COMPUTER MODELING OF NUTRIENT MOVEMENT IN SOILS

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ABSTRACT

The movement of nutrients through the soil to the plant root is an important consideration in the nutrition of plants. Ion species differ in their mobility, concentration, adsorption properties and uptake rates, yet the soil-plant system remains electrically neutral. This illustrates the complexity of the interactions which often occur so close to the root surface that measurements of them are extremely difficult.

Mathematical analysis can be used profitably as a tool to predict and evaluate the relative importance of the various factors. The usefulness of mathematical analysis is usually limited by the extent to which the mathematical model corresponds to the real system. Modern digital computers can be used not only to obtain numerical solutions of differential equations, but also to simulate, through numerical calculation, the behavior of the system under a

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variety of condition. This technique usually requires less restrictive assumptions and thus permits the model to be more complex and realistic.

THEORY

The simplest simulation approach is analogous to bookkeeping, where each account loses and gains value in a variety of ways and rates. The root is visualized as an account that takes some ions from the adjoining soil and releases others to maintain electrical neutrality. The soil is divided into a number of accounts that correspond to concentric cylinders of increasing size surrounding the root, Fig. 1. The ions move into each cylinder from the adjacent cylinders according to the flow of water and the differences in the concentrations that exist. After each small increment of time in which movement occurs, each account is updated, not only for the total amount of each ion that is present but also for the distribution of each between the adsorbed and solution phases.

The equation for the movement including terms for mass flow and electro-chemical force, is calculated from the concentrations and concentration gradients of all ion species. Mass action equations for cation exchange between the solution and the soil are used to equilibrate each cylinder between periods of movement.

The simulation calculations, whose arrangement is shown in Fig. 2, start with the first or innermost cylinder. The amount of each ion taken up or liberated by the root is calculated. Then the amount moved between the first and second cylinders is calculated. Finally the new concentration is calculated by adding to the old concentration the net change in the amount of the ion divided by the volume of the cylinder. For the second cylinder the amount moved to or from the

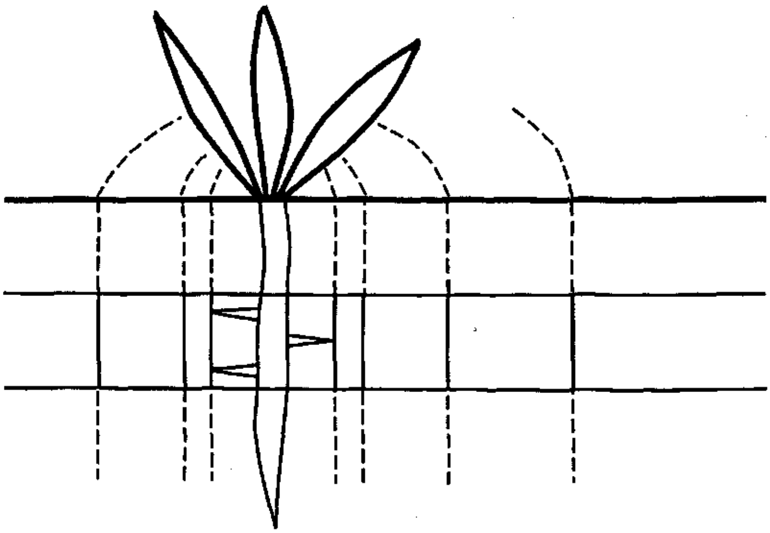

FIG. 1. A diagram of the soil around a unit length of root divided into concentric cylinders.

first cylinder has already been calculated and only the amount to or from the third cylinder needs to be calculated. In this way the calculations progress from cylinder to cylinder out to the last one. Since the rates are calculated and then the concentrations are changed, this method of integration corresponds with the simple point-slope method of Euler. In this model it is assumed that the concentration beyond the last cylinder never changes. An alternate assumption would be that the last cylinder is midway between two roots

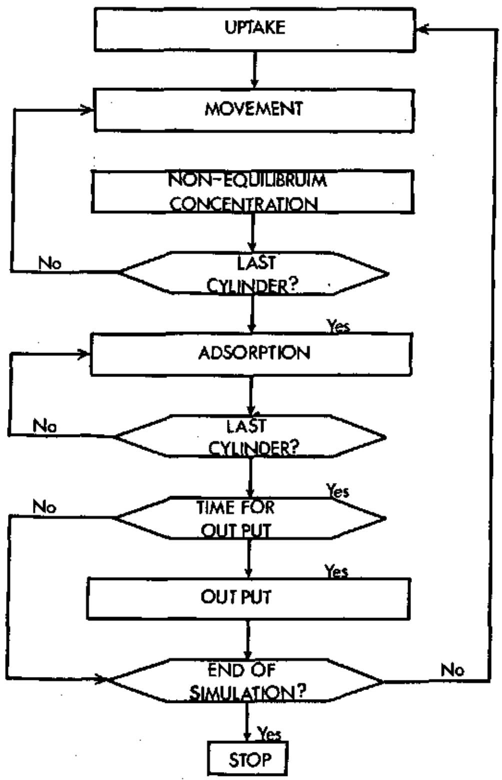

FIG. 2. The flow diagram of the calculations for simulating nutrient movement through the soil to plant roots.

and moves equal amounts of ions in both directions.

