tion, conservation of soil water may result in greater soil evaporation, especially if the top soil layers remain wetter, and the full benefit of sustained plant physiological activity will be lost. Therefore, the relative benefit of the two traits depends on temporal pattern in the rainfall and severity of the drying event. Experimental and simulation studies are presented in the book to indicate the environment conditions and locations where each of the water-conservation traits may result in increased high probability of yield increase.

This book offers a review of both water-conservation traits and their potential impact on crop yield. Since there are major differences among crop species, this book is organized to present various crop species individually. These case studies include many of the major global crop species. However, before considering each of the species, the first two chapters background the nature of each of the water-conservation traits. The goal of the book is to provide a report on the current status on the water-conservation traits by partial stomatal closure at earlier stages of soil drying and under elevated VPD. In addition, suggestions for further exploitation of these two traits are discussed.

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Chapter 2
Early Partial Stomata Closure with Soil Drying

Thomas R. Sinclair

Soil drying has long been recognized as a major limitation on plant gas exchange, mediated by early partial stomatal closure. To quantify the response of stomata to water deficit, relationships have been explored between stomatal conductance and bulk leaf water potential. Unfortunately, unique relationships could not be established, likely as a result of the ephemeral nature of water potential. Leaf water potential itself is dependent on the water balance of the leaf and hence responsive to stomatal conductance. Further, the difficulty in measuring or estimating leaf water potential makes it ill-suited as an independent variable in estimating stomatal conductance in the field (Bennett et al. 1987). An alternative approach that has proved to provide a more stable and consistent independent parameter in defining water-deficit stress for plants has been soil volumetric water content (Sadras and Milroy 1996). Hence, the soil volumetric water content at which partial stomatal closure is initiated is a critical variable in comparing the sensitivity of plants to soil drying. Those plants that initiate stomatal closure at higher soil water contents causing soil water conservation and allowing water use to be spread over more days result in sustained crop physiological activity during the ongoing development of water deficit.

2.1 Background for Stomatal Response to Soil Drying

About 75 years ago, Martin (1940) and Kramer (1944) related plant water loss to volumetric soil water content. They reported that there was little change in water loss rate until about two-thirds of the extractable soil water was removed from the soil. Ritchie (1981) formalized the relationship by suggesting that expressing water

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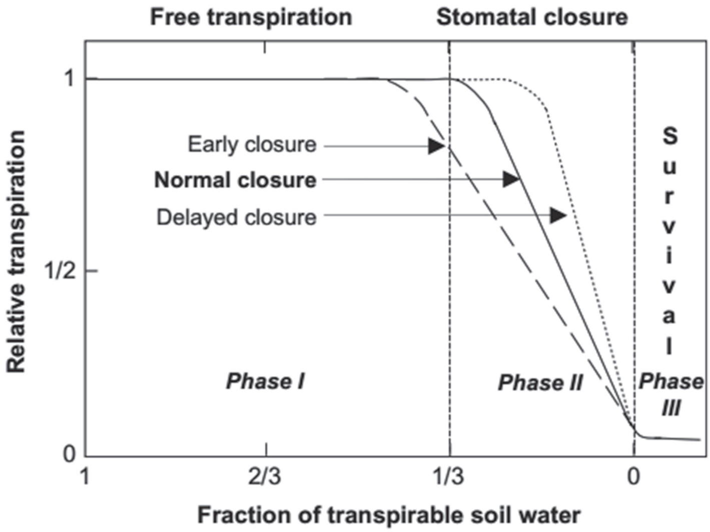

Fig. 2.1 Plot of transpiration rate of plant subjected to soil drying relative to well-watered plants versus the fraction of transpirable soil water (FTSW) remaining in the soil (Sadok and Sinclair 2011). The FTSW value of 1 is pot or field capacity, and a value of 0 is when relative transpiration has reached a value of 0.1 indicating little leaf gas exchange, and transpiration rate is no longer decreasing linearly

loss as a fraction of the extractable soil water resulted in a similar response function that was appropriate for a number of crop species and under a range of conditions.

