J. Japan. Soc. Hort. Sci. 50(4) : 487—496. 1982.

Salt Tolerance of Green Soybeans as Affected by Various Salinities in Sand Culture

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Summary

Green soybeans (*Glycine max.* Merr.) were grown in sand to determine the salt tolerance affected by salinization of sea water, NaCl, Na_2SO_4, $MgCl_2$ and $MgSO_4$ at osmotic potentials of −1.20, −1.70 and −2.70 bars as compared to a control of −0.70 bars of base nutrient solution. Dry weight of the whole plant, fresh weight of seeds and pods, and number of pode were greatest in the control and decreased in each salinity with decreasing osmotic potentials. Growth was greatest in the $MgSO_4$ series, less in the sea water and Na_2SO_4 series, and least in the NaCl and $MgCl_2$ series. There was a marked suppression of growth in the NaCl and $MgCl_2$ series at −2.70 bars. Chloride-salinity caused markedly different symptoms from those caused bysulfate-salinity. In chloride-salinity treatments chlorosis and necrosis were observed on margins of leaves, and developed acropetally at the middle and late stages of growth. The lower the osmotic potentials the more pronounced the symptoms. In sulfate-salinity treatments at only −1.70 bars interveinal chlorosis was found. Na, Mg, Cl and SO_4 content of leaves and sand solution (SS) tended to increase with decreasing osmotic potentials of treatment solutions in sodium-, magnesium-, chlo ride- and sulfate-salinities, respectively. EC values of SS increased and osmotic potentials of SS decreased as osmotic potentials of treatmentsolutions decreased. The values were similar at the isosmotic potential in each salinity.

Introduction

A previous experiment(10) showed that green soybeans (*Glycine max.* Merr.) were a relatively salt sensitive plant to high concentration (more than 1,000 ppm Cl.) of diluted sea water. It has been considered(1, 13) that the primary cause of growth reduction by high salinity was the low osmotic potential of the medium and the secondary cause was specific ion effects, such as Na and Cl. If the low osmotic potential was dominant as compared to specific ion effects, various salinities must affect the growth of plants to the almost same extent at the isosmotic potential. However, there are several reports that the response of plants differed according to salinity type(4, 5, 6, 8, 14, 15). Under natural conditions the salts in well water contaminated by sea water are almost always mixtures of several cations and anions. It is difficult to ascertain the specific ion effects from a study of such sea water. This study, with single salts added to base nutrient solution, was undertaken to determine the salt tolerance of green soybeans under controlled conditions and to more adequately explain the effects of salt source and concentration on the growth and development. Salts added to the base nutrient solution were classified as sodium- and magnesium-salinities, and chloride-and sulfate-salinities. Sea water was regarded as sodium-and chloride-salinities because Na and Cl are dominant ions.

Green soybeans were selected for this experiment because it is one of the main crops at Miho, Shimizu, where the highest salinity was detected in well water(9).

Materials and Methods

Twenty-seven seeds, cv. 'Hakucho' were directly sown in a wooden container (40×40 ×12 cm) filled with 12 *l* of Tenryu River sand and placed in the greenhouse, on April 6, 1978. Seedlings were thinned to 9 uniform plants per container on April 19, when the primary leaves were completely expanded.

Received for publication June 4, 1981.

Table 1. Composition of treatment solutions and base nutrient solution.

Treatment			Added salt concentrations	EC (m℧/cm)	Composition of base nutrient solution
No.	Salinities	π (bars)			
1	Base Nutr. soln.	−0.70	none	2.43	1. $Na_2HPO_4 \cdot 12H_2O$ 1 mM
2	Sea water*	−1.20	1.9%	3.45	2. K_2SO_4 3 mM
3		−1.70	3.8%	4.50	3. $MgSO_4 \cdot 7H_2O$ 2 mM
4		−2.70	7.6%	6.60	4. $Ca(NO_3)_2 \cdot 4H_2O$ 4 mM
5	NaCl	−1.20	687 mgNaCl/l	3.38	5. Fe 1 ppm (EDTA-Fe)
6		−1.70	1,374	4.65	6. Zn 0.05ppm ($ZnSO_4 \cdot 7H_2O$)
7		−2.70	2,748	7.05	7. Cu 0.02ppm ($CuSO_4 \cdot 5H_2O$)
8	Na_2SO_4	−1.20	1,261 mgNa_2SO_4/l	3.66	8. B 0.5 ppm (H_3BO_3)
9		−1.70	2,521	5.18	9. Mo 0.05ppm ($Na_2MoO_4 \cdot 2H_2O$)
10		−2.70	5,042	8.08	10. Mn 0.5 ppm ($MnSO_4$)
11	$MgCl_2$	−1.20	1,728 mg$MgCl_2 \cdot 6H_2O$/l	3.67	pH ≒ 6.0.
12		−1.70	3,456	5.24	
13		−2.70	6,912	8.21	
14	$MgSO_4$	−1.20	3,875 mg$MgSO_4 \cdot 7H_2O$/l	3.94	
15		−1.70	7,750	5.52	
16		−2.70	15,500	8.28	

π : Osmotic potential. The π of treatment solutions includes −0.70 bars of base nutrient solution.
* : Sea water contains 20,500 ppm Cl, 10,082 ppm Na, 2,632 ppm SO_4, 1,262 ppm Mg, 445 ppm K and 393 ppm Ca.

