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SOLUTE TRANSPORT IN AGGREGATED SOILS

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Environmentally harmful anthropogenic chemicals frequently enter groundwater ecosystems through the unsaturated zone of field soil, either by accident or by accepted management practices. If irrigation water is applied to the soil surface at rates higher than the infiltration rate of the soil matrix, and macropores are connected to the soil surface, some portion of water will pass rapidly down the macropores and disappear to the subsoil without being of benefit to plants and without wetting and leaching the soil between macropores. The ratio of rate at which water bypasses the soil matrix to the application rate (rain or irrigation intensity) is called the bypassing ratio.

A radioactive tracer technique (Lichner, 1995) was used in a detailed investigation of water flow and solute transport in the unsaturated zone of a clay loam soil during small-scale field experiments made in a structured clay-loam soil at the Experiemental Basis of the Research Institute of Irrigation in Most near Bratislava in the years 1993-96. The soil under study is classified as a Chernozem (FAO: Chernozem, U.S. system: Mollisol Boroll). The macropores in the above-mentioned clay loam soil can roughly divided into biologically induced pores (biopores) and nonbiologically induced pores. Biopores, formed by the soil fauna (ants, earthworms) and plant roots, were tubular in shape. They were more than 1 m deep and their diameter ranged from less than 1 mm to 10 mm. Pores formed by soil physical forces included interaggregate pores, interpedal voids, cracks and fissures resulting from shrinking and swelling of the clay loam soil. With their size depending on changes in soil moisture, they were more than 40 cm deep and up to 3 mm wide during a warm and rainless period.

The probes, by means of which the transport of a selected radioactive tracer in the unsaturated zone of soil can be monitored, consists of a duralumin tube in which a Geiger-Mueller (G-M) detector and analog interface unit, connected to the nuclear analyser with coaxial cable, can be placed in any desired position. The tubes (10 mm O.D., 8 mm I.D.) are inserted horizontally from a pit or vertically from the soil surface into the holes made by a 10 mm diam. steel rod into the soil below the 1 m^2 square infiltrometer. Conical soil sealing was made for each vertical probe to prevent water from bypassing past the probe. Owing to its small size (21 mm length and 6.3 mm outer diameter) the G-M detector can be considered as a point detector.

After non-ponded infiltration of the $^{131}I^-$ solution (at a rate slightly higher than the matrix saturated hydraulic conductivity) and its redistribution, an easily detectable infiltration front in the soil matrix is formed. Additional infiltration of the non-tagged water (at a rate higher than the matrix saturated hydraulic conductivity) results in the $^{131}I^-$ leading edge displacement from which the bypassing ratio can be calculated. In a macroporous soil with two-domain flow, the cumulative infiltration I of the nontagged water is divided into two parts, viz. $I = I_m + I_h$, where I_m is the unknown cumulative infiltration into macropores, [L], and I_h is the unknown cumulative infiltration into matrix, [L]. Considering the facts that the radioactive tracer occurs in the soil matrix only, and that some part of matrix water (expressed by θ_r) is immobile, the cumulative infiltration I results in an infiltration front displacement $h = I_h/ln_{ef}$ in the matrix domain, where $n_{ef} = \theta_s - \theta_r$ is the effective porosity, $[L^3\ L^{-3}]$, θ_s is the saturated water content, $[L^3\ L^{-3}]$, and θ_r is the residual water content, $[L^3\ L^{-3}]$, of the soil matrix. The infiltration front displacement h, [L], is then used to estimate the cumulative infiltration into matrix $I_h = h\ n_{ef}$ and the cumulative infiltration into macropores $I_m = I - h\ n_{ef}$. The bypassing ratio BR can then be expressed as: $BR = I_m/I = I - h\ n_{ef}/I$.

An estimation of the bypassing ratio has shown that the macropore flow was about 49% of the total flow in the barley field in the 1993 experiment, 19% in the maize field in the 1995 experiment, and 55% in the untilled soil covered with grass in the 1996 experiment. It can be seen that the warm and rainless second half of April 1993 resulted in nearly as high macropore flow in the barley field as that in the untilled soil. The bypassing ratio can be used to estimate the irrigation and fertilizer efficiency and to predict groundwater vulnerability to various pollutants. The dose of radioactive tracer necessary for one measurement is very small and in the case of $^{131}I^-$ it is one sixth of the dose for thyroid gland therapy.

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