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POTASSIUM DEPLETION OF THE SOIL-ROOT INTERFACE IN RELATION TO SOIL PARAMETERS AND ROOT PROPERTIES

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ABSTRACT

Potassium depletion in the vicinity of plant roots was studied by quantitative autoradiography and thin slicing rhizospheric soil. Steep gradients of the K concentration were found in a radius of about 3 mm around young maize and rape roots. Both the degree of depletion and the spatial extent of the depletion zone depended on soil texture and K level. Within a few days the quantity of K released per unit of rhizospheric soil exceeded exchangeable K by a factor of two. Soil solution of different soils was depleted to about 2 µmoles K/l.
In order to simulate the K depletion by roots, soil samples were repeatedly extracted with soil solution devoid of K. In this way equilibrium concentration was also reduced to 2 µmoles K/l and large quantities of nonexchangeable K released from the soil.
With 5 plant species, the rate of K uptake per unit root differed markedly in relation to the length of root hairs. K concentration of the shoot of 3 species was closely correlated with the product of (a) rate of K uptake per cm root (b) root/shoot ratio and (c) mean root age.

INTRODUCTION

Availability of soil potassium is influenced by both soil and plant factors. Since K concentration of the soil solution is low, K transport from the soil to the plant root proceeds mainly by diffusion (Barber 1962). Diffusion depends on concentration gradients. The degree of K depletion at the root surface should therefore be important for the movement of K to the roots. In addition, depletion of the soil solution will enhance the release of K from nonexchangeable sources. Of the plant factors in this regard root/shoot ratio will be important. Other morphological properties of roots, however, will also affect K supply of plants as for example the formation of root hairs. The aim of the work presented here is to provide quantitative information on the K depletion of soil in the vicinity of roots with particular reference to the influence of the factors mentioned above.

MATERIALS AND METHODS

K distribution around roots was determined by two different methods: (1) Quantitative autoradiography as described by Claassen et al. (1981) after the soil K was labelled with ^{43}K.

Film density of the autoradiographs were measured by a microscope photometer. K concentration profiles were determined in combination with desorption studies. (2) Plants were grown in small containers in which roots were separated from soil by a nylon screen as outlined by Kuchenbuch and Jungk (1982). The soil adjacent to the roots was then sliced into layers 0.1 mm thick which were individually analysed and the results plotted as a function of distance from the root. It is thus possible to combine the determination of the K distribution near roots with a balance sheet of the quantity of K measured as (a) lost from the soil and (b) taken up by the plant.
Length of roots were estimated according to Newman (1966) and root hairs as published by Hendriks et al. (1981). Soil solution concentration was determined in the displaced solution (Adams, 1974). The reciprocal of the relative growth constant was taken as mean root age.

RESULTS AND DISCUSSION

Depletion profiles of two soils obtained by autoradiography are shown in fig. 1. The profile of the quantity of K released from the soil is similar to phosphate depletion profiles of Bhat and Nye (1967). The zone of maximum depletion is about the average length of root hairs (0.7 mm) of the maize plants used. Degree of depletion was related to exchangeable K which is indicated by arrows in fig. 1. However, the quantity of K released from the soil near the root surface was about twice the exchangeable amount present before depletion, showing that plants can use considerable percentages of nonexchangeable K. This effect, however, is restricted to the close vicinity of roots.

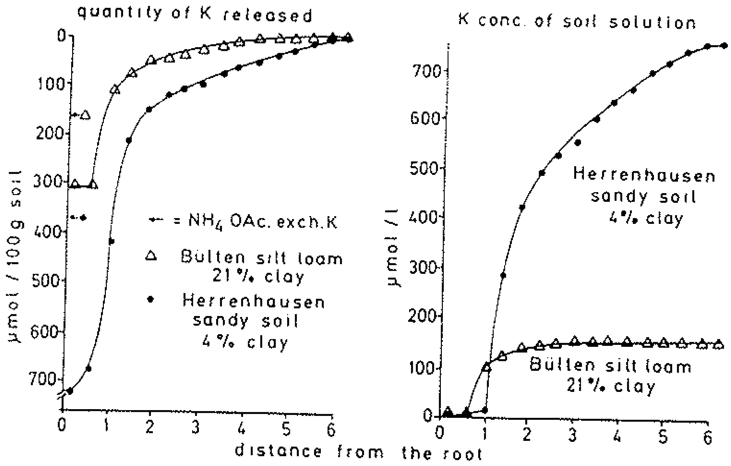

Fig. 1 Depletion of ^{43}K labelled potassium in the vicinity of maize roots 2.5 days old in a sandy and a silt loam soil. Arrows indicate exchangeable K before depletion.

