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The Influence of Saline Substrates upon the Absorption of Nutrients by Bean Plants[1]

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SODIUM and calcium salts are the main components of saline accumulations in the irrigable lands of the western states. Soils investigators know that these two cations have very diverse effects upon the physical characteristics of soils. In addition to the differential influence of various salts upon the physical condition of soils and the resultant effect upon plant response, salt accumulations per se in the soil solution have a direct effect upon the growth of plants. In order to better evaluate the specific factors in saline soils contributing to the integrated plant responses, it became expedient to ascertain first of all the responses of the test plant to saline stresses uncomplicated by the more elusive contingencies induced by soil colloids. It is interesting to note in this connection, however, that Collander (1) and others, have observed that in a comparison of plants grown in solution culture and in soil, most of the peculiarities in cation selection were unaltered. When the proportionality of cations in plants grown in soil deviated from that of plants grown in solution, the relative unavailability (assuming no deficiency in the soil) of certain cations was indicated.

Dwarf red kidney bean plants, from the early seedling stage to the time of incipient flowering, were subjected to serial concentrations of added salts in aerated solution culture. The type of solution culture equipment used has been described by Eaton (2). The added salt in

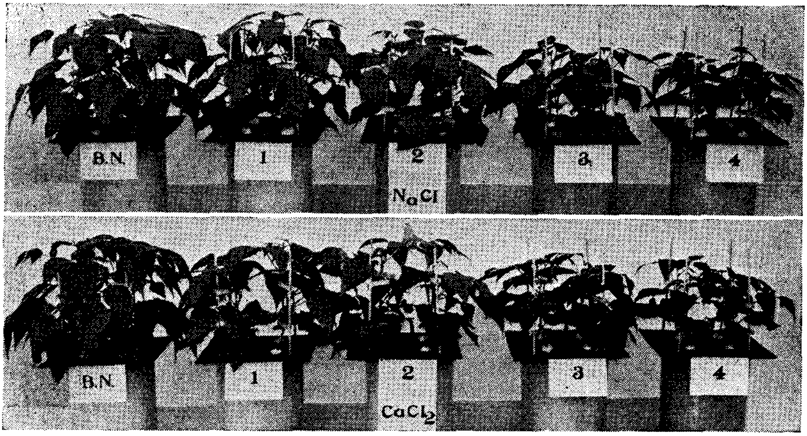

FIG. 1. General appearance of bean plants at time of harvest. (Base nutrient-0.5 atmosphere osmotic concentration ; 1, 2, 3, and 4--atmospheres osmotic concentration of added salt).

[1]Contribution from the United States Regional Salinity Laboratory, Bureau of Plant Industry, United States Department of Agriculture, in cooperation with the eleven western states, and the Territory of Hawaii.

one series was NaCl, and in the other, calcium chloride. In addition to the base nutrient culture (0.5 atmosphere osmotic concentration), there were four salt levels of 1, 2, 3, and 4 atmospheres osmotic concentration of added salt over and above the base nutrient solution. There were four plants per culture, and treatments were thrice-replicated and randomized within the greenhouse. Each culture contained 13 liters of solution which was adjusted to volume daily with distilled water. Frequent additions of small amounts of 1-N HCl were added to the substrate to maintain the pH between 5.5 and 6.5.

During the 32 days of growth (from the start of germination until harvest) no diagnostic leaf or other symptoms appeared in either set of plants. There was, however, a reduction in size of plant in direct relation to intensity of salt concentration (Fig. 1). Average dry weights of the plants are given in Table I. The stems and petioles (B) and

TABLE I-Average Dry Weights of Bean Plants as Influenced by Increments of NaCl and $CaCl_2$ in the Substrate

