Salt Tolerance of Crops

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It has been acknowledged that irrigation agriculture would fall into decay after the lapse of some 500 years and such decayed lands are not rare in the regions of Asia irrespective of the lapse of years.

This agricultural decline is attributed mainly to the invasion and accumulation of salt piled up on lands by the back current of sea water which was caused by the soil heaped up at the lower part of the river.

One of the most well known examples of this phenomenon can be seen in the plain of Mesopotamia. The infertile land of this region developed extensively owing to the stagnation of the Tigris, Euphrates and Shatt-al-Arab rivers. The major component of the accumulated salts in this area is Na_2SO_4.

The staff of the U.S. Salinity Laboratory has studied for years the cause of salt injury and obstruction of plant growth and they arrived at the following conclusions: 1) reduced water absorption because of the high external osmotic pressure and 2) specific effects of certain ions on metabolism when they are present in the medium at a high concentration.

It is not easy to distinguish between these two possibilities. The osmotic pressure theory can be applied to many plants but some kinds of plant suffer rather greatly from the effect of ion.

The sensitivity of plant against salt varies according to the kind of plant. Some plants are sensitive to sulfate and others to chloride but bicarbonate checks severely the growth of many plants. Table 1 shows the growth of tobacco and tomato experimented by the author. There appeared serious injury caused by bicarbonate.

Table 1. Yield of tomato and tobacco plants grown in excessive salt solutions (dry matter)

	Plnt			
	Tomato		Tobacco	
Dry wt.	Stems (g)	Leaves (g)	Stems (g)	Leaves (g)
Exptl. plot				
Cont.	46	55	35	38
S—10	59	65	39	40
20	40	49	34	36
30	41	44	29	28
Cl—10	51	66	34	52
20	39	60	31	45
30	46	54	30	46
HCO_3—10	52	61	37	44
20	41	51	33	41
30	11	12	18	27

But as it is considered that the largest factor on salt tolerance of plant growth is each species of plant, the results of our studies of comparative physiology on the salt tolerance of plant growth are summarized here[2-11].

Though some halophyte shows strong tolerance to bicarbonate, its growth declines slightly in the concentrated salt solution of more than three per cent[12].

Glycophyte was preferred as the material plant of this experiment because it includes many food crops.

Experimental methods

About 20 species of crop plant were grown by means of constant renewed sand culture. Culture solution was prepared adding Na_2SO_4 or NaCl to the basal culture solution of which the major component was sulfate or chloride. The concentrations of Na_2SO_4 or of NaCl in the solution were 0 (for control), 20, 40 and 60 meq/l respectively.

The crop plants were grown with these culture solutions from the early stage of growth to the ripening stage.

The yield of crop plant was measured, the organic substances and mineral elements in the plant were determined, the physiological function of the plant injured by salt was examined, the cause of salt injury and the mechanism of salt tolerance were investigated.

Results and discussions

1) Yield

From the results of these experiments, it was found that the crop plants can be classified into two groups with regard to their salt tolerance—one of high tolerance and the other of low tolerance—and furthermore, the former can be divided into two subgroups by their functional differences on nutrient uptake.

Examples of the high tolerance plant are: Italian ryegrass, barley, asparagus and spinach, and that of low tolerance are cucumber and lucerne. Table 2 shows their yield of leaves and stems.

Itarian ryegrass has the highest salt tolerance and barley is also one of the crops of high tolerance though its yield shows some decrease in the 60 meq/l plot. Asparagus production is rather small in the plot of Cl-60. As for spinach, there is no significant difference between every plot and control plot. Consequently, it can be concluded that these latter two crops have also high salt tolerance. But it seems that certain qualitative difference exists between Italian ryegrass, barley, asparagus and spinach.

The yields of cucumber and lucerne decrease according to the increase of the salt concentration of the culture solution. Therefore, they are low salt tolerance plants.

As to the difference of tolerance against sulfate and chloride, generally crop plant is less tolerant of chloride than sulfate.