There were 16 treatments, as shown in Table 1, consisting of base nutrient solution (control) and sea water, NaCl, Na_2SO_4, $MgCl_2$ and $MgSO_4$ dissolved in the base nutrient solution at osmotic potentials of −0.50, −1.00 and −2.00 bars. The osmotic potential of the base nutrient solution was −0.70 bars. The composition is shown in Table 1. The sea water was taken at Miho seaside. Each treatment had 4 replications, thus, there was a total of 64 container plots. Treatment solutions were applied to the sand medium from April 14, when the soybean plants were at the 3 to 4 leaf stage, to June 12, at which time they were harvested. These applications (approximately 1 l/container/time) were made twice on clear days, once on cloudy days and none on rainy days.

Symptoms of salt injury were evaluated during the experiment and at harvest. After harvesting green soybeans were separatea as to leaves, stem (including petioles), roots, and pods (including seeds). After washing the plant parts well, measurements were made on fresh weight of seeds, number of pods, dry weight of leaves, stem, roots and seeds, and main elements in leaves. Chemical properties of sand solution were also determined. Total-N in leaves was determined by the electrode method using Orion Model 901 microprocessor ionalyzer. Sand solutions at pF 0 to 3.8 were extracted by the same methods as described previously(12). The other analytical methods were the same as described in an earlier paper(10). The data obtained were statistically analyzed by Duncan's multiple range test.

Results

Growth (*Figs. 1 and 2*) At the end of the experiment, fresh weight of seeds+pods, dry weight of whole plant, leaves, stem, roots and seeds+pods, and number of pods were greatest in the control and decreased significantly in each salinity as osmotic potentials decreased from −1.20 to −2.70 bars. At isosmotic concentrations, very similar amounts of plant growth expressed by the dry weight occurred in the sea water, Na_2SO_4 and $MgSO_4$ series, but there was a marked suppression of growth in the NaCl and $MgCl_2$ series at the low osmotic potential. At −2.70 bars, dry weight of whole plant expressed by percentage of the control was 24, 34 and

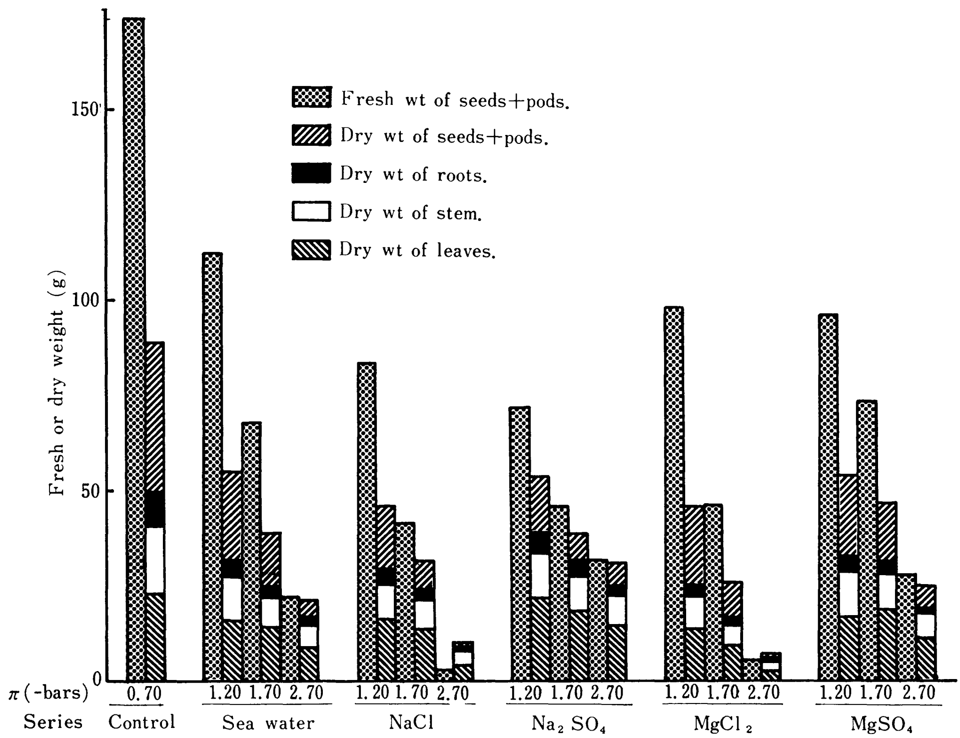

Fig. 1. Effect of various salinities on fresh weight of seeds and pods, and dry weight of plant parts (average per container). Figures below columns in Figs. 1 to 7 indicate osmotic potentials (-bars) of treatment solutions.

