J. Japan. Soc. Hort. Sci. 51(1) : 62—69. 1982.

Salt Tolerance of Green Soybeans as Affected by Various Salinities in Soil Culture[1]

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Summary

Green soybeans (*Glycine max.* Merr.) were grown in soil to determine the salt tolerance affected by salinities 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 whole plant, fresh weight of seeds and pods, and number of pods in the sea water (−1.20 bars), Na_2SO_4 (−1.20 and −1.70 bars) and $MgSO_4$ (all osmotic potentials) series were not different from those in the control. Dry weight of whole plant at −2.70 bars expressed by percentage of the control was 52.6, 39.6, 81.5, 20.4 and 88.1% in the sea water, NaCl, Na_2SO_4, $MgCl_2$ and $MgSO_4$ series, respectively. Growth in decreasing order in soil culture was $MgSO_4 \fallingdotseq Na_2SO_4 >$ sea water $>$ NaCl $> MgCl_2$ series. In the Na_2SO_4 and $MgSO_4$ series, interveinal chlorosis appeared at only −1.70 bars near harvest. Chloride-salinity treatment caused chlorosis and necrosis on leaves developing acropetally at the middle stage. The plants were almost dried up at the last stage, especially at low osmotic potentials. Na, Mg, Cl and SO_4 content of leaves and soil solution (SS) tended to increase with decreasing osmotic potentials of treatment solutions in sodium-, magnesium-, chloride- and sulfate-salinities, respectively. EC values of SS increased and osmotic potentials of SS decreased as osmotic potentials of treatment solutions decreased.

Introduction

Salt tolerance of green soybeans (*Glycine max.* Merr.) as affected by various salinities in sand culture has been reported(11). The experiment was undertaken to more adequately explain the effects of salt source and concentration on their growth and development, using single salts added to base nutrient solution. Salt tolerance of muskmelons (9, 10), green soybeans (5) and tomatoes (8) has been studied using diluted sea water in sand and soil cultures. With muskmelons, the whole plant dry weight as expressed by percentage of control was 56.0% in sand culture and 83.5% in soil culture at 1,000 ppm Cl. The relative fruit fresh weight at 1,000 ppm Cl was 66.2 and 70.5% in sand and soil cultures. Visible salt injury symptoms of green soybeans and tomatoes caused by diluted sea water were much more evident in sand culture than in soil culture. Relationships between salt tolerance of muskmelons and various salinities in sand and soil cultures were examined, using isosmotic potential solutions(6, 7). The experiment showed that visible salt injury symptoms varied with kinds of salts in sand culture, but were not observed in soil culture. The degree of growth suppression, and chemical properties of sand and soil solution also differed to some extent between sand and soil cultures.

Therefore, the present experiment was conducted to compare the effect of various salinities on salt tolerance of green soybeans in soil culture with that in sand culture at the same time and in the same greenhouse as the sand culture experiment previously reported(11).

Materials and Methods

Twenty-seven seeds of cv. 'Hakucho' were directly sown in a wooden container (40×40 ×12 cm) filled with 12 l of Takamatsu light clay paddy soil taken at Shizuoka and mixed

[1] Received for publication October 27, 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)[z]			
1	Base nutr soln	−0.70	none	2.43	1. $Na_2HPO_4 \cdot 12H_2O$ 1 mM
2	Sea water[y]	−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. Fe 1 ppm(Fe-EDTA)
5	NaCl	−1.20	687 mgNaCl/1	3.38	6. Zn 0.05 ppm($ZnSO_4 \cdot 7H_2O$)
6		−1.70	1,374	4.65	7. Cu 0.02 ppm($CuSO_4 \cdot 5H_2O$)
7		−2.70	2,748	7.05	8. B 0.5 ppm(H_3BO_3)
8	Na_2SO_4	−1.20	1,261 mgNa_2SO_4/1	3.66	9. Mo 0.05 ppm($Na_2MoO_4 \cdot 2H_2O$)
9		−1.70	2,521	5.18	10. Mn 0.5 ppm($MnSO_4$)
10		−2.70	5,042	8.08	pH≒6.0
11	$MgCl_2$	−1.20	1,728 mg$MgCl_2 \cdot 6H_2O$/1	3.67	
12		−1.70	3,456	5.24	
13		−2.70	6,912	8.21	
14	$MgSO_4$	−1.20	3,875 mg$MgSO_4 \cdot 7H_2O$/1	3.94	
15		−1.70	7,750	5.52	
16		−2.70	15,500	8.28	