In this experiment, asparagus and spinach both show almost the same tolerance against salts but sometimes they are slightly less tolerant of chloride. Italian ryegrass shows no significant difference but barley is somewhat less tolerant of chloride. Cucumber shows also no significant difference but lucerne is less tolerant to sulfate.

2) Mineral contents in crops

Table 3 lists the contents of some mineral

Table 2. Yield of leaves and stems of Italian ryegrass, barley, cucumber, lucerne, asparagus and spinach grown in excessive salt solution (dry matter)

Exptl. plot	Plant					
	Italian ryegrass	Barley	Cucumber	Lucerne	Asparagus	Spinach
S—cont.	76.5	10.2	38.9	23.2	8.5	3.1
20	69.3	10.1	40.7	20.5	8.3	2.3
40	76.3	10.7	27.3	6.2	10.8	3.2
60	81.5	6.2	24.1	5.8	7.5	2.3
Cl—cont.	80.7	10.8	42.2	23.8	10.0	2.4
20	77.2	7.3	31.6	26.3	8.5	2.3
40	80.3	7.5	34.9	29.5	8.5	1.8
60	76.5	4.6	17.9	9.7	6.5	2.2

Table 3. Contents of some mineral elements in the leaves and stems of Italian ryegrass etc. grown in excessive salt solutions (on dry matter basis)

Exptl. plot	Na (%)	S (%)	Cl (%)	K (%)	Ca (%)	Mg (%)	Mn
			Italian ryegrass				
S—cont.	0. 23	0. 52	0. 32	4. 29	0. 28	0. 29	220
20	1. 53	0. 75	0. 32	4. 37	0. 16	0. 21	165
40	2. 37	0. 93	0. 32	4. 17	0. 14	0. 19	165
60	4. 07	0. 98	0. 32	3. 47	0. 14	0. 17	138
Cl—cont.	0. 23	0. 14	1. 78	4. 10	0. 36	0. 29	275
20	1. 61	0. 14	2. 73	4. 33	0. 28	0. 24	275
40	2. 71	0. 11	2. 91	4. 02	0. 20	0. 21	165
60	3. 20	0. 11	3. 02	3. 79	0. 22	0. 19	220
			Barley				
S—cont.	0. 26	0. 27	0. 61	7. 46	0. 54	0. 21	55
20	4. 97	0. 57	0. 51	3. 38	0. 15	0. 05	63
40	6. 63	0. 93	0. 53	2. 42	0. 16	0. 05	50
60	8. 60	1. 06	0. 52	1. 02	0. 10	0. 03	34
Cl—cont.	0. 34	0. 20	2. 25	8. 40	0. 50	0. 22	118
20	4. 39	0. 18	4. 22	5. 00	0. 26	0. 10	105
40	8. 10	0. 14	6. 01	2. 95	0. 16	0. 06	105
60	9. 65	0. 15	6. 37	2. 42	0. 14	0. 06	50
			Cucumber				
S—cont.	0. 04	1. 32	0. 54	4. 58	2. 51	1. 20	1480
20	1. 03	1. 66	0. 22	4. 00	2. 16	1. 06	1010
40	1. 98	1. 85	0. 20	2. 98	1. 72	0. 86	1550
60	2. 10	1. 54	0. 10	1. 73	1. 55	0. 52	1010
Cl—cont.	0. 06	0. 35	3. 30	3. 43	3. 10	1. 33	1960
22	0. 95	0. 27	4. 37	2. 28	2. 52	0. 89	1860
40	2. 15	0. 23	5. 75	1. 80	2. 05	0. 68	1620
60	2. 88	0. 23	5. 93	1. 33	1. 61	0. 42	1260
			Lucerne				
S—cont.	0. 07	0. 28	0. 30	2. 49	0. 57	0. 22	581
20	0. 62	0. 45	0. 18	1. 95	0. 35	0. 13	267
40	0. 83	0. 55	0. 17	1. 98	0. 29	0. 13	200
60	1. 14	0. 51	0. 14	0. 76	0. 25	0. 12	154
Cl—cont.	0. 05	0. 17	0. 62	2. 49	0. 56	0. 25	442
20	0. 41	0. 16	1. 70	2. 09	0. 46	0. 13	297
40	1. 07	0. 15	2. 21	2. 06	0. 47	0. 12	350
60	1. 49	0. 10	2. 71	1. 76	0. 35	0. 14	260

