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COMPETITIVE ADAPTATION OF THE CATION EXCHANGE CAPACITY OF ROOTS

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INTRODUCTION

The differences in the ratio divalent ions/ monovalent ions between plants of one species or between plants of different species, has often been related to the variation in cation-exchange capacity (C.E.C.) of the roots [2, 6, 7, 15, 17, 18]. The explanation of the difference is based on the Donnan principle, which according to the relation *

$$\frac{\text{C.E.C.}_1}{\text{C.E.C.}_2} = \left(\frac{Ca_1}{Ca_2}\right)^2 = \frac{K_2}{K_1}$$

shows that plants with a higher C.E.C. of their roots will absorb relatively more Ca^{++} than K^+ from the same dilute solution. A low C.E.C. of the roots would lead to a relative preferential uptake of K^+.

Although adsorption is only the first step in a sequence of processes leading to accumulation of ions in the plant, the established relationship between C.E.C. and the relative amounts of mono- and divalent ions absorbed by the plant, point to its regulative influence.

Since the plant usually shows a great adaptibility in all its functions, it is to be expected that a characteristic which can govern a certain process would show variations. Indeed, it has already been demonstrated that enhanced nitrogen supply may result in an increase of the C.E.C., while induced metabolic dis-

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* Indices 1 and 2 refer to species (or plants) no. 1 and 2. *Ca* resp. *K* = amount of Ca resp. K ions adsorbed.

turbances may also give rise to differences [3 4 10 13 16 20]. In our own experiments indications of a temperature effect were found.

In the soil the roots must compete with the soil colloids for ions [14]. Hence an experiment was devised to investigate the possibility that the root may counteract the competitive action of the soil colloids by variations in its C.E.C.

METHODS

Seeds of several plant species were germinated on moist filter paper or sand. As soon as more than one root was visible or root branching had started the seedlings were transferred to the experimental vessels.

The experiment was conducted in glass jars of about one litre capacity. These jars contained a vertical partition reaching to about ¾ of the height. On one side of the partition the jar was filled with coarse sand, to which a cation-exchange resin (Amberlite IR 120), previously saturated with a mixture of cations against a Hoagland nutrient solution, had been added. The other side was filled with sand mixed with an anion-exchange resin (Amberlite IRA 400), saturated with an anion mixture by contact with the same nutrient solution. In a few cases the sand was mixed with resin saturated

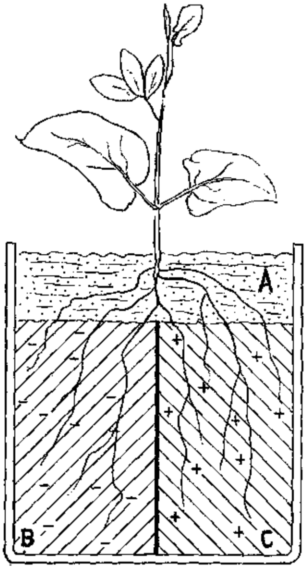

Fig. 1. Diagram of the experiment. A. Toplayer of sand. B. Compartment filled with sand mixed with an anion-loaded exchange resin. C.Compartment filled with sand mixed with a cation-loaded exchange resin.

with a single ion. The mixtures contained ab. 7 ml resin in 100 g dry sand. The top part of the jar was then filled with coarse sand, in which the young seedling was planted (Fig. 1).

After a period of a few weeks growth, when roots were clearly visible in the lower part of the jar, the roots were collected. The toplayer of sand and the upper part of the root system in it was first removed. Then the roots contained in the two compartments could be washed out of the sand–resin mixture separately. According to the amount of roots extracted, samples of one or more split root systems were used for determination of the C.E.C.

The method of determining root C.E.C. somewhat resembled that of Helmy and Elgabaly [9].

About 2 g fresh roots are rinsed in 100 ml HCl (pH 2) for exactly 40 sec. This is repeated a second time in a fresh acid solution. The roots are then rinsed with demineralized water till free from chloride. After this treatment the roots are put into a solution of KCl, 1 *N* and pH 8, for 2 minutes. The KCl solution, which has become acid by exchange against root-H^+, is titrated to a pH of 8.0 with KOH 0.03 *N*. The amount of KOH added is a measure for the amount of liberated H^+, which is itself a measure for the root C.E.C. The C.E.C. is expressed in me per 100 g dry material. As the two parts of one root system are compared it is not necessary to express root C.E.C. on a surface basis, although this method might be preferred when comparing different species [1 19].

RESULTS AND DISCUSSION

A summary of the results obtained in the experiments is given in Table 1. Most of the data are based on duplicate analyses, which generally show only minor variations.

With the exception of the experiments conducted with broad bean, where the large stock of reserves in the seed may have influenced the results, all the plant species tested showed a higher C.E.C. in the medium containing the cations.

A high C.E.C. in the cation-containing medium, where most ions are in the adsorbed state on the resin, would be of advantage for the plant in competing for ions with the resin. In the anion-containing sand–resin mixture a high C.E.C. might on the contrary even be considered as disadvantageous as on account of the Donnan equilibrium entrance of anions into "the apparent free space" might be restricted.

The conclusion can thus be drawn that in the experiments conducted the occurrence of a competitive adaptation of the root C.E.C. in relation to its surroundings has been demonstrated.

The fact that an adaptive variability of root C.E.C. occurs supports the interpretation that the level of root C.E.C. has a regulating influence on the intake of the amounts of monovalent and divalent ions absorbed. This regulating influence may be related to the effect of the Donnan equilibria, but it has also been shown that the root possesses selective adsorptive capacities relating to chemical constituents [2 5 11 12].