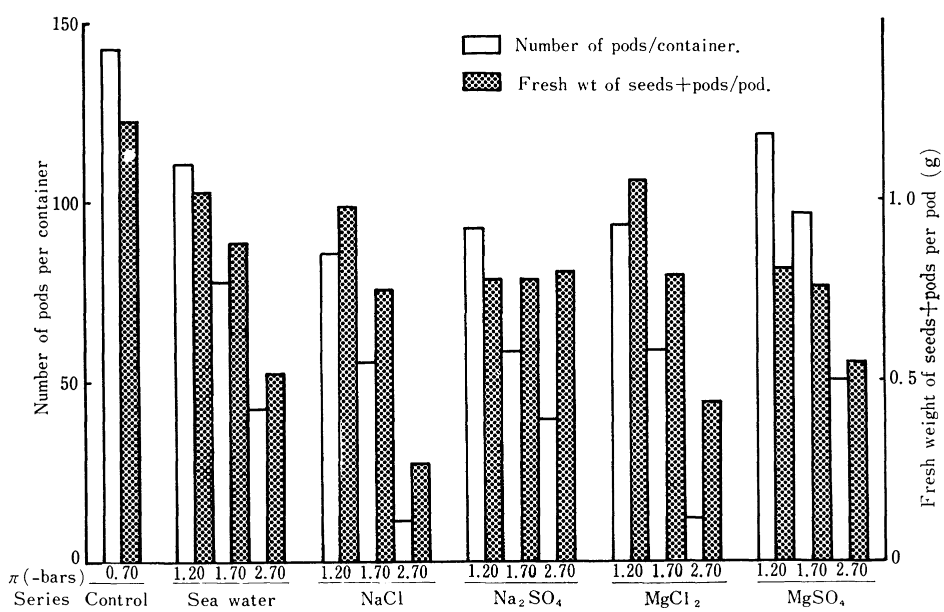

Fig. 2. Effect of various salinities on number of pods per container and fresh weight of one pod including seeds.

28% in the sea water, Na_2SO_4 and $MgSO_4$ series, respectively; and 11 and 8% in the NaCl and $MgCl_2$ series, respectively. Not only number of pods, but also fresh weight of one pod including seeds decreased with increasing salinity. The decreased rate was almost the same as dry weight of the whole plant. At −1.20 bars fresh and dry weight of seeds was less in the NaCl and Na_2SO_4 series than in the $MgSO_4$ and $MgCl_2$ series. However, at −2.70 bars the fresh and dry weight was extremely depressed in the $MgCl_2$ series and was relatively greater in the Na_2SO_4 series. The osmotic potential of treatment solutions which caused a 50% loss in whole plant dry weight was calculated by graphical interpolation and was −1.52, −1.24, −1.50, −1.23 and −1.80 bars in the sea water, NaCl, Na_2SO_4, $MgCl_2$ and $MgSO_4$ series, respectively. Based on the above calculations, the growth was greatest in the $MgSO_4$ series, less in the sea water and Na_2SO_4 series, and least in the NaCl and $MgCl_2$ series.

The salt injury symptoms of chloride (sea water, NaCl and $MgCl_2$ series)-salinity resembled each other, but were different to a great extent from those of sulfate (Na_2SO_4 and $MgSO_4$ series)-salinity, which also resembled each other.

Chlorosis first appeared on the margins of basal leaves and developed interveinally at the middle stage of growth in the chloride-salinity. The injury also progressed acropetally. At the late stage, leaves showed lighter color as compared with the control, and at the lower part of the plants they became brown and dropped. Necrosis developed from the margins inwardly on the middle leaves. Leaf margins at upper part of the plants curled up. The lower the osmotic potentials of treatment solutions the more pronounced the injury, resulting in plants almost drying up at −2.70 bars in $MgCl_2$ and NaCl series.

The plants in the sulfate-salinity were darker green and smaller as compared with the control. The lower the osmotic potentials of treatment solutions the more pronounced the response. Visible and typical symptoms induced by sulfate were not observed until several days before harvesting. Around harvesting chlorosis on leaves was observed between veins and expanded to include the entire leaf. In some plants chlorosis developed into necrosis. The symptoms markedly occurred at −1.70 bars in both Na_2SO_4 and