Exptl. plot	Na (%)	S (%)	Cl (%)	K (%)	Ca (%)	Mg (%)	Mn
			Asparagus				
S—cont.	0. 08	0. 33	0. 98	2. 64	0. 34	0. 30	193
20	0. 28	0. 34	1. 28	2. 64	0. 32	0. 27	195
40	0. 52	0. 37	1. 18	2. 53	0. 31	0. 30	182
60	0. 80	0. 38	1. 25	2. 17	0. 28	0. 26	175
Cl—cont.	0. 12	0. 20	1. 81	2. 69	0. 27	0. 29	208
20	0. 25	0. 18	1. 98	2. 53	0. 27	0. 22	220
40	0. 48	0. 18	2. 24	2. 47	0. 28	0. 21	210
60	0. 50	0. 19	1. 99	2. 42	0. 23	0. 18	220
			Spinach				
S—cont.	0. 07	0. 35	0. 29	5. 98	0. 72	0. 71	490
20	0. 95	0. 42	0. 29	5. 78	0. 51	0. 56	310
40	1. 15	0. 47	0. 19	5. 58	0. 42	0. 52	270
60	1. 55	0. 45	0. 20	5. 65	0. 39	0. 52	220
Cl—cont.	0. 09	0. 33	0. 58	6. 15	0. 80	0. 75	440
20	0. 95	0. 26	1. 60	5. 78	0. 54	0. 58	410
40	1. 95	0. 26	2. 52	5. 38	0. 48	0. 51	360
60	2. 13	0. 22	3, 46	4. 83	0. 46	0. 48	370

elements in the leaves and stems of examined crop plants. Sodium and sulfur are naturally abundant in the plants of sulfate plots, and in the same way, sodium and chlorine are ample in the plants of chloride plots. But the phase of plants to take these elements is not always the same.

According to the excessive up take of these elements, some plants showed abnormal presence of contents; that is, generally, absorption of potassium, calcium and magnesium decreased excessively and sometimes manganese, too.

Table 3 shows that Italian ryegrass and barley which are high salt tolerance plants revealed strong absorbing ability of sodium. Consequently, this ability disturbs the absorption of potassium, calcium, magnesium and manganese. But Italian ryegrass and barley grew almost normally in spite of the necessity of these elements in this experiment.

On the contrary, cucumber and lucerne, which are plants of low salt tolerance, did not show strong absorbing ability of sodium even in the solution of excessive salt, and yet, the absorption of potassium and calcium etc. was strongly disturbed. They are the plants which cannot be tolerant of the want of these elements.

On the other hand, asparagus and spinach, the plants of high salt tolerance, did not have any strong absorbing ability of sodium so the absorption of potassium and calcium etc. was not disturbed so much. This seems to be the cause of their high salt tolerance.

It is believed that some special mechanism exists in the roots of these crop plants to control sodium absorption to a certain extent.

3) *Balance of total cation to total anion*

TROUG[1] summarized that each species of plant when grown under different conditions strives to maintain a rather constant total equivalent base content. From this point of view, the author calculated the total amount of cation and anion of the plant. Table 4 shows the total amount of cation and anion

Table 4. Total amounts of basic and acidic constituents in the leaves and stems of Italian ryegrass etc. grown in excessive salt solutions (meq/l on dry matter basis)

