Velocity of nutrient uptake by excised roots as governed by the soil solution

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Introduction

To obtain maximum growth or yield of plants under a given set of conditions, nutrients must be available for intake with a certain rate of speed. A large stock of nutrients in the soil may be of little use if the availability does not meet the demand according to the possible rate of uptake. One of the important factors influencing availability is the amount of soil solution as it carries the dissolved ions and also regulates the ease of diffusion through the soil.

The exact relationship between moisture content of the soil and rate of ion-uptake is difficult to establish when intact plants are involved. Only recently have experiments been carried out, which eliminate some major complications (1, 2, 3). In general increase of moisture content seems to enhance the rate of uptake, although exceptions have been noticed. So a further study of this problem has been made, using excised roots in order to simplify the technique and interpretation of the results.

The results obtained also have some bearing on the problem whether the plant derives its nutrients from the soil solution only or also takes in adsorbed ions by "contact exchange".

Experimental method

Use was made of 3 cm long root pieces, usually cut from young primary laterals of Vicia faba pre-cultured in tap water. In each single experiment a batch of root-pieces (20—30) was put in sand or soil to which a certain amount of salt, including radio-active tracer, had been added and a varying amount of water. In this way the influence of water stress on growth of the plant is eliminated, interaction with the shoot also and water uptake is so small as to be negligible.

The uptake under favorable conditions could equal that from an aerated nutrient solution. Experiments lasted 18—24 hours while the root-pieces could stay alive for 3—4 days.

At the end of the experiment the roots were extracted and washed with tap-water. Analyses were usually carried out on the solutions obtained after wet ashing. Radio-activity measurements were carried out with an end-window Geiger counter.

Root behaviour in many experiments was compared with the ion-adsorption on small sheets of ion-exchange resin, so as to compare the living system with a physical one.

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Results of experiments

First the basic relationship between rate of uptake and moisture content had to be established. Experiments were first performed in sand to eliminate complicating factors, later soils were investigated also. In each case a fixed amount of nutrient was added to each lot of 100 g dry soil and a varying amount of water was added. The relationships obtained for a number of nutrient ion are summarised in fig. 1.

All these experiments clearly demonstrate that uptake increases as the amount of moisture in the soil rises.

The relationship established above, however, does not always hold. In experiments where varying amounts of added nutrient were tested it was found that at higher concentrations in the soil solution no increase in uptake at higher water content is found. These results are graphically expressed in fig. 2. A number of observations even show a definite decrease in uptake as moisture content is raised.

It has been possible to establish a critical level of added nutrients at which the basic relationship changes into a more or less reverse one. A few data are given in table 1. It seems that for the fine quartz sand, the most pure and inert substance used, the critical values are in the following range: P $<$ 6 mg, Rb $\pm$ 4 mg, Ca $<$ 20 mg, and Fe $>$ 2 mg.

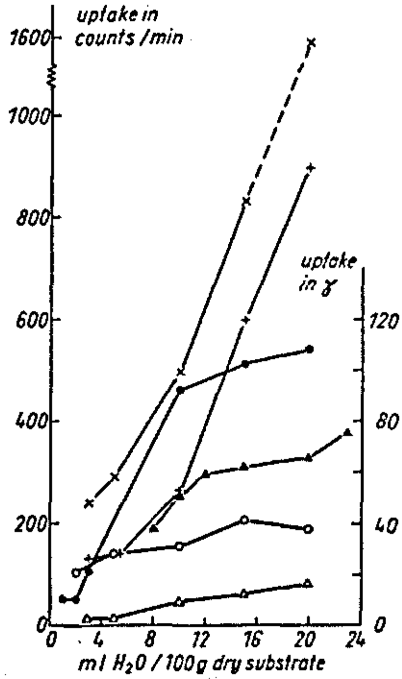
This critical level is reached when the rate of supply is in equilibrium with the rate of uptake throughout the range of moisture content. This occurs when the amount of nutrient in the immediate vicinity of the root is sufficient to meet the demand. Estimating the immediate vicinity to consist of a mantle 300 μ thick around the root, calculation shows that for a batch of 25 rootpieces about 1% of the total substrate volume is involved. It was indeed found that P uptake from sand + 6 mg P could amount to 64 γ ($\pm$ 1%) and Fe uptake from sand + 2 mg Fe could be 16 γ ($\pm$ 1%). This is indeed the amount contained in the immediate vicinity of the root.

