The Effect of Soluble Salts on Soil Water Availability

Armand Bauer

Water held in the soil between the field capacity[a] and permanent wilting point[b] is referred to as available soil water. The concept is based on the premise that the only factor affecting availability is the attraction of water for soil solid surfaces and the attraction of water molecules for each other. However, when excess amounts of soluble salts are present in the soil solution, these, too, impose a restraint on availability of water to the plant through the phenomenon referred to as osmotic potential. The effect of excess soluble salts on water availability can vary with the amount and kind of soluble salt, the kind of crop, and the atmospheric conditions as they affect rate of evaporation of water from plants and the soil.

Soluble salts in excess amounts can affect plants in ways other than by reducing water availability (6). Included in these other ways are the alteration of nutrient availability, alteration of physical condition so as to limit root penetration (especially where sodium salts are involved), and direct toxicity. However, only a few salts are found in soils in toxic concentrations (6).

The effect of soluble salt concentration on plant yield has been studied for numerous species. Sandoval *et al.* (13), for example, showed that yield of hard red spring wheat decreased from about 35 bushels per acre when the osmotic potential of the soil at the 6 to 16-inch depth at planting was about 2 atmospheres, to less than 4 bushels at an osmotic potential of 7 atmospheres. They showed, too, that the relationship between soluble salt concentration and yield reduction was curvilinear. An indication of the relative tolerance to soluble salt concentrations of various species, based on yield, is provided in USDA Agriculture Handbook 60 (14) and by others (3, 8).

[a]Field capacity is defined as the water content of a well-drained soil, initially saturated, after downward drainage has become small (usually within 5 days).

[b]Permanent wilting point is defined as the soil water content at which plants permanently wilt (a permanently wilted plant will not recover turgidity when water is added to the soil).

Dr. Bauer is professor, Department of Soils.

Soils in North Dakota affected by excess soluble salts in the upper 2 feet are estimated at about one million acres[c] by H. W. Omodt, professor of soils. Areas of these soils are present in all counties of the state, with the largest acreage on a contiguous basis probably located in Grand Forks county. Evidence of recent increases in acreage of these soils, especially in the western part of the state (5, 15) and in the semi-arid regions of northeastern Montana (7) and Saskatchewan (1), suggested by some as being in part a consequence of alternate crop-fallow, has focused attention on and increased interest in them.

This study was conducted as part of a class demonstration to illustrate the effect of a soluble salt on water availability to students enrolled in a course formerly taught by the author. The experimental approach was chosen because it circumvented differences that could arise due to differential effects of salt concentration on germination of different plant species.

[c]This does not include the acres of soils affected by sodium (alkali), but it does include soils affected by both soluble salts and sodium (saline-alkali).

Procedure

The experimental procedure was essentially that previously employed by Bauer and Lindsay (2) to evaluate the effect of temperature on zinc availability. Seeds were germinated in a perlite medium. Then the roots of the seedlings were placed on soils of varying salt content.

A non-saline fine sandy loam, 1880 grams oven-dry basis (about 4.1 pounds) per pot, was mixed with calcium chloride ($CaCl_2$), and with phosphorus and nitrogen fertilizer to supply about 100 pounds each of N and P per 2 million pounds soil. The rates of $CaCl_2$ added per pot corresponded to 0, 0.22, 0.35 and 0.55 per cent by weight of added salt. After mixing, the soil was put into plastic bag-lined cylindrical cartons 6 inches in depth and 5 inches in diameter. Sufficient water was added to bring the soil to field capacity, and the pots were covered with excess length of the plastic bag to reduce evaporation while stored in the laboratory for about 10 days. Field capacity was approximated as the water held by non-saline soil in equilibrium with 1/10 atmosphere pressure (14), and was determined to be about 22.2 per cent by weight. The permanent wilting point was approximated as the water held by non-saline soil in equilibrium with 15 atmospheres pressure (14), and was about 5.2 per cent by weight. Conductivity of a 1:1 soil-water suspension of the soil prior to addition of $CaCl_2$, was 0.05 millimhos per centimeter.

Corn and hard red spring wheat seeds, Nodak 301 and Waldron, respectively, were germinated in a perlite medium irrigated with a half-strength Hoagland solution. The perlite was in a carton about 4 inches high, with a bottom diameter of 4 inches and about 5 inches at the top, with the bottom removed, which in turn was nestled in a second carton of the same size with the bottom intact. The seedlings were periodically irrigated with the Hoagland solution to maintain plant turgidity prior to placement in contact with soil.

