EFFECT OF CALCIUM ON SALT INJURY IN PLANTS

I. Maize and Bean*

Toshio KAWASAKI and Masumi MORITSUGU

Since the classic work of Viets (1), the effect of calcium and other polyvalent cations on absorption of monovalent cations by plant roots has been the subject of intensive investigations. In the 1960's, several groups of workers (2–6) showed that calcium was essential for integrity of the selective absorption mechanism of monovalent cations. In our previous papers (7–11), it was reported that calcium stimulated rubidium absorption and inhibited sodium absorption in excised plant roots under certain conditions.

A number of studies (12–18) on salt injury or salt tolerance have shown that an unbalanced composition of mineral nutrients, especially low potassium content, is found in plants supplied high concentrations of sodium chloride. Therefore, it is presumed that calcium may be involved in salt tolerance of plants through regulation of monovalent cation absorption.

In the present investigation, solution culture experiments were undertaken to determine the effect of calcium on salt injury in plants with special reference to mineral nutrition. Furthermore, the effect of magnesium was examined and compared with the calcium effect.

MATERIALS AND METHODS

In this investigation, maize (*Zea mays* L., cv. Nagano No. 1) and bean (*Phaseolus vulgaris* L., cv. Masterpiece) were used as test plants. Seeds of the maize and bean were allowed to germinate in trays with washed sand. Seedlings (about 7 days old) were then transplanted into 3.5 *l* pots containing nutrient solution. Three replications were used in each treatment, and each pot contained two seedlings. Solution culture experiments were conducted in a greenhouse.

Table 1 shows the compositions of the nutrient solutions used for experiments with different levels of calcium chloride or magnesium sulfate. Sodium chloride was used at four levels (0, 4, 20 and 40 m*M*). During the first 3 days of solution culture experiments, all salts except micro-nutrients were used at a quarter strength of the concentrations indicated in Table 1. After the period, plants were supplied a full strength of nutrient solution. Nutrient solutions were aerated continuously, and renewed once a week. The pH was adjusted to

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TABLE 1
Nutrient solutions for maize and bean

For experiment with different levels of calcium chloride		For experiment with different levels of magnesium sulfate	
KNO_3	4.0 m*M*	KNO_3	4.0 m*M*
$NH_4H_2PO_4$	1.0 m*M*	$NH_4H_2PO_4$	1.0 m*M*
$MgSO_4$	1.0 m*M*	$CaCl_2$	1.0 m*M*
Fe	3.0 ppm	Fe	3.0 ppm
B	0.5 ppm	B	0.5 ppm
Mn	0.5 ppm	Mn	0.5 ppm
Zn	0.05 ppm	Zn	0.05 ppm
Cu	0.02 ppm	Cu	0.02 ppm
Mo	0.01 ppm	Mo	0.01 ppm
NaCl	0~40.0 m*M*	NaCl	0~40.0 m*M*
$CaCl_2$	0.1, 1.0 m*M*	$MgSO_4$	0.05*, 1.0 m*M*

* In order to obtain the same concentration of sulfate, 0.95 m*M* of sodium sulfate was added to the treatment which was supplied 0.05 m*M* of magnesium sulfate.

5.7 every 2 days, and the iron source was added twice a week as ferrous ammonium sulfate solution.

After about 3 weeks, the plants were harvested and separated into roots and tops. The tissues were dried at 100°C, and the dry weights were determined. The dried tissues were then ground and stored in polyethylene bags until analyzed.

An aliquot of ground tissue was ashed at 500°C, and the ash was dissolved with dilute hydrochloric acid. Potassium and sodium were determined by flame-photometry, and calcium and magnesium by EDTA*-titration method.

RESULTS

Experiments with Different Levels of Calcium Chloride

(*1*) *Maize plants*

Maize plants were grown in different concentrations of sodium chloride and calcium chloride. Plate 1 shows the growth of maize plants at the end of the experimental period, and Fig. 1 shows the yields of plants. In Fig. 1, bars above and below the abscissa represent the yields of the tops and roots of plants, respectively. The same system is used in the figures described below. Plate 1 and Fig. 1 show that plant growth decreased as the concentration of sodium chloride in nutrient solution was raised. However, the decrease in plant yield was severer in 0.1 m*M* calcium level than in 1.0 m*M* calcium level.

