decreased with increasing salinity. Zinc uptake also decreased significantly with increases in salinity; this was due to decreases in both yield and zinc content with increasing salinity.

The second growth chamber experiment was established to study the effect of salinity and zinc and manganese fertilization on dry matter yield, zinc content and zinc uptake by black beans. Black beans did not grow at salinity levels more than 6.5 mmhos/cm. Yields of black beans decreased more sharply than yield of wheat with increasing salinity. This indicates that black beans are more sensitive to salinity than wheat. Addition of zinc alone or with manganese increased yield significantly on the nonsaline soil and at low salinity, but yield increases were not significant at high salinity. Adding zinc alone or with manganese increased zinc content significantly at all salinity levels. Increasing soil salinity had no significant effect on zinc content. Zinc uptake by black beans decreased with increasing salinity, particularly when zinc was added. This was due mainly to the reduction in dry matter yield with increasing salinity. Zinc uptake increased significantly when zinc was applied to the nonsaline soil and to the slightly saline soil. Thus, the black bean plants responded very well to added zinc on both nonsaline and slightly saline soils.

The third growth chamber experiment was conducted to study the effectiveness of two zinc fertilizers and the best rate of application for yield; zinc content and zinc uptake by black bean plants on non-saline and saline soils. Increasing soil salinity decreased yield significantly with all treatments. Zinc application usually increased yields. Both $ZnSO_4$ and ZnEDTA were found to be effective in increasing yields and zinc content of plants. However, the relative effectiveness of the two zinc fertilizers were altered by soil salinity. In nonsaline or slightly saline soils, ZnEDTA was superior to $ZnSO_4$ as a zinc fertilizer when applied at equal concentrations. However, on saline soils, $ZnSO_4$ was equal to or slightly better than ZnEDTA when applied at equal concentrations.

The fourth growth chamber experiment was conducted to study the effect of individual salts and zinc fertilization on dry matter yield and zinc content and zinc uptake by wheat. Adding salts to nonsaline soil decreased yield with and without zinc except when $CaSO_4$ was added. Addition of zinc had no significant effect on yield. The effectiveness of different salts in depressing yield was similar with and without zinc, and followed the order NaCl (10.1 mmhos/cm) > $MgCl_2$ (8.9 mmhos/cm) > $CaCl_2$ (8.8 mmhos/cm) > $MgSO_4$ (B) (8.7 mmhos/cm) > $MgSO_4$ (A) (5.5 mmhos/cm). This indicates that depressions in yield increased with increasing osmotic pressure of soil solution. However, chloride salts seem more toxic to the plants than sulfate salts. Zinc content of wheat increased when NaCl or $MgSO_4$ was added. Zinc content decreased when the soil was treated with $MgCl_2$, $CaCl_2$ or $CaSO_4$. Zinc content increased when zinc was added. The greatest increases occurred when $MgSO_4$ was added. Zinc uptake decreased when salts were added, except when $MgSO_4$ was added where the zinc uptake increased. The decreases in zinc uptake were due to decreases in both yield and zinc content of plants. The increases in zinc uptake on soils containing $MgSO_4$ were due to increases in zinc content of plants.

The studies reported in this manuscript indicate that wheat yields on the saline and nonsaline soils studied were not restricted by zinc deficiency. Growth of black beans on both saline and nonsaline soil was improved by zinc fertilization. However, the improvement in yield was greater on the nonsaline soil than on the saline soil, indicating that zinc fertilization will not greatly improve yields of black beans on saline soils. Saline soils were found to be no more zinc deficient than corresponding nonsaline soils. The lower yield potential on saline soils would in fact indicate a smaller response to zinc than on nonsaline soils.

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