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High Temperatures Increase Water Stress in Corn

Key Points:

- Higher temperatures cause the transpiration rate of plants to increase, placing a greater demand on soil water supply and accelerating the onset of drought stress.
- The increased water demand under extreme heat is substantial – raising temperature from 80 °F to 95 °F (27 °C to 35 °C) causes water demand to double
- Corn plants respond to water stress by closing their stomates, which helps preserve water but also reduces intake in CO_2 needed for photosynthesis.

Extreme Heat Increases Water Stress

- High temperatures can impact corn directly by reducing pollination and net photosynthesis, but the greater impact comes through the interaction of heat and water stress.
- Higher temperatures create a higher vapor pressure deficit (VPD) between the saturated leaf interior and the ambient air.
- This causes the transpiration rate of plants to increase, placing a greater demand on soil water supply and potentially accelerating the onset of drought stress.

Figure 1. Corn showing the effects of extreme heat and drought stress in central Iowa in 2012.

Vapor Pressure Deficit

- Vapor pressure deficit (VPD) combines relative humidity (RH) and temperature into a single variable to describe the evaporative potential of the atmosphere.
- Air space in the interior of living plant tissue is essentially fully saturated with water (100% RH).
- Water vapor moves from an area of higher concentration to an area of lower concentration.
- As long as the ambient air is less than 100% humidity, it will pull water out of plant leaves, driving transpiration of water through the plant.
- The greater the vapor pressure deficit between the leaf interior and the surrounding air, the faster the rate at which water will be pulled out of the plant and evaporated.
- Temperature is important to this equation because VPD increases exponentially with increasing temperature, even if relative humidity stays constant (Figure 2).

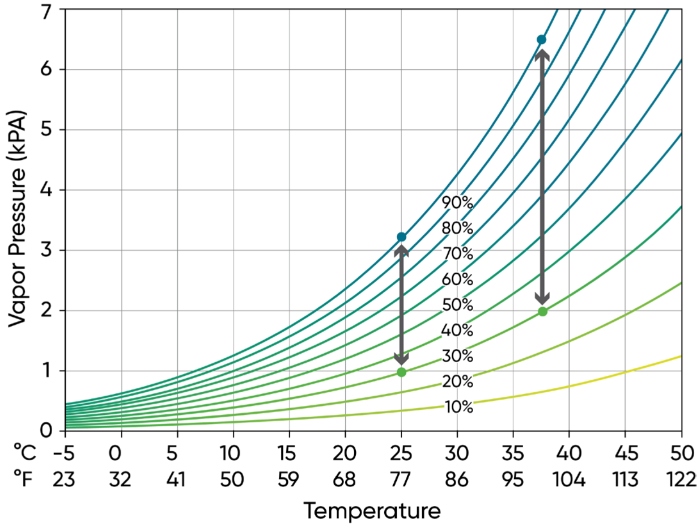


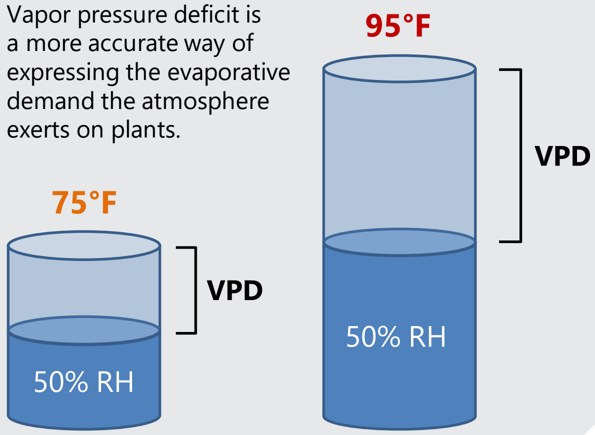
Figure 2. Vapor pressure for water by relative humidity and temperature. As temperature rises, the difference in vapor pressure between the interior of plant leaves and the ambient air increases.

Corn Response to High Vapor Pressure Deficit

- Corn plants respond to higher VPD by closing their stomates, which helps preserve water for periods when evaporative demand is lower (Figure 3).
- Reduced stomatal conductance also reduces the rate at which plants are able to take in CO_2, which lowers the rate of photo-synthetic carbon fixation during high-VPD portions of the day.
- Field experiments conducted in an environment in which temperatures reached daily highs in the mid-90s (F) showed reduced photosynthesis and growth of corn associated with high VPD (Hirasawa and Hsiao, 1999).
- On days with high atmospheric VPD, photosynthetic rate and stomatal conductance peaked during late-morning and then declined throughout the afternoon as temperature and VPD continued to climb (Figure 4).
- Even in irrigated plots, this afternoon depression in photosynthetic rate was apparent, although decline was much greater in non-irrigated plots (Figure 5).

Vapor Pressure Deficit vs. Relative Humidity

- How does VPD differ from relative humidity?
- Relative humidity refers to the amount of water vapor in the air versus what it can hold; however, the amount of water air can hold varies with temperature.
- If you think of the atmosphere as a container holding water, that container gets bigger as temperature increases so it takes more water to fill it.
- Vapor pressure deficit is a more accurate way of expressing the evaporative demand the atmosphere exerts on plants.