The contents of potassium and sodium in plants are shown in Fig. 2, and the contents of calcium and magnesium in Fig. 3. In 0.1 m*M* calcium level,

* EDTA : Ethylenediaminetetraacetic acid.

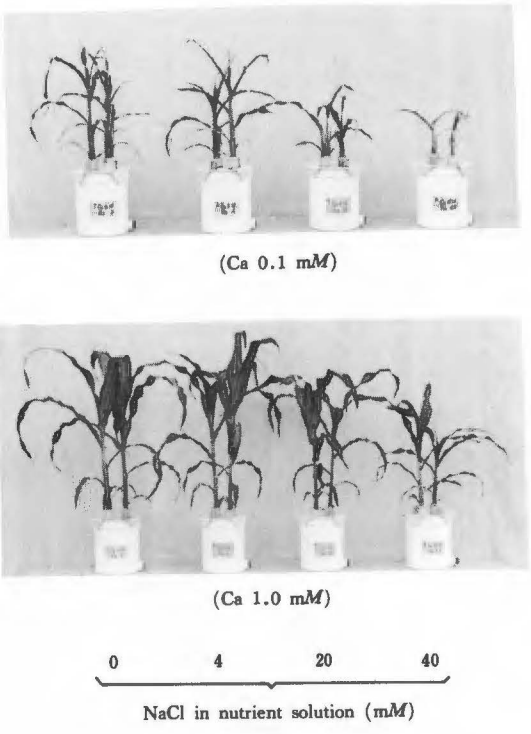

Plate 1. Growth of maize plants in different concentrations of sodium chloride and calcium chloride.

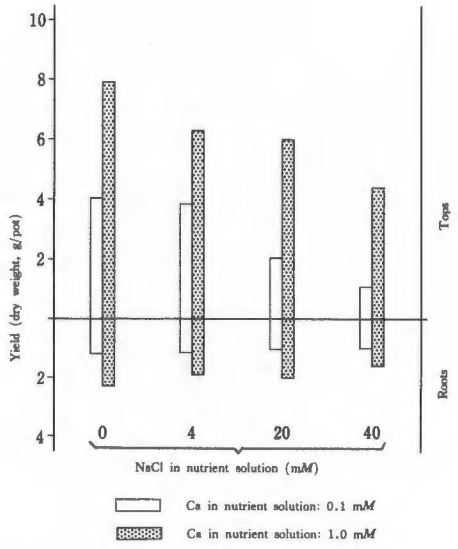

Fig. 1. Yield of maize plants in different levels of sodium chloride and calcium chloride.

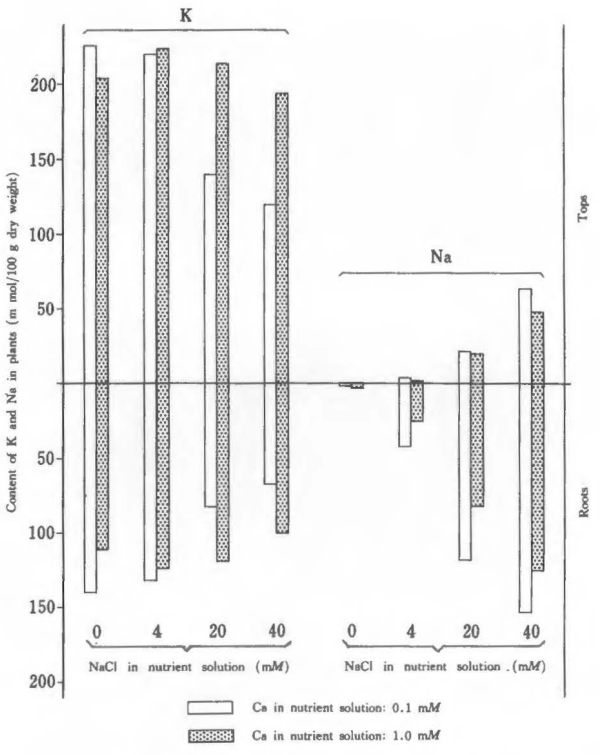

Fig. 2. Effect of different levels of sodium chloride and calcium chloride on potassium and sodium contents of maize plants.

