Journal of Agrometeorology 16 (Special Issue-I) : 250-254 (October 2014)

Dynamics of Carbon and Water fluxes in Grassland Ecosystem of Thar Desert

P. RAJA[1*], NILENDU SINGH[2], B. K. BHATTACHARYA[3], MAHARAJ SINGH[4], R. K. BHATT[5], C. B. PANDEY[6], M. M. ROY[7]

[1]*ICAR- Central Arid Zone Research Institute, Jodhpur, Rajasthan,*
[2]*Centre for Glaciology, Wadia Institute of Himalayan Geology, Dehradun,* [3]*Space Applications Centre (ISRO), Ahmedabad,* [4]*Central Arid Zone Research Institute, Regional Research Station, Jaisalmer,*
[5]*Central Arid Zone Research Institute, Jodhpur,* [6]*Central Arid Zone Research Institute, Jodhpur,*
[7]*Central Arid Zone Research Institute, Jodhpur, Rajasthan*
[*]*Present Address: ICAR-Indian Institute of Soil and Water Conservation, Udhagamandalam, Tamil Nadu,*
[*]*Email: prajanbss@gmail.com*

ABSTRACT

A study was conducted during 2011-2012 in Indian Thar desert at Central Arid Zone Research experimental station under hot arid environment to understand the coupling between micrometeorological parameters and ecophysiology of a dominant C4 grass *Lasiurus sindicus*. Energy balance components were computed at half-hourly interval. Photosynthesis and respiration of *Lasiurus sindicus* was measured using Infra-red gas analyser (LICOR-6400 XT). Biomass was collected through destructive method at every 15 days interval from 2nd Week of April to 3rd week of August during the study period. During growing season, species exhibited bimodal distribution in their diurnal photosynthetic rates with first peak (13-15 µmol $CO_2 m^{-2}s^{-1}$) around 10:00 hours and second but higher rate (18-20 µmol $CO_2 m^{-2}s^{-1}$) around 16:00 hours. The maximum light use efficiency (2.73 gMJ^{-1}) was during morning and evening hours with occasional dip (0.47gMJ^{-1}) in the noon hours. Leaf to air vapour pressure difference was more due to more difference in leaf to air temperature from 23:00 hours to early morning 05:00 hours that might have reduced stomatal conductance. Night-time leaf temperature was consistently lower than ambient, which must have favored diffusion of gases including moisture into intercellular spaces. Leaf-air temperature difference increases progressively during night from 20:00 hours to early morning 03:00 hours. The net primary productivity showed that *L. sindicus* grass acted as a carbon sink and has fixed ~3.20 t ha^{-1} carbon. Also, it has the ability to ameliorate the extreme climate on account of fixation of carbon in vegetation and soil.

Key words: *Lasiurus sindicus*, Micrometeorology, Ecophysiology, Net Primary Productivity, Photosynthesis, Light Use Efficiency.

INTRODUCTION

Arid and semi-arid regions of the world play a significant role in global climate in relation to biogeochemical and hydrological processes (Vernekar *et al.,* 2003). In view of the extent and amount of heat exchange between arid surface and the overlying atmosphere, it is necessary to understand the coupling between micrometeorological parameters and ecophysiology of dominant grassland vegetation. Uncertainties prevail in the arid grassland ecosystem with reference to carbon balance and fluxes are primarily attributed to the sensitivity of to climate variability, especially variation in annual precipitation, temperature and ecophysiological processes (Flanagan *et al.,* 2002). It is therefore necessary to resolve whether this ecosystem function as a source or sink to atmospheric CO_2.

Micrometeorological stations provide a promising observation system to measure the net exchange of radiation, energy and water over land for a footprint varying from 0.5 to 1.0 km^2 (Bhattacharya *et al.,* 2009). A very few micrometeorological experiments have been conducted for a limited period in the arid climatic region of Gujarat in the Indian subcontinent (Vernekar *et al.,* 1993; Pillai *et al.,* 1998). The long-term data on energy and water balance in arid grassland ecosystem with distinct growth cycle are scanty, particularly in India. Therefore, present study was taken up with the objectives: (i) to analyze the seasonal variation in the surface energy balance components including evapotranspiration in relation to environmental drivers and grass growth parameters (ii) to understand the diurnal behaviour of $CO_2$and H_2O exchanges in *Lasiurus sindicus* grasses and their responses to biophysical and environmental conditions, and (iii) to analyze the biomass measurements of *Lasiurus sindicus* grasses in terms of carbon fluxes.

