

This Week's Citation Classic®

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Denmead O T & Shaw R H. Availability of soil water to plants as affected by soil moisture content and meteorological conditions. *Agronomy J.* 54:385-90, 1962.
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A common view in the early 1960s was that transpiration and plant growth were insensitive to soil water content until a defined lower limit. In container experiments both processes were affected over the whole range of plant-available soil water, depending on the atmospheric evaporation demand, as predicted by physical analysis. [The *SCI*® indicates that this paper has been cited in over 180 publications.]

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I did the work for this paper when I was a graduate student in agricultural climatology at Iowa State University, with Bob Shaw as my major professor. The impetus for it came from the need to separate the influences of weather and technology on corn yield, a topic of great interest then in the agronomy departments of midwestern universities. Yield trends were often obscured by year-to-year variations in the supply and effectiveness of soil water.

Previously, the problem had been tackled by multiple regression techniques that could identify important weather elements but were of little use for prediction or understanding. During that time, publications by two rising stars of soil physics, John Philip¹ and Wilford Gardner,² provided a mechanistic framework and strongly influenced our thinking.

As Gardner noted in his *Citation Classic* commentary,² at that time there was a heated debate about the availability of soil water for transpiration and plant growth. A common view was that neither process was influenced appreciably until soil water content was de-

pleted to a defined lower limit, the wilting point. The Philip/Gardner analyses of water movement from soil to plant to atmosphere predicted that transpiration could be restricted and that plants could wilt over a wide range of soil moisture contents depending on root density, the soil's hydraulic properties, and, importantly, the potential evaporation rate. Our experimental work partially confirmed those predictions.

Despite the idealizations of the mathematical analyses and our own disclaimer about the qualitative nature of the experimental work, the relationships we observed are often applied quite literally, a tendency that brings periodic admonishments from colleagues.^{3,4} Nonetheless, many field investigations since have shown similar qualitative behaviour.

The experiment is unlikely to be repeated: it probably uses too little technology and too much physical labour for today's tastes. It is just as well since the field in which it was done, and the extensive area of Colorado soil there, is now under the new Iowa State University football stadium.

One reason the paper has probably been cited so often is that we had the benefit of consultations with experts like Philip, Gardner, and Ralph Slatyer before publication. (Science involved more personal contacts then.) But there are more cogent reasons. That the availability of soil water depended on atmospheric as well as soil conditions was a new concept. Consequently, the paper had great pedagogic value. Illustrations from it appear in a number of eminent texts on soil-plant-water relationships, even those published in the 1980s.⁵ The results also lend themselves nicely to functional representation for use in numerical models of evaporation, crop growth, and soil-water balance.⁶

Since the paper was published, much has been learned about the water relations of plant leaves⁴ but not enough about water movement in crop root zones. We join with Gardner² in hoping that some young scientist is even now preparing another future *Citation Classic* that will herald a new approach.

1. Philip J R. The physical principles of soil water movement in the irrigation cycle. *Proceedings of the 3rd Congress of the International Commission on Irrigation and Drainage*. 1957, San Francisco, CA. New Delhi, India: N.p., 1957. p. 8,125-54. (Cited 85 times.)
2. Gardner W R. Dynamic aspects of water availability to plants. *Soil Sci.* 89:63-73, 1960. (Cited 240 times.) [See also: Gardner W R. *Citation Classic*. *Current Contents/Agriculture, Biology & Environmental Sciences* 16(35):20. 2 September 1985.]
3. Ritchie J T. Water dynamics in the soil-plant-atmosphere system. *Plant Soil* 58:81-96, 1981.
4. Jarvis P G & McNaughton K G. Stomatal control of transpiration: scaling up from leaf to region. *Advan. Ecol. Res.* 15:1-49, 1986.
5. Hillel D. *Applications of soil physics*. New York: Academic Press, 1980. 385 p. (Cited 60 times.)
6. Russo D. A stochastic approach to the crop-yield irrigation relationships in heterogeneous soils: I. Analysis of the field spatial variability. *Soil Sci. Soc. Amer. J.* 50:736-45, 1986.

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