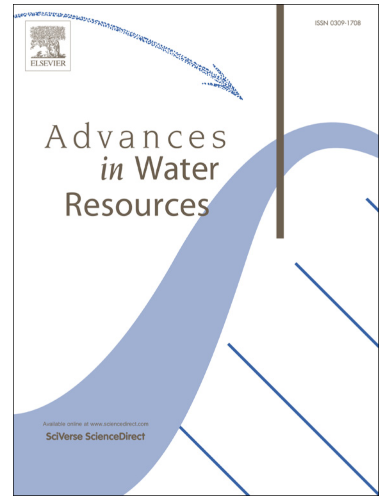

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Optimal Root Profiles In Water-Limited Ecosystems

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Abstract

The vertical distribution of roots in the soil is of central importance to the mass and energy exchange between the land and the atmosphere. It has been demonstrated that the vertical root profiles which maximize transpiration in numerical experiments reflect well the characteristics of root profiles observed in nature for water-limited ecosystems. Previous research has demonstrated how the optimal vertical root profile depends on both the Mean Annual Precipitation (MAP) and the soil texture. Recently, in the climate literature, it has been suggested [5] that increased greenhouse forcing in the tropics can lead to a simultaneous decrease in the frequency and increase in the intensity of precipitation. In this paper we demonstrate how such a change in the statistical structure of rainfall, even with no change to MAP, requires deeper root distributions to maintain optimal water use. These results raise interesting questions for future studies of nutrient dynamics, the cost of additional below ground carbon allocation, and inter plant functional type competition.

Keywords: Root distribution, Kalahari, Richards Equation, Ecosystem hydraulic dynamics

1. Introduction

A plant's growth, reproduction, and survival all depend on the plant's ability to absorb soil moisture through its root system [17, 18]. As root distributions are controlled by the survival strategy of the plant, optimization concepts have been used to identify ideal root distributions based on ecohydrological facets of the soil-plant-atmosphere system [19]. In this paper we focus on water-limited ecosystems and identify vertical root profiles that maximize transpiration in order to explore how potential shifts in the temporal structure of rainfall might affect competition between different rooting strategies, as well as how herbaceous plants would need to adjust their root profile to remain optimal in its access to water.

Knowledge of the active root layer is essential for the study of water and nutrient dynamics as needed in atmospheric science, hydrology, ecology, and geochemistry (e.g. Bhattachan et al. [2]). There are several factors that influence root depths and distributions. For example, Schenk and Jackson found a positive correlation between rooting depths and annual potential evapotranspiration (PET), mean annual precipitation (MAP), and length of the warm season [28]. In particular, Schenk and Jackson were able to use MAP to explain 62% of the observed variance in median rooting depths for herbaceous plants in water-limited ecosystems [29].

It has also been shown that root distributions [12] and absolute root depths [3] vary by vegetation type. As mentioned above, Schenk and Jackson found a positive correlation between MAP and median root distributions for herbaceous plants [29, 28], however, Bhattachan et al. showed that this correlation may not apply to woody root distributions [2].

The primary role of roots is soil water extraction to support transpiration at the leaf surface as occurs during photosynthesis. Therefore, one can think of the optimal root system as one which best supports photosynthesis.

Kleidon and Heimann [14] estimated optimal root depths by maximizing the carbon gain to the vegetation within a global Terrestrial Biosphere Model. Schwinning and Ehleringer explored potential trade-offs in water uptake and carbon cost by developing a simple model of plant water transport and carbon gain in a two-layered soil environment [30]. Similarly, Guswa provided a cost-benefit analysis of root structures [10, 11], where the optimal root depth was balanced by the carbon cost of forming the root structure.

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