When corn was in the 3-leaf and wheat in the 4-leaf stage, the outer carton was removed. The inner carton holding the perlite and the seedlings with their roots exposed was placed on the soil in the cylindrical cartons. Immediately prior to contact of the seedlings and soil, the perlite medium was irrigated with Hoagland solution, and water was added to the soil in the cylindrical cartons to replace the quantity lost by evaporation during storage (this was less than 25 grams per pot). To prevent or reduce evaporation of water, the soil exposed by the approximate 3/8-inch space between the carton holding the perlite and the cylinder holding the soil was covered with cotton batting and the excess length of plastic liner was pulled up to surround the carton containing the perlite, and taped to it.

At time of contact, the seedlings of the given species were all of uniform size (more seeds had been planted than the desired seedling population, hence selection was possible). The number of corn seedlings during the soil-seedling contact period was five, and eight of wheat.

Each treatment of each crop was replicated twice. The containers were randomly placed into two separate climate controlled growth chambers at 70° F. The relative humidity in one chamber was maintained in a range of 10 per cent to 20 per cent, or "low" humidity; the second chamber was maintained in a range of 55 per cent to 90 per cent, or "high" humidity. The containers were periodically shifted, but not in a systematic manner. "Daylight" hours were maintained from 6:00 a.m. to 8:00 p.m. Light intensity was about 2500 foot-candles at the top of the pots. No water was added to the soil during the 11 to 12 days of soil-seedling contact. At termination of the experiment, soil samples, a composite of three probings each of the 0 to 2 and 2 to 5-inch depth, were taken from each container. These soil samples were oven dried at 105-110° C to determine water content. The seedlings were cut at the upper surface of the perlite level at termination of the experiment and dried at 69° C.

The soil and plant data were analyzed as a factorial (11). The data of tissue yield and per cent soil water at the end of the experiment were subjected to correlation and linear regression analyses (11).

Results

Data in Table 1 show the soil water content, per cent by weight, after corn and wheat seedlings had grown in the soil for 11 to 12 days (by this time wilting occurred in both species, but it was not as readily observed on wheat as on corn). While these data are an average of the entire soil depth, samples taken from the 0 to 2-inch depth and from the 2-inch depth to the bottom were similar within each pot, suggesting root penetration throughout the entire soil mass.[d]

The data in Table 1 show that the amount of water remaining in the soil increased with each increase in salt added. The data also show that more water remained after corn than wheat in containers to which salt was added.

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[d]Water content differences between the 0 to 2 and 2 to 5-inch depth at "low" humidity ranged from 0.7 to 1.3 percentage units in corn and 0.3 to 2.6 in wheat. At "high" humidity, the range was 0.2 to 1.8 in corn and 0. to 2.1 in wheat. However, there was no consistency between depths; in some cases the water content at the 2 to 5-inch depth was lower than at the 0 to 2-inch depth.

Table 1. Per cent soil water by weight at termination of the experiment under two crops and under two humidity conditions.

Salt added % by weight	Per cent soil water by weight, Humidity: Corn low %	Corn high %	Wheat low %	Wheat high %	Average %
0	7.1	5.8	5.9	4.9	5.9 a[1]
.20	10.5	8.7	7.2	6.7	8.3 b
.35	14.4	12.9	8.6	9.2	11.3 c
.55	16.4	15.7	10.4	12.0	13.6 d
Average	11.4 b[2]		8.1 a[2]		

[1]Numbers followed by a different letter in this column indicate that the odds are at least 95 out of 100 that the differences are due to treatment rather than chance.

[2]The odds are better than 95 out of 100 that the soil water content under wheat was lower than under corn.

Based on statistical analysis, water remaining in the soil at a given salt level differed with crop (crop x salt level interaction was significant). The data in Table 2 show these effects.

The data in Table 2 show that the amount of water remaining in the soil without added salt did not differ significantly for the two crops. But where salt was added, the water remaining after corn at a given salt level was consistently higher than after wheat. Wheat removed as much water from the soil with 0.35 per cent added salt as did corn with only 0.20 per cent salt added.

Humidity had an effect on amount of water remaining in the soil on which corn was grown.

Table 2. Per cent soil water by weight as influenced by crop and salt added. (Average of both humidity conditions).

Salt added % by weight	Per cent soil water by weight, Crop: Corn %	Wheat %
0	6.4 ab[1]	5.4 a
.20	9.6 c	7.0 b
.35	13.7 e	8.9 c
.55	16.0 f	11.2 d

[1]Numbers followed by a different letter in the table indicate that the odds are at least 95 out of 100 that these differences are due to treatment rather than chance.

Atmospheric humidity affected water removal by corn but not wheat. More water was removed by corn under "high" than "low" humidity, but not by wheat (the humidity x crop interaction was significant). The data are shown in Table 3.

