Roots and Root Function: Introduction

Todd H. Skaggs* and Peter J. Shouse

Eleven years ago, in a review article, Clothier and Green (1997) assessed the hydrologic budget at the land surface and pronounced that plant roots are "the big movers of water and chemical" in the vadose zone. That assessment seems fair considering that all transpiration begins with the extraction of water from soil by roots and that transpiration sends approroximately 40% of global terrestrial precipitation back to the atmosphere (vs. about 20% by evaporation) (Gerten et al., 2005). Clothier and Green (1997) went on to note that considerable knowledge and understanding of roots had been gained from research begun in the 1960s, but they also indicated that many aspects of roots were at best only partially understood. Subsequent review articles (e.g., Hopmans and Bristow, 2002; Wang and Smith, 2004; Darrah et al., 2006; Skaggs et al., 2006) have struck similar themes.

A number of current issues related to climate change, water management, and ecohydrology are giving impetus to new research aimed at understanding roots and their functioning. The research is producing new experimental methods, data acquisition, and theoretical understanding. Several recent symposia have featured this work, including sessions at the 2006 Soil Science Society of America Annual Meeting (SSSA 2006, Indianapolis, IN) and the 2007 European Geosciences Union General Assembly (EGU 2007, Vienna, Austria). For this issue of *Vadose Zone Journal*, we invited authors from these symposia as well as other leading researchers to contribute research papers to this special section focusing on plant roots and their functioning. The resulting 13 papers contained herein represent a snapshot of current worldwide research on roots and root function.

A major obstacle to studying roots is that they cannot be readily observed in the soil environment. Several papers in the current issue take aim at this "out-of-sight" problem, using advanced imaging technologies to observe roots and their functioning at the scale of a single plant or root. Because the technologies were initially developed for medical imaging and industrial applications, their application to root imaging may require new procedures and protocols. Pohlmeier et al. (2008) used a magnetic resonance imaging (MRI) technique called SPRITE MRI to obtain small-scale water content maps in a soil and root system and observe water uptake patterns for a 4-wk-old *Ricinus* plant. They observed that uptake occurs predominantly in the finer root system. Segal et al. (2008a) also developed an MRI procedure to obtain three-dimensional images of a seedling root system growing in a mini-lysimeter, as well as the soil water content; they were also able to observe dynamic water uptake patterns around a single root. Segal et al. (2008b) then used a related procedure to observe the functioning of root hairs in the water uptake process. Oswald et al. (2008), on the other hand, used a different imaging technology, neutron radiography. Following calibration, Oswald et al. (2008) were able to quantitatively image a single plant root system, its growth, and resultant water infiltration and uptake processes.

While imaging holds great potential for future root investigations, this method is not always feasible or appropriate; thus, other techniques and instrumentation are needed. For example, root investigations may require measurement of in situ soil water potentials over a wide range of pressure, particularly in arid and semiarid regions where dry soil conditions may persist. In conjunction with the MRI investigations noted above, Segal et al. (2008a) used pliable-tip microtensiometers to make small-scale pressure head measurements. Likewise, van der Ploeg et al. (2008) tested a recently developed polymer tensiometer designed to measure matric potentials down to −1.6 MPa. With this new tensiometer, van der Ploeg et al. (2008) could closely follow spatial and temporal water uptake patterns in dry soil. Meanwhile, Vargas and Allen (2008) demonstrate the combined use of minirhizotron imagery with an array of soil sensors to understand root and rhizomorph dynamics. These authors observed high variation in fine roots and rhizomorphs over short time intervals and conclude that continuous minirhizotron and sensor measurements are needed to understand the biophysical factors that regulate belowground carbon dynamics.

The new experimental techniques and instrumentation will undoubtedly provide data in the future for verifying and improving mechanistic models of uptake processes at the scale of a single plant. These type of mechanistic

U.S. Salinity Laboratory, 450 W. Big Springs Rd., Riverside, CA 92506. Received 27 Mar. 2008. *Corresponding author (Todd.Skaggs@ars.usda.gov).

Vadose Zone J. 7:1008–1009
doi:10.2136/vzj2008.0076

descriptions underlie many important crop and vadose zone simulation models (e.g., Hopmans and Bristow, 2002; Wang and Smith, 2004). In the current issue, de Jong van Lier et al. (2008) propose a new uptake model that is a function of the matric flux potential in the soil. The model implicitly includes compensation mechanisms that increase uptake from the wettest layers as the soil dries. Javaux et al. (2008) performed a sensitivity analysis for several parameters in a fully three-dimensional model and used the three-dimensional modeling results to investigate whether it is possible to define an effective one-dimensional uptake model. Schröder et al. (2008) developed a method for calculating the decrease in soil hydraulic conductivity that occurs when water is extracted by an individual plant root. They incorporated this result into a three-dimensional uptake model and demonstrate that, given model assumptions concerning root geometry and uptake mechanisms, decreasing soil conductivity may significantly impact computed plant uptake and the onset of plant stress.

Simulation models featuring root water uptake have many applications. Demirkanli et al. (2008) provide one example in this issue by investigating anomalous upward plutonium transport at the Savannah River Site in South Carolina. While their modeling analysis suggests that root water extraction alone cannot explain the anomalous transport, they speculate that plutonium uptake and translocation in the transpiration stream may be the main mechanism underlying the upward movement.

