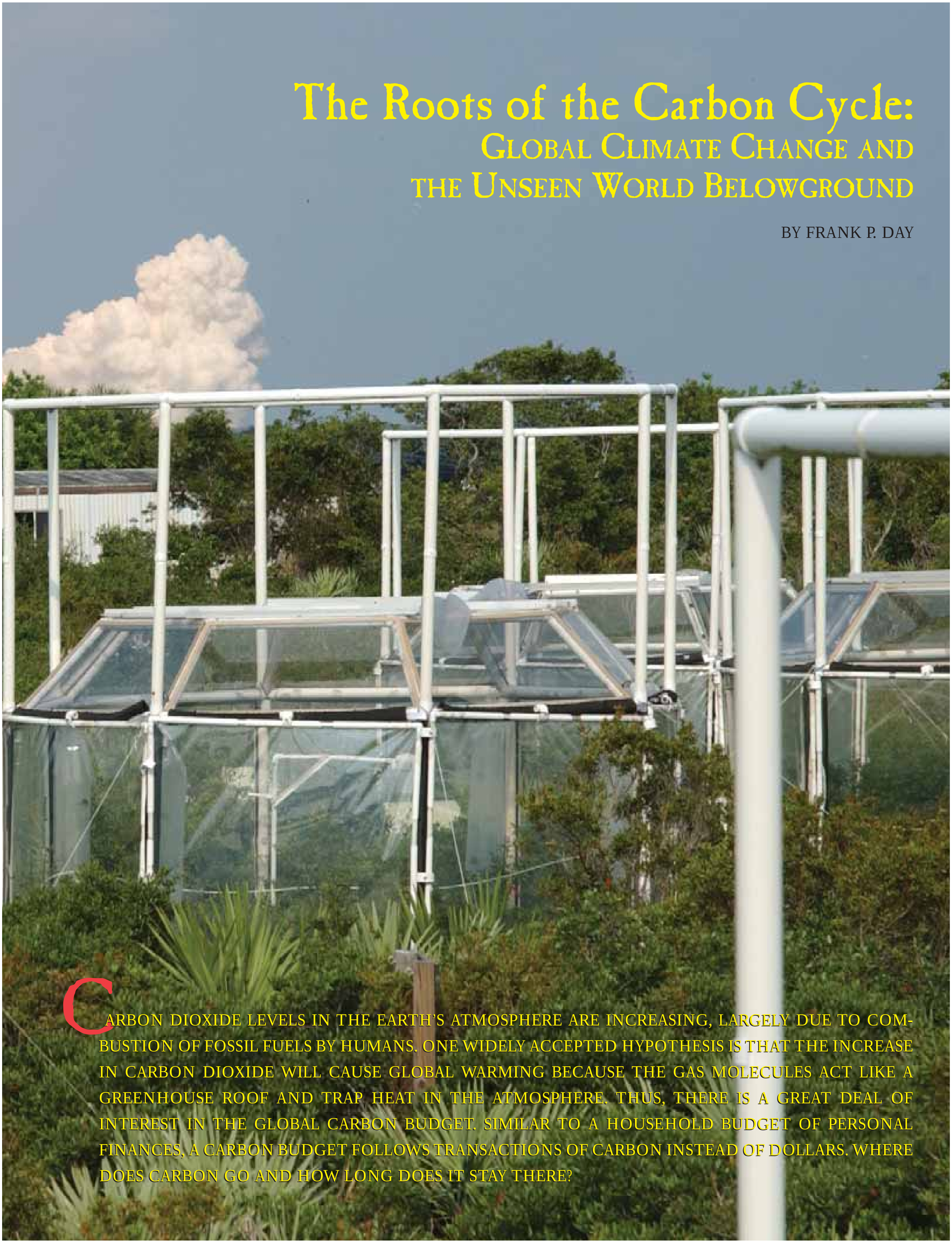


The Roots of the Carbon Cycle: Global Climate Change and the Unseen World Belowground

