INTERCONNECTIVITY OF MACROPORES AND SUBSURFACE DRAINS: INFLUENCE ON BREAKTHROUGH CURVES

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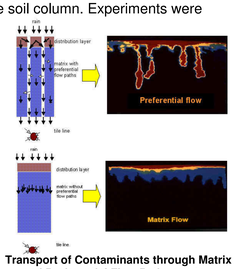
ABSTRACT

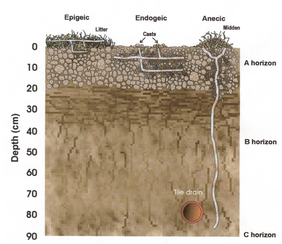
Recent research indicates immediate breakthrough of solutes and pesticides in subsurface drainage by extraordinarily efficient transport through directly connected macropores. Macropores, such as those created by earthworm burrows, allows water and solute to transfer directly to subsurface drains. Laboratory experiments are commonly utilized for investigating this effect of macropore flow on contaminant transport. In this study, the interrelationship between macropores and subsurface drains was investigated by conducting infiltration experiments in a laboratory column packed with a sandy loam soil with an artificial macropore directly connected. The goal of this study is to develop relationships relating soil, macropore and subsurface drain properties to the probability of direct connection. A novel design of the experimental setup allowed open surface and buried macropore lengths to be varied from the subsurface drain to the surface without disturbing the soil column. Experiments were completed for various macropore lengths ranging from zero (no macropore effect) to 75 cm (surface connected macropore). Breakthrough curves were plotted for both matrix and macropore flow at the outlet. The movement of the wave front of the infiltrated water down the column was observed with pencil size tensiometers mounted on the side of the column at various depths. With the surface connected macropore, breakthrough times decreased significantly compared to buried macropores. It was observed that increases in buried macropore length (i.e., as the macropore approached the soil surface) increased the percentage of total drain flow through the macropore.



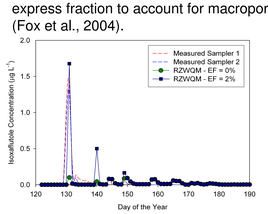
Transport of Contaminants through Matrix and Preferential Flow Pathways to a Subsurface Drain (Cornell University, 2006)

MACROPORE/DRAIN CONNECTIVITY

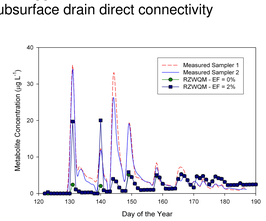
Field research on the connection between macropores and subsurface drains (Source: Shipitalo and Gibbs (2005).



Pesticide fate and transport modeling has also suggested the need to include an express fraction to account for macropore/subsurface drain direct connectivity (Fox et al., 2004).



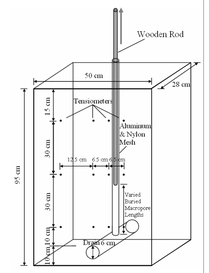
Predicted Pesticide Concentrations with and without Express Fraction (2%)

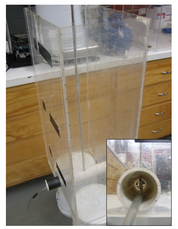


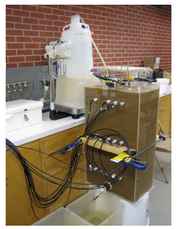
Predicted Metabolite Concentrations with and without Express Fraction (2%)

LABORATORY EXPERIMENTS

- Plexiglas column dimensions:
  - 28 cm wide, 50 cm long, 95 cm tall
- Packed with sandy loam soil (bulk samples from agricultural field near Little Topashaw Creek, Mississippi)
  - 55% Sand, 32% Silt, 13% Clay
  - Bulk density = 1.6 g/cm^3
  - Hydraulic Conductivity = 1.43 cm/hr
- Artificial macropore (1 cm diameter) created by wrapping a wooden rod with aluminum (2-mm) and nylon (0.1-mm) mesh
- Macropore directly connected to subsurface drain
- Pencil size tensiometers (bubbling pressure of 100 cm H_2O) installed to measure soil pore-water pressures:
  - Tensiometers 1-4 (T1-4): 70 cm above drain
  - Tensiometers 5-8 (T5-8): 40 cm above drain
  - Tensiometers 9-12 (T9-12): 10 cm above drain
- Data logger collects continuous data from tensiometers and two digital scales that record water flow from matrix and macropore flow regimes
- Infiltration water (distilled) contained 0.55 g/L $CaCl_2$ and 0.2 g/L Thymol
- Specified pressure head boundary condition: 1 cm ponded condition for 3 hrs
- Drain flow (matrix and macropore) and soil pore-water pressures monitored for 24 hours following infiltration
- Flow Experiments:
  - Matrix Flow: Wooden rod fully inserted into macropore and subsurface drain
  - Buried Macropores: Wooden rod raised in 20 cm increments above drain
  - Open Surface Macropores: Macropore open and backfilled to specific heights above drain (Ponded water allowed to enter macropore)

