高塩条件下での微量要素吸収における植物種間の比較

誌名	岐阜大学農学部研究報告 = Research bulletin of the Faculty College of Agriculture Gifu University
ISSN	00724513
著者	園田, 洋次 原, 徹夫
巻/号	45号
掲載ページ	p. 113-122
発行年月	1981年12月

Res. Bull. Fac. Agr. Gifu Univ. (45) : 113—122, 1981.

Comparison of Micronutrient Uptake among Crop Plants under Saline Soil Conditions (Part 1)

— Effects of Application of $CaCO_3$ and Na_2CO_3 on the Growth and Micronutrient Uptake by Crop Plants —

Yoji SONODA and Tetsuo HARA

SUMMARY

Four levels of $CaCO_3$ (0, 15, 75, 150% Ca of CEC) and Na_2CO_3 (0, 5, 25, 50% Na of CEC) were established in a diluvial organic soil (CEC = 48.7), and tomato, corn, cabbage, kidney bean and spinach plants were grown. Effects of salt stress (by applying $CaCO_3$ and Na_2CO_3) on the availability of micronutrients in soil and the growth and chemical composition of plants were studied. The following results were obtained.

(1) The pH and EC of soil increased with the increasing amount of $CaCO_3$ and Na_2CO_3, and the increase was greater in the application of Na_2CO_3 than of $CaCO_3$. The availability of iron, manganese, zinc and copper in soil decreased with the increasing amount of $CaCO_3$ and Na_2CO_3.

(2) The dry weight of tomato, corn and cabbage plants increased with the increasing amount of $CaCO_3$ from 0 to 15% and decreased from 15 to 150%. The dry weight of tomato, kidney bean and spinach plants decreased successively with the incrceasing amount of Na_2CO_3.

(3) The calciun and sodium contents in all plants increased with the increasing amount of each carbonate salt. The contents of all micronutrients (Fe, Mn, Zn, Cu), especially Mn, in all plants decreased with the increasing amount of $CaCO_3$ and Na_2CO_3.

(4) The reduced growth at higher levels of $CaCO_3$ was related mainly to calcium excess in plant-tissues, and the tolerance of plants to higher levels of calcium was in the order of cabbage >tomato> corn. The reduced growth at higher levels of Na_2CO_3 was related to high pH and EC of soil and sodium excess in plant tissues. Spinach plants were tolerant and kidney bean plants were susceptible to higher levels of sodium.

INTRODUCTION

Soil salinization and alkalinization are problems to encounter and to overcome in the fulfilment of irrigated agriculture in arid tropical regions. Soil salinization do not occur widely in Japan, therefore little study on soil salinization has been conducted. However, as the cooperation in research of crop production is extended to a global scale, Japanese scientists are being forced to learn irrigated tropical agriculture.

Many cations and anions are involved in soil salinization[1]. As soil alkalinity is raised by Na_2CO_3[2] and $CaCO_3$ [3,4], the concentration of nutrients in soil decreases. The availability of micronutrients is strongly dependent on soil pH[5]. Crop plants respond in different ways to salt stress, and are classified in their tolerance to salinity from tolerant plants to sensitive plants[6]. There is a great difference in the adaptability of crop plants to bases involved in salinization.

The present experiments were conducted to provide information on the relationship between the soil salinity by applying $CaCO_3$ and Na_2CO_3 and the growth and micronutrient uptake by several crop plants with different adaptability to calcium[7] and sodium[8].

MATERIALS AND METHODS

A simple experiment of incubating a diluvial organic soil with $CaCO_3$ and Na_2CO_3 was conducted prior to the cultivation of crop plants. The soil was obtained from the Nishine area of Iwate prefecture, and its chemical properties are shown in Table 1. One hundred g of the air-dried soil was filled in beakers. Four levels of $CaCO_3$ (0, 15, 75, 150% Ca of CEC) and Na_2CO_3 (0, 5, 25, 50% Na of CEC) were applied and mixed in the soil. The moisture in soil was adjusted to 60% with distilled water, and these beakers were incubated at 25℃ for 2 days. To determine the availability of micronutrients, the incubated soils were treated with conventional solutions (Table 2) for extracting available and exchangeable micronutrients in soil[9]. Iron, manganese, zinc and copper in the extracts were determined by atomic absorption spectrophotometry.