BY FRANK P. DAY

CARBON DIOXIDE LEVELS IN THE EARTH'S ATMOSPHERE ARE INCREASING, LARGELY DUE TO COMBUSTION OF FOSSIL FUELS BY HUMANS. ONE WIDELY ACCEPTED HYPOTHESIS IS THAT THE INCREASE IN CARBON DIOXIDE WILL CAUSE GLOBAL WARMING BECAUSE THE GAS MOLECULES ACT LIKE A GREENHOUSE ROOF AND TRAP HEAT IN THE ATMOSPHERE. THUS, THERE IS A GREAT DEAL OF INTEREST IN THE GLOBAL CARBON BUDGET. SIMILAR TO A HOUSEHOLD BUDGET OF PERSONAL FINANCES, A CARBON BUDGET FOLLOWS TRANSACTIONS OF CARBON INSTEAD OF DOLLARS. WHERE DOES CARBON GO AND HOW LONG DOES IT STAY THERE?

Plant species and community types (such as pine forests or shrubby oaks) that respond especially well to higher carbon dioxide concentrations could be cultivated in select areas of the world, and thus capture more of the excess atmospheric carbon.

An accounting of the known pathways and storage pools in the global carbon budget reveals a large amount of "missing carbon," which suggests that the Earth has natural mechanisms for removing at least some of the excess carbon from the atmosphere. Research indicates that a substantial portion of the "missing carbon" is going into oceans and plants as a result of increased plant growth. Many published studies postulate that a large portion of the excess carbon captured by plants goes belowground to the roots and eventually into the soil as organic matter. This pathway of excess carbon sequestration suggests one potential means of reducing the impacts of higher carbon inputs into the atmosphere.

Plant species and community types (such as pine forests or shrubby oaks) that respond especially well to higher carbon dioxide concentrations could be cultivated in select areas of the world, and thus capture more of the excess atmospheric carbon. The effectiveness of this approach largely depends upon the answer to a very big, as yet unresolved question: Can plant sequestration of excess carbon continue for an extended period or is it just a short-term response? Answering this question with regard to belowground sequestration via roots is complicated by the extreme difficulties in measuring the hidden environment in which roots reside.

ODU Researchers at the Kennedy Space Center

For almost nine years, my students and I have been part of an international team of ecologists conducting a long-term experiment at Kennedy Space Center in Florida. A U.S. Department of Energy grant to the Smithsonian Institution and the National Aeronautics and Space Administration (NASA) supports the research. The study involves control and experimental open-top chambers constructed to enclose small patches of the oak-palmetto scrub (shrubby vegetation) common in the subtropical climate of Florida.

The natural ecosystem in the experimental chambers has been continuously maintained under a high carbon dioxide atmosphere (twice the current atmospheric concentrations) for about eight years. The twice-ambient concentrations represent levels actually expected to exist by the middle of this century. The team is measuring many aspects of the ecosystem response to high carbon dioxide levels; my students and I are looking at the belowground responses and, in particular, we are trying to determine the long-term role of roots in storing atmospheric carbon.

Getting to the Root of the Problem

There are great challenges to studying the unseen world of roots. They are exceptionally difficult to measure because they are hidden from view and direct physical access, sometimes quite deep in the soil, and any attempt to directly examine them is extremely disruptive to not only the immediate soil environment but also to the entire ecosystem. The resulting disturbance cannot be tolerated in a long-term experiment. However, several exciting technological approaches to the study of root systems have been developed or are now in development. We are currently using mini-rhizotrons in the Kennedy Space Center project to videotape and measure fine roots in a nondestructive manner, and we are investigating the use of ground-penetrating radar to obtain images of root systems without digging a single hole in the ground.

