Specific effects of certain salts on the growth of roots of young corn seedlings

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Abstract

The effect of different concentrations of NaCl, Na_2SO_4 , MgCl_2 and MgSO_4 on the growth in length of the first seminal root of corn, and on the change in dry weight of the whole seedling and its separate parts have been studied. The effect of mannitol was also investigated for comparison and to study the osmotic effect. The effect of salts on root growth was dependent on the salt species; all effects were specific for the ions investigated, not due to osmotic activity of the solution. The growth of corn roots was suppressed by concentrations of salts much lower than those required to suppress germination. All solutions tested from 1 to 20 meq/l inhibited growth of the root; the retardation increased with increase of concentration. The effect of salts on growth of corn roots was due to both cations and anions and the effect of sodium was stronger than that of magnesium and chloride was more effects than sulphate.

INTRODUCTION

The growth of some plants is retarded when the salt content of the soil exceeds a certain value. Crop sensitivity to salts is of economic importance as well as of academic interest since yields are reduced when the salt content of soils exceeds a certain critical limit. The retardation which affects plant growth may be due to the osmotic and/or specific nature of these salts and varies with the kind of plant.

Retardation of growth of plants in saline soils is largely due to osmotic effects, although significant differences among salts such as sodium, calcium and magnesium chlorides are recognized (Gauch and Wadleigh 1944, 1945, Wadleigh and Ayers 1945, Magistad 1945, Wadleigh et al. 1947, Hayward and Wadleigh 1949, Bernstein and Hayward 1958, Bernstein 1975). Hassan and Overstreet (1952) also recorded that the depressing effects

of certain ions on the elongation of radish seedlings is not solely due to increased osmotic pressure of the medium, but the nature of the salt also may be important. Torrey (1956) pointed out that the elongating root is a highly organised and actively metabolizing system which is directly affected by the surrounding physical and chemical environment. Because of its sensitivity, the inhibition of root elongation has been used extensively in the study of the biological activity of chemical compounds. Most of these inhibition studies are based on the simple procedure of determining mean total length at the end of a given time period, expressed as a percentage of the control.

In the present paper a study of the effects of sodium and magnesium chlorides and sulphates on the growth of young intact corn root is described, in an attempt to correlate the role of ions with the overall metabolic activity. This is achieved by avoiding the adverse osmotic effects and following the action of very low concentrations of salt solution on young developing seedlings. The idea upon which this study rests is the following: if a young seedling grows in pure water as well as in a balanced nutrient solution for a certain period of time (Hatata et al. 1979), it could then be deduced that there is no need for an external supply of mineral nutrients at that stage of growth, and that it draws all its nutrient requirements from the endosperm. Under such conditions, if the seedling is grown in a single salt solution instead of distilled water, any change in the growth rate or in the chemical constituents of the seedlings as compared with the control could then be attributed to some effects of this salt on metabolism.

MATERIAL AND METHODS

Seeds of double hybrid (186) corn (*Zea mays* L.) were soaked in deionized water for 24 hours (Hatata and Farah 1982) at 27°C with continuous aeration. Seeds were then transferred to wet sawdust in pots 12 cm in diameter and 16 cm high. The sawdust was boiled in water several times then autoclaved. The pots were irrigated by sprinkling of water on the surface of the sawdust. Every pot received 17 seeds, which were arranged in vertical position with the embryo pointing downwards. Germinating seeds with 10-12 mm radicles were transferred to jars (Hatata et al. 1979). Every jar received 12 seedlings. Water or the desired salt concentration was added to the jar up to a level just below the framework holding the seedlings. The solution was changed every 24 hours throughout the experiment which was carried out in darkness at 27°C.

At 24-hour intervals 4 jars providing 48 seedlings were taken at random from every treatment, and the seedlings were photographed for measurement of root length (Younis and Hatata 1971a). The

dry weight of 0, 54 and 126-hour-old seeds or seedlings were determined, 174-hour-old seedlings were dissected into roots, grains and tops, the latter comprising the plumule with its first leaves. The dry weight of these organs was determined separately after drying the tissues at 65°C for 24 hours.