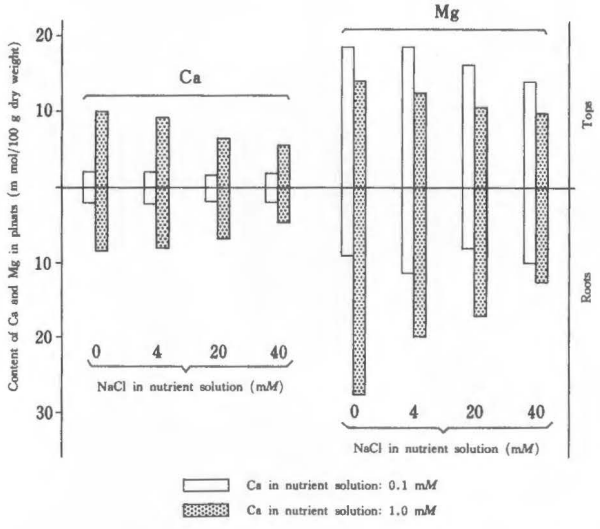

Fig. 3. Effect of different levels of sodium chloride and calcium chloride on calcium and magnesium contents of maize plants.

potassium content decreased drastically with increasing concentrations of sodium chloride in nutrient solution, whereas the decrease of potassium content was only slight in 1.0 m*M* calcium level. The sodium content was lower in 1.0 m*M* calcium than in 0.1 m*M* calcium level. Fig. 3 shows that calcium and magnesium contents decreased when high concentrations of sodium chloride were added to the nutrient solution. It was also evident that a high calcium supply increased the magnesium content of plant roots in comparison with low calcium level, though the reverse relationship between magnesium content and calcium supply was found in plant tops.

(2) *Bean plants*

Plate 2 shows the growth of bean plants at the end of the experimental period, and yields of plants are given in Fig. 4. It was shown that high concentrations of sodium chloride just slightly affected the growth of plant tops.

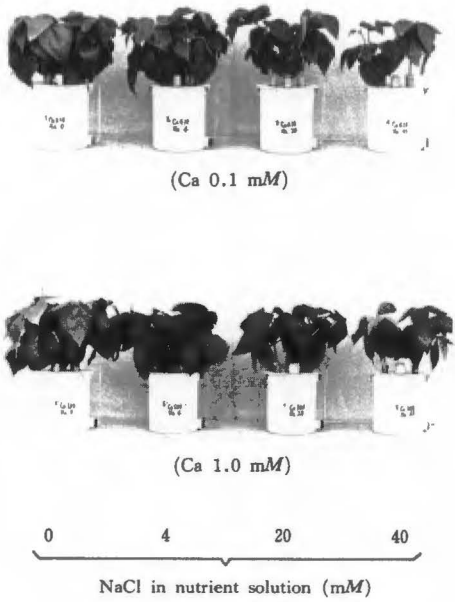

Plate 2. Growth of bean plants in different concentrations of sodium chloride and calcium chloride.

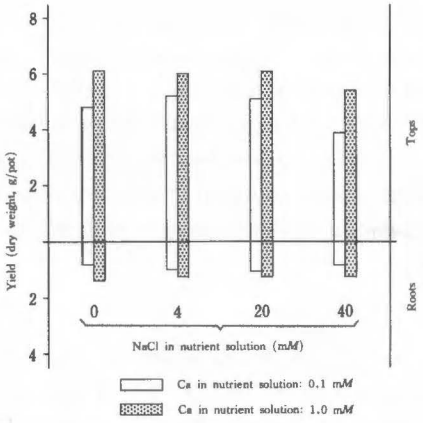

Fig. 4. Yield of bean plants in different levels of sodium chloride and calcium chloride.