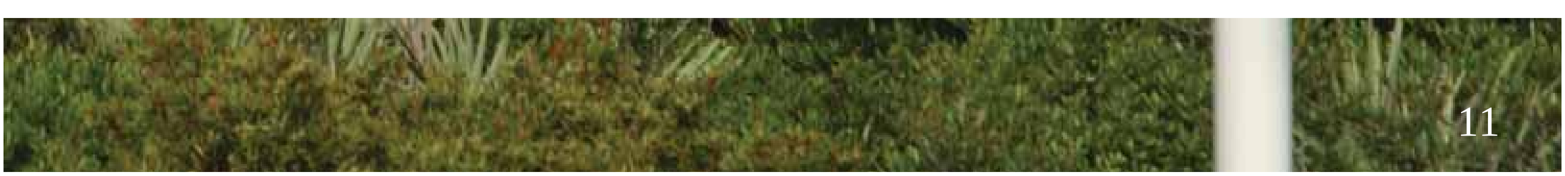
Mini-rhizotrons are clear plastic tubes installed at an angle about a meter into the soil. Once the tubes are in place, we can periodically insert a specially constructed color video camera and tape the fine roots that are visible along the side of the tube. In the lab, we then use special software to identify each root in the field of vision and digitize its length and width. From these data we can compute the total length of fine roots per section of soil. By comparing different dates, we can actually follow the fate of individual roots through time by measuring their growth rates and determining when they die. This technique provides a robust quantitative view of fine root abundance and turnover without disrupting the soil environment. We have installed mini-rhizotrons in all of the chambers in the Kennedy Space Center study. The primary limitation of this method is that it only measures very small roots (less than 2 mm in diameter). Unfortunately, this technique doesn't tell us anything about the large roots in the system, which constitute the greatest portion of total root mass. A potential solution to this dilemma is the use of ground-penetrating radar (GPR).

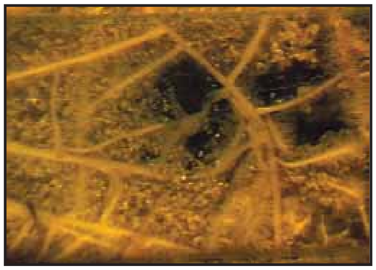
Doctoral students Alisha Pagel and Dan Stover videotaping fine roots at Kennedy Space Center.

GPR has been used primarily by archaeologists to locate foundations of old ruins, by engineers to examine the structural integrity of buildings and by forensic experts to find buried bodies. This device also has promising new applications that we are exploring as part of the Kennedy Space Center study. GPR detects belowground features by measuring the amount of time it takes for an electromagnetic signal to travel from the antenna on the soil surface to the underground object (roots, in this case) and back. This noninvasive technology may allow us to estimate the mass of roots and possibly even develop detailed maps of root systems without digging in the soil at all. We are only in the beginning stages of testing and adapting this cutting-edge technology for root imaging, but it holds great promise.

Roots Help, but for How Long?

The study is in its eighth year, and the research results have included a number of surprises. The aboveground parts of the oak trees (stems and leaves) have continued to grow at a more rapid rate under higher carbon dioxide levels throughout the course of the experiment. In the first several years of the study, the fine roots also grew more rapidly and were more abundant in the high carbon dioxide chambers. During those early years, the plants appeared to be sequestering excess carbon, with much of that carbon apparently going belowground into the roots. However, about halfway through the study, we found the difference in fine root abundance between the control and elevated carbon dioxide chambers was diminishing, and recently it disappeared altogether. In other words, there is now no difference in fine