In experiments with 12 cm^2 sheets of ion-exchange resin in no case the critical level was reached as the adsorptive capacity is very high in relation to their surface.

Table 1

Establishment of a critical amount of added nutrient at which the relationship uptake-moisture changes

substrate	moisture content	uptake from substrate + added nutrient			
		Tracer only	T + 3 mg Rb	T + 17 mg Rb	
acid washed	2 ml	206	424	597	
coarse sand	15 ml	692	811	595	
		T+30 mg P	T+35 mg P	T+40 mg P	T+45 mg P
sandy	3 ml	875	1020	1240	1360
subsoil	18 ml	1015	1060	1240	1210



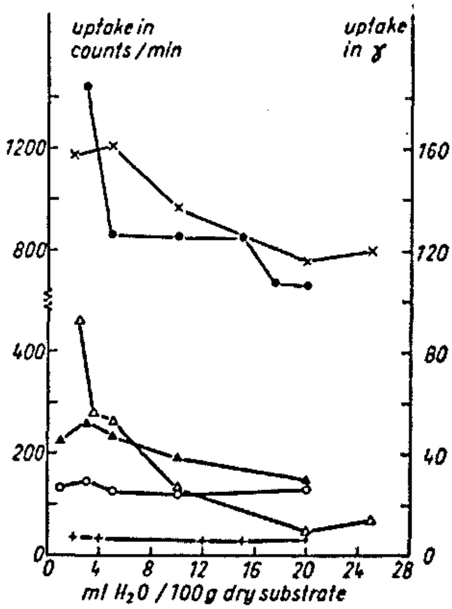


fig. 1 (on the left). The basic relationship between rate of uptake of ions and moisture content of the substrate.

- ● uptake in γP^{31}, 100 g coarse sand + 7 mg P^{31} + 7 μC P^{32}, Pisum roots
- ○ uptake in counts/min., 100 g coarse sand + 7 mg P^{31} + 7 μC P^{32}, young radish seedlings
- + uptake in counts/min., 100 g acid washed coarse sand + 4 μC P^{32}, Vicia roots
- × uptake in counts/min., 100 g acid washed coarse sand + 1,7 μC Rb^{86}, Vicia roots
- △ uptake in γ Fe, fine quartz sand + 2 mg Fe ($FeCl_3$), Vicia roots
- ▲ uptake in γ N, loam soil + 15 mg N (NO_3), Vicia roots

fig. 2 (on the right). Uptake as related to moisture content of the substrate at high nutrient concentration in the soil solution.

- ● N uptake in γ, bean roots, 10 mg N in acid washed coarse sand
- ○ Rb uptake in counts/min., bean roots, 3 mg K in untreated coarse sand
- × Rb uptake in counts/min., bean roots, 17 Rb in fine quartz sand
- + P uptake in counts/min., bean roots, 40 mg P in sandy subsoil
- △ P uptake in γ, pea roots, 6 mg P in fine quartz sand
- ▲ Ca uptake in counts/min., pea roots, 6 mg Ca in untreated coarse sand

Table 2

Amount of salt added to different substrates to attain the critical level

nutrient	quartz sand	untreated coarse sand contains Ca, K, Fe	sandy subsoil	loam
NO_3	1 mg N	—	—	25 mg N
H_2PO_4	6 mg P	60 mg P	40 mg P	—
Rb	4 mg Rb	3 mg K	—	—

Discussion:

As has already been mentioned in a preliminary paper (4) the basic relationship between soil moisture content and rate of uptake is governed by the ease of diffusion towards the root. At the critical level a thin mantle of moist substrate around the roots contains a sufficient supply, so that diffusion over greater distances is of no importance.