At the beginning of the experiment soil solution concentration in the sandy soil was much higher than in the silt loam. However, after 2.5 days this was reduced to about 2 µmoles K/l at the root surface in both soils. This indicates that the plant quickly depletes its surrounding K to a certain minimum concentration which in turn enhances diffusion by creating the maximum possible concentration gradient as well as the release of K from nonexchangeable sources.

In order to simulate K depletion of the soil by plant roots ^{43}K labelled Bülten silt loam was repeatedly extracted with a solution equal to soil solution but devoid of K. As seen from fig. 2, K concentration of the equilibrium solution decreased with the number of extractions. The value leveled off between 2 and 3 µmoles K/l, the same concentration as found in the soil solution near roots (fig.1). It appears therefore that this value depends more on the soil than on the plant root and agrees with results of Scott and Smith (1966). Woodhouse et al. (1978) have found this K concentration adequate to meet plant needs.

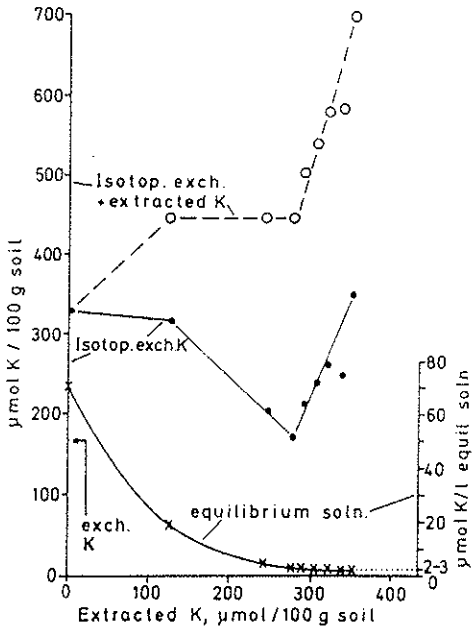

Fig. 2
Isotopically exchangeable K, K concentration of the equilibrium solution and th sum of isotopically exch. plus extracted K respectively in relation to the quantity of K determined by repeated extraction with soil solution devoid of K. Bülten silt loam (21 % clay).

Isotopically exchangeable K, which was considerably higher than NH_4OAc-exchangeable K (166 µmol/100 g), decreased with the first 4 extractions, but less than the extracted amounts. This finding indicates a release from nonexchangeable into exchangeable form. The decrease was obviously drastically enhanced after the fourth extraction when the equilibrium concentration came down to between 2 and 3 µmolar K. The quantity of K that can be regarded available is the sum of isotipically exchangeable plus extracted K. After 9 extractions, it amounted to 700 µmoles/100 g soil, 4 times the exchangeable K as determined by the conventional NH_4OAc method in the untreated soil.

The results obtained with maize were confirmed with rape plants by thin slicing and subsequent analysis of rhizospheric soil (fig.3).Hot HCl showed a stronger depletion of the soil than NH_4OAc solution, underlining the previous finding, that nonexchangeable K is released from the soil in a radius of root hair length, which is 1.3 mm for rape. It is therefore concluded that plants can mobilize large quantities of the soil K reserve by reducing the soil solution K concentration in the soil about 1 mm distant from the root.

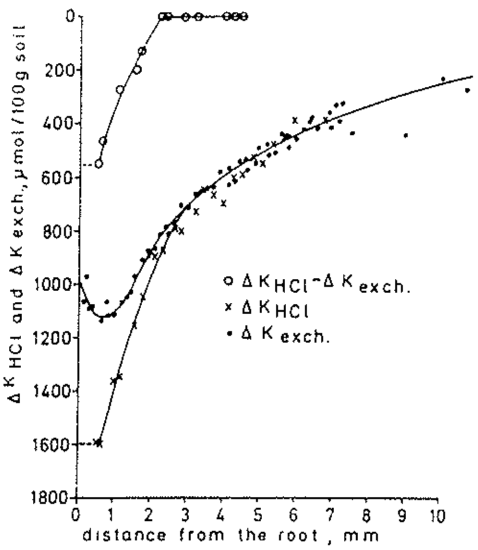

Fig. 3
K depletion of Söderhof silt loam (12 % clay) in the vicinity of rape root systems 7 days old. Data were obtained by thin slicing and extraction of the soil with 1 M NH_4OAc or hot (50°) HCl solution

The effect of different K supply on the depletion profile can be seen from fig. 4. The concentration gradient as well as the distance of depletion increased with the level of K.It was calculated from the depletion profiles that the plant could take up 125, 375 and 1500 kg K/ha from the depleted, the unfertilized and the fertilized soil respectively. The assumptions made in this calculation were as follows: cylindrical conditions for individual roots, a root density of 4 cm/cm³ (allowing for a distance of depletion of 3 mm from the root surface), and 3 million kg of soil. The quantity of K available to the root is thus increased much more by the addition of K than the level of exchangeable soil K. This picture is even more accentuated by nonexchangeable K which was not taken into account in the above calculation.

