On the Absorption of Ions by the Roots of Living Plants.

I. The Absorption of the Ions of Calcium Chloride by Pea and Maize.

BY

GLADYS M. REDFERN, B.Sc.,

University College, Reading.

INTRODUCTION.

NUMEROUS observations are on record which suggest an unequal absorption of the ions of a single salt presented in solution to living plant cells. Thus, the long-recorded observation that water-culture solutions turn acid or alkaline after a time can be explained by supposing that the two ions of a neutral salt are absorbed to different extents, and that the excess of the more absorbed ion is accompanied in its entrance into the plant by an equivalent quantity of hydrogen or hydroxyl ion, according to whether the ion in question is negatively or positively charged, with the result that a corresponding quantity of hydroxyl or hydrogen ion is left in the external solution, which in consequence reacts alkaline or acid. Also Nathansohn (5, 6, 7), Meurer (4) and Ruhland (11), by immersing discs of plant tissue in various salt solutions of known concentration and analysing the solutions after a certain time, have obtained evidence of the unequal absorption of the two ions of the salts employed. The most extensive work on this problem is that of Pantanelli (8, 9, 10), who performed a long series of experiments with representatives of all the large groups of the Plant Kingdom.

He came to the conclusion that the ions of the salts were absorbed in unequal proportions. As a rule the anions were absorbed more rapidly than the kations, but several exceptions were recorded, notably sulphates with Dicotyledons, and chlorides with *Elodea*, where kations were absorbed more rapidly than anions. In the case of the marine algae *Ulva* and *Valonia* more calcium than chloride was absorbed from a solution of calcium chloride. Pantanelli also obtained evidence of a marked periodicity in absorption; at first the plants absorbed the salts rapidly, attaining

a maximum fairly early; this absorption was followed by a definite excretion of ions, and this was succeeded by a period of intake, so that the absorption-curve exhibited a series of maxima and minima. Pantanelli made a number of experiments to determine changes in the acidity or alkalinity of the culture solutions, and the results confirmed his former conclusions.

Johnson (3) observed a slightly unequal absorption of ions in a series of experiments with beet, carrot, and maize (white field corn and sweet corn) in calcium chloride solutions. He found that more calcium was absorbed in proportion by dead tissue than by living tissue in the case of beet, carrot, and sweet corn.

These results cannot be accepted without further confirmation, because neither Pantanelli nor Johnson took account of the magnitude of the biological error arising from individual differences in the plants examined, and they give no indication whether the differences they record are within or without the limits of this error.

How serious this source of error may be is well illustrated by some figures taken from the results of the present investigation.

In one case the absorption of chloride by one member of a group of pea plants was 5.64 per cent., and by another member only 2.878 per cent., while the average for the group was 3.578 per cent., with a probable error of 0.506.

A still more striking case of individual variation is taken from the results of a series of experiments with maize plants in which absorption of calcium by one individual was 5.291 per cent. and by another 30.23 per cent.; the average of the group was 17.53 per cent., with a probable error of 2.7.

Hoagland (2) questions the unequal absorption of ions from salts such as potassium chloride in solution; in his experiment the nutrient solutions remained neutral, or, if acid or alkaline to begin with, they gradually became neutral after contact with plant roots. Analysis of sodium nitrate solutions showed that more nitrate than sodium was absorbed; the bicarbonate was formed, so that the solution did not become alkaline. In the case of potassium chloride solutions the potassium and chloride were absorbed in equal proportions.

In the present research it was considered advisable to limit the investigation in the first place to the absorption of a single salt by plants of one or two species, and to obtain sufficient data to enable the probable error of experiment to be calculated, rather than to attempt experiments with a wide range of salts and species, in which it would be impossible to obtain sufficient data with any one salt or species to indicate the degree of accuracy of the results. The salt selected was calcium chloride, and the species used were the edible pea and maize.

A pure strain of seed of each species was obtained from Messrs. Sutton and Sons.

METHODS.