Beyond the scale of a single plant, one may consider the function of root systems at the species level. Utilizing a unique 50-plus-year experimental site, Newman and Graham (2008) investigated long-term root zone water fluxes among different species (buckwheat [*Eriogonum fasciculatum* Benth. var. *foliolosum* Nutt.], chamise [*Adenstomata fasciculatum* Hooke & Arn.], scrub oak [*Quercus dumosa* Nutt.], and Coulter pine [*Pinus coulteri* D. Don.]). Species- and biomass-level differences in root zone hydrologic behavior were found to be minor, but the authors found detectible differences in how the vegetation types affect the water budget in chaparral ecosystems.

Beyond the species level, one may next consider root distributions at the level of the biome. Schenk (2008) looked at factors determining vertical root distributions for different soils, climates, and vegetation. Noting that many ecological factors favor shallow roots over deep roots, Schenk (2008) hypothesizes that root distributions for particular plant communities tend to be only as deep as necessary to meet evapotranspiration demand and demonstrates that the hypothesis is supported by data and new model calculations.

All of the papers mentioned so far refer to roots and their function here on Earth. In space, with zero gravity, things may well work quite differently if the experiments reported by Kirkham (2008) are any guide. Kirkham (2008) investigated the effects of gravity on root growth, root water uptake, and stomatal resistance and found that in the absence of gravity, plant–water relations and root growth are very different from that occurring under standard conditions.

The papers collected in this special section of *Vadose Zone Journal* suggest a number of opportunities for future plant root research. It is our hope that the special section will stimulate future work that will lead to a better understanding of the vadose zone's "big movers" of water and chemicals.

References

Clothier, B.E., and S.R. Green. 1997. Roots: The big movers of water and chemical in soil. Soil Sci. 162:534–543.

Darrah, P.R., D.L. Jones, G.J.D. Kirk, and T. Roose. 2006. Modeling the rhizosphere: A review of methods for 'upscaling' to the whole-plant scale. Eur. J. Soil Sci. 57:13–25.

de Jong van Lier, Q., J.C. van Dam, K. Metselaar, R. de Jong, and W.H.M. Duijnisveld. 2008. Macroscopic root water uptake distribution using a matric flux potential approach. Vadose Zone J. 7:1065–1078 (this issue).

Demirkanli, D.I., F.J. Molz, D.I. Kaplan, and R.A. Fjeld. 2008. A fully transient model for long-term plutonium transport in the Savannah River site vadose zone: Root water uptake. Vadose Zone J. 7:1099–1109 (this issue).

Gerten, D., H. Hoff, A. Bondeau, W. Lucht, P. Smith, and S. Zaehle. 2005. Contemporary "green" water flows: Simulations with a dynamic global vegetation and water balance model. Phys. Chem. Earth 30:334–338.

Hopmans, J.W., and K.L. Bristow. 2002. Current capabilities and future needs of root water and nutrient uptake modeling. Adv. Agron. 77:103–183.

Javaux, M., T. Schröder, J. Vanderborght, and H. Vereecken. 2008. Use of a three-dimensional detailed modeling approach for predicting root water uptake. Vadose Zone J. 7:1079–1088 (this issue).

Kirkham, M.B. 2008. Horizontal root growth: Water uptake and stomatal resistance under microgravity. Vadose Zone J. 7:1125–1131 (this issue).

Newman, B.D., and R.C. Graham. 2008. Species-level impacts on chaparral root zone hydrology. Vadose Zone J. 7:1110–1118 (this issue).

Oswald, S.E., M. Menon, A. Carminati, P. Vontobel, E. Lehmann, and R. Schulin. 2008. Quantitative imaging of infiltration, root growth, and root water uptake via neutron radiography. Vadose Zone J. 7:1035–1047 (this issue).

Pohlmeier, A., A. Oros-Peusquens, M. Javaux, M.I. Menzel, J. Vanderborght, J. Kaffanke, S. Romanzetti, J. Lindenmair, H. Vereecken, and N.J. Shah. 2008. Changes in soil water content resulting from *Ricinus* root uptake monitored by magnetic resonance imaging. Vadose Zone J. 7:1010–1017 (this issue).

Schenk, H.J. 2008. The shallowest possible water extraction profile: A null model for global root distributions. Vadose Zone J. 7:1119–1124 (this issue).

Schröder, T., M. Javaux, J. Vanderborght, B. Körfgen, and H. Vereecken. 2008. Effect of local soil hydraulic conductivity drop using a three-dimensional root water uptake model. Vadose Zone J. 7:1089–1098 (this issue).

Segal, E., T. Kushnir, Y. Mualem, and U. Shani. 2008a. Microsensing of water dynamics and root distributions in sandy soils. Vadose Zone J. 7:1018–1026 (this issue).

Segal, E., T. Kushnir, Y. Mualem, and U. Shani. 2008b. Water uptake and hydraulics of the root hair rhizosphere. Vadose Zone J. 7:1027–1034 (this issue).

Skaggs, T.H., M.Th. van Genuchten, P.J. Shouse, and J.A. Poss. 2006. Macroscopic approaches to root water uptake as a function of water and salinity stress. Agric. Water Manage. 86:140–149.

van der Ploeg, M.J., H.P.A. Gooren, G. Bakker, and G.H. de Rooij. 2008. Matric potential measurements by polymer tensiometers in cropped lysimeters under water-stressed conditions. Vadose Zone J. 7:1048–1054 (this issue).

Vargas, R., and M.F. Allen. 2008. Dynamics of fine root, fungal rhizomorphs, and soil respiration in a mixed temperate forest: Integrating sensors and observations. Vadose Zone J. 7:1055–1064 (this issue).

Wang, E., and C.J. Smith. 2004. Modelling the growth and water uptake function of plant root systems: A review. Aust. J. Agric. Res. 55:501–523.