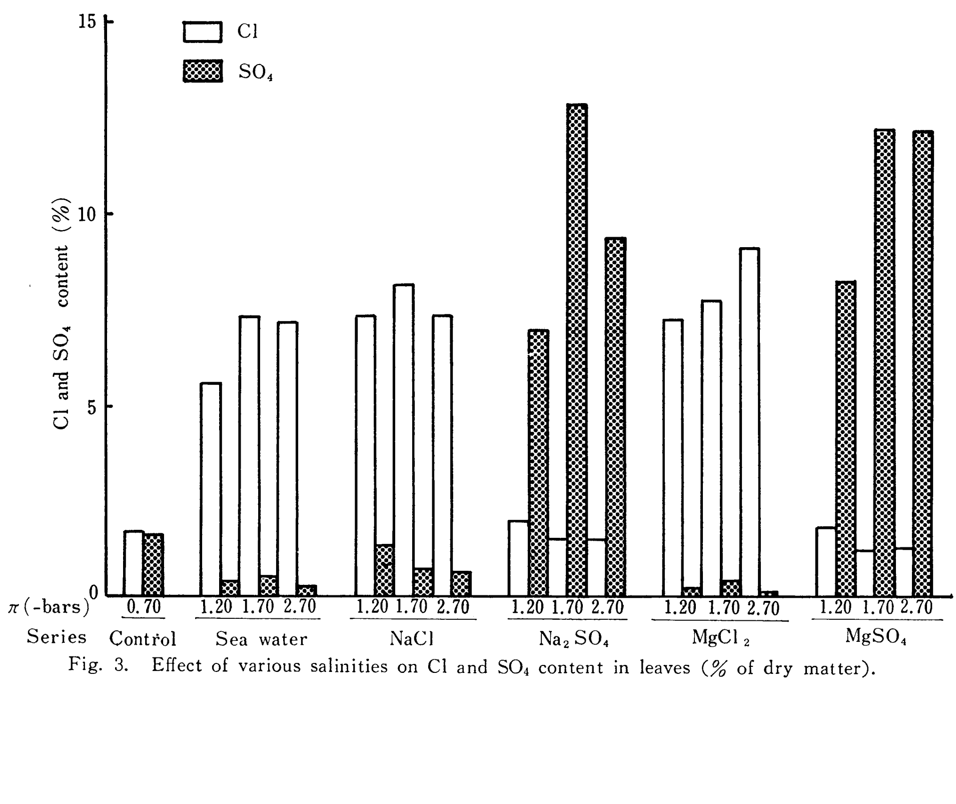

Fig. 3. Effect of various salinities on Cl and SO_4 content in leaves (% of dry matter).

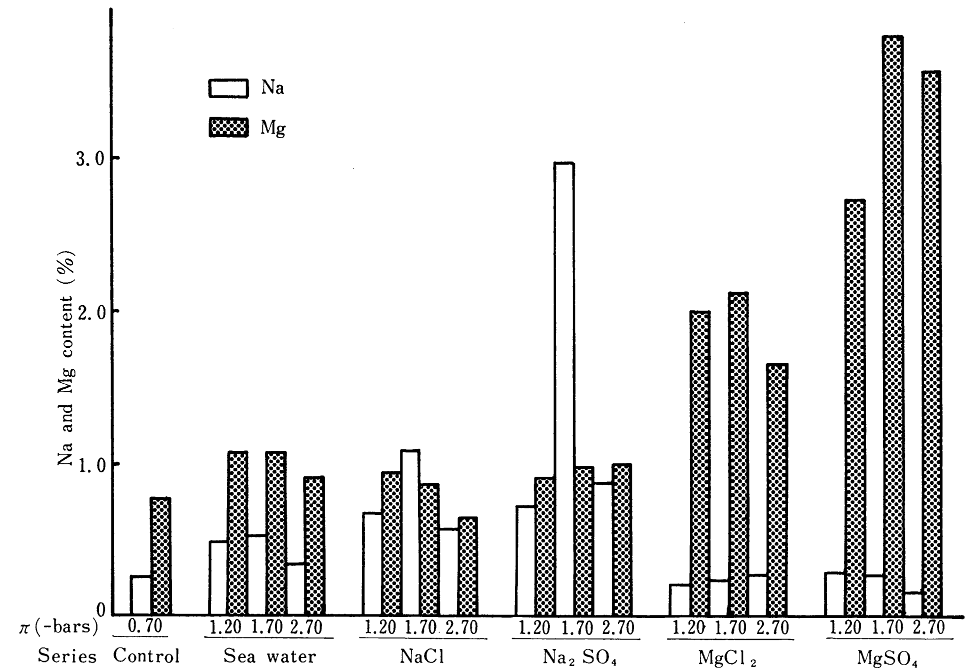

Fig. 4. Effect of various salinities on Na and Mg content in leaves (% of dry matter).

Table 2. Effect of various salinities on some elements in leaves (% of dry matter).

Osmotic potential (bars)	Salinities				
	Sea water[X]	NaCl	Na_2SO_4	$MgCl_2$	$MgSO_4$
			Total-N		
Control[Y]	3.01[a]				
−1.20	2.83[ab]	2.85[ab]	2.51[cd]	2.82[ab]	2.26[de]
−1.70	2.78[abc]	2.58[bc]	2.53[cd]	2.84[ab]	2.29[de]
−2.70	3.02[a]	3.07[a]	2.62[bc]	2.66[bc]	2.04[e]
			P		
Control	0.17[h]				
−1.20	0.19[gh]	0.23[fgh]	0.23[fgh]	0.24[fgh]	0.22[fgh]
−1.70	0.25[fgh]	0.27[efg]	0.28[def]	0.34[cde]	0.35[cd]
−2.70	0.45[b]	0.46[b]	0.59[a]	0.40[bc]	0.44[b]
			K		
Control	2.93[cde]				
−1.20	3.55[bc]	4.70[a]	4.21[ab]	2.50[def]	1.89[ef]
−1.70	3.90[abc]	4.05[ab]	4.32[ab]	2.41[def]	2.07[ef]
−2.70	4.31[ab]	4.83[a]	3.32[bcd]	1.80[f]	2.10[ef]
			Ca		
Control	1.84[abcd]				
−1.20	1.93[abcd]	1.82[abcd]	1.42[bcd]	2.46[ab]	1.07[cd]
−1.70	1.65[abcd]	1.83[abcd]	1.55[bcd]	2.86[a]	0.83[cd]
−2.70	1.59[abcd]	1.29[bcd]	1.66[abcd]	2.03[abc]	0.71[d]

X : Mean separation in each item by Duncan's multiple range test, 5% level.
Y : Control does not contain any additional salts and is maintained at −0.70 bars of osmotic potential.

