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Separating stomatal and non-stomatal responses of gross primary productivity to soil moisture

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Soil moisture is a major constraint on terrestrial gross primary productivity (GPP). In this study, we propose and test two hypotheses to explain how soil moisture limits carbon uptake: 1) plants reduce stomatal conductance around midday to conserve water, leading to a temporary decline in internal CO concentration and photosynthesis; and 2) water stress causes a more general reduction in photosynthetic capacity, expressed as a decrease in the quantum efficiency of photosynthesis (φ), thereby lowering GPP throughout the day. Here, we combine Eco-Evolutionary Optimality (EEO) Theory with eddy covariance observations to separate and quantify stomatal and non-stomatal responses of GPP to soil moisture. Our results show that both midday stomatal closure and photosynthetic capacity suppression coexist, supporting both hypotheses, with their relative importance strongly modulated by soil moisture. Across most sites, the magnitude of midday GPP depression weakens with increasing soil moisture, indicating that stomatal responses are more sensitive under low soil moisture conditions. In addition, photosynthetic capacity increases with soil moisture, contributing to an overall enhancement of daily GPP. By explicitly separating stomatal and non-stomatal pathways through which soil moisture affects carbon uptake, this study provides a mechanistic explanation for the more conservative water use strategies observed in plants from dry climates and improves the representation of diurnal GPP dynamics in water-limited ecosystems.