© 2011 Triveni Enterprises
Vikas Nagar, Lucknow, INDIA
editor@jeb.co.in
Full paper available on: www.jeb.co.in

J. Environ. Biol.
32, 333-337 (2011)
ISSN: 0254-8704
CODEN: JEBIDP

Field measurements of soil CO_2 efflux in *Heteropogon contortus* do minated grassland of semi-arid eco-system

Author Details

S. Gnaana Saraswathi (*Corresponding author*)	Department of Botany, Holy Cross College, Tiruchirappalli - 620 002, India e-mail: sgsaraswathi@yahoo.co.in
Kailash Paliwal	Department of Plant Sciences, Madurai Kamaraj University, Madurai - 625 021, India

Publication Data

Paper received:
23 October 2009

Revised received:
27 April 2010

Accepted:
11 May 2010

Abstract

Seasonal changes in soil respiration (SR), soil temperature (ST) and soil moisture (SM) were compared between a barren land with no vegetation (control) and grassland dominated by *Heteropogon contortus* (L.) of a semi-arid eco-system during 2005-2006. A statistically significant ($p<0.001$) seasonal change in SR was observed between the two sites. The variation characteristics of soil CO_2 efflux rates were observed during wet periods along precipitation gradients and it was consistently higher in grasslands than in control. A maximum soil CO_2 efflux of 13.35 ± 0.33 $\mu mol\ m^{-2}\ s^{-1}$ in grassland and 7.33 ± 0.8 $\mu mol\ m^{-2}\ s^{-1}$ in control was observed during rainy season-II, *i.e.*, from October to December, a minimum of 1.27 ± 0.2 $\mu mol\ m^{-2}\ s^{-1}$ in grassland and 0.67 ± 0.5 $\mu mol\ m^{-2}\ s^{-1}$ in control during summer season, *i.e.*, from March to June. A positive significant relation observed between soil respiration and soil moisture (r^2 above 0.8) and no significant relation was observed between soil CO_2 efflux and soil temperature (r^2 below 0.3). In water-limited semi-arid ecosystem, rewetting of the soil due to precipitation events triggered the increased pulses of soil respiration especially in grassland when compared to the barren land. The observed soil respiration rates during summer and after the subsequent precipitation events strongly indicated that the soil water-deficit conditions reduce the efflux both in barren land (control) and in grassland of semi-arid eco-system.

Key words

Semi-arid climate, Soil CO_2 efflux, Soil respiration, *Heteropogon contortus,* Seasonal variation

Introduction

Arid and semi-arid lands cover as much as two-fifths of the earth's total surface and the extent of these lands may likely to increase as a response to climate change (Reynolds, 2001). The current global climate models predict significant changes in rainfall pattern in particular with arid and semi-arid regions due to increase in atmospheric carbon dioxide concentration and temperature. Studies showed that in arid and semi-arid eco-systems, the precipitation arrives in discrete, episodic events (Loik *et al.*, 2004) and the annual net primary productivity correlates strongly with total annual rainfall (Huxman *et al.*, 2004). One of the most widespread and principal vegetation types of semi-arid systems is grasslands that cover approximately one-fifth of the world's surface area, characterized by their survival in severe environment (Zhang, 2000). Grasslands play a significant role in the global carbon cycle (Zhao *et al.*, 2007). One of the most important links in carbon cycle of the grassland eco-system is grassland soil CO_2 emissions to the atmosphere through soil respiration (SR) or soil CO_2 efflux (Li and Chen, 1998). Soil CO_2 efflux, mainly from mineralization of soil organic matter related to microbes as well as plant root system and soil animal respiration, is a complicated biological process and affected jointly by soil moisture and soil temperature. The semi-arid climate, with its pronounced seasonality of rainfall, makes these grasslands ideal eco-systems for studying changes in SR with reference to the quantity and timing of the rainfall. Hence, variations in grassland SR are highly sensitive to response of climate change and have stronger positive or negative feedbacks to climatic change (Lenton, 2000). Moreover, there exists a large uncertainty in the factors controlling SR in semi-arid eco-systems, which was evident from our previous studies in various leguminous plantation sites. Therefore, it would be appropriate to focus on the role of biotic and abiotic factors influencing SR in such eco-systems during rainfall events (Reynolds *et al.*, 2004). Understanding the role of the soil-vegetation type in the carbon cycle is imperative to determine whether the soil maintain itself as a sink or turn into a source.