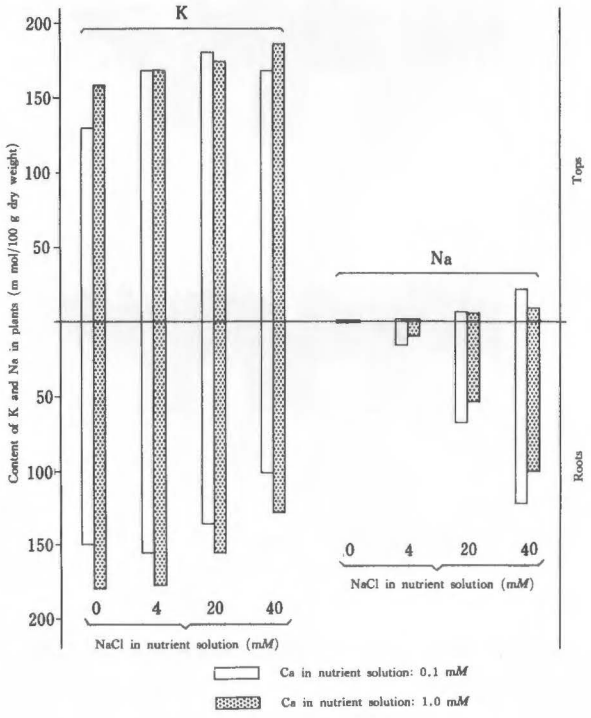

Fig. 5. Effect of different levels of sodium chloride and calcium chloride on potsssium and sodium contents of bean plants.

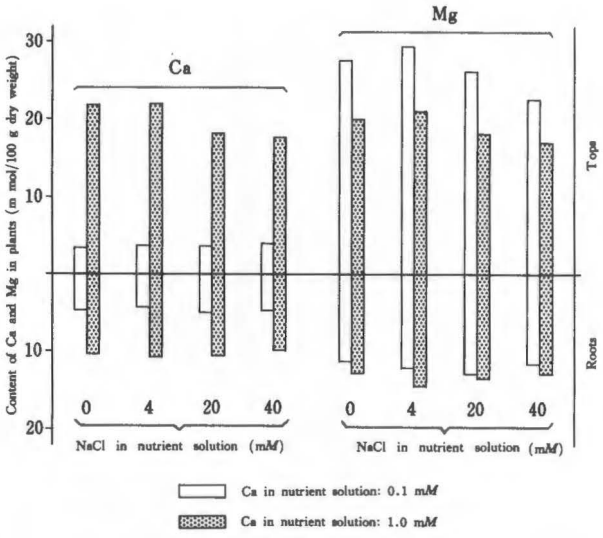

Fig. 6. Effect of different levels of sodium chloride and calcium chloride on calcium and magnesium contents of bean plants.

The contents of potassium and sodium in bean plants are shown in Fig. 5, and the contents of calcium and magnesium in Fig. 6. In plant tops, differences of potassium content were not so clear between 0.1 m*M* and 1.0 m*M* of calcium levels, but plant roots had high potassium content in 1.0 m*M* calcium level. Calcium and magnesium contents decreased slightly with increasing concentrations of sodium chloride, especially in the plant tops.

Experiments with Different Levels of Magnesium Sulfate

(*1*) *Maize plants*

The yields of maize plants grown in different concentrations of sodium chioride and magnesium sulfate are shown in Fig. 7. Plant growth decreased with increasing concentrations of sodium chloride, irrespective of low (0.05 m*M*) and high (1.0 m*M*) levels of magnesium sulfate.

As shown in Fig. 8, potassium content was lower in 1.0 m*M* magnesium than in 0.05 m*M* magnesium level, except with 40 m*M* of sodium chloride. Sodium content was also lower in 1.0 m*M* magnesium level. Calcium and magnesium contents decreased as the concentration of sodium chloride was raised in nutrient solution (Fig.,9).

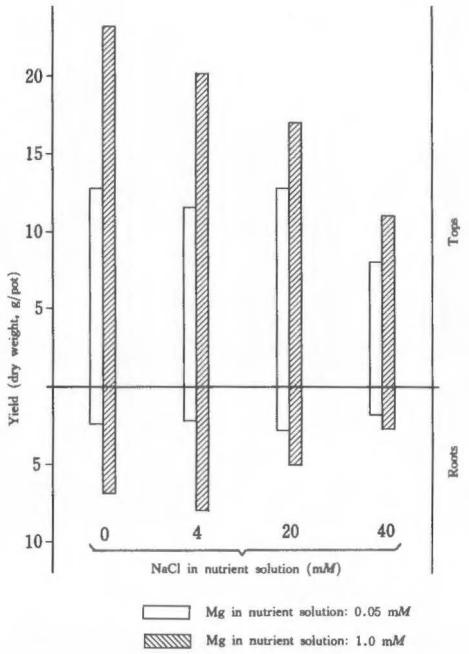

Fig. 7. Yield of maize plants in different levels of sodium chloride and magnesium sulfate.