$MgSO_4$ series. At −1.20 and −2.70 bars the symptoms were rarely observed. The plants did not wither in all treatments in the sulfate-salinity.

Major elements in leaves (Figs. 3 and 4, Table 2) Na, Mg, Cl and SO_4 content tended to increase with decreasing osmotic potentials of nutrient solutions in sodium-, magnesium-, chloride- and sulfate-salinities, respectively. Some exceptions occurred at −2.70 bars in the chloride-salinity. Mg content was higher in the $MgSO_4$ series (2.72 to 3.84%) than in the $MgCl_2$ series (1.64 to 2.09%). At −1.70 bars Na content was greater in the Na_2SO_4 series (2.95%), less in the NaCl series (1.08%), and least in the

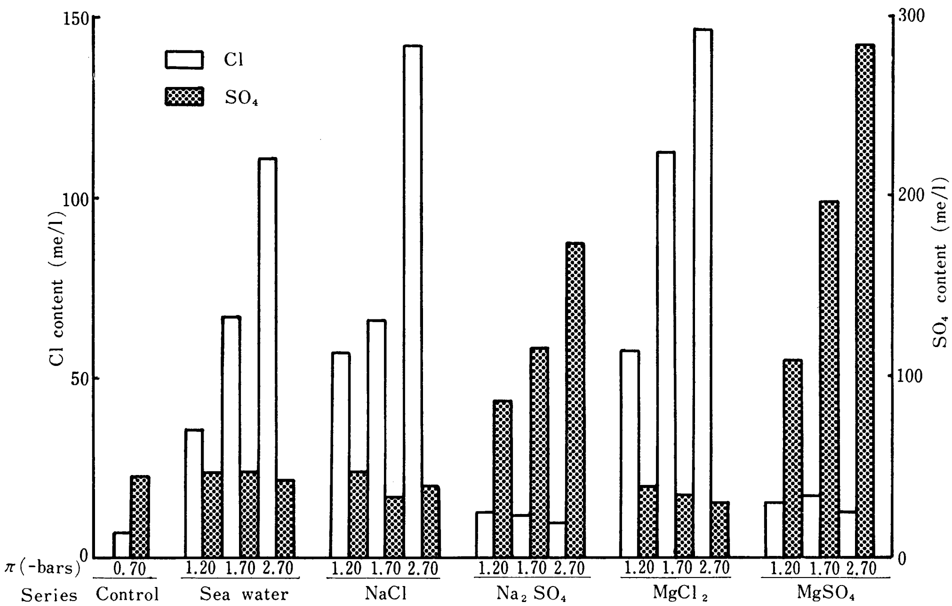

Fig. 5. Effect of various salinities on Cl and SO_4 content in sand solution at the end of the experiment.

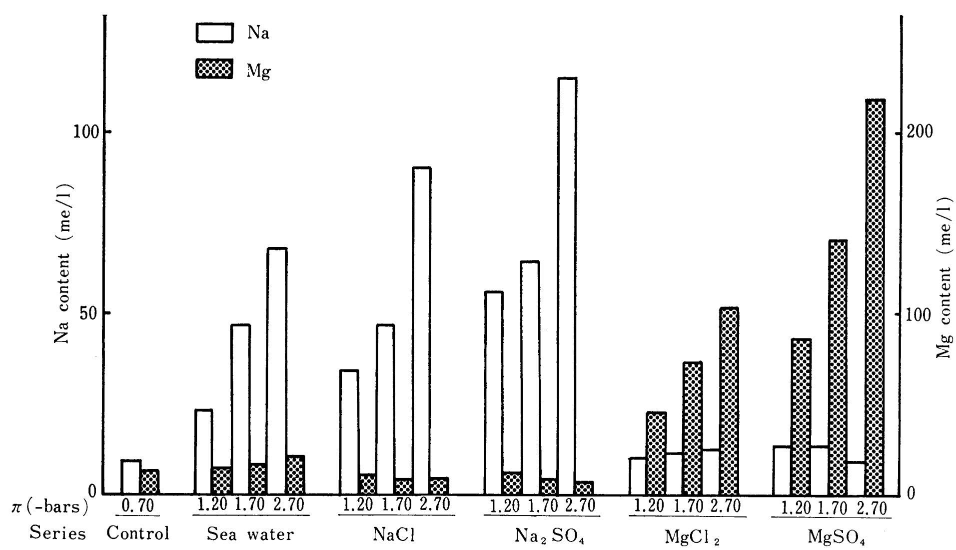

Fig. 6. Effect of various salinities on Na and Mg content in sand solution at the end of the experiment.

