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Plant gas exchange and water status in urban desert landscapes

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Gas exchange and water status were evaluated for plants at irrigated residential and unirrigated remnant Sonoran Desert sites in the greater Phoenix area, Arizona, U.S.A. Gas exchanges fluxes were higher for plants at the residential sites than for those at the desert sites. Plant water status was more favorable at residential sites for every season except the late summer monsoon, and time of day for maximum photosynthesis was later for residential plants during summer and winter months. These data suggest that yearly CO_2 uptake was a function of plant water status and summer heat stress, and land use in these urban desert landscapes.

Keywords: conductance efficiency; irrigation; landscape design; photosynthesis; water potential; water use efficiency

Introduction

Cities in arid ecosystems are rapidly expanding worldwide. Phoenix, AZ, is one of the most rapidly growing metropolitan areas in the U.S.A. Phoenix is situated in Maricopa County in the lower Salt River basin of the Sonoran Desert. According to the United States Census, Maricopa County added more residents than any other county in the U.S.A between 1990 and 1996 (U.S. Census) with land development occurring at a rate of over 1 acre h^{-1} (Morrison, 1998). Prior to 1970, urban residential and commercial development in Phoenix occurred mostly on agricultural lands. More recently, urban sprawl of the Phoenix metropolitan area has encroached onto large tracts of Sonoran Desert lands previously undisturbed by agricultural activities.

The abundance, diversity, and distribution of managed vegetation in Phoenix differ greatly from that of the surrounding desert because human preferences and anthropogenic activities dictate the community structure of urban and suburban landscape plantings (Peterson & Martin, 2000). Historically, the character of urban vegetation in Phoenix has been that of an oasis, and has been typified by landscape greenery. Prior to the advent of air conditioning in the early 1960s, amenity landscapes exemplified by large shade trees, lush vegetation and grassy lawns called

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mesiscapes, were commonly planted. Since the late 1980s, public policy has shifted towards advocating xeriphytic plants for amenity landscaping purposes because of concerns about the distribution, abundance, and quality of fresh water resources. Many municipalities in the Phoenix metropolitan area and the south-western United States encourage installation of water conserving landscape designs called xeriscapes, and some offer financial incentives to convert more traditional mesic landscapes to xeriscapes that are assumed to be more water conservative (Arizona Department of Water Resources, 1988). It is not known to what extent these practices affect patterns of urban landscape carbon and water cycling in the Phoenix area.

Stomata control the carbon–water balance of plants by acting as antiportals for diffusive CO_2 uptake and water vapor loss (Farquhar & Sharkey, 1982). In undisturbed desert systems, conservation of water via stomatal closure limits CO_2 assimilation (A) in most C_3 plant species (Szarek & Woodhouse, 1977; 1978). Instantaneous water-use efficiency has been defined as the ratio of A to transpiration (E) fluxes (Eamus, 1991), and is a function of several factors, including plant water status, leaf temperature, and the CO_2 partial pressure within the leaf mesophyll (C_i) (Cowan, 1977; Campbell *et al.*, 1990). Under well-watered and near-optimal temperature conditions, A/E is more affected by changes in E than A, because as stomatal conductance (g_s) increases, changes in A are usually small relative to E, causing A/E to decrease rapidly (Buckley *et al.*, 1999). In theory, optimal A/E is a function of a balance between maximum uptake of ambient CO_2 (C_a) and minimal E, and might be driven primarily by C_i and regulation of g_s (Schulze *et al.*, 1975; Cowan & Farquhar, 1977; Mott, 1988). This definition of 'optimal' A/E might be useful in assessing vegetation function in urban desert ecosystems, where maximum uptake of CO_2 and minimal water loss might be considered beneficial attributes. Although Phoenix's urban plant community and xeriscape landscape designs include many drought tolerant, exotic and native species, there may be no advantage for vegetation that is adapted to desert conditions of rapid evaporation and sporadic water supplies to conserve water in irrigated desert landscapes.

Many ecological benefits have been attributed to urban vegetation, including increased water recycling relative to paved surfaces, amelioration of the urban heat island effect through shading and evapo-transpiration, and reduction of atmospheric CO_2 concentration (Botkin & Beveridge, 1997; Nowak, 1994; McPherson *et al.*, 1997). Our research aimed to determine how urban development and landscape planting designs might affect carbon and water cycling and carbon sink potential in a desert area. We hypothesized that vegetation in irrigated, managed residential landscape would have higher gas exchange fluxes than those in nearby non-irrigated, undisturbed desert areas because of differential water availability and plant water status. We also hypothesized that vegetation in residential landscapes with xeric design themes would have higher A/E than those in residential landscapes with mesic design themes because of the presence of xeriphytic vegetation and residential homeowner watering practices. To test these hypotheses, we measured maximum gas exchange fluxes of predominant, ornamental, C_3 woody plant species in mesic and xeric residential landscapes of similar age and proximity and compared them to those of C_3 woody plants in adjacent remnant Sonoran Desert patches at monthly intervals for one year. Residential land use was chosen as representative of urban vegetation in Phoenix because it constitutes the majority of urban land use by area in the Phoenix area (Maricopa Association of Governments, 1995). We also compared seasonal patterns of pre-dawn plant water potential, soil water content, and diurnal gas exchange and water content of residential and desert plants. From these data we made estimates of annual carbon acquisition potential (CAP) as an indicator of the atmospheric CO_2 sink potential of urban vegetation. During the study interval, irrigation application volumes and microclimate conditions were monitored continuously at select residential sites.