MATERIALS AND METHODS

2.1. Characteristics of the study site

Present study was conducted in arid grassland of the Thar Desert using half-hourly micrometeorological data on radiation and energy balance components recorded during the years 2011 and 2012, through a INSAT (Indian National Satellite) linked 10 m micrometeorological tower with multi-level sensors having a fetch ratio of 1:50 (Bhattacharya *et al.,* 2009; Bhattacharya *et al.,* 2013) located at the Central Arid Zone Research Institute (CAZRI) experimental area (26°50' 83" N, 71°18' 83" E; 195 m) at Chandan grassland farm covering ~ 96 hectares consisting predominantly of *Lasiurus sindicus*.

2.2. Biophysical and ecophysiological measurements

Systematic sampling plan was laid out for measuring leaf area index (LAI), plant height, biomass and phenological observations. Twenty-five (5 × 5 m) randomly selected permanent quadrats were laid down for *Lasiurus sindicus* grass system. The LAI was measured at 10-day interval using plant canopy analyzer (LAI-2000; Li-Cor, Inc., Lincoln, NE). Leaf level photosynthesis (L_{nar}) data acquired with LI-6400XT portable photosynthesis system was up scaled to canopy level according to Campbell and Norman (1998) assuming single light assimilation response relation for all the leaves in the canopy. Biomass of *Lasiurus sindicus* was collected in 3 replicates from area of $1m^2$ at every 15 days interval through destructive method. Fresh weights of both shoots and roots were taken using digital balance and the dry weights after keeping them in oven at 55^o C for 24 hours.

2.3. Radiation balance and net available energy

To batch process the micrometeorological data IDL (Interactive Data Language) routine was written to convert all half-hourly fluxes into daily averages. Radiation balance components and ground heat fluxes were averaged for daytime and for 24 hours period as well. Ten-day (dekadal) and monthly averages of fluxes were computed from daily averages. The data quality was screened to remove spurious spikes in the instantaneous and daily averages to have smooth temporal transition (Leuning *et al.,* 2012) and to obtain reliable dekadal averages. The net radiation (Rn), net available energy (Q), sensible heat (SH) and latent heat (LE) fluxes were computed using standard procedures (Raja *et al.*, 2013). Dekadal (10 days) and monthly averages of these energy fluxes were also computed. The residual energy for energy balance closure was computed as the difference between net available energy (*Q*) at surface and sum of sensible and latent heat fluxes from surface computed through MOST approach (Raja *et al.*, 2013).

RESULTS AND DISCUSSION

3.1. Ecophysiology, LAI dynamics and Biomass

The *Lasiurus sindicus*, locally known as '*Sewan*', is a perennial C4 grass, and is one of the important nutritive fodders with other agronomic values. The initiation of green cover was found to vary and dependent upon the temporal variation of the monsoon rainfall. It gradually greened up within 2 to 3 days of start of rainfall (10.0 mm). The time-period from July to September exhibited the green stage characterized by green canopy. From the 1st week of October, traces of leaf browning began to appear then progressively entered into physiologically dormant stage with the onset of dry winter and the rate of browning increased rapidly. By the first week of December canopy turned brown.

Systematic canopy measurements carried out during growth cycle of species to assess the temporal dynamics of the LAI (Fig. 2) which ranged from 0.24 to 1.5. Results showed that LAI followed a unimodal seasonal pattern. The maximum range of LAI (1.3-1.5) was recorded during peak monsoon (beginning of August to mid of September). Declining trend in LAI was observed after withdrawal of monsoon and setting of dormant dry winter season when leaves got discolored and dried gradually (Fig. 1). Biomass studies of *L. sindicus* indicates that average shoot and root weight is 296 and 414 gm m^{-2}, respectively. The net primary productivity (NPP) showed that *L. sindicus* grass acted as a carbon

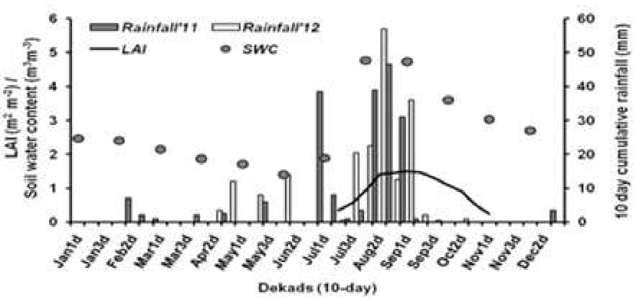

Fig.1: LAI dynamics of *L. sindicus* and soil water content (SWC) in relation to rainfall

sink and has fixed 3.20 t ha^{-1} carbon.

