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Impact of Water Constraints on Tree and Forest Growth

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Tree growth is intimately linked to water use, as in all terrestrial plants. Photosynthetic production requires CO2 uptake through stomatal pores in the leaf surfaced, and because most terrestrial plants grow in an environment with less than 100% air humidity, water from the wetter leaf interior is lost to the atmosphere when stomatal pores are opened to let CO2 in. Water loss from the foliage is the price a plant has to pay for CO2 uptake. From the physical transport processes involved, the water loss invoked by CO2 uptake and photosynthesis can be calculated, as well as the efficiency of water use: the amount of water lost per amount of CO2 uptake. Next, detailed models of canopy microclimate can be used to characterise the immediate surroundings of a leaf, and by upscaling throughout the canopy, total stand evapotranspiration can be derived from weater conditions above the canopy, and the surface characteristics of the forests.

As part of these surface characteristics, the degree of opening of the stomatal pores is crucial. This determines the trade-off between water loss from the foliage, leading to dessication when water supply from the soil is limited, and uptake of CO2, which is necessary to maintain the photosynthesis process. The opening of stomatal pores depends on metabolic activity (notably photosynthesis as induced by interception of light, amount of photosynthetic enzymes, and temperature in the leaf interior), and on leaf water status. Also for this biophysical control of stomatal opening, detailed models can be derived. As a result, it is possible to quantify water relations of trees and stand with a high degree of detail. Detailed process-based models of canopy photosynthesis and transpiration have been validated against measurements of CO2 uptake and water loss, and can now be used to quantify the link between water availability and growth of trees and stands. Using such models, the impacts of changes in weather conditions, as well as changes in soil water availability can be studied, e.g. when soil drainage alters water availability for the trees. More recent applications include temperature increases associated with climate change, that increase evaporative demand of the air and subsequent water loss by transpiration.

When trees and stands develop, water availability and xylem conductance in combination with the local environmental conditions determine, within the constraints of the morphogenetic growth pattern, the distribution of biomass over fine roots, conducting tissue (coarse roots, stems and branches) and foliage. This is to ensure that a functional balance can develop between these tissues. Under dry conditions, more fine roots develop relative to transpiring leaf surface, whereas under wet conditions more foliage is formed. Dry in this case can dry atmospheric conditions, dry soil, or a combination of the two. When trees grow taller and bigger, water limitations may become more limited as the distance between uptake and loss through transpiration becomes larger. As a result of this, xylem resistance to transport of water may increase. In addition, the sheer height above the ground of the foliage induces a gravitation effect whereby stomates will close earlier during the day, and CO2 uptake is increasingly hampered, even under conditions of ample water supply. This partly explaines why tree growth and stand productivity may decline at higher tree age.

On sites where water is severly limited, as in dry Mediterranean regions or in Savanna climates, these processes lead to low tree height, low total leaf area, and open stands of low stem density. Because of the functional acclimation of trees to site conditions, any change in site conditions, e.g. associated with climate change, requires adjustment of this functional balance. Because of this, water relations of trees and stands play a crucial role in the resilience of forest ecosystems to changes in growing conditions associated with global climate change. Because of the relevance of tree water relations in the structural development of trees and forests, and because of the fact that water availability is already a limiting factor in many forested areas, a good understanding of tree water relations is crucial for the analysis of forest resources and forest productivity under climate change.