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Leaf and Ecosystem Gas Exchange Responses of Buffel Grass-Dominated Grassland to Summer Precipitation

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ABSTRACT

Sporadic rain events that occur during summer play an important role in the initiation of biological activity of semi-arid grasslands. To understand how ecosystem processes of a buffel grass (*Cenchrus ciliaris* L.)-dominated grassland respond to summer rain events, an LI 6 400 gas exchange system was used to measure the leaf gas exchange and plant canopy chambers were used to measure net ecosystem CO_2 exchange (NEE) and ecosystem respiration (R_{eco}), which were made sequentially during periods before rain (dry) and after rain (wet). Gross ecosystem photosynthesis (GEP) was estimated from NEE and R_{eco} fluxes, and light use efficiency parameters were estimated using a rectangular hyperbola model. Prior to the monsoon rain, grassland biomass was non-green and dry exhibiting positive NEE (carbon source) and low GEP values during which the soil water became increasingly scarce. An initial rain pulse (60 mm) increased the NEE from pre-monsoon levels to negative NEE (carbon gain) with markedly higher GEP and increased green biomass. The leaf photosynthesis and leaf stomatal conductance were also improved substantially. The maximum net CO_2 uptake (*i.e.*, negative NEE) was sustained in the subsequent period due to multiple rain events. As a result, the grassland acted as a net carbon sink for 20 d after first rain. With cessation of rain (drying cycle), net CO_2 uptake was reduced to lower values. High sensitivity of this grassland to rain suggests that any decrease in precipitation in summer may likely affect the carbon sequestration of the semiarid ecosystem.

Key Words: biomass, CO_2 exchange, photosynthesis, respiration, soil moisture, stomatal conductance

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INTRODUCTION

Arid and semiarid lands cover approximately 41% of the world area (Reynolds *et al.*, 2007) and are considered important organic carbon (C) sink, storing between 750 and 950 Pg of carbon (Eswaran *et al.*, 2000). The extent and distribution of arid and semiarid lands are subject to modification because of changing climate, fire and land use (Asner *et al.*, 2003). In India, semiarid lands have resulted from excessive forest clearing and are located mainly on the Deccan Plateau and the eastern side of Western Ghats, where the region experiences semiarid climate and is considered as one of the most important agro-ecological zones in India (Tejwani, 1994; Planning Commission, 2007).

Buffel grass (*Cenchrus ciliaris* L.) is a perennial pasture grass that commonly dominates in the semiarid regions and is widely planted in India for cattle fodder and livestock production (Batra and Kumar, 2002). Though it is moderately palatable and contains 6%–16% dry matter crude protein, it is regarded as a pasture because of its high biomass production (Jacobs *et al.*, 2006). Buffel grass is a low water-demanding grass that grows rapidly under warm condition, and persists even under the heavy grazing and drought conditions (Lazarides *et al.*, 1997; Nawazish *et al.*, 2006). Though it is exotic to India, its C_4 photosynthetic metabolism supports substantial productivity and enables it to spread well beyond the planted areas, offering it a competitive advantage over the native herbaceous vegetation (Sage and McKown, 2006). In some tropical semiarid regions, it invades wetter and more fertile parts of the landscape that are important for the survival of native plant communities (Dixon *et al.*, 2002; Cook *et al.*, 2005).

The semiarid regions are characterized by low, erratic and infrequent rainfall events, high temperatures and high evapotranspiration. Most of the precipitation