Of the plant factors it can be assumed that root/shoot ratio as well as uptake rate per unit of root may be of major influence on K supply of the shoot. Time of contact between a root and soil or mean root age may also have such an effect. These three factors varied considerably between plant species. However, no close correlation was found between one of these

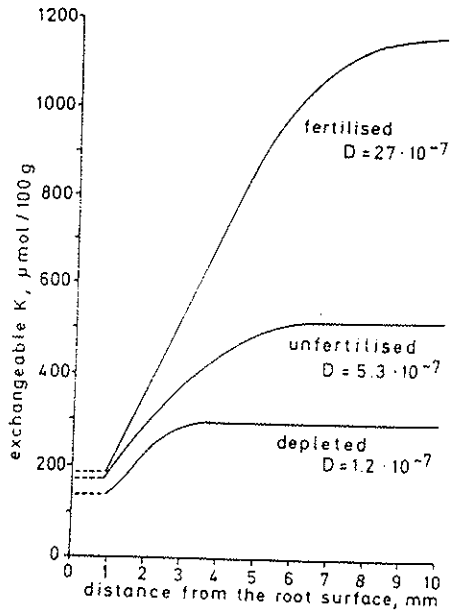

Fig.4
K depletion profiles of Söderhof silt loam at different levels of exchangeable K. The depleted soil was precropped by maize in a pot culture, the fertilizer supplied with 1 mmol K/100 g. D = diffusion coeff. (cm^2/sec)

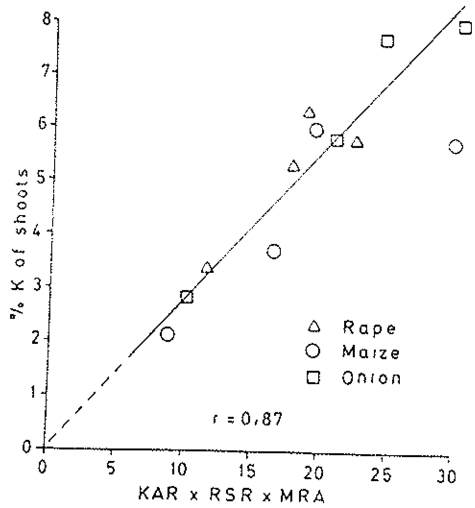

Fig. 5
K concentration of rape, maize and onion shoots in relation to the product of K uptake rate per cm root (KAR), root/shoot ratio (RSR) and mean root age (MRA)

factors and K concentration of the shoot. K concentration of the shoot is regarded to be an indicator of the availability of soil K provided K supply is short. The product of the three factors however was highly correlated to shoot K content in case of 3 species grown in Bülten silt loam at 4 levels of K (fig.5).

In the view of this work, rate of K uptake per cm root is of major interest and especially the reasons for differences. From the result presented it is clear that the distance of transport from soil to root is limited. The length of root hairs will therefore be important for the spatial access of the roots to soil nutrients of low mobility. Using a soil limited in K supply it appears indeed (fig. 6) that there is a positive relation between K uptake rate per cm of root and the volume of the root hair cylinder, which was calculated from average root hair length.

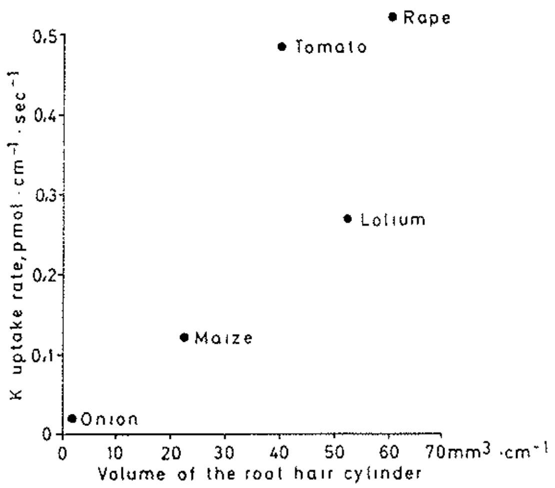

Fig. 6.
Rate of K uptake per cm root of different plant species grown in Bülten silt loam (21 % clay) in relation to the volume of the root hair cylinder.

The results of this work support the general conclusion that the availability of soil potassium depends on a number of both soil and plant factors as well as on interaction between them.

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