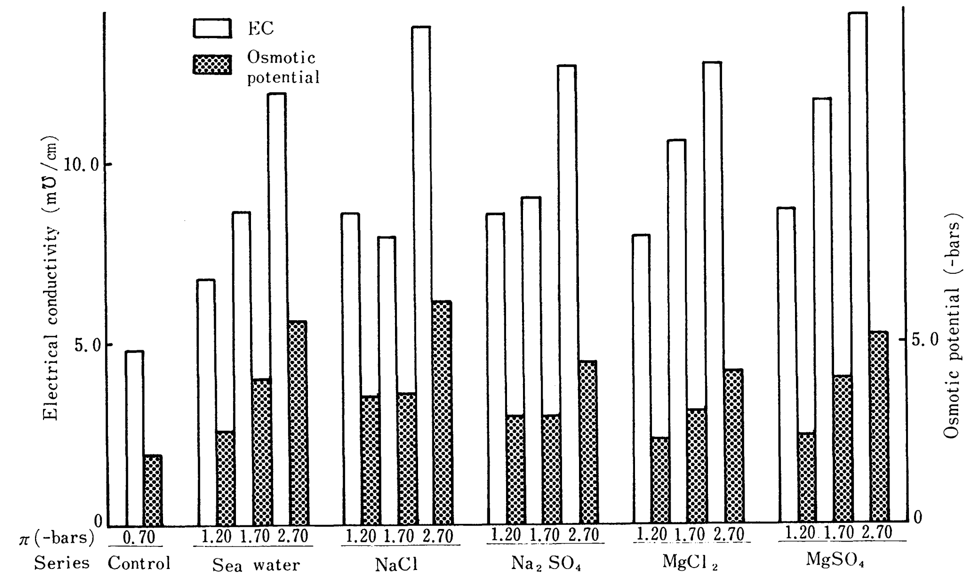

Fig. 7. Effect of various salinities on EC and osmotic potentials of sand solution at the end of the experiment.

sea water (0.52%) in the sodium-salinity. There seemed to be a slight increase of Cl content in NaCl (7.32 to 8.17%) and $MgCl_2$ (7.23 to 9.11%) series as compared to the sea water series (5.63 to 7.34%). SO_4 content was little different at the isosmotic potential in the sulfate-salinity and tended to be lower in the chloride-salinity (0.18 to 1.36%) than in the control (1.66%). Ca content was relatively higher in the $MgCl_2$ series (2.03 to 2.86%) and lower in the $MgSO_4$ series (0.71 to 1.07%), although these values were not significantly different from the control (1.84 %). K content tended to be higher in the sodium-salinity (3.32 to 4.83%), and to be lower in the magnesium-salinity (1.80 to 2.50%) than in the control (2.93%). Tatal-N was significantly lower in the sulfate-salinity (2.04 to 2.62%) than in the control (3.01%). There was no significant difference in Ca, K and total-N content in each of the series. P content was higher in all treatments than in the control and increased with decreasing osmotic potentials.

Chemical properties of sand solution at the end of the experiment (*Figs.* 5, 6 *and* 7. *Table* 3) EC values increased and osmotic potentials decreased as osmotic potentials of treatment solutions decreased. The values were similar at the isosmotic potential in each series, although EC values were slightly higher at −1.70 bars in the magnesium-salinity. Na, Mg, Cl and SO_4 content markedly increased with decreasing osmotic potentials in sodium-, magnesium-, chloride- and sulfate-salinity, respectively. Mg in the $MgCl_2$ series and SO_4 in the Na_2SO_4 series were lower than Mg and SO_4 in the $MgSO_4$ series. Na content was relatively lower in the sea water series, higher in the NaCl series, and highest in the Na_2SO_4 series in the sodium-salinity. Cl increased at almost the same magnitude in the chloride-salinity with decreasing osmotic potentials of treatment solutions. Mg in the $MgSO_4$ series, and P in the $MgCl_2$ and $MgSO_4$ series were signif-'cantly higher than those in the other treatments. There was no distinct difference in pH values and K content. NO_3-N was not affected by the treatments.

Discussion

The presence of excess salts in the medium is known to adversely affect the growth and development of most plants. Common effects of salinity are in inhibition of germination, stunting of growth, chlorosis on leaves and depression of yields(10, 11). It has been con-

Table 3. Effect of various salinities on NO_3-N, P, K and Ca content in sand solution* at the end of the experiment.