[z] Osmotic potential. The π of treatment solutions includes −0.70 bars of base nutrient solution.
[y] 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.

with 3 l of decomposed rice straw, on April 6, 1978. The container was placed in the greenhouse. Seedlings were thinned to 9 uniform plants per container on April 19. There were 16 treatments, as shown in Table 1, consisting of control (base nutrient solution), 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 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 soil medium for 60 days from April 14 to harvest, June 12. These applications (approximately 1 l/container/time) were made once or twice a day whether it was cloudy or sunny. No solution was applied on rainy days. At the end of the experiment, green soybeans were separated into leaves, stem, roots, and seeds and pods. The other experimental procedures, and methods of analysis on leaves and soil solutions were the same as the sand culture experiment(11).

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 pcds tended to decrease in each salinity as osmotic potentials of treatment solutions decreased from −1.20 to −2.70 bars. However, dry weight of whole plant, leaves and stem in the control was not significantly different from that in the sea water series at −1.20 bars, in the Na_2SO_4 series at −1.20 and −1.70 bars, and in the $MgSO_4$ series at all concentrations. Fresh weight of seeds+pods, and number of pods in the control were also not significantly different from those in the NaCl and $MgCl_2$ series at −1.20 bars, in addition to above mentioned treatments. At −2.70 bars, whole plant dry weight as expressed by percentage of the conteol was 52.6, 39.6 and 20.4% in the sea water, NaCl and $MgCl_2$ series, respectively. At −2.70 bars, whole plant dry weight was 81.5 and 88.1% in the Na_2SO_4 and $MgSO_4$ series. These results showed that green soybeans were sensitive to chloride-salinity. Fresh weight

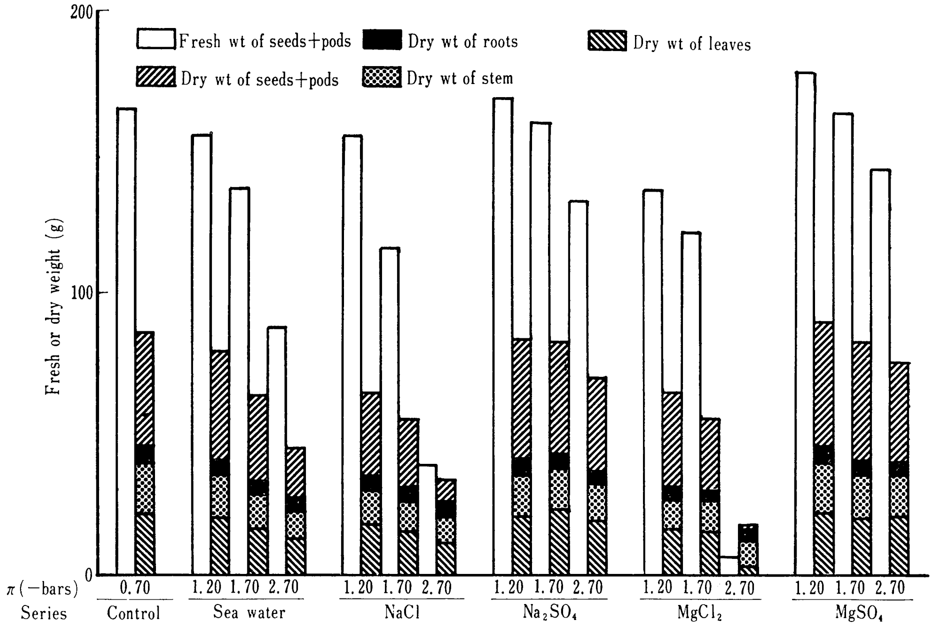

Fig. 1. Effect of various salinities on fresh weight of seeds and pods, and dry weight of plant parts (average per container). Figures below columns in Figs. 1 to 3 indicate osmotic potentials (−bars) of treatment solutions.