Heteropogon contortus (L.) is one of the most dominant C_4 grass species growing in the red soil of the study area in semi-arid region. Studies reveal that the red soils are one of the typical agricultural soils in the subtropical region, which plays an important role in the global carbon budget due to their large potential to store carbon and return atmospheric carbon through soil CO_2 efflux (Lou *et al.*, 2003). SR is a source of atmospheric carbon dioxide in the carbon cycle of terrestrial ecosystem and its releasing amount is one of the largest effluxes from the terrestrial ecosystem to the atmosphere through soil surface carbon dioxide efflux. Rates of carbon dioxide emission were measured using soils as one of the most important components of the global carbon budget due to their capacity to store large quantity of carbon. Thus, measurement of SR rate has been carried out in various eco-systems under a range of environmental conditions and there is a large amount of literature on SR from many parts of the world (Mielnick and Dugas, 2000; Li *et al.*, 2008). However, little is known about the functioning of grassland eco-system, in particular with respect to the carbon turnover in the semi-arid region of Southern India.

The present study focused on the measurement of soil respiration (SR) in grassland dominated with grass *H. contortus* species in the semi-arid eco-system in Southern India over a season and to analyze the effect of soil moisture (SM) and soil temperature (ST) on soil respiration (SR).

Materials and Methods

Site description: The study area is semi-arid and the season is characterized as rainy season-I (Jul to Sep), rainy season-II (Oct to Dec), winter (Jan and Feb) and summer (Mar to Jun). The study was carried out in the grassland dominated by *Heteropogon contortus*, a C_4 grass species, located in the University campus (latitude 10°00' N; longitude 78°10' E; elevation 133 m above m.s.l.) in Southern India. This is an un-grazed and fenced site for around 10 yrs.

The adjacent site with no vegetation (barren land) was considered as control. The soil at the experimental site is lateric loam with pH 8.5. The maximum temperature recorded between 40.5-43.6°C during summer and minimum between 25.0-27.8°C during rainy and winter season.

Soil CO_2 efflux measurements: The soil respiration was measured by the dynamic closed chamber, connected to Li 6400 portable photosynthesis system (Li-Cor, NB, USA) for data collection, fitted with a Li-Cor, 6400-09 soil CO_2 efflux chamber. Before starting the measurement, ambient CO_2 concentration at the soil surface was measured. Once the chamber was installed, using CO_2 scrubber the CO_2 in the closed system was drawn down below the ambient concentration. When the scrubber was turned off, soil CO_2 efflux caused the CO_2 concentration in the chamber headspace to rise. Data were logged while the CO_2 concentration rose through the ambient level. The measurement cycles were repeated in as many plots as required.

A soil collar with a height of 4.4 cm and a diameter of 10.6 cm was inserted into the soil at each sampling spot. The collars were installed at least 24 hr prior to the start of the measurements. The soil respiration chamber was set on top of these collars allowing an undisturbed measurement of soil CO_2 efflux rates.

Soil CO_2 efflux measurements were made on three consecutive days in a month in each plot from May 2005 to April 2006. Each measurement included approximately 8-10 values. Measurements were made in ten plots both in control (no plants) and in grassland. Each measurement took approximately 30-35 sec, depending upon the efflux rate. To bracket the ambient air CO_2 concentration during the measurement period, the CO_2 concentration of the chamber air was reduced by diverting it through soda lime for a very short period (1 or 2 min) before logging the data.