Table 3. Effect of humidity on per cent soil water by weight under wheat and corn. (Average of all salt levels).

Humidity	Per cent soil water by weight, Crop: Corn %	Wheat %
"Low"	12.1 c[1]	8.0 a
"High"	10.8 b	8.2 a

[1]See Table 2 for explanation.

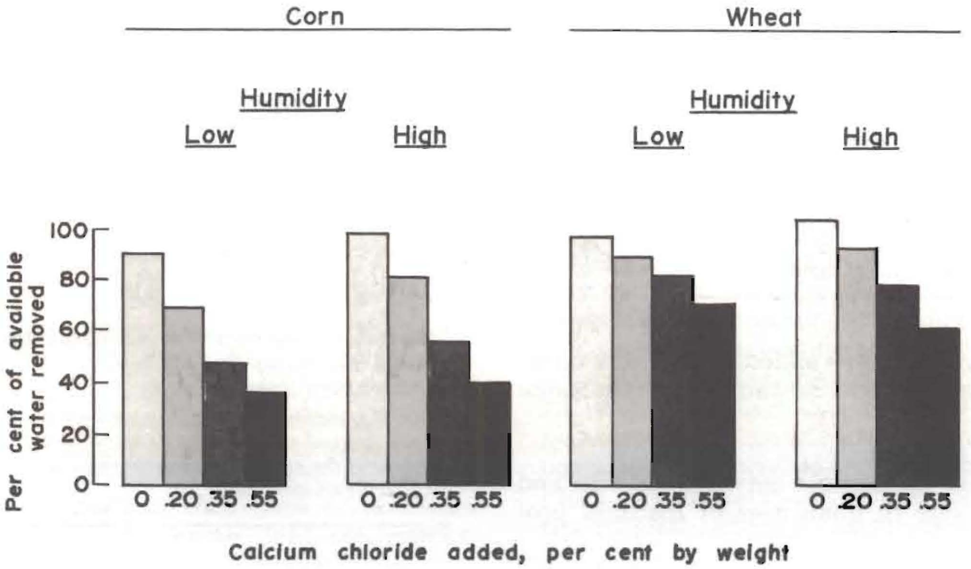

Figure 1. Per cent of "available" water removed by corn and wheat seedlings from fine sandy loam containing four levels of calcium chloride, grown under two humidity conditions.

The data in Table 1 are plotted in Figure 1 in terms of per cent of available water removed by crops at the various salt levels and humidity conditions. These show that as little as 35 per cent and as much as 98 per cent of the water held between field capacity and permanent wilting point[e] was removed by corn grown on soil with 0.55 per cent by weight of added $CaCl_2$ and no added salt, respectively, and as much as 100 per cent to as little as 61 per cent by wheat with no added salt and 0.55 per cent added salt, respectively.

The yield of above-ground tissues at the end of the experiment was affected by salt added, humidity and plant species. In addition, the species by salt added interaction was significant. Data showing these effects are presented in Tables 4 and 5.

The effect of the added salt, averaged over both humidities, was to decrease corn tissue yield at added concentrations of 0.35 and 0.55 per cent as compared to lower salt amounts, but this was not the case with wheat. The data with wheat (Table 4) indicate a lower yield where salt was not added. The reason for the outcome with wheat is likely experimental error; one of the containers with

Table 4. Oven-dry weight of above-ground corn and wheat tissues as affected by per cent by weight of calcium chloride added to soil.

Salt added % by weight	Crop: Corn grams	Crop: Wheat grams	Average grams
0	3.18 d[1]	1.25 a[1]	2.22 b[2]
.20	2.86 d	1.59 b	2.22 b
.35	2.24 c	1.59 b	1.92 a
.55	2.12 c	1.57 ab	1.84 a
Average	2.60 b[3]	1.50 a[3]	

[1]Numbers followed by a different letter in the corn and wheat columns indicate that the odds are at least 95 out of 100 that these differences are due to treatment rather than chance.

[2]Numbers followed by different letters in this column indicate that the odds are at least 95 out of 100 that these differences are due to treatment rather than chance.

[3]The odds are at least 95 out of 100 that the average corn tissue weight was greater than that of wheat.

wheat, where no $CaCl_2$ was added, produced a much lower yield than the other container with the same treatment.

The difference in outcome between the corn and wheat may be due to quantities of material produced under the conditions of the experiment. Since more corn tissue was available, in terms of weight, differences due to the effect of added $CaCl_2$ may have been more readily detectable in corn than in wheat. Another reason may be that conditions, temperature especially, were more favorable for the corn, and hence it made relatively more growth.