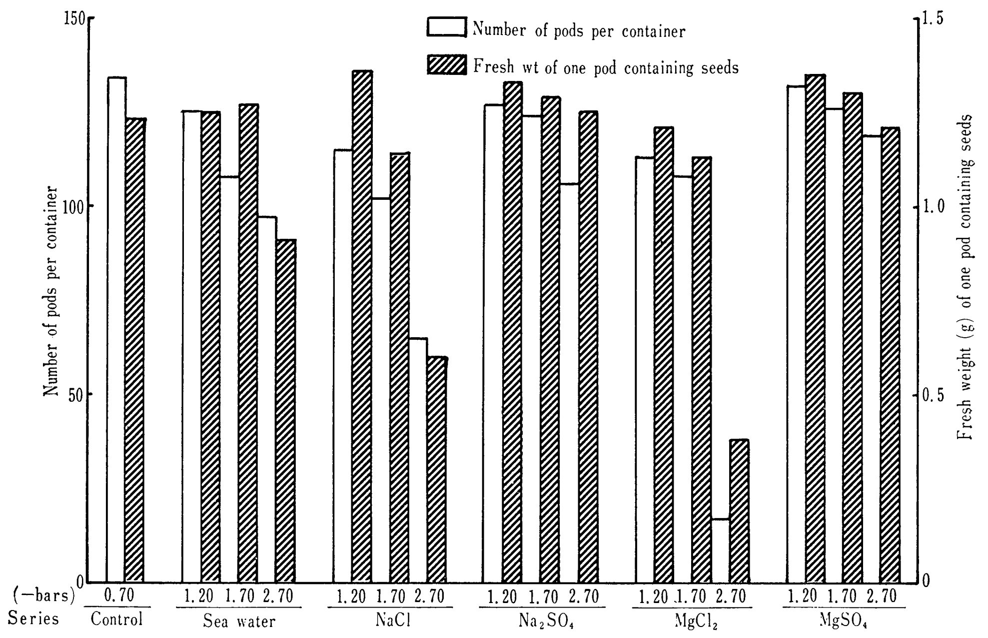

Fig. 2. Effect of various salinities on number of pods per container, and fresh weight of one pod containing seeds.

of one pod containing seeds was markedly suppressed in the NaCl and $MgCl_2$ series and almost the same as the control in the Na_2SO_4 and $MgSO_4$ series. Based on these observations the growth was greatest in the Na_2SO_4 and $MgSO_4$ series, followed by the sea water, and then NaCl series, and least in the $MgCl_2$ series.

The salt injury symptom, chlorosis on leaves, was observed only in the sea water and $MgCl_2$ series at −2.70 bars at the middle stage of growth and did not appear in the other treatments. At the late stage, margins of lower leaves showed chlorosis in the sea water, NaCl and $MgCl_2$ series. The symptoms developed to marginal necrosis progressing acropetally. In the Na_2SO_4 and $MgSO_4$ series, although the plants became smaller and darker green as osmotic potentials of treatment solutions decreased, visible symptoms were not observed at any osmotic potentials. Several days before harvesting, plants were almost dried up in chloride-salinity, and interveinal chlorosis suddenly appeared in sulfate-salinity, especially in the Na_2SO_4 series at −1.70 bars.

Major elements in leaves (Tables 2 and 3) Mg and SO_4 content in the magnesium- and sulfate-salinities increased with decreasing osmotic potentials of treatment solutions, respectively. Mg content was higher in the $MgSO_4$ series (1.41 to 3.43%) than in the $MgCl_2$ series (1.13 to 2.00%). Na content tended to increase in the sea water and Na_2SO_4 series as osmotic potentials of treatment solutions decreased. In the NaCl series, Na content was not significantly different (0.96 to 1.05%) and higher than in the other series. Cl content increased in the sea water and NaCl series with decreasing osmotic potentials of treatment solutions, but was not significantly different in the $MgCl_2$ series (5.67 to 6.31%). Ca tended to decrease in

Table 2. Effect of various salinities on Na, Mg, Cl and SO_4 content in leaves (% of dry matter).