Osmotic potential (bars)	Salinities				
	Sea water[X]	NaCl	Na_2SO_4	$MgCl_2$	$MgSO_4$
			NO_3-N(ppm)		
Control[Y]	206^{bc}				
−1.20	183^{bcd}	128^{efg}	138^{defg}	155^{cdef}	189^{bcd}
−1.70	112^{fg}	150^{def}	106^{fg}	118^{efg}	262^{a}
−2.70	119^{efg}	162^{cde}	127^{efg}	91^{g}	224^{ab}
			P(ppm)		
Control	7.0^{fg}				
−1.20	5.9^{g}	7.8^{fg}	7.0^{fg}	13.1^{cd}	16.6^{ab}
−1.70	8.2^{efg}	11.3^{de}	6.4^{fg}	15.3^{bc}	16.8^{ab}
−2.70	9.6^{ef}	11.4^{de}	6.3^{fg}	14.5^{bcd}	18.7^{a}
			K(me/l)		
Control	10.58^{abc}				
−1.20	10.53^{abc}	13.68^{a}	11.12^{abc}	12.36^{abc}	10.85^{abc}
−1.70	11.06^{abc}	10.34^{abc}	9.19^{bc}	11.28^{abc}	13.41^{a}
−2.70	10.66^{abc}	11.86^{abc}	8.53^{c}	10.78^{abc}	12.64^{ab}
			Ca(me/l)		
Control	15.87^{cdef}				
−1.20	18.24^{bcd}	16.73^{cdef}	14.29^{def}	16.36^{cdef}	19.38^{bc}
−1.70	18.57^{bcd}	15.92^{cdef}	11.94^{f}	17.47^{bcd}	21.76^{ab}
−2.70	16.11^{cdef}	13.98^{def}	12.16^{ef}	17.09^{bcde}	24.27^{a}
			pH		
Control	8.20^{a}				
−1.20	8.22^{a}	8.11^{a}	8.30^{a}	8.02^{a}	8.13^{a}
−1.70	8.12^{a}	8.11^{a}	8.22^{a}	8.07^{a}	8.20^{a}
−2.70	8.11^{a}	8.01^{a}	8.16^{a}	7.59^{b}	8.22^{a}

X : Mean separation in each item by Duncan's multiple range test, 5% level.
Y : Control does not contain any additional salts and is maintained at −0.70 bars of osmotic potential.
* : pF=0 to 3.8.

sidered(2, 3, 13) that plant growth reduction is primarily due to low osmotic potential of the soil solution. However, Dirr(4) stressed that the injury of honeylocust exposed to Cl salts suggested a specific effect. There are many reports that plant responses varied with different salts at isosmotic concentration(5, 6) and the degree also varied with kinds of crops and cultivars(7, 13). Even if the cause of injury is primarily due to osmotic effects, variations of responses affected by various salinities need to be determined.

The plant responses to different types of salinity were reported by other investigators. Joolka et al. (7) found that the grape cultivars differed in their response to Cl or SO_4 salts, 'Beauty Seedless' and 'Early Muscat' being relatively more tolerant to chloride-salinity, and 'Thompson Seedless' to sulfate-salinity. Bean growth was affected to the same extent by isosmotic potentials of sodium chloride and sulfate(5, 6), although some parameters such as leaf thickness and relative water content showed different responses according to salinity type. With tomatoes(6) and rice(15), the growth was more suppressed in the sulfate-salinity than in the chloride-salinity at isosmotic concentration. Therefore, the response to chloride-and sulfate-salinity must vary with crops. The quality and quantity of the growth of green soybeans produced in the presence of chloride salt differed radically from those at isosmotic concentration of the sulfate salt, especially at −2.70 bars. The plants in the chloride-salinity dried up at −2.70 bars, but in the sulfate-salinity they did not show any visible salt injury symptoms. In the present experiment, the chloride-salinity suppressed growth more than did the sulfate-salinity.

The growth in the sea water series was greater than in the NaCl series. Cl and Na concentrations of treatment solutions were somewhat higher in the NaCl series than in the sea water series at the isosmotic potential. At the end of the experiment, EC values of sand solutions seemed to be higher in the NaCl series than in the sea water series, although there was no significant difference at the isosmotic potential. Cl and Na content in leaves tended to be higher in the NaCl series than in the sea water series. Thus, it is considered that more accumulated Na and Cl induced much more suppression of growth and increased severe injuries. However, at −1.70 bars Na content in leaves was highest in the Na_2SO_4 series in the sodium-salinity. Moreover, the osmotic potential which caused a 50% loss in whole plant dry weight was almost the same (−1.23 bars) in the chloride-salinity, and was lower in the $MgSO_4$ series (−1.80 bars) than in the Na_2SO_4 series (−1.50 bars) in the sulfate-salinity. This may suggest that Na and Mg affect the growth of green soybeans similarly. Therefore, the suppresion may be mainly attributed to the specific ion effect of Cl.

The marked difference in the adverse effect of Mg on the growth response as compared with that of Na was reported by Gauch and Wadleigh(5) with beans and by Osawa(13) with some vegetable crops. In the present experiment, plant growth in the magnesium-salinity was much suppressed by $MgCl_2$ salinity, but less by $MgSO_4$ salinity. Mg content in leaves was higher in the $MgSO_4$ series (2.72 to 3.57%) than in the $MgCl_2$ series (1.64 to 2.09%). Cl and SO_4 content in leaves was higher in the $MgCl_2$ and $MgSO_4$ series, respectively. Ca content in leaves was higher in the $MgCl_2$ series (2.03 to 2.86%) than in the $MgSO_4$ series (0.71 to 1.07%), but was not significantly different within respective salinity. Therefore, with respect to the major elements in leaves, the adverse effect of Mg on the plant growth was not observed and the plant growth suppression in the $MgCl_2$ series seems to be attributed to the specific ion effect of Cl, when comparing $MgCl_2$ and $MgSO_4$ series.