Seeds were germinated in sawdust watered with tap-water, and when the roots were two or three inches long the seedlings were transferred to a water-culture solution of the following composition (Crone (1)):

KNO ₃	1.0 gm.
Ca(NO ₃) ₂	0.25 gm.
MgSO ₄	0.25 gm.
Fe ₃ (PO ₄) ₂	0.5 gm.
Distilled water up to 1,000 c.c.	

The plants were grown in this solution for about a fortnight in order to obtain healthy, uninjured roots. From these plants a number were selected which possessed, as far as could be judged, an approximately equal root development, and these were transferred to the calcium chloride solutions.

Three concentrations of the salt were employed:

$$\frac{N}{10}, \quad \frac{N}{100}, \quad \text{and} \quad \frac{N}{1000},$$

the solutions being contained in wide-mouthed bottles of 1,200 to 1,300 c.c. capacity, such as are generally used for water-culture experiments. Only one plant was grown in each bottle. The usual precautions necessary for growing plants in water-cultures were taken. After various times a number of plants were withdrawn from the experimental solutions. The following quantities were then determined in the solutions: (1) the concentration of calcium, (2) the concentration of chloride, (3) the electrical conductivity, (4) the hydrogen-ion concentration, (5) the presence of other metallic ions.

The calcium was determined gravimetrically as calcium oxide, and the chloride volumetrically. In the case of the more dilute solutions a large bulk of solution was evaporated down for each determination. As a number of plants were removed from each solution at the same time, it was possible to calculate the probable error of the results. The electrical conductivity was measured in the ordinary way by Kohlrausch's method, and the hydrogen-ion concentration was determined colorimetrically.

EXPERIMENTAL RESULTS.

Series 1. A number of plants of the edible pea were grown in the culture solution indicated in the preceding section, and groups of sixteen plants transferred to each of the three calcium chloride solutions:

$$\frac{N}{10}, \quad \frac{N}{100}, \quad \frac{N}{1000}.$$

Four plants from each group were removed from the culture solutions after a lapse of 36 hours, another four from each group after 60 hours, and the remaining four of each group after 84 hours. The mean percentage absorption of calcium and chloride in each case is set out in the two following tables along with the probable error of the mean, though, owing to the small number of plants used, the errors can claim no high degree of accuracy.

TABLE I.

Percentage absorption of calcium by roots of edible pea from various strengths of calcium chloride solutions.

Concentration.	36 hours.	Percentage absorption after 60 hours.	84 hours.
$\frac{N}{10}$	17.74 ± 1.376	12.77 ± 1.84	14.61 ± 1.68
$\frac{N}{100}$	19.61 ± 2.33	8.244 ± 1.471	—
$\frac{N}{1000}$	23.10 ± 5.30	—	—

TABLE II.

Percentage absorption of chloride by roots of edible pea from solutions of calcium chloride of various strengths.

Concentration.	36 hours.	Percentage absorption after 60 hours.	84 hours.
$\frac{N}{10}$	3.578 ± 0.506	4.021 ± 0.073	3.856 ± 0.351
$\frac{N}{100}$	12.47 ± 1.66	10.66 ± 0.856	12.47 ± 1.16
$\frac{N}{1000}$	15.09 ± 3.736	—	—

In the case of solutions of $\frac{N}{1000}$ concentration, the results became very irregular after the first day, and the analyses were not continued. With a concentration of $\frac{N}{100}$ the results of the calcium analyses were irregular after the second day, so that no average for the absorption of calcium could be calculated for the third day. On the fourth day there was no uniformity in the results obtained from any of the analyses, so no averages were calculated.

The mean electrical conductivity of the solutions for each day is given in Table III.

TABLE III.

Relative electrical conductivity of solutions of calcium chloride in which peas had been growing for different lengths of time.

Concentration.	Relative electrical conductivity after		
	36 hours.	60 hours.	84 hours.
$\frac{N}{10}$	0.05225	0.053	0.0524
$\frac{N}{100}$	0.00669	0.00716	0.00722
$\frac{N}{1000}$	0.000707	0.000745	—

Series 2. A second series of experiments with peas confirmed the unequal absorption of ions from the solutions, by the roots of those plants, which was shown by the results of the first series.