Table 1. Chemical properties of the experimental soil.

pH	CEC	Exchangeable cations				Total micronutrients			
(H_2O)	(me/100g)	Ca	Mg	K	Na	Fe	Mn	Zn	Cu
		(me/100g)				(ppm)			
5.2	48.7	9.3	4.9	0.4	0.6	16000	190	31	14

Table 2. Solutions for extracting available and exchangeable micronutrients from soil.

Micronutrients	Available	Exchangeable
Fe	0.05M Na-EDTA (pH=4.0)	1N sodium acetate (pH=4.8)
Mn	1N ammonium acetate (0.2 % hydroquinone, pH=7.0)	1N ammonium acetate (pH=7.0)
Zn	0.1 N HCl	0.05 N KCl (pH=3.2)
Cu	0.1 N HCl	0.05 N KCl (pH=3.2)

Two cultivation experiments were conducted from June 1 to July 18 (Exp. I) and from September 7 to October 31 (Exp. II). Three kg of the same soil (Table 1) was filled in 1/5000 a Wagner's pots, and the same levels of $CaCO_3$ and Na_2CO_3 were applied together with a uniform dose (1 g) of N, P_2O_5 and K_2O as ammonium sulfate, superphosphate and potassium sulfate, respectively. In Exp. I, tomatoes *(Lycopersicum esculentum* MILL.) and corn *(Zea mays* L.) were sown in the $CaCO_3$-treated soil, and tomatoes and kidney beans *(Phaseolus vulgaris* L.) in the Na_2CO_3-treated soil. In Exp. II, tomatoes and cabbage *(Brassica oleracea* L. var. *capitata* L.) were sown in the $CaCO_3$-treated soil, and tomatoes and spinach *(Spinacia oleracea* L.) in the Na_2CO_3-treated soil. Ten seeds of each plant were sown and irrigated with tap water, and some of the seedlings were later thinned out to two plants per pot. These plants were harvested simultaneously at 47 days after sowing in Exp. I and 54 days after sowing in Exp. II, separated into plant tops and roots, dried, weighed and milled for chemical analysis. The pH and EC (soil : water = 1 : 2.5) of soil were measured before and after the cultivation of plants.

The milled samples of plant tops were digested with sulfuric-nitric-perchloric acid mixtures, and calcium, iron, manganese, zinc and copper in the digested solution were determined by atomic absorption spectrophotometry and sodium by flamephotometry.

RESULTS

Availability of micronutrients in soil

Application of $CaCO_3$ and Na_2CO_3 in soil resulted in a decrease in the concentration of all

