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ROOT POSITION EFFECTIVITY RATIO, R_{per}, A SIMPLE MEASURE OF THE EFFECTS OF NON-HOMOGENEOUS ROOT DISTRIBUTION ON UPTAKE OF HOMOGENEOUS RESOURCES

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SUMMARY: The root position effectivity ratio is introduced as a single parameter to relate realistic, irregular root distributions with incomplete root soil contact, to the geometry used in uptake models.

INTRODUCTION: Root distribution in soils is usually non-homogeneous and root-soil contact may be incomplete, but most models of uptake of water and nutrients assume a regular distribution and complete root-soil contact. The irregular distribution of roots found in arable soils (DE WILLIGEN and VAN NOORDWIJK, 1987a) and the incomplete contact between root and soil (KOOISTRA *et al.*, 1992) both reduce the effectivity of the root system for uptake of homogeneous resources. An increase in root length density may, however, overcome these problems. The reduced effectivity can now be expressed in a single parameter, the positional effectivity ratio, or R_{per}. The required increase in root length density is $1/R_{per}$.

DE WILLIGEN and VAN NOORDWIJK (1987b) found that a simple G-function determined by root length density and root radius (see below) describes the geometrical aspects of diffusive transport to a single root located in the centre of a soil cylinder. The amount of a nutrient left in the soil at the moment that its uptake requirement can only just be met is proportional to this G-function. Uptake rate in a period when nutrient supply is limiting is also proportional to this G-function. The first step in the derivation of R_{per} is to find an approximation for this G-function for non-regular root distributions. Next, the root length density in a regular pattern is sought which has the same value for the G-function.

Steps in deriving R_{per}

1. Make a map of root distribution in a horizontal or vertical plane, digitize this map and derive a list of the X,Y coordinates of roots,
2. Introduce 'barriers' in the root map, e.g. representing incomplete root-soil contact,
3. Derive the frequency distribution of distances from points in the soil to its nearest neighbour root,
4. Derive an 'annulus fraction' representation of these nearest-neighbour distances by dividing the fraction of soil in each distance increment by that for an equivalent annulus; by 'cutting the pie', determine circle frequencies f_i, the part of a full circle with radius i in the annulus fraction representation (Fig. 1; VAN NOORDWIJK, 1987; RAPPOLDT, 1990),
5. Derive the G-sum, $\Sigma f_i\ G(\rho)_i$, where the G-function is used for a situation without mass flow (DE WILLIGEN and VAN NOORDWIJK, 1987b):

$$G(\rho) = \frac{1}{2}\left\{\frac{1 - 3\rho^2}{4} + \frac{\rho^4 \ln\rho}{\rho^2 - 1}\right., \text{ with } \rho = 2/(D_r \sqrt{\pi\, L_{rv}})$$

where D_r is the average root diameter and L_{rv} the root length density

6. Find ρ^* for which $G(\rho^*) = \Sigma f_i\ G(\rho)_i$ and the corresponding L_{rv}^*.
7. $R_{per} = L_{rv}^*/L_{rv}$.

A programme for steps 2 to 7 has been developed for a Quantimet 570 image analyzer, and is available on request.

DISCUSSION: The derivation of R_{per} is based on a large number of assumptions. The most critical are probably that all roots are represented on a root map, that all roots have the same activity and that soil water content and initial nutrient concentrations are distributed homogeneously in the soil layer for which R_{per} was derived. Uncertainties in the validity of the method exist in translating 2-dimensional maps to 3-dimensional reality.

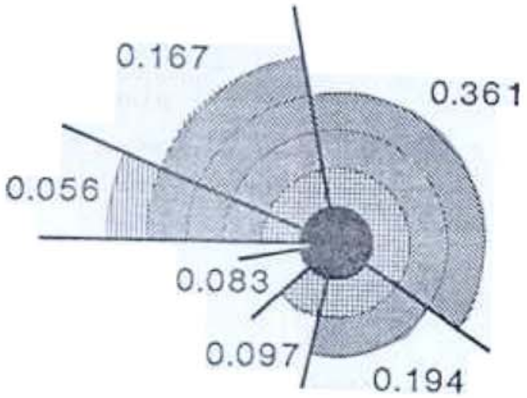

Fig. 1. Combination of annulus fractions which has the same distribution of distances from random points in soil to the nearest root surface as found for an average root in a realistic root distribution pattern. Division in circle sectors is performed in step 4 of the R_{per}-derivation

If nearest-neighbour distances are derived by image analysis methods (KOOISTRA et al., 1992), geometrical complexities of incomplete root-soil contact can be included in the R_{per} derivation. This will result in some negative f_i values, but this is not a problem. In fact any other geometrical complication, e.g. by gaps, cracks or stones blocking diffusive transport, can be handled in the same way. Initial results suggest that R_{per} for root maps is normally in the range 0.5 - 0.9. For heterogeneously distributed resources, a measure of *synlocalization* or spatial correlation of roots and resources is needed.

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