From these experiments it is clear that a concentration of calcium chloride approximately $\frac{N}{10}$ is the most satisfactory for experimental purposes, as the results with this concentration throughout were more uniform than those obtained with the more dilute solutions; further, toxic effects were apparently postponed until the plant had been growing in the solution for three or four days, whereas, with the more dilute solutions, the harmful effects, indicated by the irregularity of the results, appeared before sixty hours had elapsed after the cultures were started.

Accordingly, in later experiments the plants were all grown in calcium chloride solutions of approximately $\frac{N}{10}$ concentration.

Series 3. Maize plants which had been growing in tap-water for about a fortnight were used for these experiments; the plants were divided into three sets, each set consisting of six plants, and the plants were removed after they had been growing in the experimental solutions for 23, 48, and 57 hours respectively. A large percentage absorption was obtained in every case; approximately the same amount of chloride was absorbed by each set, so that equilibrium is evidently reached very quickly; in the case of calcium, equilibrium is reached before 48 hours have elapsed. The results are given in Table IV.

TABLE IV.

Percentage absorption of calcium and chloride by roots of Zea Mais from

$\frac{N}{10}$ *solutions of calcium chloride.*

Duration of experiment.	Percentage absorption of calcium.	Percentage absorption of chloride.
23 hours	17.53 ± 2.7	6.512 ± 0.1227
48 hours	25.28 ± 1.04	6.54 ± 0.2202
57 hours	26.98 ± 2.2	5.875 ± 0.2597

The hydrogen-ion concentration was determined by the colorimetric method for all solutions in which plants of *Zea Mais* had been growing. With two exceptions, the P_H of the solutions remained 7.3, the same as that of the original solution; in the two exceptional cases the solutions were slightly more alkaline, having a P_H of approximately 8.0.

The fact that the solutions remained approximately neutral, in spite of the more rapid absorption of calcium than chloride, suggested that other metallic ions might have diffused out from the roots, to replace the calcium. Accordingly, qualitative tests were made, and it was found that potassium and magnesium were present in appreciable quantity in the external solutions. The replacement of part of the excess of calcium ions absorbed, by the much more mobile potassium ions, might be sufficient to account for the slight increase in electrical conductivity of the external solution recorded in Table III.

DISCUSSION.

(a) *Unequal absorption of ions.* The results given above show that the two ions of calcium chloride are absorbed at different rates by the roots of young plants of pea and maize. The percentage absorption of calcium is considerably in excess of the percentage absorption of chloride throughout the experiments. Thus the conclusion reached by Pantanelli, as regards the unequal absorption of ions, is confirmed by these results. It is noteworthy that the kation is absorbed more rapidly than the anion throughout the experiments. Pantanelli's results show a higher absorption of the anion, except in the case of sulphates, and in experiments with *Elodea*; the latter absorbed kations more rapidly than anions when chlorides were used. Pantanelli, however, did not use peas, though he used closely related species in his experiments (*Phaseolus multiflorus*, *Vicia faba*, *Lupinus albus*).

The difference in the rate of absorption of the two ions is very much lessened in more dilute solutions, and when the concentration is as low as $\frac{N}{1000}$ this difference is hardly outside the range of experimental error. In this case the results fall into line with those obtained by Hoagland (2).

The results of the experiments on the hydrogen-ion concentration of the solutions in which maize plants had been grown show that the P_H remains approximately the same as that of the original solution ($P_H = 7.3$) in spite of the more rapid absorption of calcium than chloride. Hence the excess of calcium absorbed is not accompanied by hydroxyl ions in its entrance into the roots. Further experiments show that potassium and magnesium diffused out from the roots, and presumably they take the place, in the external solution, of the excess of calcium absorbed.

(b) *Course of absorption.* The results obtained in these experiments seem, at first sight, to indicate a slight periodicity in absorption, as described

by Pantanelli; consideration of the probable error in the present case, however, shows that no real significance can be attached to the differences. The average percentage absorption for each day is approximately equal in the case of peas, having regard to the magnitude of the probable error. In the case of maize there is a distinct rise in the percentage absorption of calcium on the second day. This indicates that equilibrium is reached quickly, probably during the first twenty-four hours that the plant is growing in the experimental solutions, with peas, but rather later with maize.