The exact pF of the soil is of less importance int his respect than the volume of pore space filled with water, as this forms the pathway for diffusion.

It was found that quite different amounts of salts must be added to varying substrates before the critical level is attained. Some data are given in table 2.

The conclusion drawn from the latter fact is that part of the added nutrient does not remain dissolved in the soil solution and is chemically or physically bound in some way or the other.

All these results, especially the different critical levels for various soils, show that the content of soluble ions in the soli solution is dominatino the rate of uptake.

References:

(1) *Dean, L. A.*, and *Gledhill, V. H.:* Soil Science 82, 71–81 (1956). — (2) *Danielson, R. E.*, and *Russell, M. B.:* Soil Sci. Soc. Amer. Proc. 21, 3–7 (1957). — (3) *Mederski, H. J.*, and *Wilson, J. H.:* Agron. Abstr. Nov. 18–22, 5 (1957). — (4) *Wiersum, L. K.:* Nature 181, 106–107 (1958).

Summary

The relationship between soil moisture content and rate of ion-uptake for excised root pieces was investigated in short term experiments. At low nutrient concentration in the soil solution uptake increases with a rise in moisture content, as uptake depends on ease of diffusion towards the root surface over greater distances. Above a certain critical level, at which enough solved nutrient is available in the immediate vicintiy around the root, the relationship is lost and sometimes changes into a more or less reverse one.

Depending on the substrate, sand or soil used, a different amount of

salt has to be added to attain the critical level on account of chemical or physical binding of the ions.

These results demonstrate that the rate of uptake is governed by the amount of ions solved in the soil solution and ease of diffusion therein.

Résumé:

Dans des essais de courte durée la relation entre la teneur en eau du sol et la vitesse d'absorption des ions dans des bouts de racines découpés fut étudiée. Lorsque les solutions du sol ne contiennent que peu d'ions, l'absorption accroit avec une teneur d'eau croissant, parceque l'absorption dépend de la diffisibilité des ions sur des grandes distances. Au-dessus d'un niveau critique, lorsqu'il se trouve suffisamment d'élements nutritifs en solution dans l'entourage directe de la racine, cette relation disparait et change parfois en une faible relation inverse.

Pour atteindre ce niveau critique les substrats utilisés, sables ou autres sols, doivent être pourvus de quantités de sels minéraux différentes, parceque une partie des ions est fixée physiquement ou chimiquement.

Les résultats donnés montrent que la vitesse d'absorption est régularisé par la quantité d'ions se trouvant dans la solution du sol et par leur diffisibilté.

Zusammenfassung:

Der Zusammenhang zwischen Wassergehalt des Bodens und Aufnahmegeschwindigkeit der Ionen isolierter Wurzelabschnitte wurde untersucht in kurz dauernden Versuchen. Wenn die Bodenlösung nur wenige Ionen enthält, steigt die Aufnahme mit zunehmendem Wassergehalt, weil die Absorption abhängig ist von der Ionendiffusibilität über größere Entfernung. Oberhalb eines kritischen Niveaus, in dem sich genügend gelöster Nährstoff in der direkten Umgebung der Wurzel befindet, verschwindet diese Abhängigkeit und verändert bisweilen in ein schwach umgekehrtes.

Um das kritische Niveau zu erreichen, müssen den benutzten Substraten, Sand oder Boden, sehr verschiedene Salzmengen hinzugefügt werden, weil ein Teil der Ionen chemisch oder physikalisch gebunden wird.

Diese Resultate zeigen, daß die Aufnahmegeschwindigkeit reguliert wird durch die Menge der sich in der Bodenlösung befindenden Ionen und deren Diffusibilität.