Soil moisture (SM) and soil temperature (ST): Soil moisture was determined by gravimetric method. The soil samples (0-10 cm) were collected from the plots in which soil respiration measurements were made, weighed and oven dried at 105°C for 24 hr to constant weight and weighed again. Soil temperature was measured at the depth of 0-10 cm immediately next to each collar along with the CO_2 evolution measurements, using a soil temperature probe connected to the Li-Cor 6400-09 soil CO_2 flux chamber.

Statistics: Analysis of variance (one-way ANOVA) was performed to test the significance of differences in seasonal means of soil respiration rate, soil moisture and soil temperature. Regression analysis was carried out to examine the relationships between (i) soil CO_2 efflux and soil moisture and (ii) soil CO_2 efflux and soil temperature.

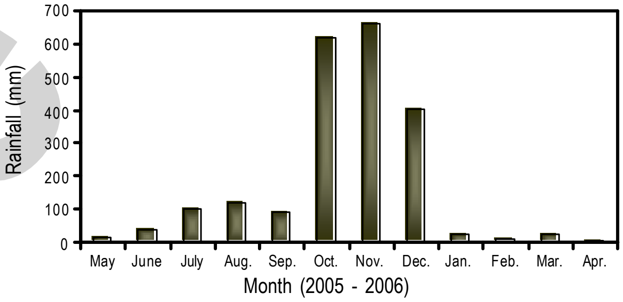

Fig. 1: Monthly rainfall (mm) during the study period (May 2005-April 2006)

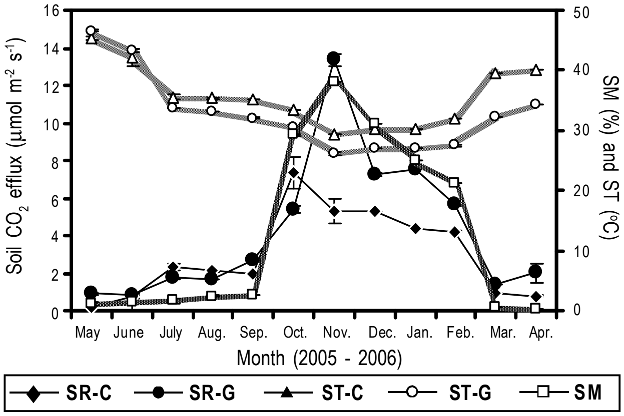

Fig. 2: Seasonal pattern of soil CO_2 efflux rate (SR), soil moisture (SM in %) and soil temperature (ST in °C) in control (C) and in C_4 grassland (G). Values are mean±SE of 10 analyses at $p<0.001$

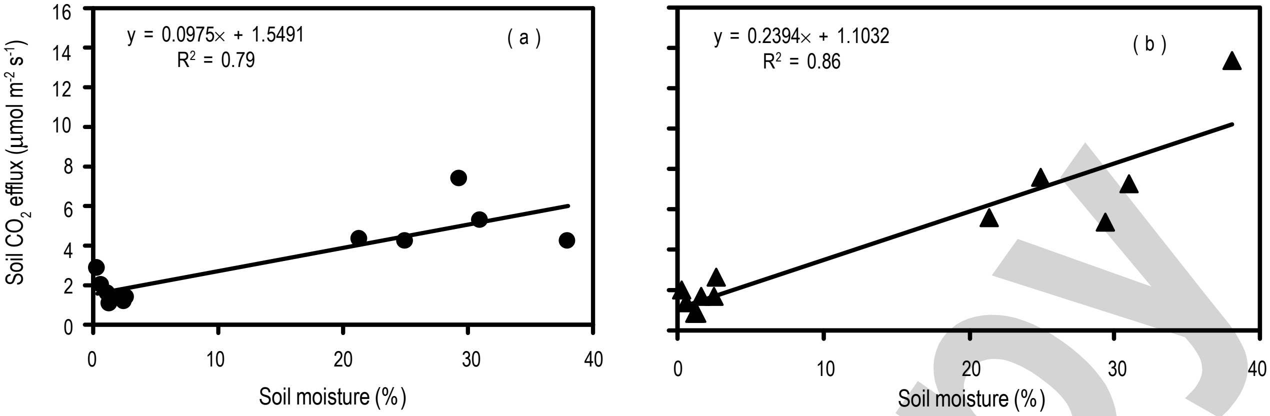

Fig. 3: Relationship between soil CO_2 efflux rate and soil moisture in control (a) and grassland (b)