TABLE 1

Comparison of the C.E.C. (expressed as me per 100 g dry root weight) of two parts of split root systems of a single plant in two different media

Plant species	Root medium	
	Amberlite + cation mixture	Amberlite + anion mixture
Wheat (*Triticum vulgare*) . . .	2.2	2.0
Bean (*Phaseolus vulgaris*) . . .	7.6	5.4
Pea (*Pisum sativum*)	10.4	8.8
Cress (*Lepidium sativum*) . . .	20.3	16.2
Broad bean (*Vicia faba*). . . .	7.3	10.4
	Amberlite + Ca^{++}	Amberlite + $H_2PO_4^-$
Broad bean (*Vicia faba*). . . .	9.2	9.7
Tomato (*Solanum lycopersicum*)	4.7	4.5
	Amberlite + Mg^{++}	Amberlite + SO_4^{--}
Turnip (*Brassica rapa*)	10.7	10.2

Nevertheless the regulative influence of the root C.E.C. is not the only factor governing ion uptake. In the "active phase" of ion absorption, which is supposed to be performed by "carriers" with an expenditure of energy released in metabolism, indications have been obtained of very specific selectivities for separate ions [8].

The role of root C.E.C. in influencing the relative amount of mono- and divalent ions absorbed may best be understood as governing the ionic composition in the "apparent free space" and thus regulating the supply of ions to the carrier system.

SUMMARY

The capability of root C.E.C. in exerting a regulative influence on the relative amount of mono- and divalent cations absorbed is underlined by demonstrating an adaptivity of this characteristic.

It is shown that root C.E.C. is raised in a medium where it must compete for cations, while it is somewhat lower in a medium where only anions are available. This adaptive variation was demonstrated on the roots of single plants of several species using split root-systems.

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REFERENCES

1 Bell, C. W. and Walker, R. B., Studies of cation exchange capacity on a surface area and a dry weight basis. Plant Physiol. **32** Suppl., XXI–XXII (1957).

2 Blanc-Aicard, D., Études préliminaires sur l'adsorption radiculaire des cations. Ann. Agron. **4**, 615–633 (1955).

3 Blanc, D., Influence de la nutrition azotée sur les propriétés d'échange des racines. Compt. Rend. **246**, 2035–2037 (1958).

4 Cahoon, G. A. and Crummet, D. O., The potassium nutrition of stocks (*Matthiola incana*). Proc. Am. Soc. Hort. Sci. **66**, 364–373 (1955).

5 Deuel, H. und Hutschneker, K., Über die Selektivität von Ionenaustauschern. Potassium Symposium. Ann. Meeting Board Tech. Advisers Intern. Potash Inst. Zürich **1954**, 41–70 (1954).

6 Drake, M., Colby, W. G., and Vengris, J., Cation exchange of plant roots. Soil Sci. **72**, 139–147 (1951).

7 Dunham, C. W., Hammer, C. L. and Asen, S., Cation exchange properties of the roots of some ornamental plant species. Proc. Am. Soc. Hort. Sci. **68**, 556–563 (1956).

8 Epstein, E., Mineral nutrition of plants: mechanisms of uptake and transport. Ann. Rev. Plant Physiol. **7**, 1–24 (1956).

9 Helmy, A. K. and Elgabaly, M. M., Exchange capacity of plant roots. I. Factors affecting the titration value. Plant and Soil **9**, 78–92 (1958).

10 Helmy, A. K. and Elgabaly, M. M., Exchange capacity of plant roots. II. Some factors affecting the cation exchange capacity. Plant and Soil **9**, 93–100 (1958).

11 Keller, P. und Deuel, H., Kationenaustauschkapazität und Pektingehalt von Pflanzenwurzeln. Z. Pflanzenernähr. Düng. u. Bodenk. **79**, 119–132 (1957).

12 Keller, P. und Deuel, H., Kationenaustauschgleichgewichte an abgetöteten Pflanzenwurzeln. Trans. 2nd and 4th Comm. Intern. Soc. Soil Sci. Hamburg **1958**, 164–168 (1958).

13 Macaulay Institute, Ann. Rept. **1956–1957**.

14 Mattson, S., Laws of ionic exchange. III. Donnan equilibria in plant nutrition. Kgl. Lantbruks-Högskol. Ann. **15**, 308–316 (1948).

15 Mc Lean, E. O., Plant growth and uptake of nutrients as influenced by levels of nitrogen. Soil Sci. Soc. Am. Proc. **21**, 219–222 (1957).

16 Mc Lean, E. O., Adams, D., and Franklin Jr., R. E., Cation exchange capacities of plant roots as related to their nitrogen contents. Soil Sci. Soc. Am. Proc. **20**, 345–348 (1956).

17 Smith, R. L. and Wallace, A., Preliminary studies of some physiological root characteristics in citrus and avocado. Proc. Am. Soc. Hort. Sci **63**, 143–146 (1954).

18 Smith, R. L. and Wallace, A., Cation-exchange capacity of roots and its relation to calcium and potassium content of plants. Soil Sci. **81**, 97–109 (1956).

19 Smith, R. L. and Wallace, A., Influence of cation ratio, temperature, and time on adsorption and absorption of calcium and potassium by citrus and other plant species. Soil Sci. **82**, 9–21 (1956).

20 Smith, R. L. and Wallace, A., Influence of nitrogen fertilization, cation concentration, and root cation-exchange capacity on calcium and potassium uptake by plants. Soil Sci. **82**, 165–172 (1956).