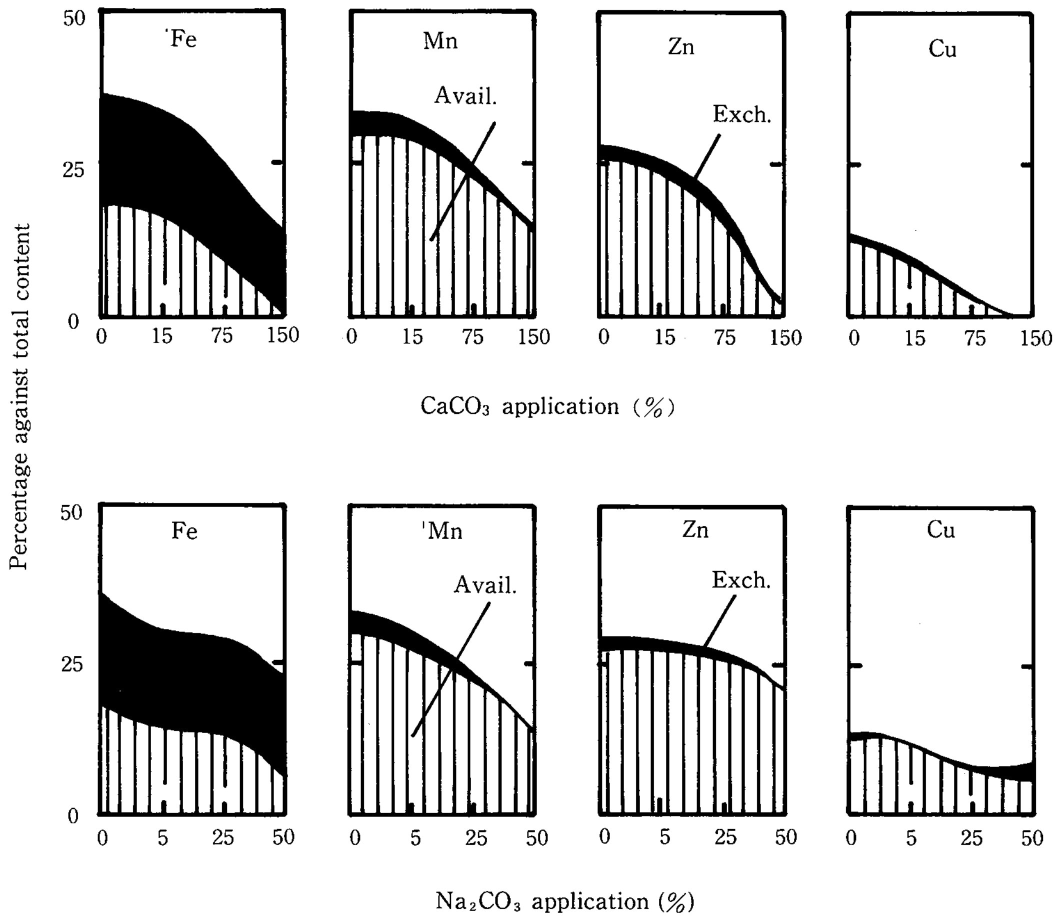

Fig. 1. Effects of application of $CaCO_3$ and Na_2CO_3 on the availability of micronutrients in soil.

micronutrients (Fe, Mn, Zn, Cu), and the decrease was greater in the application of $CaCO_3$ than of Na_2-CO_3 (Fig. 1). Iron occurred in both the available and exchangeable forms, but at higher levels of $CaCO_3$ and Na_2CO_3 it occurred dominantly in the exchangeable form. The amount of manganese, zinc and copper in the exchangeable form was very small and tended to disappear at higher levels of $CaCO_3$.

Soil pH and EC

The pH of soil before sowing increased with the increasing amount of $CaCO_3$ and Na_2CO_3, and the increase was greater in the application of Na_2CO_3 than of $CaCO_3$ (Table 3). The pH of soil increased from the time of sowing to harvest in the application of $CaCO_3$ and decreased in the

Table 3. Effects of application of $CaCO_3$ and Na_2CO_3 on the pH and electronic conductivity(EC) of soil

Application	pH(H_2O)			EC (m℧)		
(%)	Before*	After*	Average	Before*	After*	Average
$CaCO_3$ 0	5.2	5.0	5.1	0.69	0.62	0.66
$CaCO_3$ 15	6.1	5.6	5.9	0.87	0.87	0.87
$CaCO_3$ 75	6.4	6.9	6.7	1.02	1.01	1.02
$CaCO_3$ 150	6.5	7.2	6.9	1.05	1.15	1.10
Na_2CO_3 0	5.2	5.0	5.1	0.69	0.62	0.66
Na_2CO_3 5	5.8	5.3	5.6	0.82	0.75	0.79
Na_2CO_3 25	6.9	6.5	6.7	1.62	1.32	1.47
Na_2CO_3 50	7.4	7.2	7.3	2.94	2.41	2.69

* Before sowing and after harvest

application of Na_2CO_3.