Osmotic potential (bars)	Salinities				
	Sea water^{z}	NaCl	Na_2SO_4	$MgCl_2$	$MgSO_4$
			Na		
Control^{y}	0.47^{cd}				
−1.20	0.50^{cd}	1.05^{a}	0.46^{cd}	0.58^{bcd}	0.45^{cd}
−1.70	0.98^{a}	0.96^{a}	0.60^{bcd}	0.27^{d}	0.36^{d}
−2.70	0.80^{abc}	0.98^{a}	0.89^{ab}	0.49^{cd}	0.36^{d}
			Mg		
Control	0.71^{h}				
−1.20	0.93^{fgh}	1.24^{de}	0.83^{gh}	1.13^{ef}	1.41^{cd}
−1.70	1.08^{efg}	0.98^{fg}	0.89^{fgh}	1.61^{c}	2.17^{b}
−2.70	0.99^{fg}	0.93^{fgh}	0.95^{fgh}	2.00^{b}	3.43^{a}
			Cl		
Control	2.11^{f}				
−1.20	5.40^{e}	5.78^{de}	2.93^{f}	6.23^{cde}	2.45^{f}
−1.70	6.93^{bcd}	7.44^{bc}	3.38^{f}	6.31^{cde}	2.73^{f}
−2.70	8.86^{a}	7.94^{ab}	2.16^{f}	5.67^{de}	2.22^{f}
			SO_4		
Control	0.86^{cd}				
−1.20	0.35^{d}	0.13^{d}	0.37^{d}	0.02^{d}	0.61^{d}
−1.70	0.32^{d}	0.02^{d}	1.11^{cd}	0.26^{d}	1.72^{c}
−2.70	trace^{d}	0.12^{d}	3.48^{b}	0.29^{d}	5.49^{a}

^{z} 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.

Table 3. Effect of various salinities on total-N, P, K and Ca content in leaves (% of dry matter).

Osmotic potential (bars)	Salinities				
	Sea water^{z}	NaCl	Na_2SO_4	$MgCl_2$	$MgSO_4$
			Total-N		
Control^{y}	2.02^{h}				
−1.20	2.56^{g}	2.84^{efg}	3.11^{cde}	3.14^{cde}	3.72^{ab}
−1.70	3.00^{defg}	2.65^{fg}	3.11^{cde}	3.51^{abc}	3.46^{abcd}
−2.70	3.29^{bcde}	3.21^{cde}	3.06^{cdef}	3.81^{a}	2.58^{g}
			P		
Control	0.25^{bc}				
−1.20	0.23^{cd}	0.21^{cd}	0.23^{cd}	0.22^{cd}	0.24^{bcd}
−1.70	0.23^{cd}	0.24^{bcd}	0.25^{bc}	0.24^{bcd}	0.23^{cd}
−2.70	0.25^{bc}	0.28^{b}	0.25^{bc}	0.43^{a}	0.20^{d}
			K		
Control	1.25^{bcd}				
−1.20	1.25^{bcd}	2.20^{a}	1.17^{cd}	2.44^{a}	1.22^{bcd}
−1.70	1.94^{abc}	2.13^{ab}	1.67^{abc}	1.08^{cd}	0.68^{d}
−2.70	1.88^{abc}	2.47^{a}	2.56^{a}	1.06^{cd}	0.67^{d}
			Ca		
Control	2.13^{ab}				
−1.20	2.56^{a}	2.55^{a}	2.28^{ab}	2.75^{a}	2.35^{ab}
−1.70	2.51^{ab}	2.51^{ab}	1.94^{ab}	2.61^{a}	2.14^{ab}
−2.70	2.32^{ab}	2.32^{ab}	1.59^{a}	1.91^{ab}	1.61^{b}

^{z} The same as Table 2.

^{y} The same as Table 2.

each salinity as osmotic potentials of treatment solutions decreased. K tended to be higher in the sodium-salinity (1.17 to 2.56%) and lower in the magnesium-salinity (0.67 to 2.44%) than in the control (1.25%). Total-N was higher in all treatments than in the control. There seemed to be no difference in P content in each salinity.