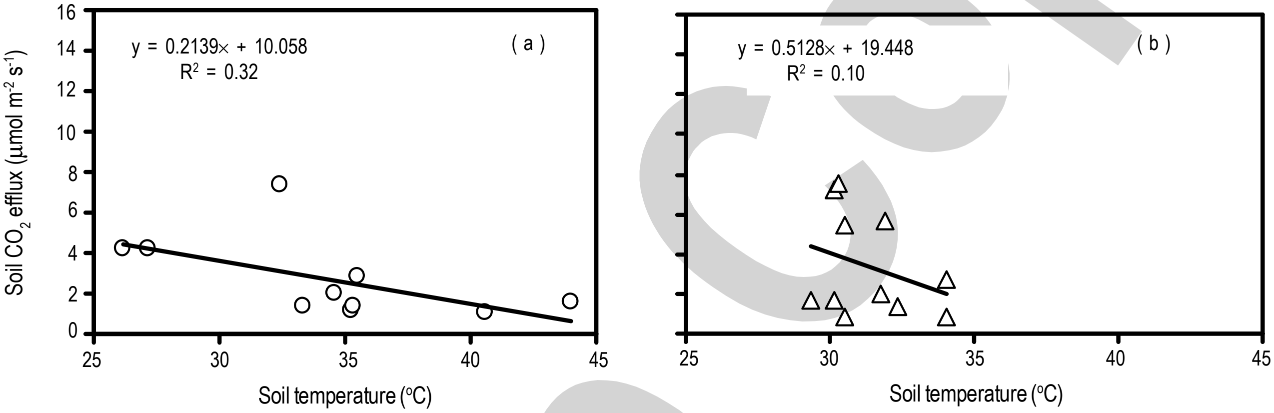

Fig. 4: Relationship between soil CO_2 efflux rate and soil temperature in control (a) and grassland (b)

Results and Discussion

Most of the rainfall occurred during October to December in 2005-2006. Few showers were recorded during July (98.9 mm), August (81.5 mm) and September (80.2 mm). However, the rest of the study periods showed relatively low or no rainfall (Fig. 1).

Seasonal pattern of soil respiration (SR): Statistically significant ($p<0.001$) annual variation in soil carbon dioxide efflux was observed both in control and in grassland. Rainy season-I (July to Sept.) had no significant effect on soil respiration both in control (2.13 ± 0.1 µmol m^{-2} s^{-1}) and in grassland (2.01 ± 0.3 µmol m^{-2} s^{-1}). Increased rates of SR was observed during rainy season-II (Oct. to Dec.) followed by winter. The maximum soil CO_2 efflux, 13.35 *µ*mol m^{-2} s^{-1}, was observed in the grassland dominated with *H. contortus*, in November followed by control, 7.32 µmol m^{-2} s^{-1}, in October. However, average SR in grassland during rainy season-II was 8.7 ± 1.4 and 5.96 ± 0.6 µmol m^{-2} s^{-1} in control. Significant difference ($p<0.001$) in SR was observed both in grassland (6.58 ± 0.8 µmol m^{-2} s^{-1}) and in control (4.30 ± 0.06 µmol m^{-2} s^{-1}) during winter season. Summer (Mar. to June.) followed by slight showers during the rainy season-I (July to Sept.) showed similar rates of soil CO_2 efflux. The minimum soil CO_2 efflux of 1.27 ± 0.2 µmol m^{-2} s^{-1} in grassland and 0.67 ± 0.5 µmol m^{-2} s^{-1} in control was observed during summer (Fig. 2).