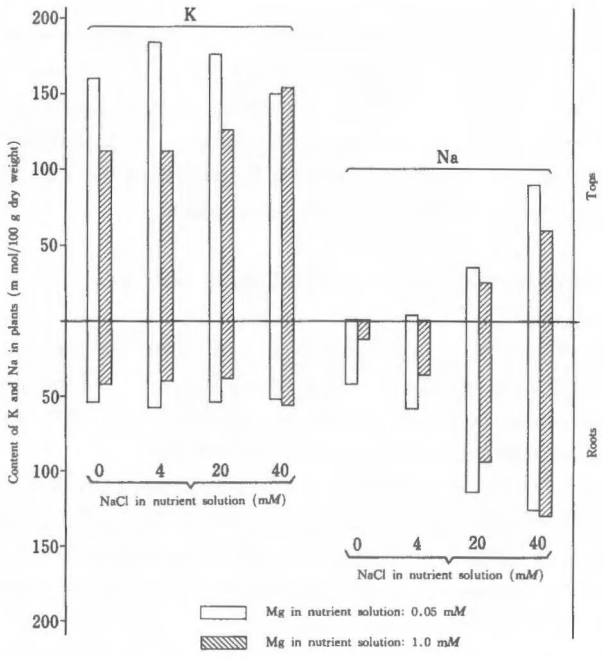

Fig. 8. Effect of different levels of sodium chloride and magnesium sulfate on potassium and sodium contents of maize plants.

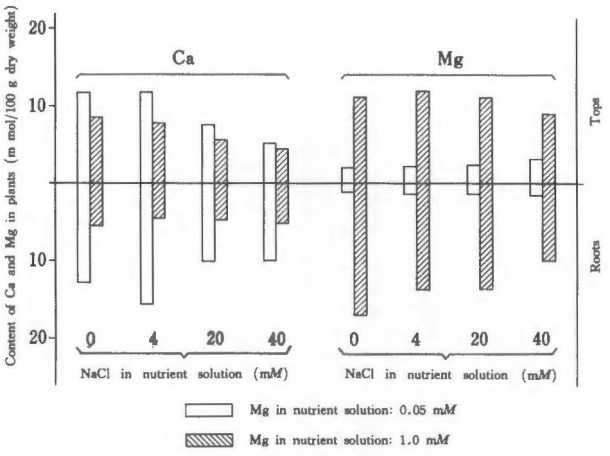

Fig. 9. Effect of different levels of sodium chloride and magnesium sulfate on calcium and magnesium contents of maize plants.

(2) *Bean plants*

Fig. 10 shows that the yields of bean plants decreased with increasing concentrations of sodium chloride. As shown in Fig. 11 and 12, the effect of sodium chloride concentration on potassium, calcium and magnesium contents was not so clear, though the potassium, sodium and calcium contents were lower in 1.0 m*M* than in 0.05 m*M* of magnesium in nutrient solution.

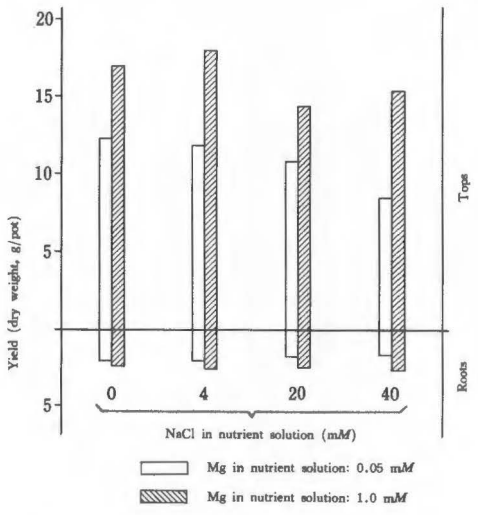

Fig. 10. Yield of bean plants in different levels of sodium chloride and magnesium sulfate.