The EC of soil before sowing increased with the increasing amount of $CaCO_3$ and Na_2CO_3, but the increase was very small at higher levels of $CaCO_3$ (Table 3). The EC of soil did not change greatly from sowing to harvest in the application of $CaCO_3$, but decreased slightly in the application of Na_2CO_3.

Plant growth

The dry weight of corn plants was greater than that of tomato plants at all levels of $CaCO_3$ in

Table 4. Effects of application of $CaCO_3$ on the dry weight of several plants (g/pot).

$CaCO_3$	Exp. I		Exp. II	
(%)	Tomato	Corn	Tomato	Cabbage
0	10.8(100)	23.4(100)	4.7(100)	2.8(100)
15	11.6(107)	24.8(106)	4.9(105)	3.4(118)
75	10.6(98)	11.6(50)	1.9(41)	1.8(64)
150	9.1(84)	9.8(42)	0.8(16)	1.2(41)

( ) : Relative growth on the basis of plants without $CaCO_3$

Exp. I (Table 4). The dry weight of both plants increased with the increasing amount of $CaCO_3$ from 0 to 15% and decreased from 15 to 150%. The decrease at higher levels of $CaCO_3$ was greater in corn plants than in tomato plants. The dry weight of tomato and cabbage plants in Exp. II increased with the increasing amount of $CaCO_3$ from 0 to 15% and decreased from 15 to 150%. The decrease at higher levels of $CaCO_3$ was greater in tomato plants than in cabbage plants.

The dry weight of tomato and kidney bean plants in Exp. I and of tomato and spinach plants in Exp. II decreased successively with the increasing amount of Na_2CO_3 (Table 5). At higher levels of Na_2CO_3, the dry weight of tomato plants was larger than that of kidney bean plants in Exp. I. The germination of plants at the highest levels of Na_2CO_3 was damaged. Especially in the case of spinach plants, the number of plants which germinated was only one, so the dry weight of this plot at the

Table 5. Effects of application of Na_2CO_3 on the dry weight of several plants (g/pot).

Na_2CO_3	Exp. I		Exp. II	
(%)	Tomato	Kidney bean	Tomato	Spinach
0	10.8(100)	6.3(100)	4.7(100)	1.6(100)
5	9.5(88)	5.5(87)	4.1(89)	1.4(86)
25	8.0(74)	3.3(52)	3.0(64)	1.2(73)
50	5.1(47)	2.0(32)	1.1(24)	0.1(7)

( ) : Relative growth on the basis of plants without Na_2CO_3.

highest level of Na_2CO_3 was extremely small.

Nutrient contents in plants

The calcium content in Exp. I increased greatly in tomato plants with increasing amount of $CaCO_3$, and increased slightly in corn plants (Table 6). The calcium content in Exp. II increased greatly in tomato plants with the increasing amount of $CaCO_3$, and increased slightly in cabbage plants, although the calcium content in cabbage plants was always very high. The contents of iron, manganese, zinc and copper of all plants in Exp. I and Exp. II decreased with increasing amount of $CaCO_3$. The decrease was greater in manganese and smaller in copper than in other micronutrients.

The sodium content in Exp. I and Exp. II increased in all plants with the increasing amount of

Table 6. Effects of application of $CaCO_3$ on the contents of calcium and micronutrients in several plants.