Chemical properties of soil solution at the end of the experiment (Tables 4 and 5, Fig. 3) EC values increased and osmotic potentials decreased as osmotic potentials of treatment solutions decreased. At −2.70 bars EC values were highest in the NaCl, Na_2SO_4 and $MgCl_2$ series, followed by the sea water series, and then the $MgSO_4$ series. Mg, Na, Cl and SO_4 increased with decreasing osmotic potentials of treatment solutions in magnesium-, sodium-, chloride- and sulfate-salinities, respectively. Mg in the Na_2SO_4 series also increased with decreasing osmotic potentials. Mg in the $MgCl_2$ series was higher than that in the $MgSO_4$ series. The decreasing order of Cl in the chloride-salinity was the $MgCl_2$, NaCl and sea water series. That of Na in the sodium-salinity was the Na_2SO_4, NaCl and sea water series. K was higher in all treatments, except for −1.20 bars in the Na_2SO_4 series and −1.20 and −1.70 bars in the $MgSO_4$ series, than in the control. Ca increased in the chloride-salinity with decreasing osmotic potentials. The pH tended to be lower in the chloride-salinity than in the control. No definite tendency was observed in NO_3-N content in each salinity.

Table 4. Effect of various salinities on NO_3-N, P, K and Ca content in soil solution[x] at the end of the experiment.

Osmotic potential (bars)	Salinities				
	Sea water[z]	NaCl	Na_2SO_4	$MgCl_2$	$MgSO_4$
	NO_3-N(ppm)				
Control[x]	356^{bcd}				
−1.20	253^{defg}	437^{bc}	115^{g}	406^{bcd}	161^{efg}
−1.70	106^{g}	315^{cdef}	414^{bcd}	418^{bcd}	149^{fg}
−2.70	323^{bcde}	499^{ab}	600^{a}	375^{bcd}	620^{a}
	P(ppm)				
Control	3.8^{c}				
−1.20	4.2^{bc}	3.8^{c}	4.3^{bc}	5.7^{abc}	4.0^{bc}
−1.70	3.4^{c}	4.8^{abc}	6.9^{a}	6.3^{ab}	4.8^{abc}
−2.70	4.0^{bc}	3.8^{c}	7.0^{a}	4.3^{bc}	4.3^{bc}
	K(me/l)				
Control	8.83^{de}				
−1.20	10.74^{cd}	15.74^{bc}	5.29^{e}	17.85^{b}	6.78^{de}
−1.70	15.07^{bc}	17.53^{b}	19.72^{b}	18.17^{b}	5.76^{de}
−2.70	19.60^{b}	18.97^{b}	26.55^{a}	17.33^{b}	19.64^{b}
	Ca(me/l)				
Control	23.98^{e}				
−1.20	32.90^{d}	33.84^{d}	19.13^{ef}	52.34^{b}	20.97^{ef}
−1.70	36.56^{cd}	42.18^{c}	15.26^{f}	65.09^{a}	21.35^{ef}
−2.70	41.44^{c}	49.99^{b}	15.60^{f}	68.95^{a}	19.60^{ef}

[z] The same as Table 2.
[y] The same as Table 2.
[x] pF=0 to 3.8.

Table 5. Effect of various salinities on Mg, Na, Cl and SO_4 content in soil solution[x] at the end of the experiment.

Osmotic potential (bars)	Salinities				
	Sea water[z]	NaCl	Na_2SO_4	$MgCl_2$	$MgSO_4$
	Mg(me/l)				
Control[y]	26.58^{hi}				
−1.20	48.49^{gh}	43.43^{ghi}	17.48^{i}	128.53^{cd}	101.97^{de}
−1.70	59.10^{fg}	50.89^{gh}	49.19^{gh}	223.75^{b}	135.31^{c}
−2.70	83.78^{ef}	59.89^{fg}	69.30^{fg}	338.28^{a}	198.24^{b}
	Na(me/l)				
Control	25.95^{hi}				
−1.20	87.81^{fg}	116.42^{ef}	69.78^{gh}	47.19^{hi}	19.02^{i}
−1.70	129.41^{e}	186.55^{d}	334.90^{b}	36.52^{hi}	12.04^{i}
−2.70	222.97^{d}	287.12^{c}	429.22^{a}	27.77^{hi}	36.97^{hi}
	Cl(ppm)				
Control	738^{f}				
−1.20	4281^{e}	7201^{d}	851^{f}	7555^{d}	855^{f}
−1.70	6458^{d}	10203^{c}	1356^{f}	12183^{b}	624^{f}
−2.70	12274^{b}	15221^{a}	1244^{f}	16073^{a}	1166^{f}
	SO_4(ppm)				
Control	2557^{c}				
−1.20	2608^{c}	2614^{c}	4909^{c}	3105^{c}	6759^{c}
−1.70	2902^{c}	4175^{c}	17324^{b}	2841^{c}	8437^{c}
−2.70	3125^{c}	3352^{c}	29560^{a}	3040^{c}	24094^{a}

[z] The same as Table 2.
[y] The same as Table 2.
[x] pF=0 to 3.8.

