Wilford R. Gardner

1925–2011

BIOGRAPHICAL *Memoirs*

A Biographical Memoir by
William Jury

NATIONAL ACADEMY OF SCIENCES

WILFORD ROBERT **GARDNER**

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Wilford Gardner was a humble man with a razor-sharp mind and a penetrating wit, whose many contributions to the field of soil physics will remain significant far beyond his own lifetime. His brilliant research career was relatively short and was followed by years of successful administration in academia. He never took himself too seriously, and he was generous in his praise of others. He placed his family at the center of his life, was a leader in his church, and throughout his career remained a tireless champion of progress and reform within his chosen field of soil science. Wilford was married for 62 years to Marjorie, had three children—Robert, Caroline, and Patricia—13 grandchildren, and nine great-grandchildren.

Photography courtesy of University of Wisconsin-Madison Archives.

By William Jury

The Gardner legacy

Wilford was born October 19, 1925, to Robert and Nellie Barker Gardner in Logan, Utah. His pathway to soil physics was all but inevitable, given that much of the foundational work in the field had been done by members of his own family. The study of physical processes in unsaturated soils did not really begin until early in the 20th century with the arrival of Wilford's uncle Willard Gardner at the Utah State Agricultural College (now Utah State University) in Logan in 1917. Willard had received the eighth Ph.D. ever granted in physics by the University of California at Berkeley, and over the next 30 years he elevated the field of soil physics from a small area within agricultural science to a legitimate branch of physics. Wilford's father, Robert, became a soil chemist and taught soil physics for a time at Colorado State University. Willard's son, Walter, had a long career in soil physics at Washington State University, earning a reputation as a skilled scientist and one of the finest teachers in the field. Thus, almost inevitably, both Wilford and his brother Herb entered the field of soil physics as well.

Like so many of the World War II generation, Wilford enlisted after high school in 1943. He served overseas with the Army Corps of Engineers until 1946, when he returned on the GI Bill to college and then to graduate school. Wilford majored in physics, as had his Uncle Willard, obtaining a B.S. from Utah State Agricultural College, and a M.S. and a Ph.D. in solid-state physics from Iowa State University in 1953. While at Iowa State he took a minor in soil physics with Don Kirkham, another of the field's pioneers who had been trained as a physicist. The two of them worked together to develop the use of neutron scattering as a method for measuring the quantity of water held in soil. This device was to become the principal means for quantifying water storage in soil for the next three decades.

At the U.S. Salinity Laboratory

Wilford had a number of job offers when he graduated, and he eventually chose to work with the U.S. Department of Agriculture in Beltsville, Maryland. However, the Beltsville laboratory would not have room for him for another year, so he instead went to the U.S. Salinity Laboratory in Riverside, California, to work temporarily with L. A. Richards. Richards had received his degree in physics at Cornell, but before that had earned an M.S. from the Agricultural College of Utah under Wilford's Uncle Willard. Richards was a legendary experimentalist who designed and built many of the earliest measuring devices to sense water in soil. He was to prove a valuable mentor for Wilford.

At the time Wilford arrived in Riverside, scientific understanding of water retention and flow in soil was in its infancy. Equations for water transport had been formulated, largely through the efforts of Willard Gardner, but they were highly nonlinear and therefore unsolvable by any methods available before the advent of high-speed computers. Moreover, the equations contained transport coefficients that were nonlinear functions of water content, and methods had not been developed to measure their values in soil. This field was ready to be plowed by the new wave of scientists trained in physics and mathematics.

Soon after Wilford started at the Salinity Lab he began analyzing data on the water-saturated permeability of soils. He discovered that the variation of this value within a soil-mapping unit was much better described by a lognormal distribution than the commonly used normal distribution. Further study showed him that soil particle size distribution was also better described as lognormal than normal. This observation, which he published, was the first indication that soil property variability deviated greatly from the assumed normal distribution upon which most sampling statistics were based.