	Base Nutrient (Gms)	NaCl Series (Gms)				$CaCl_2$ Series (Gms)			
Osmotic Concentration	0.5	1.5	2.5	3.5	4.5	1.5	2.5	3.5	4.5
(A) Leaf blades	3.71	3.24	2.62	2.11	1.52	3.13	2.70	1.85	1.58
(B) Stems + petioles	1.57	1.39	1.20	0.91	0.68	1.35	1.16	0.81	0.66
(C) Tops (A + B)	5.28	4.63	3.82	3.02	2.20	4.48	3.86	2.66	2.24
(D) Roots	1.21	1.13	0.97	0.74	0.58	1.00	0.93	0.60	0.54
Whole plant (C + D)	6.49	5.76	4.79	3.76	2.78	5.48	4.79	3.26	2.78

roots (D) of the NaCl series of plants consistently, though slightly, exceeded in weight those of the $CaCl_2$ series. The actual total dry weight and the reduction in weight of whole plants, however, was very similar in both series. It is readily apparent (Table I) that for both series there is a linear relationship between osmotic concentration of the substrate and reduction in dry weight of the whole plants.

Despite the fact that the general appearance of the plants and the growth reduction by salt increments were so similar in the two series, there were some very significant differences in the concentration, absolute amount, and distribution of Ca, Na, K, Cl, P, and total-N within the plant and, as is discussed in a later paper (6), differences in the proportions of various nitrogen fractions. As is shown in Table II increases in the concentrations of Ca, Na, and Cl in the substrate were associated with increasing concentrations of these respective elements in the plants. With the exception of specific cation effects (Na vs. Ca) on the *relative levels* of P and K within the plants of the two series, increases in concentration of either added salt (NaCI or $CaCl_2$) in the substrate had little consistent effect on the *concentration* of P and K in the plants. However, increases in amount of either added salt in the substrate did result in a serial decrease in the N content.

It was the primary aim of this study to ascertain whether or not the prevalence of excess of Ca vs. Na salt in the growing medium had a

TABLE II-Composition of Bean Plants as Influenced by Increments of NaCl and $CaCl_2$ in the Substrate (Dry Weight Basis)

Treatment	Milliequivalents per Kilo of Dry Matter					
	Ca	Na	K	Cl	PO_4	Total-N
Leaves						
Base nutrient..	1826	21	946	56	833	3700
Base nutrient + 1 NaCl	1850	26	1057	451	828	3510
Base nutrient + 2 NaCl	1911	42	1047	760	780	3310
Base nutrient + 3 NaCl	2017	50	1088	1064	768	3280
Base nutrient + 4 NaCl	1990	52	1037	1302	773	3000
Base nutrient + 1 $CaCl_2$	2630	——	776	638	753	3300
Base nutrient + 2 $CaCl_2$	2091	——	777	1034	702	3260
Base nutrient + 3 $CaCl_2$	3056		738	1305	667	2870
Base nutrient + 4 $CaCl_2$	2996		622	1599	538	2710
Stems						
Base nutrient.	612	64	1708	123	653	2080
Base nutrient + 1 NaCl	605	91	1878	412	651	1935
Base nutrient + 2 NaCl	598	175	1879	545	666	1930
Base nutrient + 3 NaCl	600	229	1732	535	583	1764
Base nutrient + 4 NaCl	722	388	1695	671	592	1671
Base nutrient + 1 $CaCl_2$	1001		1613	466	637	1972
Base nutrient + 2 $CaCl_2$	1130		1573	651	564	1830
Base nutrient + 3 $CaCl_2$	——					
Base nutrient + 4 $CaCl_2$	1362		1419	893	563	1588
Roots						
Base nutrient..	417	85	1625	118	1859	2800
Base nutrient + 1 NaCl	326	555	1350	631	1708	2572
Base nutrient + 2 NaCl	342	1101	1222	872	1722	2495
Base nutrient + 3 NaCl	355	1406	945	893	1620	2318
Base nutrient + 4 NaCl	359	1558	990	949	1868	2350
Base nutrient + 1 $CaCl_2$	783		1479	613	1951	2430
Base nutrient + 2 $CaCl_2$	760		1245	633	1612	2387
Base nutrient + 3 $CaCl_2$	——					
Base nutrient + 4 $CaCl_2$	824		1455	733	1912	2208