$CaCO_3$	Exp. I					Exp. II				
(%)	Ca (%)	Fe	Mn (ppm)	Zn	Cu	Ca (%)	Fe	Mn (ppm)	Zn	Cu
	Tomato					Tomato				
0	0.65	290	220	252	20	0.88	225	159	143	15
15	0.84	262	124	254	17	1.27	175	62	183	14
75	1.28	190	70	254	17	2.69	175	44	105	15
150	2.08	185	60	149	13	2.94	175	38	97	12
	Corn					Cabbage				
0	0.24	235	114	85	18	2.32	325	130	105	10
15	0.24	281	90	67	18	2.76	250	38	39	10
75	0.32	160	52	48	17	2.82	113	33	33	7
150	0.40	175	47	42	13	2.94	108	33	40	9

Na_2CO_3 (Table 7). The increase was greater in Exp. II than in Exp. I and was the greatest in spinach plants among these plants. The contents of iron, manganese and zinc decreased in all plants with the increasing amount of Na_2CO_3, and the decrease was the greatest in manganese among these micronutrients. The copper content decreased in tomato and kidney bean plants in Exp. I, but not in tomato and spinach plants in Exp. II.

Table 7. Effects of application of Na_2CO_3 on the contents of sodium and micronutrients in several plants.

Na_2CO_3 (%)	Exp. I Na (%)	Fe (ppm)	Mn (ppm)	Zn (ppm)	Cu (ppm)	Exp. II Na (%)	Fe (ppm)	Mn (ppm)	Zn (ppm)	Cu (ppm)
	Tomato					Tomato				
0	0.13	290	220	252	17	0.12	275	159	143	15
5	0.43	289	184	267	15	0.19	350	99	135	17
25	1.48	289	104	267	13	2.07	300	48	140	18
50	1.77	180	47	205	12	3.03	250	30	100	15
	Kidney bean					Spinach				
0	0.06	342	137	182	20	0.19	525	684	255	18
5	0.09	252	129	152	13	0.73	375	377	240	17
25	0.29	217	53	172	15	2.42	275	158	215	16
50	0.79	152	80	167	5	3.85	250	85	120	18

Discussion

The relative growth of tomato plants in Exp. I was different from that in Exp. II (Tables 4 and 5), although the same amount of $CaCO_3$ and Na_2CO_3 was applied in both experiments. These different results are derived from different meteorological conditions (such as light, temperature, etc.) under which the plants were grown. However, the data of meteorological conditions during spring (Exp. I) and autumn (Exp. II) were not recorded, so the difference in the relative growth could not be interpreted in this paper.

The reduced growth of all plants resulting from high levels of $CaCO_3$ and Na_2CO_3 was obvious. To find out which factor was the dominant cause for the reduced growth, relationships between the relative growth and the average pH and EC of soil were evaluated initially (Fig. 2). There is a negative correlation between the relative growth and the pH of soil in the application of Na_2CO_3. In the application of $CaCO_3$, the relative growth is maximum at a pH of about 6, but at higher pH values the correlation is not clear. This means that the reduced growth is more related to the pH in the application of Na_2CO_3 than of $CaCO_3$, although $CaCO_3$ was added in larger amounts in soil. There is no great difference in the growth responses to pH among these plants. There is no correlation between the relative growth and the EC of soil in the application of $CaCO_3$, but in the application of Na_2CO_3 there is a negative correlation. The EC at the highest level of Na_2CO_3 is far greater than the critical level of EC (1.5—2.0) inducing the reduced growth of vegetable crops[10].

Most Na_2CO_3 added in soil is hydrolyzed to form 2 Na^+, 2 OH^- and $H_2CO_3(H^+ + HCO_3^-)$, and these are largely present in free ionic forms. A smaller amount of $CaCO_3$ added to the soil is also hydrolyzed to form Ca^{++}, 2 OH^- and H_2CO_3, and Ca ions are absorbed by soil colloids. The difference in chemical properties between $CaCO_3$ and Na_2CO_3 brings about different values of pH and EC in soil and different growth responses of crop plants as mentioned above. The salt stress in the application of Na_2CO_3 may change physical properties of soil through dispersing soil colloids and organic matters, but the effect of the change on plant growth could not be estimated. Therefore, in future study, changes of physical properties of soil as well as availability of nutrients should be clarified.