The effect of humidity on above-ground yields, shown in Table 5, averaged over all salt levels and crops, resulted in less production under "low" than "high" humidity. This is expected because a plant water shortage (referred to as a deficit) is more likely to occur under "low" humidity conditions. Whenever a plant water shortage occurs, plant metabolic processes contributing to dry matter accumulation are adversely affected (10).

Table 5. Oven-dry weight of above-ground corn and wheat tissues as affected by humidity level.

Humidity	Grams tissue
"Low"	1.80a[1]
"High"	2.31 b

[1]See Table 2 for explanation.

Results of correlation analyses are presented in Table 6. Correlation coefficients were calculated for yield versus water content at the 0 to 2, 2 to 5 and 0 to 5-inch depth, but only the latter are shown because of the similarity of coefficients among the depths. Further, differences in water content between the 0 to 2 and the 2 to 5-inch depth varied little, and neither depth was consistently higher or lower.

Table 6. Correlation coefficients "r" of above-ground tissue yields versus per cent soil water content at end of experiment, under two humidity levels.

Crop	Humidity	"r"
Wheat	"Low"	.691 [1]
Wheat	"High"	.363 [1]
Corn	"Low"	-.920**[2]
Corn	"High"	-.886**

[1]The odds are less than 95 out of 100 that there was a significant mutual relationship between tissue yield and per cent soil water content at end of the experiment.

*[2]The ** indicates the odds are at least 99 out of 100 that there was a mutual relationship between tissue yield and soil water content at the end of the experiment. The minus (-) sign indicates an inverse relationship.*

The tissue yields of corn decreased as the per cent soil water content at termination of the experiment increased. The corn data are plotted in Figure

[e]The amount of water held in a soil between field capacity and permanent wilting point in a non-saline soil is referred to as available water.

2, and the simple linear regression equations are shown. The regression equations indicate that corn tissue yield changed 0.121 grams for each percentage unit change in soil water content at the "high" humidity and 0.107 grams for the same change at "low" humidity. Thus, the water removed from the soil was used more efficiently in producing dry matter under "high" than "low" humidity conditions.

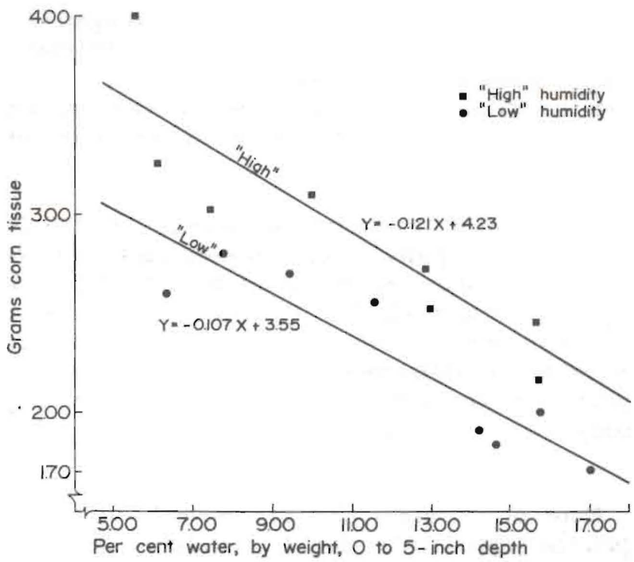

Figure 2. Relationship between corn tissue yield and per cent water remaining in the soil at termination.

Discussion

While excess soluble salts in soil can be detrimental to plant growth because of toxic effects, the primary cause of reduced productivity can be attributed to a decrease in water availability. *A SOIL SALINITY PROBLEM IS, ESSENTIALLY, A WATER PROBLEM.* The presence of the soluble salts increases the number of "particles" (molecules and ions) in the soil solution. These impede or restrict the movement of water into roots, hence its availability to plants is reduced. As the "particle" concentration increases, availability of water decreases. Among theories that have been proposed to explain why solvent movement through semi-permeable membranes is restricted by the presence of a solute (salt) are [1] that the solute constitutes a physical barrier that impedes solvent movement, and [2] that the solvent moves through the semi-permeable membrane in the vapor phase, and because salts reduce the vapor pressure, passage is restricted (4).

The presence of soluble salts does not affect the amount of water a soil can hold against the force of gravity[f]. Soils, identical in every respect except in soluble salt content, retain the same quantity of water per given depth after drainage essentially ceases. But, the amount retained in the saline soil when plants wilt will be greater than in the non-saline soil.