Wilford's initial major contribution to soil physics research was to make the first measurement of the unsaturated hydraulic conductivity (then called the capillary conductivity) as a function of the energy state of water. Water in unsaturated soil is adsorbed to the surface of soil minerals, which causes the air-water interface within soil pores to curve inward toward the liquid, thereby lowering the pressure of the water held in soil pores relative to free water. L. A. Richards had designed and built a pressure membrane apparatus to measure the equilibrium relation between the water content in soil and its energy state. Using this device called for placing a wetted soil sample held in a ring on a water-saturated ceramic plate within a sealed chamber connected to the outside through a tube attached to the plate. When the air pressure in the chamber was raised, the water was expelled from the soil through the membrane and out the chamber, leaving the remaining water at an energy state opposing the applied air pressure.

Wilford enhanced this method by measuring the rate at which the water left the chamber and interpreting this rate through a linearized form of the flow equation, which allowed him to measure the coefficient of permeability (the hydraulic conductivity) as a function of both the energy state of the water and the water content of the soil. His published paper reported measurements of hydraulic conductivity over six orders of magnitude, something that had never been accomplished before.

Wilford went on to publish 13 papers over the next few years on unsaturated water flow, using approximate solutions to the flow equation. One of his approximations was to assume that the transport coefficients were exponential functions of the water content or of the energy state of the water (expressed as a soil water potential). This functional relationship, which was a reasonable approximation over a practical range of water content for many soils, allowed him to transform the flow equation into a linearized form and create solutions to a variety of hitherto unsolvable problems. In his classic paper of 1958 he used this method to calculate the maximum possible evaporation of water from a water table as a function of the depth of the water table below the soil. He also demonstrated that coarse-textured sandy soils conduct far less water upward to the surface than their finer-textured counterparts, even though sandy soils are much more permeable than finer-textured ones when both are saturated.

Some six years after earning his Ph.D. Wilford was able to obtain a prestigious fellowship from the National Science Foundation that allowed him to take a sabbatical leave for one year overseas. Because his baccalaureate and graduate study had been in physics, he decided to use this opportunity to broaden his education in fields relevant to soil science and agriculture, such as colloid chemistry, micrometeorology, physical chemistry, applied mathematics, and plant science. He chose to divide his year overseas into stays with E. C. Childs at Oxford and W. R. van Wijk at Wageningen University, a world-class agricultural research center in the Netherlands. The Oxford portion of his stay was dominated by library research on the aforementioned science areas in which he felt deficient, while his time in the Netherlands was largely spent expanding his understanding of microclimatology. This sabbatical experience allowed him later to broaden greatly his areas of research within soil science.

When he returned to Riverside, Wilford initiated what was to become a hugely fruitful segment of his career accomplishments in research, the study of soil-plant relationships. Through countless experiments with his colleague Carl Ehlig, Wilford was able thoroughly to characterize the factors limiting plant growth under conditions of both adequate and inadequate water supply. In a classic paper in *Science* he and Ehlig demonstrated that the limiting resistance to water flow from the soil to the plant shifted from that produced by plant tissue and membranes under wet conditions to the soil permeability under dry conditions. In a second paper in *Science*, Wilford and Neimann demonstrated through measurements of plant transpiration, cell division, and cell enlargement that no single lower limit of available water could be defined for these three plant processes. The soil-water content at which permanent wilting is exhibited does not represent a true lower limit for any of these. This paper largely dispelled the previous belief that plant-available water is a measurable soil characteristic.

Many other foundational papers on soil-plant relations and evaporation of water from soil and plant were to follow. Wilford did much of the early work dividing evaporation from initially wet soil into an early stage regulated by external climatic conditions followed by a falling-rate stage limited by upward movement of water through the soil to the surface. He also derived a solution for water flow to a cylindrical surface area and used the results to identify many features relevant to water flow toward plant roots.