RESULTS

ROOT LENGTH

Figure 1 shows that elongation of the root was suppressed by all concentrations of sodium and magnesium salts. The lowest concentration of NaCl and Na₂SO₄ used, namely 1 meq/l inhibited growth of the root and reduced its length to 41 and 61 per cent of its length in water within 5 days from transferring to salt solution. In the same concentrations of MgCl₂ and MgSO₄ it is particularly interesting to note that it inhibited the growth of the root during the first 24 hours and reduced it to 90 and 93 per cent, respectively. However, this retarding effect of MgCl₂ and MgSO₄ disappeared in the second day and the roots recovered the length lost during the earlier stages and were almost as long or slightly longer than the control roots in water, the increase being 3-5 per cent only. After that period the growth of the root was affected adversely (Fig. 1). It means that a very dilute NaCl, Na₂SO₄, MgCl₂ and MgSO₄ solutions of 1 meq/l which contains only about 58, 71, 101 and 123 ppm and has no measurable osmotic activity induced a pronounced suppression of root activity. Since the volume of the solution was rather large as compared to the volume of the roots, and since the solution was renewed every 24 hours, the reversion of the effect of these salts on root elongation could not be due to a change in the concentration of the bathing solution but should be attributed to a change in the metabolic activity of the root.

It can also be noticed from Fig. 1 that the suppressive action of sodium salts was more pronounced than that of magnesium, and that of chlorides stronger than of sulphates. For example, 5 meq/l NaCl and Na₂SO₄ reduced the root length by 72 and 61 per cent below its length in water, while the same concentration of MgCl₂ and MgSO₄ reduced it by 55 and 46 per cent at the end of the experiment, respectively.

From the above results it was evident that the growth of corn root was greatly suppressed by all the concentrations of the salt solutions used, which had either a rather low or an immeasurable osmotic activity. Although it is quite evident that the retardation of root growth by these solutions could not be due to osmotic effects, in order to find out the role of the non-ionic osmotic activity of the bathing solution

Fig. 1. Effects of different concentrations of salts on the relative root length of corn as per cent of control

on the growth of the root, an experiment was conducted in the same manner, but with mannitol as bathing solution. After 5 days in 20 g/l mannitol solution (Fig. 1) the length of the roots was about the same as in water. Admittedly there was a suppression effect in 38 g/l and 50 g/l mannitol solutions after 5 days and the length was 17 and 31 per cent lower than in the control. Comparing the results of the four experiments with salts with the effects of mannitol the following results are found after 5 days:

NaCl 20 meq/l or 0.96 atm. reduced root length by 80 per cent; Na_2SO_4 20 meq/l or 0.72 atm. reduced root length by 71 per cent; MgCl_2 20 meq/l or 0.72 atm. reduced root length by 66 per cent; MgSO_4 20 meq/l or 0.48 atm. reduced root length by 59 per cent; Mannitol 20 g/l or 2.9 atm. reduced root length by 5 per cent.

DRY WEIGHT

It is clear from the results in Fig. 2 that the dry weight of whole seedlings decreased with advance of time whether in distilled water or in different concentrations of single salt solutions. The highest loss in dry weight was shown by seedlings cultured in distilled water, and this loss in dry weight decreased with increase of salt concentrations. Thus, it may be concluded that the growth of seedlings was greatly inhibited by salinization. The results also indicated that the inhibitory effects of both sodium salts on metabolic activity of corn seedlings were more pronounced than the equi-equivalent concentrations of magnesium salts. It is also evident that the cations in association with chloride have a more inhibitory effect than in association with sulphate. On the other hand, the dry weight of seedlings grown in mannitol solution of 2.9 atm. was almost the same as in distilled water (Fig. 2). This result also indicates that the effect of the salts investigated on the growth of corn seedlings could not be due to osmotic effects.

