Stomatal response to soil oxygen

New findings in stomatal response to oxygen could lead to changes in flood irrigation practices.

Diffusive resistance, measured on tomatoes by Robert Sojka, indicates stomatal opening.

Oxygen levels in the voids between soil particles can vary over a wide range of concentrations. Flooding, recent incorporation of fresh organic matter, elevated soil temperatures, or combinations of these factors can lower soil-oxygen concentrations, either by stimulating rapid consumption of oxygen by microorganisms or by physically excluding oxygen from soil pores. Plant roots require adequate oxygen to respire and carry on various metabolic activities. When soil-oxygen availability to roots—as measured by the soil oxygen diffusion rate (ODR)—is low, plants develop a variety of stress symptoms. Unrelieved oxygen stress quickly damages plants and eventually reduces yields of most crops.

One mechanism resulting in plant damage involves the regulation of stomatal aperture. Stomata are the small pores in leaves and fleshy plant parts that allow gas exchange between internal leaf tissue and the atmosphere. The size of each pore is regulated by guard cells in response to light, water status of the plant, and various regulating chemicals in the plant. The importance of gas exchange through the stomata is linked to the need for atmospheric carbon dioxide (CO_2) for photosynthesis and for transpiration of water vapor.

Since low ODRs most often result from flooding, little attention has been paid to their effect on stomata. Stomatal response is generally regarded as a soil-water-related phenomenon. When soil-water availability is high, stomata are open; as soils dry, stomata begin to close. Therefore, one would expect stomata to be open in leaves of plants growing in flooded soil. Recent work, however, shows that this, in fact, is not the case.

Some plants have long been known to be more sensitive to soil aeration than others. Wilting, for example, commonly occurs shortly after soil-oxygen is excluded from roots of high-value cash crops like tomato or tobacco. Another interesting fact is that plants generally decrease water use when oxygen is excluded from the root zone—even if this exclusion is caused by flooding.

Several experiments conducted at the University of California, Riverside, have shown

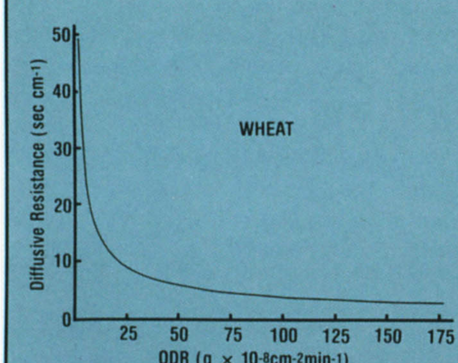

Fig. 1. Relation between oxygen diffusion rate (ODR) and leaf diffusive resistance.

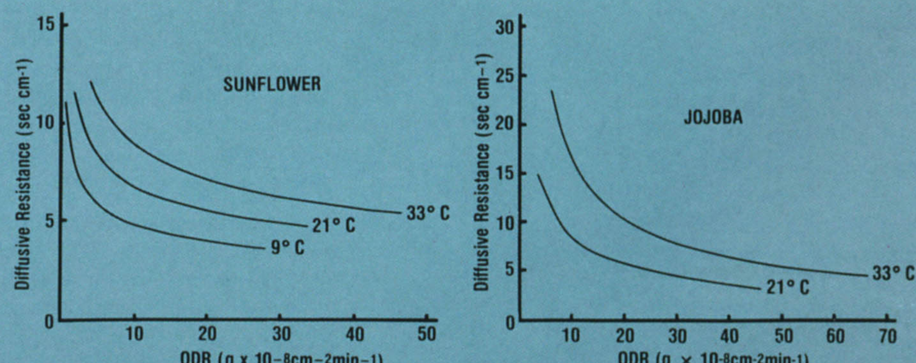

Fig. 2. Relationship between oxygen diffusion rate (ODR), leaf diffusive resistance (R_s), and soil temperature for sunflower and jojoba.

Robert E. Sojka

Lewis H. Stolzy

that as the ODR of a soil decreases, stomata close, independently of other factors like soil-water status or light intensity.