Decreases in the availability of micronutrients by the application of $CaCO_3$ and Na_2CO_3 result in

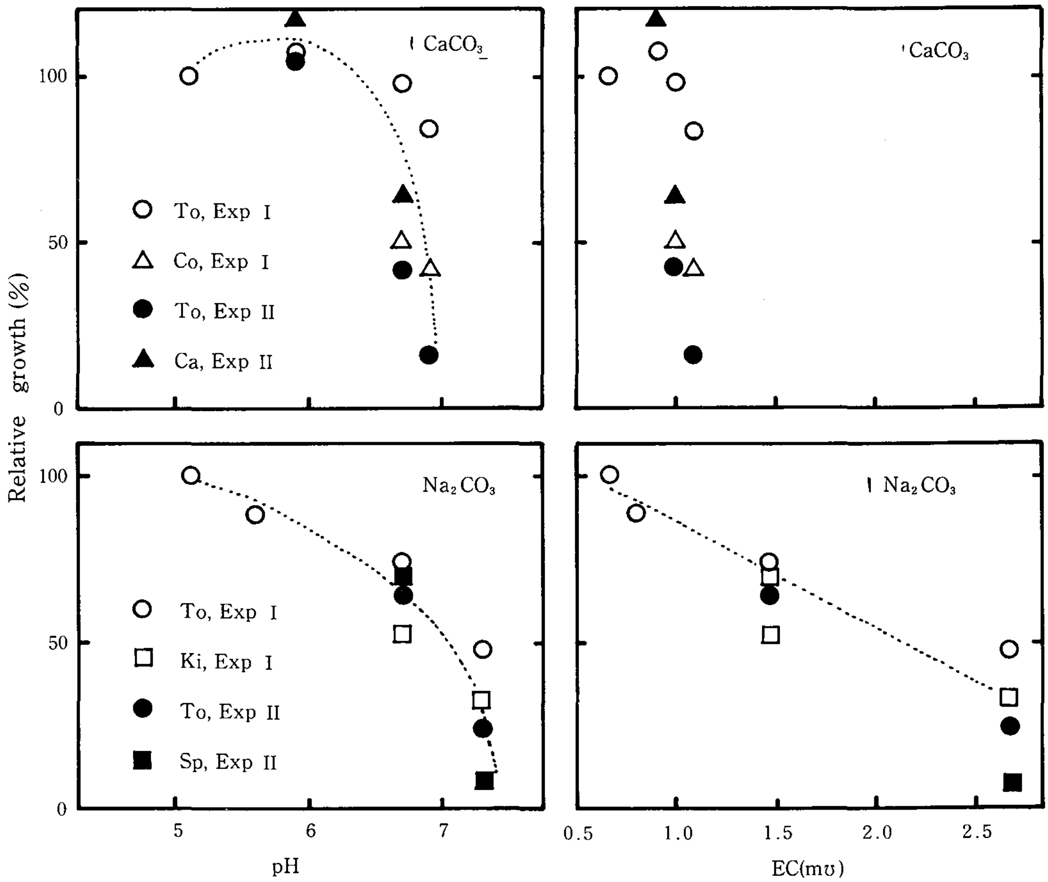

Fig. 2. Relationship between the relative growth and the pH and EC of soil.
To ; Tomato, Co ; Corn, Ca ; Cabbage, Ki ; Kidney bean, Sp ; Spinach.

the low contents of micronutrients in plants. The available forms of micronutrients are closely related to the micronutrient uptake of all plants. No difference in the micronutrient uptake specific to each plant is recognized. The contents of micronutrients in all plants (Tables 6 and 7) are higher than the critical levels of micronutrient deficiency[11], so the contents of micronutrients are not the dominant cause for the reduced growth at higher levels of $CaCO_3$ and Na_2CO_3.