The fall in absorption at the end of the experiment is probably due to the toxic effect resulting from the presence of an unbalanced solution external to the roots.

It is hoped to extend these observations to other species and solutions and also to mixed solutions.

This research was undertaken at the suggestion, and under the direction, of Professor Stiles, and was financed by a grant from the Department of Scientific and Industrial Research.

SUMMARY.

1. Further evidence has been obtained in support of the unequal absorption of the ions of a salt by the roots of growing plants.

2. The difference in the rate of absorption of the ions was greatly reduced in less concentrated solutions; in very dilute solutions, which alone affect the plant under normal conditions, it was almost nil.

3. No evidence in support of periodicity in absorption was obtained.

4. Equilibrium in the intake of this single salt, by roots of living plants, is reached within the first twenty-four hours of exposure to the salt solution in the case of peas, and within the first forty-eight hours with maize.

5. Potassium and magnesium diffuse out from the roots to replace the excess of calcium absorbed, which explains how it is that the hydrogen-ion concentration of the solutions remained approximately the same.

LITERATURE CITED.

1. CRONE, G. V. D.: Ergebnisse von Untersuch. über d. Wirkung der Phosphorsäure auf d. höhere Pflanze. Diss., Bonn, 1904.
2. HOAGLAND, D. R.: The Relation of the Plant to the Reaction of the Nutrient Solution. Science, xlviii. 422-5, 1918.
3. JOHNSON, H. V.: The Absorption of Ions by Living and Dead Roots. Amer. Jour. Bot., ii. 250-4, 1915.
4. MEURER, R.: Über die regulatorische Aufnahme anorganischer Stoffe durch die Wurzeln von *Beta vulgaris* und *Daucus Carota*. Jahrb. wiss. Bot., xlvii. 503-67, 1909.

5. NATHANSOHN, A.: Ueber die Regulationserscheinung im Stoffaustausch. Jahrb. wiss. Bot., xxxviii. 249-290, 1903.
6. ———: Ueber die Regulation der Aufnahme anorganischer Salze durch die Knollen von *Dahlia*. Jahrb. wiss. Bot., xxxix. 607-44, 1904.
7. ———: Weitere Mitteilungen über die Regulation der Stoffaufnahme. Jahrb. wiss. Bot., xl. 403-42, 1904.
8. PANTANELLI, E.: Über Ionenaufnahme. Jahrb. wiss. Bot., lvi (Pfeffer-Festschrift), 689-733, 1915.
9. ———: Assorbimento elettivo di ion nelle piante. Bull. Orto Bot., R. Univ. Napoli, v. 1-54, 1915.
10. ———: Decorso dell' assorbimento di ioni nelle piante. Bull. Orto Bot., R. Univ. Napoli, vi. 1-37, 1918.
11. RUHLAND, W.: Zur Frage der Ionenpermeabilität. Zeitschr. f. Bot., i. 747-62, 1909.

Redfern, Gladys M. 1922. "On the absorption of ions by the roots of living plants I. The absorption of the ions of calcium chloride by pea and maize." *Annals of botany* 36, 167–174.

<https://doi.org/10.1093/oxfordjournals.aob.a089791>.

View This Item Online: <https://www.biodiversitylibrary.org/item/234428>

DOI: <https://doi.org/10.1093/oxfordjournals.aob.a089791>

Permalink: <https://www.biodiversitylibrary.org/partpdf/319034>

Holding Institution

Smithsonian Libraries

Sponsored by

Biodiversity Heritage Library

Copyright & Reuse

Copyright Status: Not in copyright. The BHL knows of no copyright restrictions on this item.

This document was created from content at the **Biodiversity Heritage Library**, the world's largest open access digital library for biodiversity literature and archives. Visit BHL at <https://www.biodiversitylibrary.org>.