Leaf diffusive resistance (R_s) is an indicator of stomatal aperture. When R_s is high, stomata are closed; when R_s is low, stomata are open. Figure 1 shows the effect of ODR on R_s for wheat grown in soil at equilibrium with gas mixtures of 0, 4, and 21 percent O_2. Soil temperatures were varied also to give 9°, 15°, and 21° C treatments. These two factors combined to create a range of ODRs. At low ODRs R_s increases sharply, indicating stomatal closure. This occurs despite the maintenance of uniformly favorable soil water status in all treatments.

Similar responses have also been found in tomato, cotton, sunflower, and jojoba. Figure 2 demonstrates the R_s increases of sunflower and jojoba in an experiment similar to the wheat experiment. Evidently, the R_s of both sunflower and jojoba responds to soil temperature. At high soil temperatures, the respiration rate of roots (O_2 demand) increases, as does competition for soil O_2 by soil microorganisms. Higher soil temperatures thus induce an oxygen shortage, which results in greater stomatal closure. Interestingly, crop damage caused by excessive soil water is usually more severe in warm weather than in cool weather. This follows from our results since stomatal closure due to flooding would prevent the normal transpirational cooling of plant tissues.

These findings have practical implications. When stomata are closed, we can expect not only heat stress to occur, but also photosynthesis to be reduced. These data may promote rethinking of the practice of flood-irrigating some crops, particularly on fine-textured soils, or when excessive canopy temperatures are likely. They also help us to better understand one mechanism of crop damage resulting from unwanted soil flooding.

Robert E. Sojka is Agronomist, Agricultural Research, Science and Education Administration, U.S. Department of Agriculture, Florence, South Carolina; and Lewis H. Stolzy is Professor of Soil Physics, Department of Soils and Environmental Sciences, University of California, Riverside. This article is a joint contribution of the Coastal Plains Soil and Water Conservation Research Center, USDA-SEA-AR, Florence, South Carolina, and the University of California, Riverside.

Simplified but scientific irrigation scheduling

Elias Fereres □ Patricia M. Kitlas □ Richard E. Goldfien

William O. Pruitt □ Robert M. Hagan

In the past, when irrigation water was ample and its cost negligible, the obvious management strategy was to eliminate water as a limiting factor in producing crops at the lowest possible cost. As irrigated agriculture competes for the limited water supplies and costs of both energy and water rise, effective on-farm water management programs are needed to maximize irrigation efficiency. This report describes a new approach to developing and disseminating irrigation scheduling information among California's agricultural water users.

In designing their seasonal water-management programs, farmers are confronted with three essential questions: (1) how often should each field be irrigated; (2) how much water should be applied at each irrigation; and (3) which irrigation management techniques should be used to efficiently apply the needed amounts of water at the appropriate levels? Although we address only the first two questions here, the answers may be academic without evaluating the adequacy and efficiency of individual irrigation practices.

Among the many procedures commonly used to schedule irrigations, the water-budget method is the most prevalent. In the water budget the crop root zone is visualized as a reservoir of crop-available water. Water is withdrawn from the reservoir through evapotranspiration (ET) or drainage and added through rainfall and irrigation. If the volume of the reservoir and the amount that can be used without stressing the plant (called the allowable depletion [AD]) are known, along with the depletion rate (ET), the date of the next irrigation can be predicted. Effectiveness of the method hinges on an accurate determination of AD and ET. Research over many years has established the ET requirements of several crops in California and made possible the day-by-day prediction of ET. Water retention properties of the principal soils are also well known, as are typical rooting depths of many crops. What is now needed is to make this information available in a form that the average farmer or irrigator can use.

A useful characteristic of summer weather in California's interior valleys is the constancy in evaporative demand. The absence of rainfall and the small year-to-year variations in summer weather make long-term averages of weather parameters attractive for use in prediction. Early studies conducted by the University of California at Davis and the State Department of Water Resources in several locations throughout the Central Valley documented the variability in ET rates during the irrigation season, indicating that 90 percent of the time, 10-day to 2-week forecasts of ET based on long-term averages are within 10 percent of actual ET.

The relative constancy in ET demand during a good part of the irrigation season and the availability of long-term ET records and accurate crop coefficients for many crops in the Central Valley make it possible to use average or normal year crop ET to predict irrigation dates and amounts for management purposes. Recently, many large-scale irrigation scheduling programs have been implemented by various agencies and private consultants. Computer programs based on the water-budget concept are now being used to help provide irrigation scheduling services in large areas of the western states.

Field verification of computer predictions is necessary, however, because of uncertainty