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Root Biomass and Distribution Patterns in a Semi-Arid Mesquite Savanna: Responses to Long-Term Rainfall Manipulation

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Abstract

Expansion of woody plants in North American grasslands and savannas is facilitated in part by root system adaptation to climatic extremes. Climatic extremes are predicted to become more common with global climate change and, as such, may accelerate woody expansion and/or infilling rates. We quantified root biomass and distribution patterns of the invasive woody legume, honey mesquite (*Prosopis glandulosa*), and associated grasses following a long-term rainfall manipulation experiment in a mixed grass savanna in the southern Great Plains (United States). Root systems of mature trees were containerized with vertical barriers installed to a depth of 270 cm, and soil moisture was manipulated with irrigation (Irrigated) or rainout shelters (Rainout). Other treatments included containerized, precipitation-only (Control) and noncontainerized, precipitation-only (Natural) trees. After 4 yr of treatment, soil cores to 270 cm depth were obtained, and mesquite root length density (RLD) and root mass, and grass root mass were quantified. Mesquite in the Rainout treatment increased coarse-root ($>$ 2 mm diameter) RLD and root mass at soil depths between 90 cm and 270 cm. In contrast, mesquite in the Irrigated treatment increased fine-root ($<$ 2 mm diameter) RLD and root mass between 30 cm and 270 cm depths, but did not increase total root mass (fine+coarse) compared to the Control. Mesquite root-to-shoot mass ratio was 2.8 to 4.6 times greater in Rainout than the other treatments. Leaf water stress was greatest in the Rainout treatment in the first year, but not in subsequent years, possibly the result of increased root growth. Leaf water use efficiency was lowest in the Irrigated treatment. The increase in coarse root growth during extended drought substantially increased mesquite belowground biomass and suggests an important mechanism by which woody plant encroachment into grasslands may alter below ground carbon stocks under climate change scenarios predicted for this region.

Key Words: carbon isotope ratio, carbon sequestration, climate change, leaf water potential, root-to-shoot ratio, woody plant encroachment

INTRODUCTION

Woody plant encroachment into grass-dominated systems has been among the most important global land cover changes over the past two centuries (van Vegten 1983; Scholes and Archer 1997; Van Auken 2000, 2009; Archer et al. 2001; Tape et al. 2006; Maestre et al. 2009). This dramatic and geographically widespread vegetation change appears to be driven primarily by land uses including reduced fire frequency and livestock grazing, but may also be a response to environmental changes such as increased atmospheric CO_2, increased atmospheric deposition, and climate change (Archer et al. 1995; Kramp et al. 1998; Bond and Midgley 2000; Asner et al. 2004; Wigley et al. 2010). Although this vegetation change is well-documented and widely reported, the causes and potential consequences at ecosystem to global scales remain poorly understood.

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In the southern Great Plains region of North America, the leguminous tree/shrub honey mesquite (*Prosopis glandulosa* Torr. var. *glandulosa*) has increased dramatically in abundance during the past 150 yr, and now covers $>$ 20% of the land surface in large portions of this region (Shelford 1963; Johnson and Mayeux 1990). This deep-rooted, nitrogen-fixing woody species has significantly altered above- and belowground primary productivity, biogeochemistry, and hydrologic processes at ecosystem to regional scales (Schlesinger et al. 1990; Boutton et al. 1999, 2009; Archer et al. 2001; Asner et al. 2003; Zou et al. 2005; Dai et al. 2006; Hughes et al. 2006; Boutton and Laio 2010).

A key biological attribute that has likely enabled mesquite to expand its range and dominance in this region is a dimorphic root system comprised of shallow lateral roots that can extend well beyond the canopy drip line, as well as a deep taproot (Heitschmidt et al. 1988; Ansley et al. 1990; Gile et al. 1997; Gibbens and Lenz 2001). The taproot accesses deeper water during drought; however, on sites with limited deep water, mesquite can also adjust leaf water potential, stomatal conductance, and whole plant leaf area during droughts (Ansley et al. 1992, 1998). While many studies have documented point-in-time root distribution of perennial shrubs in arid and semi-arid (i.e., "dryland") ecosystems (Castellanos et al. 1991; Jackson et al. 1996; Gibbens and Lenz 2001;