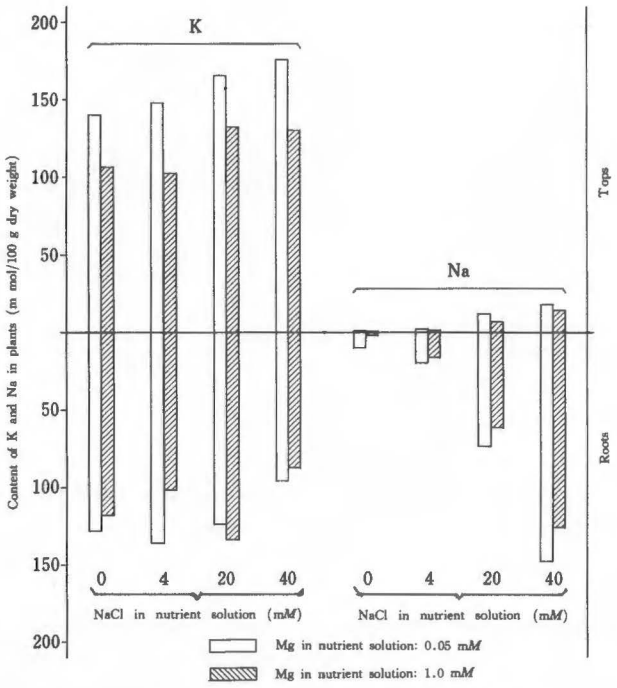

Fig. 11. Effect of different levels of sodium chloride and magnesium sulfate on potassium and sodium contents of bean plants.

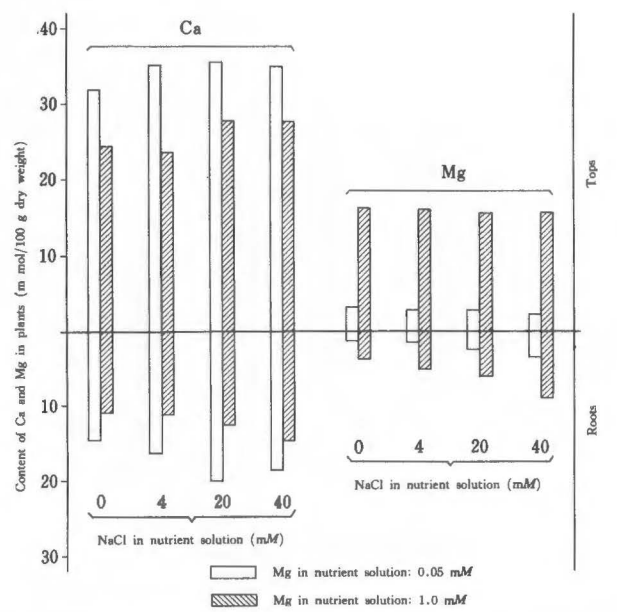

Fig. 12. Effect of different levels of sodium chloride and magnesium sulfate on calcium and magnesium contents of bean plants.

DISCUSSION

A number of workers (2–6, 19) have shown that calcium was closely related to selective ion absorption or permeability of cell membrane. In addition, it was reported that a small amount of calcium caused a drastic depression in sodium absorption by plant roots (3, 20).

The present experiment also showed that when an adequate amount of calcium was supplied, potassium absorption and translocation were accelerated and sodium absorption and translocation were depressed in plants. However, these conclusions need to be reconsidered, because the results were based on potassium and sodium contents in plants which differed in growth with treat-

TABLE 2

Effect of different levels of sodium chloride and calcium chloride on the ratio of potassium to sodium in maize plants

Concentration in nutrient solution (m*M*)		K/Na value	
Na	Ca	Tops	Roots
0	0.1	399.1	56.5
4	0.1	56.4	3.1
20	0.1	6.6	0.70
40	0.1	1.9	0.44
0	1.0	558.8	37.7
4	1.0	132.2	5.0
20	1.0	10.4	1.5
40	1.0	4.1	0.81

TABLE 3

Effect of different levels of sodium chloride and calcium chloride on the ratio of potassium to sodium in bean plants

Concentration in nutrient sodultion (m*M*)		K/Na value	
Na	Ca	Tops	Roots
0	0.1	194.3	102.0
4	0.1	104.6	9.5
20	0.1	28.7	2.0
40	0.1	7.4	0.83
0	1.0	253.7	157.1
4	1.0	107.0	18.0
20	1.0	30.7	2.9
40	1.0	20.7	1.3

ment as can be seen in Plate 1 and 2. Therefore, the ratio of potassium to sodium content (K/Na value) in the same plant was calculated to eliminate the influence of plant growth on mineral balance. The K/Na values of maize and bean plants supplied different levels of sodium chloride and calcium chloride are shown respectively in Table 2 and 3, which were calculated on the basis of Fig. 2 and 5. Furthermore, the K/Na values of maize and bean plants supplied different levels of sodium chloride and magnesium sulfate are shown respectively in Table 4 and 5, which were calculated on the basis of Fig. 8 and 11.