3.1.1. *Ecophysiology*

During growing season, the species exhibited bimodal distribution in their diurnal photosynthetic rates with first peak (13-15 µmol $CO_2m^{-2}s^{-1}$) around 10:00 hours and second but higher rate (18-20 µmol $CO_2m^{-2}s^{-1}$) around 16:00 hours. The maximum light use efficiency (2.73 gMJ^{-1}) was during morning and evening hours with occasional dip (0.47 gMJ^{-1}) in the noon hours. The leaf to air vapour pressure difference was more due to more difference in leaf to air temperature from 23:00 hours to early morning 05:00 hours that might have reduced stomatal conductance. Night time leaf temperature was consistently lower than ambient, which must have favored diffusion of gases including moisture into intercellular spaces. Leaf-air temperature difference increases progressively during night from 20:00 hours to early morning 03:00 hours (Fig. 2).

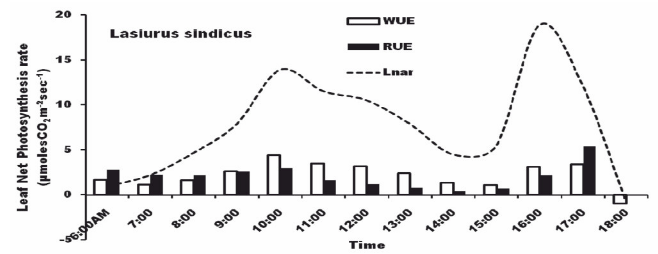

Fig.2: Ecophysiological responses of *Lasiurus sindicus* at peak growth stage.

3.2. *Surface energy fluxes*

3.2.1. *Heat - moisture fluxes and their drivers*

The temporal variation of daytime, 10-day averaged sensible and latent heat fluxes (SH, LE) and 10-day cumulative rainfall (Fig. 3) showed that the maximum sensible heat flux (SH) was > 300 Wm^{-2} in both the years (2011, 2012) which occurred during peak summer (May). Mean SH was 211 ± 70 Wm^{-2} (Mean ± SD). In the year 2011, the SH was 210 ± 84 Wm^{-2} whereas in 2012 it was 212 ± 53 Wm^{-2}. The coefficient of variation (CV) for the year 2011 and 2012 were 40% and 25%, respectively. Thus, it appeared that the maintenance of nearly constant inter-annual sensible heat fluxes is characteristic of the great Indian arid ecosystem. This characteristic may chiefly be attributed to little inter-annual variation in air temperature (AT) (mean of 3-height). Mean AT in 2011 was 26.5 ± 7.8 ^{0}C (CV = 29.4%), where as in 2012 AT was 25.9 ± 7.3 ^{0}C (CV = 28.2%). This variability may also be related to wind speed (CV: 42% and 59%) and wind direction (CV: 19% and 11%) in 2011 and 2012, respectively. However, there was significant inter-seasonal variation with bimodal distribution. The dekadal day-time SH was found to vary from 82 Wm^{-2} to 368 Wm^{-2} during 2011 (Raja *et al.,* 2013) and from 90 to 316 Wm^{-2} in 2012 with the lowest in winter and monsoon dekads and peak during summer and post-monsoon (Fig. 3). Advection of heat and moisture by winds from surrounding regions may alter temperature and humidity distribution at the experimental location (Leuning *et al.,* 2012).

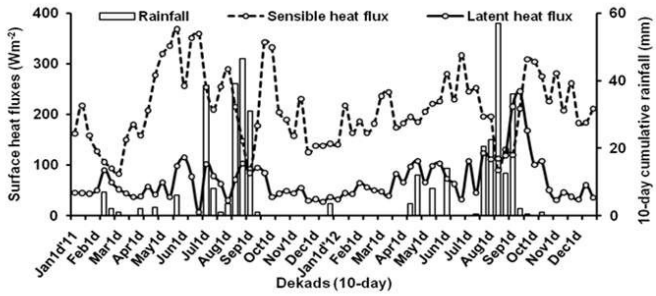

Fig.3: Dekadal variations of sensible and latent heat fluxes with rainfall (2011 & 2012)

The sensible heat flux was about three times higher than the latent heat flux in both the years indicating the energy transport to atmosphere occurred mainly by dry processes rather than through moisture transport. This could be attributed to the characteristics of arid atmosphere associated with poor rainfall and poor soil moisture quantities to support only sensible heat transfer. Both the absolute magnitude and the seasonal variability of sensible heat fluxes are the largest at noon time, with