The Wisconsin years

Wilford left the Salinity Lab in 1966 and accepted a professorship in the renowned Soil Science Department at the University of Wisconsin in Madison. The group who assembled there over Wilford's 14-year stay was undoubtedly the greatest assemblage of soil physics expertise at one institution in the history of the United States. Among the many talented colleagues on hand for Wilford to interact with were Ed Miller, Champ Tanner, Chris Dirksen, George Thurtell, and Pieter Raats. The educational environment was constantly stimulating, with weekly seminars that lasted as long as people had questions, and coffee breaks that ended up filling chalk boards with new ideas. Wilford and Champ Tanner (also to become an NAS member) were the driving forces behind these meetings, and the soil physics students were the beneficiaries. This atmosphere produced a number of students who went on to distinguished careers in the field.

Microclimatology was an emerging field, and Champ Tanner was expert at field measurement of evapotranspiration and indices of plant water stress. This unique combination of expertise allowed the Madison group to become among the first to conduct rigorous field experiments and apply soil physics theory in their interpretation. Wilford was an active collaborator on a series of important experiments conducted by Tanner's student T. A. Black. Tanner's group had a large field lysimeter (a cylinder filled with soil placed in a larger field) equipped with both suction at the bottom to measure and sample drainage and a scale for weighing the entire cylinder to allow measurement of water loss. The data obtained from the study allowed the researchers to model the water balance components in a realistic field environment with or without plant cover.

In 1965 Wilford was asked to develop a monograph on the movement of nitrogen through soil. Nitrate was being detected in a number of monitoring wells in groundwater underneath agricultural fields and concern was growing about the contamination risk from widespread fertilization of major crops in the United States and worldwide. However, little was known about the mechanisms governing the transport of nitrogen compounds and their biological or chemical transformations in the subsurface. Wilford had not worked in this area before, but after substantial reading he was able to develop the first comprehensive review of what was known about nitrogen transport mechanisms.

Wilford later collaborated at Wisconsin on research conducted by colleague Dennis Keeney's graduate student Paul Saffigna looking at nitrate movement under a potato crop in a sandy field in Wisconsin. This landmark study produced some of the first data obtained showing the extensive variability of downward nitrate movement, and allowed Wilford and colleagues to develop a model for the simultaneous transport of water and nitrate under field conditions.

Wilford also continued his work on plant-water relations while at Wisconsin. His student Mary Beth Kirkham conducted a number of studies examining the effect of soil salinity on plant water stress, cell growth, and cell division. They simultaneously monitored turgor pressure and stomatal conductance, developing a number of relationships between soil conditions and plant response.

Wilford had previously studied plant roots' resistance to water uptake arising from soil and plant conditions, and with his student Frank Dalton he examined in detail the simultaneous movement of water and solutes across plant membranes. He and Dalton published a theory describing the hydraulic and osmotic transport of water and the diffuse, convective, and active transport of solutes across root membranes. The theory predicted a nonlinear relationship between the flux of water and the pressure difference across root membranes, which was in good qualitative agreement with a variety of observations on simultaneous uptake of water and solutes.

Wilford's final foray into plant-soil research at Wisconsin was in collaboration with Ed Miller and his student Bill Herkelrath. For his dissertation, Herkelrath conducted experiments on a growing plant that had portions of its root system isolated by wax layers. A measurement of the average root potential was obtained by allowing a thin "test section" of soil to dry toward equilibrium with the root water potential while the rest of the soil was kept wet. The equilibrium water potential reached by this isolated soil layer was quite low (~-5 bars) even though the rest of the soil was high in water content.

From this the researchers concluded that substantial resistance was encountered between the soil and root xylem, even though the permeability of the soil was quite high at the average water content of the soil in the experiments. This result was at variance with previous diffusion-based models, which predicted up to 8 times higher water uptake rates than they observed under these conditions. The researchers developed an alternative model that assumed the loss of contact area between soil and root was responsible for the discrepancy, something that had never before been proposed.