The results of this experiment showed that growth of green soybeans was greatest in the $MgSO_4$ series, and least in the NaCl and $MgCl_2$ series. Chloride-salinity reduced the growth much more than did sulfate-salinity. However, at −1.20 bars $MgCl_2$ salinity did not depress the dry and fresh weight of seeds when compared with other salinities. The degree of growth suppression may vary with not only the type of salinity, such as chloride or sulfate, but also the kinds of cation accompanied with anions and concentrations of the individual salt.

Acknowledgement

Recognition is given Drs. W. J. Clore and T. Asahira for their critical reading of this manuscript.

Literature Cited

1. Bernstein, L., and H. E. Hayward. 1958. Physiology of salt tolerance. Ann. Rev. Plant Physiol. 9 : 25—46.
2. Bernstein, L. 1961. Osmotic adjustment of plants to saline medium. I. Steady state. Amer. J. Bot. 48 : 909—918.
3. Bernstein, L. 1963. Osmotic adjustment of plants to saline medium. II. Dynamic phase. Amer. J. Bot. 50 : 360—370.
4. Dirr, M. A. 1974. Tolerance of honeylocust seedlings to soil-applied salts. Hortscience 9 : 53—54.
5. Gauch, H. G., and C. H. Wadleigh. 1944. Effects of high salt concentrations on growth of bean plants. Bot. Gaz. 105 : 379—387.
6. Hayward. H. E., and E. M. Long. 1941. Anatomical and physiological responses of the tomato to varying concentrations of sodium chloride, sodium sulphate and nutrient solutions. Bot. Gaz. 102 : 437—462.
7. Joolka, N. K., J. P. Singh, and A. P. Khera.

1977. Mineral composition of grape as affected by chloride and sulphate salts of sodium in soils. Indian J. Agric. Sci. 47 : 201—203.

8. Meiri, A., J. Kamburoff, and A. Poljakoff-Mayber. 1971. Response of bean plants to sodium chloride and sodium sulphate salinization. Ann. Bot. 35 : 837—847.

9. Masui, M., A. Nukaya, and A. Ishida. 1975. Salt content of well water of greenhouse growers in Shizuoka Prefecture. Bull. Fac. Agr., Shizuoka Univ. Japan. 25 : 15—22. (In Japanese with English summary).

10. Nukaya, A., M. Masui, A. Ishida, and T. Ogura. 1977. Salt tolerance of green soybeans. J. Japan. Soc. Hort. Sci. 46 : 18—25.

11. Nukaya, A., M. Masui, and A. Ishida. 1979. Salt tolerance of tomatoes. J. Iapan. Soc. Hort. Sci. 48 : 73—81.

12. Nukaya, A., M, Masui, and A. Ishida. 1981. Relationships between salt tolerance of green soybeans and calcium sulfate applications in sand culture. J. Japan. Soc. Hort. Sci. 50 : 326—331.

13. Osawa, T. 1963. Studies on the salt tolerance of vegetable crops with special reference to osmotic effects and specific ion effects. J. Japan. Soc. Hort. Sci. 32 : 211—223. (In Japanese with English summary).

14. Porath, E., and A. Poljakoff-Mayber. 1964. Effect of salinity on metabolic pathways in pea root tips. Israel J. Bot. 13 : 115—121.

15. Shimose, N. 1963. Physiology of salt injury of crops (Part 1). Effect of isosmotic pressure prepared by NaCl and Na_2SO_4 on the growth and on the absorption of mineral elements by rice plants. J. Sci. Soil & Manure, Japan. 34 : 107—110. (In Japanese).

各種塩類が砂耕におけるエダマメの耐塩性に及ぼす影響

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摘　要

エダマメの耐塩性と塩の種類との関係を明らかにするため，砂耕により本実験を行った．海水，NaCl, Na_2SO_4, $MgCl_2$, $MgSO_4$ の塩類源をそれぞれ −1.20, −1.70, −2.70 bar とし，生育を基本培養液（−0.70 bar）の対照区と比較した．全植物体の乾物重，莢と種子の新鮮重，着莢数は，対照区で最大となり，浸透ポテンシャルが低下するにつれ，それぞれの塩類源で減少した．生育は，$MgSO_4$ ですぐれ，海水と Na_2SO_4 でやや劣り，NaCl と $MgCl_2$ では最も劣った．NaCl と $MgCl_2$ の −2.70 bar 区の生育は，著しく抑制された．Cl 塩処理の塩害症状は，SO_4 塩処理による症状とはかなり異なっていた．Cl 塩処理では，クロロシスとネクロシスが葉縁にみられ，生育の中・後期には上位葉にも進行した．その程度は浸透ポテンシャルが低くなるにつれて著しくなった．SO_4 塩処理では，−1.70 bar 区のみに葉脈間クロロシスがみられた．葉中及び砂溶液の Na, Mg, Cl, SO_4 含量は，それぞれの処理区で，処理培養液の浸透ポテンシャルが低下するにつれて増加する傾向がみられた．また，処理培養液の浸透ポテンシャルが低下するにつれ，砂溶液の EC は増加し，浸透ポテンシャルは減少した．それらの値は，等浸透ポテンシャルの場合，各塩類区でほぼ同じ値を示した．