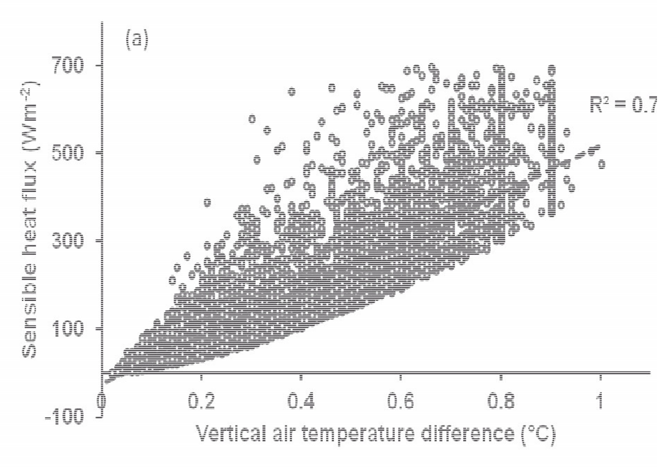

Fig. 4: Variation of sensible heat flux with vertical air temperature difference

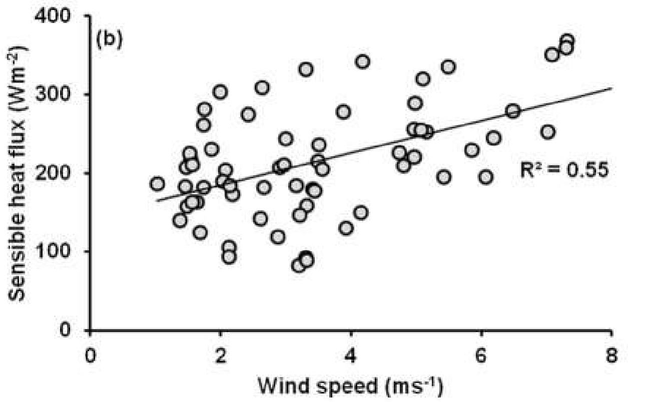

Fig. 5: Variation of 10-day averaged sensible heat flux with wind speed

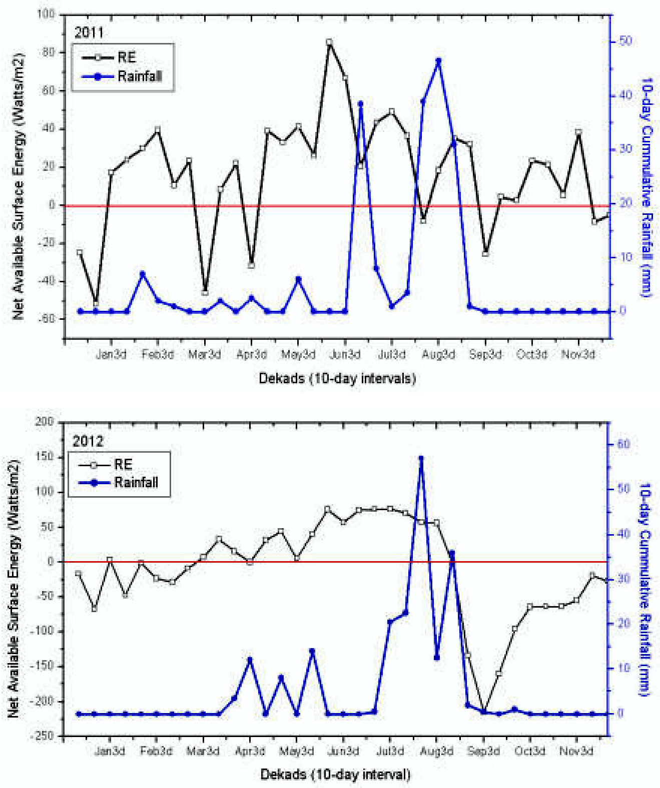

Fig.6 a& b: Time variation of Net Available Energy (RE) and Rainfall (a.2011 & b.2012)

maximum values in April-June during both the years. The seasonal variations in sensible heat fluxes are related to those in vertical air temperature difference (VATD) (difference between temperature at heights 1.25 and 7.5 m) ($R^2 = 0.7$, $P < 0.05$) (Fig. 4) and surface wind speed ($R^2 = 0.55$, $P < 0.05$) (Fig. 5). These changes are linked with atmospheric circulation, solar radiation, and land surface conditions. The sensible heat flux was also seen to increase linearly with wind speed (Fig. 5, *i.e.,* higher winds producing stronger heat fluxes and indicates the role of aerodynamic and advection effects.