Discussion

The results of the sand culture experiment (11) showed the growth of green soybeans was more suppressed in chloride-salinity than in sulfate-salinity. In this experiment similar results were obtained, but the degree of

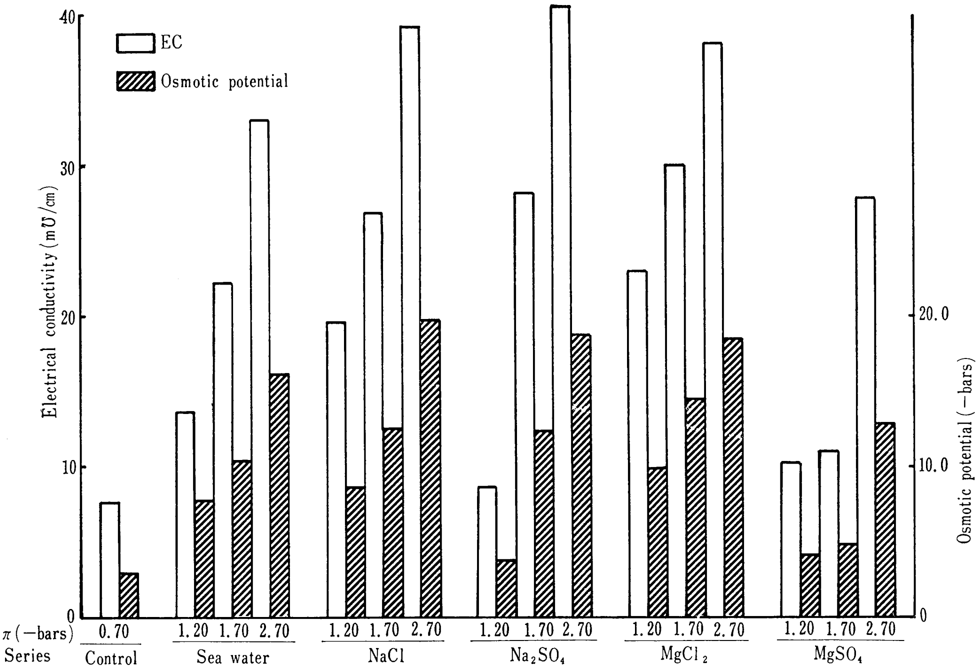

Fig. 3. Effect of various salinities on EC and osmotic potentials of soil solution at the end of the experiment.

growth suppression was to some extent different from the sand culture experiment. In soil culture green soybeans were more tolerant of salinity. For example, the osmotic potential of treatment solutions which caused a 50% loss in whole plant dry weight was calculated by graphical interpolation. It was −1.5, −1.2, −1.5, −1.2 and −1.8 bars in sand culture, but −2.9, −2.3, about −6.0, −2.0 and about −9.0 bars in soil culture, in the sea water, NaCl, Na_2SO_4, $MgCl_2$ and $MgSO_4$ series, respectively. The dry weight expressed by percentage of the control was also greater in soil culture than in sand culture in each salinity. Above all, in sulfate-salinity, the growth was rarely suppressed in soil culture, and the dry weight of whole plant, fresh weight of seeds+pods, number of pods, and fresh weight of one pod containing seeds almost corresponded to the control even at −2.70 bars.

Mean Cl content of leaves was 6.72, 7.61 and 8.02% in sand culture, and 7.06, 7.05 and 6.07% in soil culture, in the sea water, NaCl and $MgCl_2$ series, respectively. The mean Cl content in the NaCl and $MgCl_2$ series was higher in sand culture than in soil culture. In the sea water series mean Cl content of leaves exclusive of −2.70 bars was also higher in sand culture (6.49%) than in soil culture (6.17%). SO_4 content of leaves was markedly higher in sand culture than in soil culture. The mean SO_4 content was 9.72 and 10.88% in sand culture, but 1.65 and 2.61% in soil culture, in the Na_2SO_4 and $MgSO_4$ series. According to above observations, it is considered that one of the causes which induced the difference of growth between sand and soil cultures is the difference of leaf Cl or SO_4 content.