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in this region occurs during late summer when the vegetation is mostly sparse and dormant and soil is dry. Sporadic rain events, depending on the pulse size, trigger variety of biogeochemical and biological transformations within the ecosystem. The immediate ecosystem responses include the wetting of the uppermost soil layer and increases in soil water potential (Sala and Lauenroth, 1982). For the semiarid regions, precipitation pulse size between 10 and 25 mm is normally required for the triggering of seedling emergence and plant establishment (Noy-Meir, 1973; Sala *et al.*, 1982; Bowers, 1996; Huxman *et al.*, 2004). As reported in the semiarid ecosystems dominated with deserts and deciduous shrubs and in some C_4 grasses, a rainfall pulse of 5 mm or above can trigger microbial activity and release of nutrients (Austin *et al.*, 2004, Huxman, 2004), and can increase leaf water status and plant carbon fixation (Sala and Lauenroth, 1982; Nobel, 1994; Emmerich, 2003; Lalrammawia and Paliwal, 2010; Scott *et al.*, 2010), which all eventually translate into growth of new vegetative structural biomass. Thus, the precipitation input during summer is critically important and likely to affect the ecosystem production through the direct effects of altered soil water availability and, thereafter, plant processes.

Although several studies have investigated the role of summer precipitation on the plant function and productivity of several semiarid ecosystems, information is still lacking for buffel grass-dominated semiarid grassland found in India. How changes in soil water resulting from sporadic summer rainfall influence leaf phenology, plant and ecosystem-level CO_2 exchange and biomass development in this ecosystem remains to be investigated. The main objectives of the present study were to evaluate the leaf and plant CO_2 exchange of a buffel grass-dominated grassland during periods prior to rain (dry) and after rain (wet) and to study the influence of ecosystem processes on the grassland productivity.

MATERIALS AND METHODS

Site description

The experimental site was located in the botanical garden of Madurai Kamaraj University, Madurai (10°00′ N, 78°10′ E, 133 m a.s.l.), Tamil Nadu State of India. The site topography is relatively flat. It is an undisturbed site with pure stands of *C. ciliaris* and has been protected from animal grazing for about 20 years. The climate in Madurai is usually semiarid with a warm winter and hot summer and average annual rainfall is 600 mm. The soil type is reddish-brown lateritic loam with pH of 8.5, bulk density of 1.54 g cm^{-3} and water holding capacity of 34.3%.

Environmental variables and CO_2 exchange measurements

Daily precipitation and temperature were measured from a weather station at Madurai Airport (13 km from the study site), which is assumed to be representative for the study region. Photosynthetic photon flux density (PPFD, μmol photons m^{-2} s^{-1}), air temperature (T_{air}, °C) and soil temperature (T_{soil}, °C) were recorded at the study site during gas exchange measurements. A quantum sensor (190 S, LI-COR Biosciences, USA) for PPFD measurements was mounted on a vertical bar above the canopy inside the chamber. A LI-6400 (LI-COR, USA) gas exchange system was used to measure the vapor pressure deficit (VPD) along with each leaf CO_2 exchange measurement. Soil temperature at 10 cm depth was measured using digital thermometers (Einstich thermometer, Conrad, Germany). All micro-meteorological variables at the site were recorded at 5-min intervals.

CO_2 exchange measurements were conducted between August 3 and September 21, 2007. For CO_2 exchange measurements, three replicated plots of 15 m by 15 m were randomly established in the grassland site with a distance of about 3 m between the plots. During each measurement campaign, one soil collar was established in each of 15 m by 15 m plots. The soil collar had a base area of 39.5 cm × 39.5 cm and 7 cm height, externally fitted with a 3 cm wide platform (3 cm from the top) on which the chamber rested. They were inserted 4 cm into the soil at least 2–3 d before measurements. In the following text, the soil collar plots will also refer to chamber plots.

CO_2 exchange at whole plant level

Manually operated closed chambers were used to measure the net ecosystem CO_2 exchange (NEE) and R_{eco} of grassland as described by Hussain *et al.* (2009). Chambers with 40 cm × 40 cm × 54 cm dimension and made from transparent plexiglass (3 mm XT type 20070; light transmission 95%) were used to measure NEE. A dark chamber of similar dimensions made from opaque polyvinyl chloride, covered with reflective aluminum foil, was used to measure R_{eco}. Extensions of various heights adjusted the chamber to the canopy height. The chambers were placed on the soil collars and a flexible rubber gasket sealed the chamber to the soil collar surface to avoid any leakage. The chambers were firmly secured using shock cords anchored to the ground on two sides. A 12-mm opening at the