Administrative and professional leadership

Wilford left Wisconsin in 1980 to chair the Department of Soil and Water at the University of Arizona, a position he would hold for seven years. Although this was a full-time administrative position, he remained active in soil science research, both in collaboration with colleagues at Wisconsin, and with his departmental faculty at Arizona. During this time, Wiford worked with Arizona professor Art Warrick on an important paper that demonstrated the effects of soil and irrigation application variability on the relation between water application and crop yield. He also maintained a collaboration with Wisconsin microbiologist Robin Harris studying the effects of soil physical properties on bacterial metabolism. In 1987 he accepted the position of Dean of the College of Natural Resources at UC Berkeley and held that position until his retirement in 1994. Under his leadership at Berkeley, the College underwent a significant reorganization, merging eight departments into four large multidisciplinary units. This reorganization not only produced cost savings and more efficient administration, it also allowed the faculty to address large interdisciplinary research problems more effectively.

Wilford was active in professional affairs throughout his entire career, sitting on a large number of committees in the Soil Science Society of America and serving as society president in 1990. He was also active in the International Soil Science Society and was elected president of the Soil Physics Division. He provided expertise on soil and water issues for a number of agencies, serving on the Science Advisory Board of the Environmental Protection Agency, the Arizona Water Quality Council, an advisory panel of the International Atomic Energy Agency, and as an advisor to the Office of Technology Assessment.

Wilford's contributions to the National Academy of Sciences were extensive. He served on 10 different panels of the National Research Council and was a two-term member of the Water Science and Technology Board over an eight-year span. He also was also the driving force behind the creation of a National Soil Science Committee reporting to the NAS.

Wilford was a Fellow of the Soil Science Society of America, the American Society of Agronomy, and the American Association for the Advancement of Science. He received the Soil Science Research Award, the top honor of that society, was a Centennial Alumnus from Utah State University, received the Berkeley Citation from UCB and an honorary doctorate from Ohio State. Overseas he was honored with the Faculty award from the University of Ghent and was given an honorary professorship from the Chinese Academy of Sciences.

He was elected to the National Academy of Sciences in 1983.

Personal recollections

I was fortunate to be at Wisconsin during the golden years of soil physics, when Gardner and Tanner ran their weekly seminar for the soil and plant physics groups. I was working on a Ph.D. in physics under Ed Miller, who had a joint appointment in Physics and Soil Science, and both Wilford and Champ Tanner were on my research advisory and dissertation committees. Upon graduation I took a one-year postdoc appointment under Wilford's direction before accepting a professorship at the University of California-Riverside. Wilford influenced my professional career as a mentor more than anyone else in the stellar group assembled at Wisconsin. He was a marvelous facilitator of complex information and probably the most efficient person I ever worked with. He pumped me with questions continuously, as much to further educate himself as to see how I answered them. He worked independently much of the time, and encouraged me to do the same, but he was very generous with his time when I needed assistance or wanted to talk.

In larger groups he didn't say much, but when he spoke everyone listened. He always seemed to be able to zero in on the critical issue or ask the key question, and he had a gift for doing it without upsetting the person under interrogation. He had a huge repertoire of stories and laughed a lot, at least before he got into administration. He was fun to be around and genuinely liked people. He never seemed to regard his career as a job, but more as a privilege. That was perhaps the most valuable lesson that he taught me.

After he retired he wrote his memoir, a massive document covering hundreds of pages. Although he wrote of his research, he placed it in the context of his entire life and shared his observations throughout. It was fascinating reading for me, as he recounted his amazing life and numerous world travels, always with a touch of humor and a great deal of humility. I didn't read it until after he had passed on, and it exposed me to many facets of his life about which I had known little or nothing. After finishing it I thought: his was a life well lived.

Wilford Gardner was first my teacher and mentor, then a professional colleague, and always my friend. The profession of soil science is greatly the poorer for his loss, because until the very end he served it and fought to keep it a rigorous and respected discipline. It was a privilege to know him and an honor to work with him. Although not a large man, he left huge shoes to fill.

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