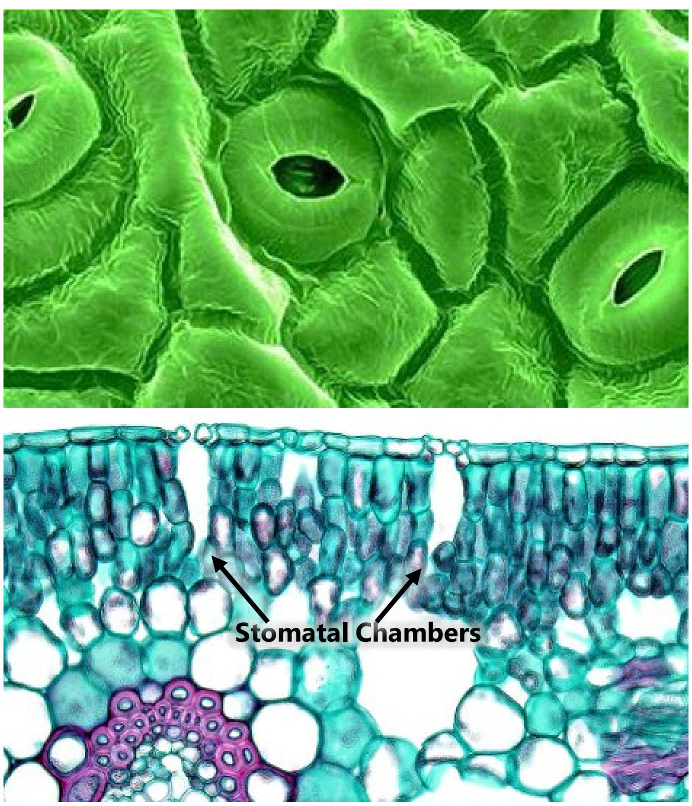


Figure 3. Stomatal pores and stomatal chambers. Stomatal pores allow for the exchange of water and CO_2 between the atmosphere and leaf internal structures. Stomatal chambers serve as locations where liquid water converts to water vapor and escapes into the atmosphere. There are approximately 36,000 stomates/in^2 on the upper surface and 50,000 stomates/in^2 on the lower surface of a corn leaf.

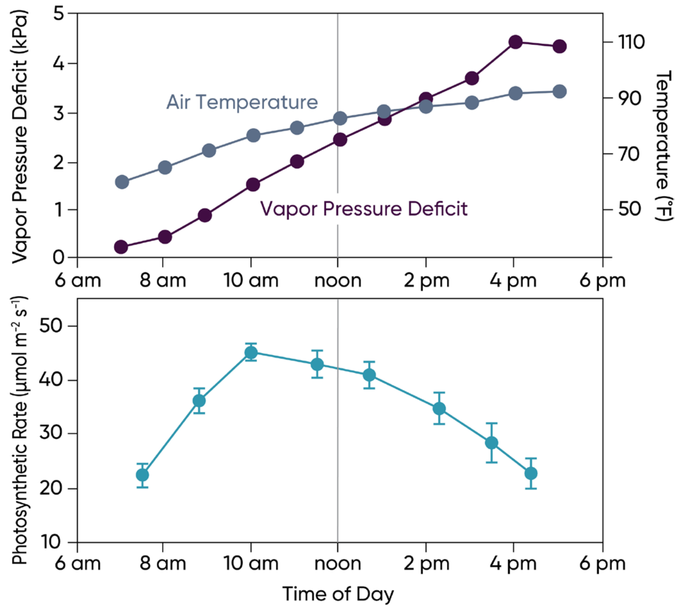


Figure 4. Air temperature, atmospheric vapor pressure deficit, and leaf photosynthetic rate in irrigated corn over the course of a day (Hirasawa and Hsiao, 1999).

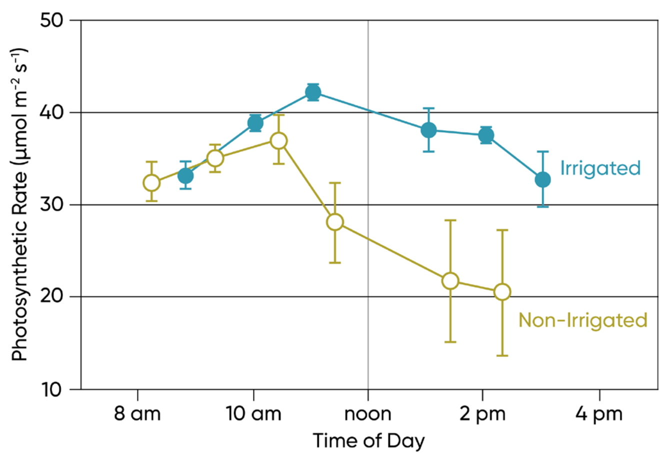


Figure 5. Leaf photosynthetic rate by time of day for irrigated and non-irrigated corn (Hirasawa and Hsiao, 1999).

Extreme Temperatures Increase VPD

- The increased water demand under extreme heat is substantial – **raising temperature from 80 °F to 95 °F (27 °C to 35 °C) causes water demand to double** (Lobell et al., 2013).
- The damage caused by extreme heat can be partially mitigated by increased precipitation, but not eliminated (Roberts et al., 2013).
- Lobell et al. (2013) compared the water stress effect caused by a 20% reduction in precipitation over month-long period with that caused by a 2 °C increase in temperature over the same time period and found that increased temperature had a greater impact on water stress than reduced precipitation.
- Total seasonal rainfall was found to have a relatively weak relationship with corn yield, indicating that water *demand* can matter as much or more than water *supply*.

Hirasawa, T. and T.C. Hsiao. 1999. Some characteristics of reduced leaf photosynthesis at midday in maize growing in the field. Field Crops Research 62:53-62; Lobell, D.B., G.L. Hammer, G. McLean, C. Messina, M.J. Roberts, and W. Schlenker. 2013. The critical role of extreme heat for maize production in the United States. Nature Climate Change 3:497-501; Roberts, M.J., W. Schlenker, and J. Eyer. 2013. Agronomic weather measures in econometric models of crop yield with implications for climate change. Am. J. Agricult. Econom. 95:236-243.