Salts vary in their solubility in water, and in degree of dissociation of molecules into ions, hence in their effect on reducing water availability. A salt such as calcium carbonate (lime) is only very slightly soluble in water, so its presence in soil has very little effect on water relations.

Equal amounts of soluble salts on a weight basis do not affect water availability to the same degree (all other factors equal) because the number of "particles" contributed to the soil solution may not be the same. For example, it requires about 1.3 grams of potassium chloride (KCl) to provide the same number of particles as 1 gram of sodium choride (NaCl), assuming that both salts ionize completely or to the same degree. Also, the number of particles resulting from dissociation of a molecule may differ. Dissociation of a molecule of KCl or NaCl produces 2 particles while $CaCl_2$ produces 3 particles.

Sodium[g], when adsorbed to soil colloidal materials (clay and organic matter) to the extent of about 15 per cent or more of the cation exchange sites, can have a deleterious affect on soil physical properties. The affect of the sodium on soil is to cause dispersion; that is, a breakdown of aggregated soil particles to smaller aggregated particles or into single grains, resulting in an increase in number of small pores at the expense of pores of larger size. Water movement through small pores, when water content is about in the upper half of the "available" range or wetter, is slower than through larger pores. So, when sodium causes soil dispersion, its water transmission characteristics are affected. Thus, a sodium problem, too, is essentially a water problem.

Relative humidity is an indication of the amount of water vapor present in the air in relation to the amount it can hold at a given temperature. Water evaporation rate at a given temperature, whether from a leaf or other surface, is influenced by the amount of water vapor present in the atmosphere — the greater the atmospheric water content at a given temperature the lower the evaporation rate. At lower transpiration rates, water uptake rate by plant roots to maintain a favorable plant water condition is lower than at higher transpiration rates. When the plant is not under water stress, the stomata, through which most of the evapora-

[f]This assumes that density of the solution is not affected by salts present.

[g]Magnesium may also cause dispersion in some soils (12).

tion from plants takes place, can remain open. As atmospheric humidity decreases, the potential transpiration rate is increased, and water uptake from the soil must increase to keep up with the loss by transpiration in order to maintain favorable plant water conditions.

When water uptake by the roots is too slow to supply water rapidly enough to keep up with transpiration, a plant water deficit occurs with subsequent stomatal closure, to reduce transpiration loss. Stomatal closure may have contributed to the reason for differences in water removal by corn under the two environmental conditions in this study.

Root proliferation also can have an influence upon the capacity of a plant to maintain a desirable water level in the plant. The greater the root proliferation in a given soil volume, the shorter is the average distance water needs to move from a given point in the soil to a root. Therefore, with greater root proliferation, soil water is more "accessible" and a plant water deficit under a given atmospheric condition may not occur as readily as with lesser proliferation. This may be a contributing factor, in this study, to the differences in water removal by wheat as compared to corn under a given environmental condition.

Crops vary in their sensitivity to soluble salts. The exact reason is not clear. But it may be related to differences in the osmotic potential of cell sap. Species with the higher cell sap osmotic potential would be expected to have the greater tolerance to soluble salts in the soil. The reason for this is that there must be a gradient to effect water uptake. One of these gradients is a difference in osmotic potential between the soil solution and cell sap. The direction of water movement is toward the higher osmotic potential. Hence, the greater the difference in osmotic potential between root cell sap and the soil, the greater the amount of water that can be withdrawn from the soil. This could explain, in this study, the difference in extent of water withdrawal from soil by wheat as compared to corn. A difference in osmotic potential in tissues among wheat varieties has been suggested as a possible contributing factor to grain yield differences among varieties in "dry" years (9).

Summary

A study conducted in growth chambers shows that corn and wheat seedlings — at the 3-leaf and 4-leaf stage, respectively, when placed in contact with the soil — removed essentially all water held between the field capacity and permanent wilting point of a non-saline fine sandy loam soil over a 11 to 12-day period. When calcium chloride (a water soluble salt) was added to the soil at rates of 0.22, 0.35 and 0.55 per cent by weight, the amount of water removed was as much as 93 per cent and as little as 35 per cent of the amount removed from the non-saline soil, depending upon kind of crop and atmospheric condition. For a given soil salt level or atmospheric condition, corn seedlings removed less water than wheat. Under "low" humidity conditions corn removed more water from soil at a given soil salt level than under "high" humidity conditions.

The amount of above-ground wheat dry matter produced did not significantly differ among salt levels added to the soil, but the amounts of corn dry matter were affected. Under "low" humidity conditions an increase in water content of one percentage unit at termination of the experiment decreased corn tissue yield by 0.107 grams, while at "high" humidity the decrease was 0.121 grams.

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