differential effect upon the absorptive availability of the primary fertilizer components, N, P, and K, when the amounts of these elements present in the nutrient solution were uniform. In a comparison of absolute amounts of N-P-K absorbed, with but few exceptions, at each respective level of salt there was more N and P in the leaves, stems, and roots of the NaCl series than in the $CaCl_2$ series. There was a very similar distribution of the N and P within the control and NaCl and $CaCl_2$ series of plants. Similarly at each respective level of salt there tended to be a higher total amount of K in the leaves, stems, and roots of the NaCl series than in the $CaCl_2$ series. Also there was a marked difference in the distribution of K within the plants of the two series. With approximately equal percentages of the total K in stems, the leaves of the NaCl series contained 19 per cent more and the roots 29 per cent less of the total amount of K in the plants than did these same plant parts in the $CaCl_2$ plants. These increases in total amounts of N, P, and K absorbed by the NaCl plants as compared with the $CaCl_2$ plants are in agreement with and of interest in connection with the work of Osterhout (4) and that of True and Bartlett (5) which demonstrated an increase of permeability to salts associated with Na and a decrease in permeability with calcium.

These differences in N, P, and K absorption should be further interpreted in the light of the variations in absorption of Ca, Na, and Cl among these series of plants. Although Ca and Cl concentrations in the various portions of the plants were commensurate with the concentrations of these ions in the respective substrate, the percentage of Na in these plants as affected by concentration of Na in the nutrient solution presented a striking contrast to that observed for these two ions. There was practically no Na accumulation in the leaves, small amount in the stems, but a very large amount in the roots as a result of increasing Na concentrations in the substrate. On an absolute basis Na was distributed nearly equally among the leaves, stems, and roots in the control plants, but throughout the NaCl series approximately 74 per cent of the total Na absorbed was in the roots, 18 per cent in the stems, and only 8 per cent in the leaves. Thus on an amount per plant basis there was only 5.5 per cent more Na in the leaves of the plants receiving a one atmosphere addition of NaCl but 526.0 per cent more in the roots of these cultures than in the analogous tissues of the control plants. The question arose concerning the mechanism by which such an ion as Na may be held so exclusively in the roots, but the present study offered no satisfactory explanation. Another striking observation, however, was that the concentration of Ca in the leaves, stems, and roots of the NaCl plants remained nearly uniform throughout the series and equal to that found in the control plants even though the mass action phenomena in the substrate would have tended to inhibit this absorption of calcium. Assuming that Cl per se may accumulate in toxic concentrations in leaves, it is noteworthy that in this experiment with serial increases in the concentration of Cl in the substrate, there were successively increasing proportions of the total Cl in the leaves and decreasing proportions of the total in the stems and roots. Although the proportion of total Cl in the stems was nearly the same in both series, there was a higher percentage of the total in the leaves and a smaller percentage in the roots of the $CaCl_2$ series of plants than in the NaCl series. Inasmuch as a stoichiometrical balance of ions must exist in the plant system the accumulation of Cl, without a corresponding accumulation of Na in the leaves of the NaCl series, must have been equalled by the absorption of some other cation. The trend toward increased basicity of the substrate suggested that primarily hydrogen ions were absorbed to effect this balance. Eaton (3) reported that the pH of the expressed sap is usually lower in high-chloride plants than in the control plants.

SUMMARY

Despite the similarity in appearance of the bean plants grown in serial, high osmotic concentrations of NaCl and $CaCl_2$, there were marked differences in total absorption and distribution of the basic nutrient elements, N-P-K, as well as of Na and calcium. In both series of plants the concentration of Ca greatly predominated over that of Na in the leaves and stems, while in the NaCl series the roots were relatively high in Na and in the $CaCl_2$ series relatively high in calcium. Larger total amounts of N, P, and K were absorbed by the NaCl plants, in which Na predominated in the roots, than by the $CaCl_2$ plants. The inverse effect of Na vs. Ca on permeability of cells to salts is considered a major factor.

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