If we compare the effects of different salts on the dry weight of different parts of seedlings (Fig. 3), one can observe that the decrease in dry weight of roots and tops of seedlings raised in the lowest concentration of salts was as follows: 39, 35, 29 and 20 per cent for roots lower than in the control, and 16, 13, 9 and 4 per cent for tops of seedlings grown in NaCl, Na_2SO_4 , MgCl_2 and MgSO_4 , respectively. Relative to the control in water, the dry weight of roots decreased by about 76, 61, 54 and 47 per cent, whereas, the dry weight of tops decreased by about 32, 26, 22 and 16 per cent with the highest concentrations of NaCl, Na_2SO_4 , MgCl_2 and MgSO_4 , respectively. These results indicated that growth of roots and tops was determined chiefly by the toxic effect of the cations and anions and that sodium ions exerted the

Fig. 2. Effects of different concentrations of salts on the oven-dry weights of whole corn seedlings. Values are means of 4 replicates and expressed as g/100 seedlings. The error did not exceed 5%.

greatest inhibitory effects. The dry weight of the grains, however, showed a completely different picture: those in the higher concentration of salt solutions exhibited a substantially higher dry weight than those of the controls, the increase was about 98, 78, 67 and 56 per cent higher than in the control for seedlings grown in NaCl, Na_2SO_4 , MgCl_2 and MgSO_4 , respectively.

Fig. 3. Effects of different concentrations of salts on the oven-dry weights of various parts of corn seedlings. Values are means of 4 replicates and expressed as g/100 parts. The error did not exceed 5%. 0 — control; 1, 10, 20 — concentrations of salts in meq/l

DISCUSSION

Different ions vary in their effects on plants: while certain ions stimulate growth, others seem to restrict it. This effect is more pronounced in single salt solutions. A combination of two or more ions usually produces greater stimulation than a single one does. Whereas certain ions cause retardation of growth in high concentrations, other ions are "toxic" in low concentrations (Elgabaly 1955, 1958, Elgabaly and Abdel Ghani 1958). This brings to focus the specific effects of these ions on plant growth. It has been shown (Hassan 1954, Hassan and Overstreet 1952, Younis and Hatata 1971b) that the depressing effect of certain salts is not necessarily due to increased osmotic pressure, but rather to certain specific effects produced by the ion. Since ions of equal valency differ in their physico-

-chemical properties in solution, it is worth while to examine whether or not these properties are associated with specific effects in plants.

The first fact calling for attention in this study is that, under conditions of salinization of the medium the rate of increase in root length decreased significantly as compared with the rate of seed germination (Farah 1975), this decrease being the greater the higher the concentration of salt in the ambient solution. For example, 400 meq/l of NaCl was required to suppress germination of corn by about 50 per cent, and 1 meq/l NaCl was adequate to suppress elongation of root by about 50 per cent.

The growth of corn root was greatly suppressed by all concentrations of the salt solutions used within 3 to 5 days. These salt concentrations had a rather low or an immeasurable osmotic activity. Root elongation of the seedlings is sharply inhibited by an increase in the salt concentration. This inhibition of growth processes in the seedlings may be caused by a decrease in the rate of cell division and elongation and by a sharp reduction in the size of the cells that have finished growth in a plant under salinization (Gonzalez-Bezaaldez, 1970, as quoted by Udovenko and Alekseyeva 1973).

One of the purposes of this study was to elucidate whether the influence of these salts on root growth was due to their cations or anions. When comparing the effects of NaCl and $MgCl_2$ in the lowest concentration (1 meq/l), it could be noticed that, while the relative root length after 5 days was 46 per cent in NaCl, it was 69 in $MgCl_2$. It is safe to conclude that sodium chloride reduced root elongation considerably, while magnesium chloride exerted a weak effect. Also when comparing the effect of NaCl and Na_2SO_4 on root elongation we found that sodium in association with chloride reduced root elongation more than sodium in association with sulphate. However, the suppressive effect was not always of the same order as that mentioned above. It changes from species to species. Our results with broad bean (Shehata et al. 1981) showed that the detrimental effect on root growth was mainly due to cations; the suppressive effect decreasing in the order $Mg^{++} > K^+ > Na^+$.