After a new concentration is calculated for each cylinder, the new equilibrium between the adsorbed and solution phases is calculated for each cylinder. Before returning to the uptake calculations for a new increment of time, the accumulated time increments are checked to determine if it is time to print the current status of the system and/or time to stop the simulation.

RESULTS AND DISCUSSION

The change in the concentrations of the nutrients in the root hair zone as a function of time is illustrated in Fig. 3 and the change in the concentration with distance from the root surface after 1-hour is illustrated in Fig. 4.

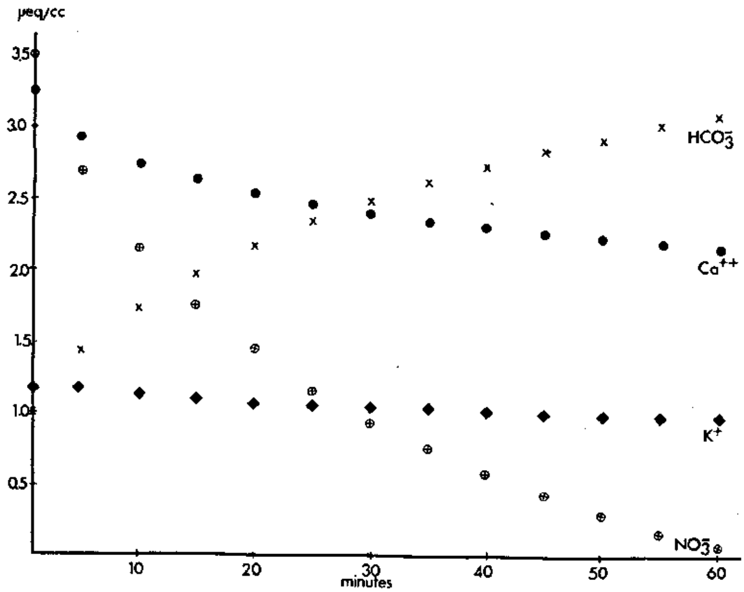

FIG. 3. The nutrient concentration in the solution of the root hair zone as a function of time with zero water flow.

The buffering effect of the exchange capacity on the cation concentrations compared to the rapid depletion of the nitrate concentration is clearly illustrated in these figures. This was suggested some time ago by Bray (1954) but the actual time period involved, about an hour, and the resulting steep gradients can only be obtained from actual numerical examples.

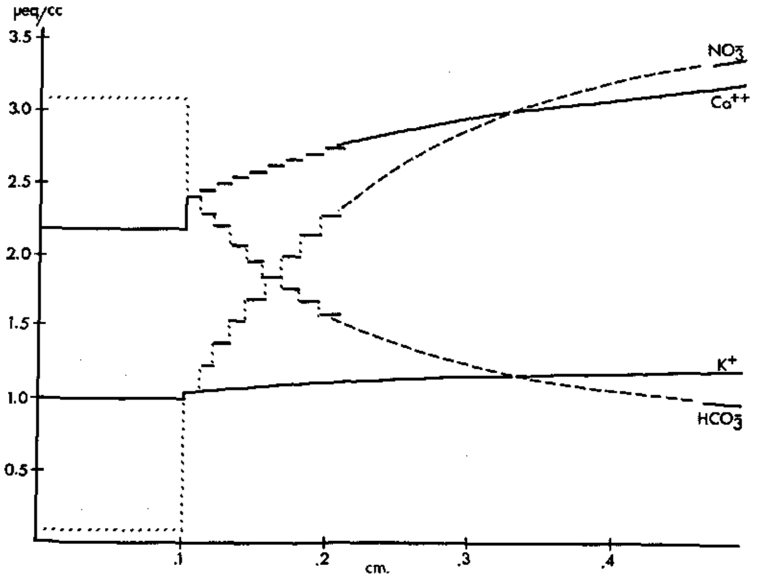

FIG. 4. The nutrient concentration as a function of the distance from the root surface after 1-hour of simulated time with zero water flow.

The rates of uptake used are moderate and correspond to each centimeter of root supporting a growth rate of 7 mg of dry matter per day containing 1.9% N, 2% K, and 0.35% Ca.

The relative importance of different factors in the system can be studied by repeating the simulations with different values for those factors. An example of this is a recent study of the electrical interaction between ions (Frere, 1969).

REFERENCES

1. BRAY, H.R. (1954) A nutrient mobility concept of soil-plant relationships by cylindrical roots of onion and leek. *Soil Sci. 78*: 9-22.

2. FRERE, M.H. (1969) Ionic interaction in diffusion. *Soil Sci. Soc. Amer. Proc. 33*: 883-886.

Questions to Prof. de Wit

BARBER: I note that you did not have mass flow operating in your simulation.

DE WIT: Yes. In fact, if mass flow is operating, calcium around the root is much higher.