The dominant cause other than the pH and EC of soil is calcium or sodium excess in plant-tissues. Figure 3 shows the relationship between the relative growth and the calcium and sodium contents in plants. When the calcium content of corn, tomato and cabbage plants exceeds a critical level of calcium excess for each plant, the plant growth decreases abruptly. The critical levels of calcium excess for corn, tomato and cabbage plants are about 0.3, 2.5 and 3.0%, respectively. Similarly, the critical levels of sodium excess for kidney beans, tomatoes and spinach plants are about 0.3, 2.0 and 3.0%, respectively. The order of plant tolerance to calcium excess is in agreement with that of their adaptability to calcium in nutrient solution[7]. The germination of spinach plants is easily damaged by high levels of Na_2CO_3, but young plants which germinate normally are tolerant to high levels of sodium in soil and plant-tissues. As demonstrated in a water-culture experiment on adaptability of crop plants to sodium, *phaseolus* group plants (e.g., kidney beans and red beans) are susceptible to high

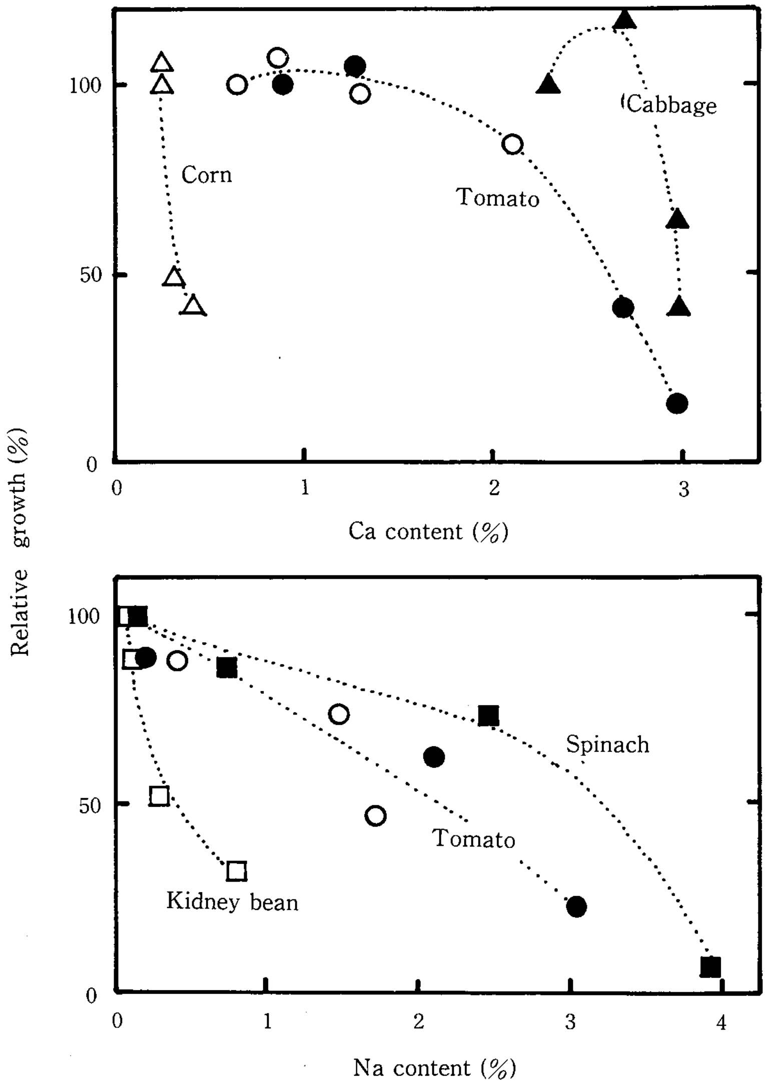

Fig. 3. Relationship between the relative growth and the Ca and Na contents in plants. Symbols are same as in Fig. 2.

levels of sodium in plant-tissues[8].

Acknowledgement. The authors are grateful to Mr. I. Suzuki for his assistance. This study was supported in part by the Science Research Fund of the Ministry of Education of Japan.

REFERENCES

1) Joshi, G. V. & Naik, G. R.: Response of sugarcane to different types of salt stress. Plant and Soil **56** : 255-263, 1980.