Meiri *et al.* (4) have reported that increase in K ion concentration and decrease in Ca ion concentration in the sap of bean leaves were more pronounced in sulfate-salinity. Joshi and Naik (3) found that SO_4 salts decreased the uptake of K and Ca ions in sugarcane. In the present experiment leaf Ca content was not affected by salinities and not significantly different from the control. K content of leaves tended to be higher in sodium-salinity and lower in magnesium-salinity. These difference between the present experiment and other reports might be due to differences of tested crops, culture regimes, etc..

Several days before harvesting, interveinal chlorosis appeared in sulfate-salinity at -1.70 bars in both sand and soil culture experiments. The symptom may be caused by a combination of the excess SO_4 ion or an imbalance of ions induced by the excess SO_4 ion, and the stage of green soybeans at which seeds are just swelling and photosynthates and some elements are translocating to the seeds. It is considered that at -1.20 bars SO_4 content was not high enough to induce the symptom and at -2.70 bars the plants had not reached that stage. Therefore, interveinal chlorosis might appear only at -1.70 bars.

Soil solutions were centrifugally extracted at pF 0 to 3.8 to explain the difference of growth suppression between two cultures (Tables 4 and 5, Fig. 3). Cation and anion concentrations, EC of the solutions were lower in sand culture, regardless of much more severe growth suppression in sand culture. Questions remain on this point. Therefore, extracting procedures of the soil solutions must be more examined to clarify the mechanism of salt tolerance.

There are several different reports on relationships between plant growth retardation and types of salinity when expressed on an osmotic basis. Meiri *et al.* (4) have reported that isosmotic concentrations of sodium chloride and sodium sulfate affected the growth of bean plants almost to the same extent. Gauch and Wadleigh(2) have stated the specific Mg toxicity of bean plants, showing very similar amounts of plant growth occurred in the NaCl, $CaCl_2$ and Na_2SO_4 series, but there was marked depression of growth with $MgCl_2$ and $MgSO_4$. Osawa(12) also reported the specific Mg toxicity of some vegetable crops. Dirr(1) reported that honeylocust was severely injured by exposure to Cl salts. Joshi and Naik(3) concluded that the degree of toxicity of different ions in decreasing order in sugarcane cv. Co 740 is $SO_4 > Na > Cl > Mg$. The result in the present experiment shows that, apart from osmotic effect, Cl and SO_4 have their own effect on the growth of green soybeans. Cl salts were most deleterious to green soybeans, but SO_4, Na and Mg salts rarely affected the growth in soil culture. These are similar to the result on honey locust, but do not agree with that of beans and sugarcane. These differences are mainly due to the crops tested and their environments.

Acknowledgement

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

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各種塩類が土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，土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) で育てた対照区と比較した．海水の −1.20 bar 区，Na_2SO_4 の −1.20 と −1.70 bar 区，$MgSO_4$ の全区の全植物体乾物重，種子とさやの新鮮重，1箱当たりのさや数は，対照区と有意な差がみられなかった．−2.70 bar 区における全乾物重は，対照区を 100% とした場合，海水で 52.6%, NaCl で 39.6%，Na_2SO_4 で 81.5%，$MgCl_2$ で 20.4%，$MgSO_4$ で88.1% であった．土耕栽培における生育は，$MgSO_4$ 及び Na_2SO_4 で最大となり，海水，NaCl, $MgCl_2$ の順に減少した．Na_2SO_4 と $MgSO_4$ では，収穫直前の −1.70 bar 区のみに葉脈間クロロシスがみられた．Cl 塩処理では，生育中期の葉にクロロシスとネクロシスが現れ，次第に上位葉まで進行した．生育後期には，特に低い浸透ポテンシャル区においてほとんどの植物体が枯死した．葉中及び土壌溶液の Na, Mg, Cl, SO_4 含量は，それぞれ Na, Mg, Cl, SO_4 を処理した区で，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．処理培養液の浸透ポテンシャルが低下するにつれ，土壌溶液の EC 値は増加し，浸透ポテンシャルは減少した．