Unlike SH fluxes there were marked annual and seasonal variability in 10-day daytime averaged LE. As shown in figure 3, mean LE during study period was 69 ± 41 Wm^{-2}. LE was higher in 2012 (81 ± 50 Wm^{-2}) relative to 2011 (57 ± 26 Wm^{-2}) with CV of 45% and 62%, respectively.

The peak was recorded during monsoon in both the years. The LE was observed high (70 – 245 Wm^{-2}) during monsoon and low (5 – 50 Wm^{-2}) during the dry period. The higher latent heat during monsoon season is obvious due to replenishment of soil moisture by rainfall and increased evapotranspiration (ET).

3.2.2. Time variation of Net Available Energy and Rainfall

Surface energy balance (SEB) averaged over 10-day intervals leads to a residual energy (net available energy (RE) = Rn-(SH+LH+G). It is either +ve or –ve depending on the relative magnitudes of surface fluxes. A +ve RE indicates a wet spell and –ve RE indicates a dry spell. Long period analysis of RE indicate that there are more wet spells in 2011 relative to 2012. Though +ve RE is relatively less in 2011 many +ve peaks found in almost all months indicating occurrence of rainfall in a better distribution. Time variation of RE in 2012 indicates wet spells are mostly concentrated in July-Aug (monsoon) and with higher rainfall (Fig.6 a & b).

CONCLUSION

The present study indicated that the energy transport to atmosphere in arid ecosystem occurred mainly by dry processes rather than through moisture transport. The diurnal and seasonal dependence of sensible heat flux variations related to diurnal cycle of mean vertical air temperature differences and wind speed. Frequent occurrence of dust storms leads to energy imbalance. Seasonality in energy balance closure were controlled by the amount of rainfall, soil moisture, ground heat flux and associated advective transports of heat or moisture. The water-carbon use efficiency and biomass productivity of perennial grasses have been ascertained for efficient management of soil moisture and to estimate net carbon trapping in the water stressed desert ecosystem. The study would help to evaluate land surface processes and over the period of time would be useful to evolve reliable regional climate model.

ACKNOWLEDGEMENTS

This work has been carried out under the project titled "Energy and Mass Exchange in Arid Grassland System" and as a part of National level project of Vegetative System (EME-VS) in ISRO's Geosphere-Biosphere programme. Authors are thankful to the Directors, ICAR- Central Arid Zone Research Institute, Jodhpur and Satellite Application Centre (ISRO), Ahmedabad for providing necessary logistics and financial support.

REFERENCES

Bhattacharya, B. K. *et al.* (2009). Protocol Development of Energy-Water Flux Computation from AMS and Model Development. SAC/RESA/ARG/EMEVS/SR, *Chapter,* 3: 34-53.

Bhattacharya, B.K., *et al.,* (2013). Canopy-scale Dynamics of Radiation and Energy Balance over Short Vegetative Systems. Scientific report SAC/EPSA/ABHG/IGBP/EME-VS/SR/ 02/ 2013, pp.97.

Campbell, G.S., Norman, J.M. (1998). Introduction to Environmental Biophysics. Springer Science and Business Media Inc., New York, USA, pp. 71.

Leuning, R., Gorsela, E. V., Massmanb, W. J., Isaacc, P. R. (2012). Reflections on the surface energy imbalance problem. *Agric. For. Meteorol.,* 156: 65-74.

Flanagan, L.B., Wever, L.A. and Carlson, P.J. (2002). Seasonal and interannual variation in carbon dioxide exchange and carbon balance in a northern temperate grassland. *Global Change Biology,* 8: 599-615.

Pillai, J.S., Saxena, S. and Vernekar, K.G. (1998). Diurnal Variation of Meteorological Parameters in the Land Surface Interface. Boundary-Layer Meteorol., 89: 197–209.

Raja, P. *et al.,* (2013). Surface Energy Balance and its Closure in Arid Grassland Ecosystem: A case study over Thar Desert. *J., Agrometeorol.,* spl.issue, 1: 94-99.

Vernekar, A.D., *et al.,* (1993). Global structure of the Madden-Julian oscillations during two contrasting summer monsoon seasons over India. *Meteorol. Atmos. Phys.,* 52: 37-47.

Vernekar, K. G. *et al.,* (2003). An overview of the land surface processes experiment (LASPEX) over a semi-arid region of India, *Boundary-Layer Meteorol.,* 106:561–572.