Gauch and Wadleigh (1944), recorded that the effect of magnesium salts on plant growth is the result of excessive accumulation of magnesium or breakdown of calcium uptake. There is also an extensive literature on the role of magnesium in enzyme activity which has been reviewed by Hewitt (1951), McElroy and Nason (1954), Richards and Berner (1954), Dixon and Webb (1961).

Some investigators assumed that the decrease in dry matter with increasing salinity might be due to a change in the water regime of the plant in addition to the toxic action of the salt. Thus, Hassan et al. (1970) concluded that the decrease in dry matter in salt-treated barley and corn plants could be attributed to the decreased water availability

and increasing toxicity of sodium chloride and sulphate in the soil solution. Others (Janes 1966, Nieman and Poulsen 1967, Meiri et al. 1970) reported that a large part of the reduction in plant growth or decrease in the yield is the result of the combined suppressing action of salinity and transpiration on the plant water potential.

It is concluded from our results that the recorded suppression of root growth could not be attributed to the osmotic action of the salt, but rather to the specific effects of its ions. This conclusion is based on two facts. First, the concentrations used were too low to exert an osmotic action; the 20 meq/l of any of the salts chosen ranges between 0.48 to 0.96 atm. Second, when mannitol solutions of osmotic activity higher than those of the salts investigated were used, no suppression of water uptake was noted. Similar conclusions were drawn by Younis and Hatata (1971b) in experiments with wheat grains and by Shehata et al. (1981) with broad bean.

Disagreement in the conclusions of the various investigators as to whether the effect on growth is due to the role of specific ions or to the osmotic action of the salt, or else to the disturbed water potential could be traced back to: variations in the techniques, the species or even the variety of the plant and also to the different anions and cations in the medium. Some investigators applied the salt to the soil, and others raised the plants in nutrient water cultures and investigated the effects of salt addition. Salt treatments and analytical studies of metabolism were usually performed in these types of experiments when the plants had reached conspicuous stages of vegetative development. Under such conditions synergism and antagonism between the different ions could not be ruled out nor assessed precisely. Furthermore, the introduction of photosynthesis into the field adds to the complexity of the picture. Also, a conclusion regarding the effectiveness of, say, Cl^- and SO_4^{--} with a cation like Mg^{++} may not be true with another cation like Na^+ .

In this study these complications were taken into consideration to a great extent by applying the following technique:

1. Germination of corn seedlings in darkness eliminates the factors of photosynthesis and restricts the analysis of metabolites found initially in the endosperm.
2. No external nitrogen source was available to the seeds so there is no possibility of *de novo* synthesis of carbohydrates or nitrogen compounds.
3. The use of single salt solutions eliminates the complexity due to interaction of ions.
4. The use of very low concentrations of the salt rules out the possible osmotic action of the salt.

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Specyficzny wpływ niektórych soli na wzrost korzeni młodych siewek kukurydzy

Streszczenie

Badano wpływ różnych stężeń NaCl , Na_2SO_4 , MgCl_2 i MgSO_4 na wzrost pierwszego korzenia siewek kukurydzy i na ilość suchej masy całych siewek i ich części. W celu porównania i zbadania wpływu osmotycznego, siewki poddano działaniu mannitolu. Wzrost korzeni zależał od rodzaju użytej soli i wydaje się, że wynik działania soli był specyficzny dla jonów natomiast nie zależał od aktywności osmotycznej roztworu. Stosowane stężenia soli w mniejszym stopniu ograniczały wzrost korzeni kukurydzy niż kiełkowanie nasion. Wszystkie użyte stężenia od 1 do 20 meq/l inhibowały wzrost korzeni; efekt był tym większy im większe było stężenie soli. Zarówno kationy jak i aniony soli wpływały na wzrost korzeni kukurydzy; wpływ jonu sodowego był silniejszy niż magnezowego, a chlorek działał wyraźniej niż siarczan.