2) Mashhady, A. S. & Rowell, D. L. : Soil alkalinity. II. The effects of Na_2CO_3 on iron and manganese supply to tomatoes. J. Soil Sci. **29** : 367-372, 1978.

3) Schinas, S. & Rowell, D. L. : Lime-induced chlorosis J. Soil Sci. **28** : 351-368, 1977.

4) Dahiya, S. S. & Singh, R. : Effect of farm yard manure and $CaCO_3$ on the dry matter yield and nutrient uptake by oats *(Avena sativa)*. Plant and Soil **56** : 391-402, 1980.

5) Lucas, R.E. & Davis, J. F. : Relationships between pH values of organic soils and availabilities of 12 plant nutrients. Soil Sci. **92** : 177-182, 1961.

6) Bernstein, L. & Hayward, H. E. : Physiology of salt tolerance. Ann. Rev. Plant Physiol. **9** : 25-46, 1958.

7) Tanaka, A., Tadano, T. & Yamada, M. : Comparison of adaptability to bases among crop plants. I. Adaptability to calcium. Studies on the comparative plant nutrition. J. Sci. Soil Manure, Japan **44** : 334-339, 1973. (in Japanese)

8) Tanaka, A., Tadano, T. & Tada, Y. : Comparison of adaptability to bases among crop plants. III. Adaptability to sodium. Studies on the comparative plant nutrition. J. Sci. Soil Manure, Japan **45** : 285-292, 1974. (in Japanese)

9) Ishizawa, S. *et al.* : "Procedures for analyzing nutrients in soil" Tokyo : Yokendo 297-374, 1970. (in Japanese)

10) Hashida, S. & Yanai, K : Salinity injury of vegetables and the simple determination. Agric. & Hortic. **39** : 1389-1392, 1964. (in Japanese)

11) Hara, T., Sonoda, Y. & Iwai, I. : Growth response of cabbage plants to transition elements under water culture conditions. II. Cobalt, nickel, copper, zinc, and molybdenum. Soil Sci. Plant Nutr. **22** : 317-325, 1976.

高塩条件下での微量要素吸収における植物種間の比較（第1報）

── $CaCO_3$ および Na_2CO_3 添加が植物の生育と微量要素吸収に及ぼす影響 ──

園田洋次・原　徹夫

要　　約

腐植質洪積土(CEC＝48.7)に4段階の $CaCO_3$（CECの0, 15, 75, 150%）および Na_2CO_3（CECの0, 5, 25, 50%）を加え，トマト，トウモロコシ，キャベツ，インゲンマメ，ホウレンソウを栽培した。添加塩類の微量要素可給度，作物生育および化学組成に及ぼす影響を検討し，以下の結果を得た。

(1) 土壌pHとECは $CaCO_3$ および Na_2CO_3 添加により上昇し，その上昇は Na_2CO_3 添加において大きかった。土壌中のFe, Mn, Zu, Cuの可給度は $CaCO_3$ および Na_2CO_3 添加により低下した。

(2) トマト，トウモロコシ，キャベツの乾物重は $CaCO_3$ 添加により0から15%まで上昇し，15から150%にかけて低下した。トマト，インゲンマメ，ホウレンソウの乾物重は Na_2CO_3 添加により順次低下した。

(3) 作物体のCa, Na含有率は $CaCO_3$, Na_2CO_3 それぞれの添加により上昇した。作物体のFe, Mn, Zn, Cu含有率（とくにMn含有率）は $CaCO_3$ および $NaCO_3$ 添加により低下した。

(4) $CaCO_3$ 添加高濃度区における乾物重の低下は作物体の高Ca含有率によると考えられ，Ca耐性の強い作物ほど（キャベツ＞トマト＞トウモロコシ），相対生育量が大きかった。Na_2CO_3 添加高濃度区における乾物重の低下は土壌の高pHとECおよび作物体の高Na含有率によると考えられ，ホウレンソウはNa耐性が強く，インゲンマメは弱かった。