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Salinity controls on the coupled transport of water and carbohydrates in plants

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Few dispute the claim that soil salinization is a major threat to food security and sustainable development of arid and semi-arid regions. In response to this threat, salt-tolerant plants (halophytes) are now being promoted as a significant component in future agro-systems. The first step towards assessing the potential of halophytic agriculture entails an in-depth inquiry into how salinity regulates the leaf-level gas exchange of water and carbon dioxide, carbohydrate production and their translocation within the plant, where they are ultimately used to produce biomass. The controls exerted by salinity on carbon allocation strategies and, ultimately, on crop yield depend on how salt concentration limit water, CO_2, and carbohydrate movement within the soil-plant system. Although a number of experiments have been performed to measure these variables at the ecosystem scale and leaf level, the link between salinity and plant-water relations remains a formidable scientific challenge and a subject of inquiry. The major obstacle to progress remains the difficulty in simultaneously measuring leaf-level gas exchange, water movement in the plant system, and carbohydrate transport in the phloem. On the theoretical side, developing the transport laws governing water and carbohydrate movement in the plant as well as their interaction with leaf-level processes in the presence of fluctuating environmental conditions and salinity remains complex and forbidding. Here, the short-term impacts of salinity on plant-water relations are considered using a physically based model that combines leaf-gas exchange theories of biochemical demand and atmospheric supply with the Munch osmoregulation mechanism in the phloem and cohesion-tension theory in the root-plant xylem. The proposed formulation remains mathematically ‘unclosed’ requiring an additional expression for stomatal conductance or leaf water pressure. To arrive at this ‘missing’ expression, three hypotheses are put forth and are formulated as ‘goal-seeking’ objectives by the plant. The first is a conventional representation that assumes plants maximize water uptake to maintain leaf turgor and elevated stomatal conductance. The second postulates that plants maximize instantaneous carbon gain for a given amount of saline water uptake. The third assumes that plants regulate leaf-water potential to maximize carbohydrate export from the source (i.e., leaf) to the sinks. In this contribution, these three different hypotheses are separately formulated as constraints on the aforementioned transport model through the xylem, leaf gas exchanges (H_2O and CO_2), and carbohydrate loading into the phloem. The mathematical framework explicitly accounts for salinity in the soil and within the plant. This model allows evaluation of the impacts of salinity on plant productivity across different levels of salt tolerance as well as the possible “stress-mitigation effect” of future atmospheric CO_2 enrichment for all three goal-seeking objectives.