Exptl. plot	Total cation (c)	Total anion (a)	c/a×100	Exptl. plot	Total cation (c)	Total anion (a)	c/a×100
Italian Ryegrass				Lucerne			
S—cont.	237	278	85	S—cont.	195	219	89
20	280	287	98	20	180	223	81
40	310	298	104	40	200	251	80
60	358	281	127	60	204	259	79
Cl—cont.	228	275	83	Cl—cont.	191	217	88
20	281	293	96	20	176	235	75
40	313	291	108	40	219	233	94
60	326	294	111	60	224	305	73
Barley				Asparagus			
S—cont.	309	209	148	S—cont.	190	218	87
20	378	227	167	20	198	227	87
40	422	242	174	40	207	227	91
60	463	238	195	60	206	234	88
Cl—cont.	339	249	136	Cl—cont.	182	220	83
20	392	308	127	20	188	239	79
40	487	384	127	40	190	241	79
60	543	416	131	60	190	243	78
Cucumber				Spinach			
S—cont.	423	350	121	S—cont.	335	422	79
20	427	339	126	20	342	412	83
40	402	358	112	40	332	391	85
60	346	345	100	60	355	402	88
Cl—cont.	446	383	117	Cl—cont.	344	414	83
22	389	393	99	20	339	413	82
40	388	420	92	40	364	432	84
60	363	441	82	60	347	425	82

in the leaves and stems of six material plants used in this experiment.

In Italian ryegrass and barley, the absorption increases according to the increase of salt concentration and the ratio of cation to anion showed an upward trend. The crop plant of this type generally shows high salt tolerance. But barley could not grow normally in the excessive salt solution of this experiment owing to the need of calcium, magnesium and manganese as it is shown in Table 3.

The amount of cation and anion in cucumber and lucerne increases in accordance with the increase of salt concentration of solution but its ratio drop. The plants of this type have low salt tolerance.

This is probably attributed to relative decrease of cation owing to the strong hindrance on the absorption of potassium and calcium etc. caused by some increase of sodium absorption.

On the contrary, the amount of cation and anion in asparagus and spinach does not increase so much despite the increase of salt concentration of solution so the ratio of cation to anion is maintained at rather constant value.

The specific function of the permeable membrane of root seems to restrain the absorption of sodium and as the result, the plant is not prevented so severely from absorbing potassium and calcium, etc. This may be one of the reasons why the plant of this type reveals also high salt tolerance as shown in Table 3.

Though it is not easy to determine which is the plant of higher salt tolerance, Italian ryegrass or the asparagus type, it can be assumed from the results of the experiment[10] in the arid land under high temperature that the asparagus type plant could have better growth and higher salt tolerance because of its special controlling function for sodium absorption.

4) Carbohydrate contents

As the total amount of carbohydrate contained in almost all plants grown in excessive salt solution did not change in this experiment, the photosynthesis and carbohydrate metabolism were not affected by excessive salt. However, the carbohydrate contents of lucerne decreased according to the increase of salt concentration, especially in the chloride solution[9]. Therefore, it seems that the carbohydrate metabolism of the low salt tolerance plant is influenced by excessive salt.

5) Salt tolerance of rice plant

Table 5 indicates the results of sand culture of rice plant which is the main crop in Japan and Southeast Asian countries. It is believed that the salt tolerance of rice plant is moderate from the viewpoint of yield and the ratio of cation to anion. As for the mineral contents of the rice plant grown in excessive salt solution, total nitrogen and potassium decreased, but the change of other elements was not detected.

The heavy dressing of nitrogenous fertilizers makes the plant grow very well[7].

6) Order of crop plants with regard to salt tolerance

From the data of yield and the ratio of cation to anion in the rainy regions of the temperate zone, the salt tolerance of the plants treated with neutral salts of which concentration is below 60 meq/l could be arranged as follows;

Italian ryegrass, barley, asparagus, spinach >wheat, onion, rice>corn, mat rush, celery >tomato, tobacco>cucumber, eggplant>broad bean, kidney bean and lucerne.