Figure 2.1 illustrates the changes in transpiration as soil water content decreases. In this illustration, the amount of water in the soil is expressed as the fraction of the water that is used by the plant to support transpiration, i.e., fraction transpirable soil water (FTSW). Phase I is when water is readily available to the plant, and there is usually no limitation on transpiration rate. However, eventually the soil dries to a point, usually around 1/3 FTSW, where transpiration rate decreases. This point is the initiation of Phase II in soil drying. In Phase II, transpiration rate decreases approximately linearly with further decreases in soil water content until soil water available to support transpiration is exhausted, i.e., FTSW = 0 (Fig. 2.1). At FTSW = 0, the plant is substantially stressed and in nearly all cases wilted, but senescence has not yet occurred. Phase III is the survival phase where stomatal closure allows low amounts of water loss rates as defined by the leaf epidermal conductance. Of course, under this situation there is very little or no CO_2 diffusion into the leaf.

The transition from Phase I to Phase II generally occurs at about 1/3 FTSW. Sadras and Milroy (1996) concluded in their review that the range for this transition was about 0.25–0.40 fraction extractable soil water. The basis for such a general pattern in transpiration response to soil drying was suggested by Sinclair (2005) to be a consequence of decreasing soil hydraulic conductivity with soil drying. Figure 2.2 shows the calculated response in relative transpiration rate with decreasing FTSW

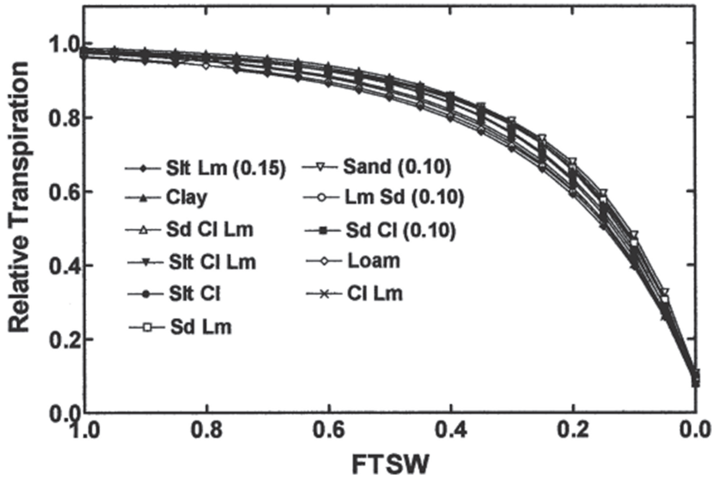

Fig. 2.2 Derived transpiration rate at various fraction transpirable soil water (FTSW) contents based on changes in soil conductivity with soil drying (Sinclair 2005)

for several soils. In these calculations there is a nonlinear decrease in relative transpiration, but the major change is initiated at about 1/3 FTSW.

The basis for initiation of early stomatal closure with soil drying is not resolved. An obvious hypothesis is that those genotypes with early closure may have low plant hydraulic conductivity resulting in a combined low soil conductivity and low plant conductivity causing the threshold for the initiation of decrease in stomatal conductance to occur at higher soil water content. This hypothesis was not supported, however, by measurements of plant conductivity of well-watered sorghum plants. Choudhary and Sinclair (2014) found those genotypes that had thresholds for initiation of stomatal closure at higher soil water content actually had higher plant hydraulic conductivity. However, they did not test for possible differences in decreases in plant conductivity among genotypes as the soil dried, which is a possible explanation for genetic differences in the threshold for decrease in stomatal closure.

2.2 Consequences of Early Stomatal Closure

Partial stomatal closure with soil drying will, of course, result in restricted plant gas exchange. The immediate negative consequence of partial closure is a decrease in CO_2 assimilation with a long-term possibility of yield decrease. The positive consequence of partial stomatal closure is that transpiration rate is decreased so that there is conservation of soil water. The initiation of soil water conservation will better position plants to sustain physiological activity over a longer time period as drought develops than those plants that delay stomatal closure until a lower FTSW is

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