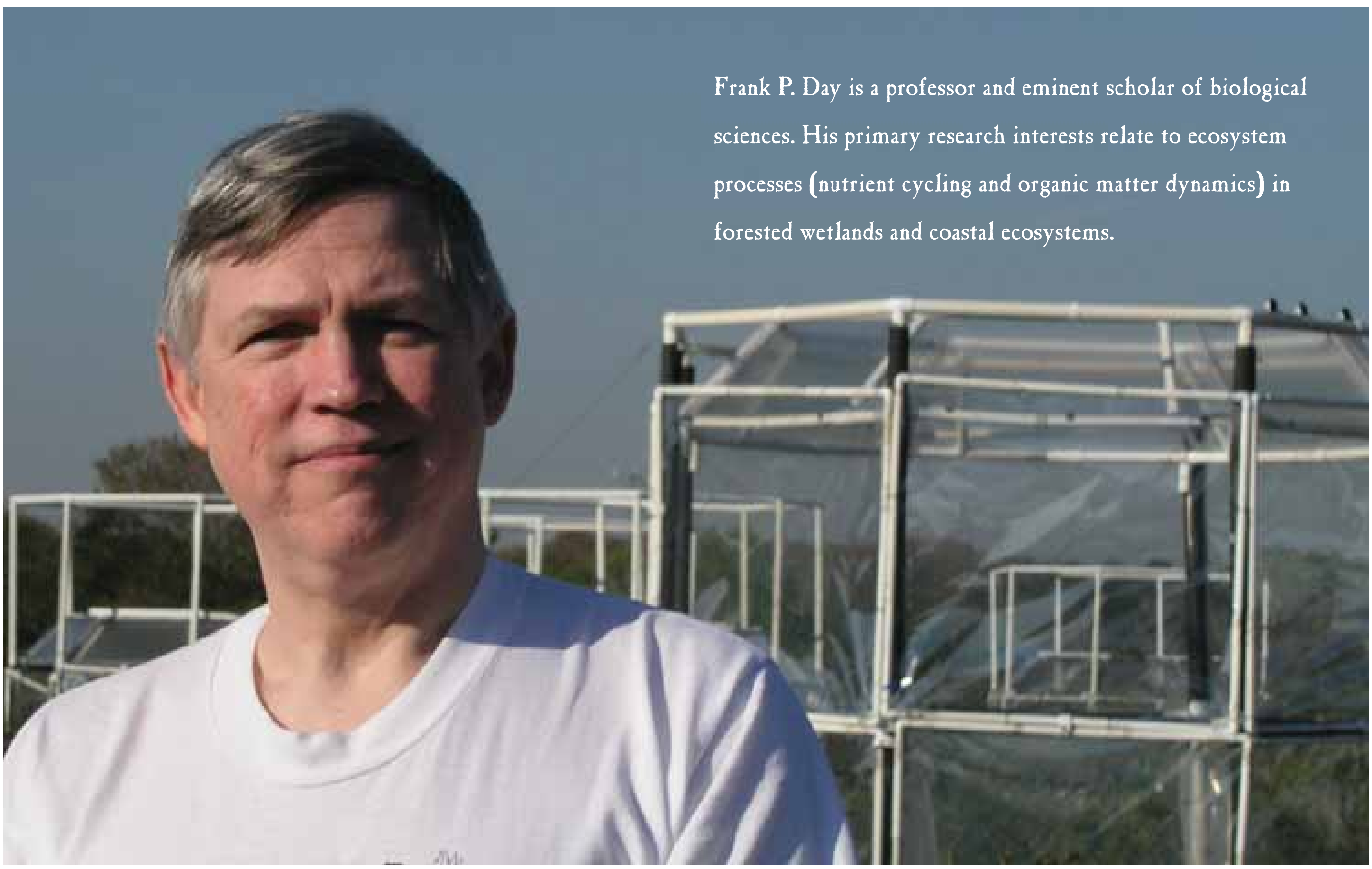


Fine roots seen through mini-rhizotron

Mini-rhizotrons are clear plastic tubes installed at an angle about a meter into the soil.

root abundance between the control and elevated chambers. One hypothesis is that soil nutrient limitations (especially nitrogen) encountered by the more rapidly growing plants cause the carbon dioxide-enriched plant growth to slow down. Therefore, the ability of some plants to store excess carbon from the atmosphere may be limited by other factors in the environment and thus last for only a few years.

Our results are inconclusive at this point. Much remains to be done on this project, and we hope to continue to follow the ecosystem's responses for many more years. NASA also has interests in the outcome of the study that go well beyond the Earth's carbon cycle. One of the most daunting challenges of long space voyages, habitation of space stations and the establishment of living facilities on the moon or Mars is how to handle the accumulation of carbon dioxide, since it is toxic to humans in high concentrations. The inability to deal with this problem was the primary reason the Biosphere II project in Arizona failed. Carbon dioxide increased to toxic levels, and the project participants were forced to leave the enclosed structure. NASA wants to learn how enclosed living spaces can be engineered to be self-sustaining and to better deal with excess carbon dioxide. The processing of carbon by plants is at the core of these engineering efforts since this colorless, odorless gas is essential to the process of photosynthesis.



Frank P. Day is a professor and eminent scholar of biological sciences. His primary research interests relate to ecosystem processes (nutrient cycling and organic matter dynamics) in forested wetlands and coastal ecosystems.