Summary

About 20 species of crop plant were examined by means of constant renewed sand culture. Culture solution was prepared adding

Table 5. Yield and total amounts of basic and acidic constituents in the leaves and stems of rice plants grown in excessive salt solutions

Exptl. plot	Dry weight (g)		Cation and anion (meq/l)		
	Leaves and stems	Ears	Cation (c)	Anion (a)	c/a×100
S—cont.	22.8	17.4	192	137	140
20	18.1	18.2	213	167	128
40	17.6	14.7	220	204	108
60	17.2	13.1	225	190	118
Cl—cont.	18.5	21.0	210	154	136
20	20.5	22.5	233	164	142
40	17.2	14.5	235	191	123
60	11.5	9.0	245	209	117

Na_2SO_4 or NaCl to the basal nutrient solution. The concentration of prepared solution was 20, 40, 60 meq/l respectively. The results are as follows;

1) Though Italian ryegrass, barley, asparagus and spinach revealed similar high salt tolerance, they can be classified into two types in terms of the difference of nutrient uptake; that is, Italian ryegrass, barley type and asparagus, spinach type. The salt tolerance of the latter seemed to be higher than the former.

   Cucumber and lucerne showed low salt tolerance.

   Generally, the tolerance against chloride was lower than that against sulfate.

2) As for the mineral elements in the plants of the Italian ryegrass type, the absorption of sodium and the ratio of cation to anion increased in accordance with the increase of the salt concentration of culture solution, and the hindrance on the absorption of potassium, calcium, magnesium and manganese decreased antagonistically.

   But the decline of yield was not much because the plant of this type was able to endure excessive sodium and the want of potassium and calcium, etc.

   Cucumber and lucerne revealed also similar phase of nutrient uptake but their endurance against excessive sodium and the want to potassium and calcium, etc. caused by the decrease of the ratio of cation to anion according to the increase of the salt concentration of solution was not strong as that of the Italian ryegrass type. Consequently, the salt tolerance of cucumber and lucerne was not high.

   The crop plant of the asparagus type seemed to have the controlling function for the absorption of sodium so that hindrance on the absorption of potassium and calcium, etc. was not strong and the ratio of cation to anion did not vary greatly.

3) The salt tolerance of rice plant seemed to be moderate from the viewpoint of the yield, the absorption phase of mineral elements and the ratio of cation to anion.

References

1) Troug, E.: Mineral nutrition of plants. The Univ. of Wisconsin Press, 25–56 (1953).
2) Shimose, N.: Physiology of salt injury in crops. I. *Jour. Sci. Soil Manure*, **34**, 107–110 (1963). [In Japanese.]
3) Shimose, N.: Physiology of salt injury in crops. II. *Jour. Sci. Soil Manure*, **34**, 111–113 (1963). [In Japanese.]
4) Shimose, N.: Physiology of salt injury in crops. III. *Jour. Sci. Soil Manure*, **34**, 147–149 (1963). [In Japanese.]
5) Shimose, N.: Physiology of salt injury in crops. IV. *Jour. Sci. Soil Manure*, **35**, 143–147 (1964). [In Japanese.]
6) Shimose, N.: Physiology of salt injury in crops. V. *Jour. Sci. Soil Manure*, **35**, 148–151 (1964). [In Japanese.]
7) Shimose, N.: Physiology of salt injury in crops. VI. *Jour. Sci. Soil Manure*, **36**, 169–173 (1965). [In Japanese.]
8) Shimose, N.: Physiology of salt injury in crops. VII. *Jour. Sci. Soil Manure*, **39**, 548–553 (1968). [In Japanese.]
9) Shimose, N.: Physiology of salt injury in crops. VIII. *Jour. Sci. Soil Manure*, **39**, 554–557 (1968). [In Japanese.]
10) Shimose, N.: Physiology of salt injury in crops. IX. *Sci. Rept. Fac. Agr.* Okayama Univ., **40**, 57–68 (1972). [In Japanese with English summary.]
11) Shimose, N.: Physiology of salt injury in crops. X. *Sci. Rept. Fac. Agr.* Okayama Univ., **41**, 69–78 (1972). [In Japanese with English summary.]
12) Sutcliffe, J. F.: Mineral salts absorption in plants. Pergamon Press, 149–162 (1962).