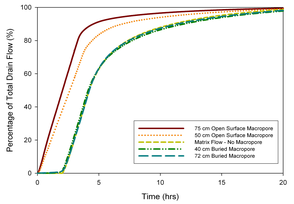




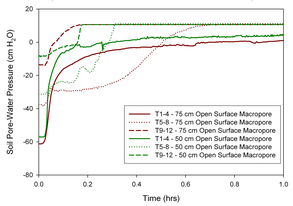


OPEN-SURFACE MACROPORES

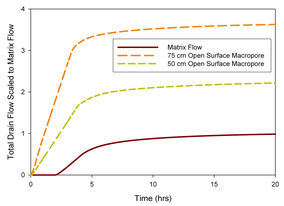
- Macropores open to the surface capable of transmitting 2-3 times as much water as matrix flow
- Instant response from drain after initiation of infiltration
- Soil pore-water pressures reach steady-state faster for surface connected macropores as compared to buried macropores
- Middle tensiometers (T5-8) had delayed response for 75 cm compared to 50 cm macropore due to flow divergence back into soil matrix at bottom of 50-cm macropore
- Bottom tensiometers (T9-12) responded earlier for 75 cm macropore



Breakthrough Curves for Matrix Flow, Buried Macropore, and Open Surface Macropore Experiments



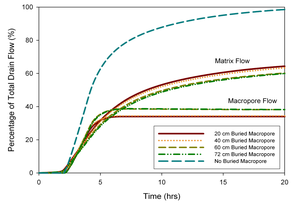
Open-Surface Macropore Experiments (T1-4: Top, T5-8: Middle, T9-12: Bottom Tensiometers)



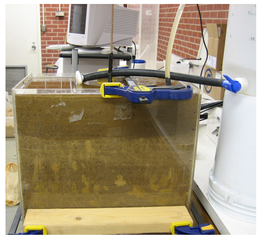
Drain Flow Volumes Scaled to Matrix Flow

BURIED MACROPORES

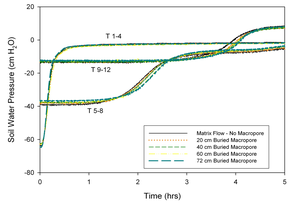
- Percentage of drain flow by macropore flow increased as length of buried macropore increased
- Presence of buried macropore resulted in faster breakthrough
- Total infiltration controlled by matrix flow above the buried macropore
  - Total drain flow equivalent among all flow experiments
- Top tensiometers (T1-4) equivalent among all experiments
- Buried macropores delayed wetting front arrival to middle (T5-8) and bottom (T9-12) tensiometers due to flow convergence at macropore opening



Breakthrough Curves for Matrix Flow and Buried Macropore Experiments

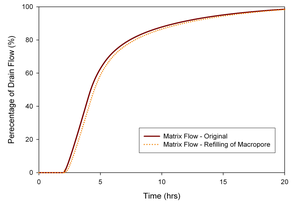


Wave Front Propagation at Early Stages of Infiltration



Buried Macropore and Matrix Flow Experiments (T1-4: Top, T5-8: Middle, T9-12: Bottom Tensiometers)

- Uniform migration of wave front suggested negligible preferential flow along column walls
- Additional matrix flow experiment was performed to verify the nonexistence of preferential flow around macropore
  - Minimal differences in breakthrough curves between original matrix flow and matrix flow with reinserted rod
  - Differences hypothesized to be the result of reduced conductivity by surface crusting over time



Original Matrix Flow and Reinsertion of Wooden Rod after Buried Macropore Experiments

CONCLUSIONS

- Direct macropore/subsurface drain connectivity observed from field tests
- Express fraction modification significantly improved numerical model predictions
- Buried macropores can play an important role in flow and contaminant transport by diverting as much as 40% of matrix flow when directly connected to subsurface drains
- Open-surface macropores do not require direct connectivity to subsurface drains for rapid drain flow response
- Future column experiments planned with macropores shifted away from the drain

REFERENCES

Cornell University, Department of Biological and Environmental Engineering (BAE), Extension Service. "Why preferential flow is important?", http://www.bee.cornell.edu/swlab/SoilWaterWeb/Research/pfweb/educators/intro/why.htm, Accessed January 31, 2006.

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Shipitalo, M.J., and F. Gibbs. 2005. Preferential flow of liquid manure in macropores and cracks. *Proceedings of the American Society of Agricultural and Biological Engineers*, 2005 Annual Conference, Tampa Bay, FL.