TABLE 4

Effect of different levels of sodium chloride and magnesium sulfate on the ratio of potassium to sodium in maize plants

Concentration in nutrient solution (m*M*)		K/Na value	
Na	Mg	Tops	Roots
0	0.05	121.3	1.3
4	0.05	42.1	1.0
20	0.05	5.0	0.48
40	0.05	1.7	0.42
0	1.0	117.9	3.6
4	1.0	104.6	1.1
20	1.0	4.7	0.41
40	1.0	2.5	0.43

TABLE 5

Effect of different levels of sodium chloride and magnesium sulfate on the ratio of potassium to sodium in bean plants

Concentration in nutrient solution (m*M*)		K/Na value	
Na	Mg	Tops	Roots
0	0.05	105.4	12.9
4	0.05	63.3	6.7
20	0.05	14.7	1.7
40	0.05	10.4	0.65
0	1.0	139.5	60.8
4	1.0	67.3	6.6
20	1.0	20.2	2.2
40	1.0	9.5	0.70

In comparison between data at the same sodium level, the K/Na values were generally larger at the high calcium level (1.0 m*M*) than at the low calcium level (0.1 m*M*) in both tops and roots of plants (Table 2 and 3). These results mean that calcium accelerated the absorption and translocation of potassium and decreased those of sodium. Previous studies (7–11) showed the stimulating effect of calcium on rubidium absorption and the inhibiting effect on sodium absorption with excised plant roots. It is evident that similar mechanisms work in interrelation between potassium and sodium in intact plants. On the other hand, the effect of magnesium on K/Na values was not so clear as that of calcium (Table 4 and 5), though magnesium decreased the sodium absorption and translocation in plants (Fig. 8 and 11).

As shown in Plate 1 and Fig. 1, injury in maize plants, which was caused by high concentrations of sodium chloride, was less severe in the presence of an adequate amount of calcium. Although complicated mechanisms are involved in induction of salt injury in plants, regulation of monovalent cation absorption by calcium may be one reason for decreased salt injury. This calcium effect was more pronounced in maize plants than in bean plants. These results are prncipally in agreement with the reports of LaHaye et al. (21, 22), in which the effect of calcium on salt tolerance was investigated with bean plants.

Some interesting results were evident in figures of calcium and magnesium contents in plants. Generally, it has been considered that the interrelation between calcium and magnesium is competitive in plant tissues. In this experiment, however, a large amount of magnesium accumulated in plant roots, especially in maize, under high calcium supply (1.0 m*M*), though a competitive interrelationship was found between calcium and magnesium in plant tops (Fig. 3 and 6). On the other hand, the interrelationship between calcium content and magnesium supply was only competitive for tops and roots of plants (Fig. 9 and 12). This apparent stimulating effect of calcium on magnesium absorption by plant roots may be an important subject in nutritional study of divalent cations in plants.

SUMMARY

The effect of calcium on salt injury in plants was investigated with special reference to mineral nutrition, especially to the interrelationship between potassium and sodium. Maize and bean plants were cultured for about 3 weeks with nutrient solutions containing different levels of sodium chloride and calcium chloride. Furthermore, the effect of magnesium sulfate was examined and compared with that of calcium chloride.

1) At a low concentration of calcium (0.1 m*M*), plant growth, especially in maize, was depressed with increasing concentrations of sodium chloride in nutrient solution. On the other hand, plant growth at a high concentration of calcium (1.0 m*M*) suffered less damage with high concentrations of sodium chloride.

2) At a high concentration of calcium (1.0 m*M*), plants absorbed and translocated relatively more potassium and less sodium than at a low concentration of calcium (0.1 m*M*).

3) These effects of calcium on absorption and translocation of monovalent cations were more pronounced in maize plants than in bean plants.

4) The effect of magnesium on the absorption and translocation of monovalent cations in plants was not so significant as the effect of calcium.

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