Seasonal trend in soil moisture (SM) and soil temperature (ST): Soil moisture varied markedly with season ($p<0.001$). However, there is no statistically significant differences were observed between control and grassland site. Soil moisture content in both the sites followed the similar pattern as that of soil respiration, in that, it showed the minimum during summer (0.84%) followed by rainy season-I (2.23%). The maximum soil moisture content was observed during rainy season-II (32.46%) followed by winter (23.16%). Even though the soil moisture was low during summer and rainy season-I, it increased sharply during the rainy season-II due to heavy precipitation (Fig. 2).

Unlike soil moisture, soil temperature varied significantly ($p<0.001$) between the control and grassland. In control, the soil temperature of 35.36 ± 0.12°C was observed during rainy season-I. However, it decreased to 30.95 ± 1.2 and 31.09 ± 0.8°C during rainy season-II and winter respectively. Maximum soil temperature of 41.8 ± 1.3°C was recorded in the summer.

The soil temperatures recorded in the grassland were comparatively lower than that of the control site throughout the season except during summer. Minimum soil temperatures of 27.9 ± 1.3 and 27.3 ± 0.19°C were recorded in the rainy season-II and winter respectively, whereas a significant increased soil temperature of 32.9 ± 0.4°C was observed during rainy season-I. Maximum soil temperature of 39.1 ± 1.6°C was recorded in the summer (Fig. 2).

Correlations with soil moisture (SM) and soil temperature (ST): Soil CO_2 efflux changes had a seasonal tendency that more closely resembled to that of soil moisture. During the experimental period, soil moisture effects on soil CO_2 efflux was greater than soil temperature, which was explained by simple regression analysis with soil efflux against soil moisture and soil temperature.

Soil CO_2 efflux strongly correlated with soil moisture positively and a weak negative correlation were observed with soil temperature. The correlation coefficients (r) for both control and grassland were above 0.8 for soil CO_2 efflux as a function of soil moisture (Fig. 3a,b) whereas r was below 0.3 for soil temperature in both the sites (Fig. 4a,b).

Soil CO_2 effluxes: A significant seasonal variation ($p<0.001$) in soil respiration along with soil moisture and soil temperature was observed both in the control and grassland site. In general, soil CO_2 efflux decreased during summer and increased sharply with precipitation events during rainy season-II followed by winter season and moderate effluxes were observed during rainy season-I.

Control plots in our study represent the barren land with no vegetation at all and so the respiration was purely depended on the microbial flora (heterotrophic respiration) present in the soil. Monsoonal rain enhanced the microbial activity along with the respiration of soil fauna, thereby showing a significant increase in soil CO_2 efflux during rainy season-II. As the land was completely exposed to the direct sun light, the soil temperature was seemingly higher than that of the grassland, which would have suppressed the microbial activity thereby low soil respiration during summer and rainy season-I. Similar results were observed in previous studies (Conant *et al.*, 2000).

The overall trend in SR did not vary significantly between the study sites, but significant differences ($p<0.001$) were evident in the seasonal trends especially during rainy season-II and winter. This was evident from our previous studies in newly developed plantation sites, where, the seasonal trends are very typical and the different plantation sites showed significant variations in soil respiration during rainy season. However, during all the other seasons, they exhibited almost similar rate of SR (Gnaana Saraswathi *et al.*, 2008). As far as the grassland is concerned, soil microclimate plays an important role in quantifying the seasonal differences in soil CO_2 efflux and many previous studies have shown that SR also varies with vegetation types and among major biomes significantly (Raich and Tufekcioglu, 2000).

The seasonal changes in the grassland may also be due to the soil microbial biomass, which were found to be correlated with soil CO_2 efflux as observed by Yi *et al.* (2007). Adachi *et al.* (2006) found that the soil CO_2 efflux increased not only with microbial biomass but also with fine root biomass in the tropical soils. Although we have not conducted any experiments in the grassland about the influence on biotic factors, these reports suggest that the seasonal change of soil CO_2 efflux was affected not only by the seasonal change of abiotic but may also by the biotic factors (Han *et al.*, 2007). Such findings indicate that the vegetation type is an important determinant of the efflux of CO_2 and therefore, changes in vegetation have the potential to modify the response of soils to environmental changes. One of the reasons that can be attributed for increased soil respiration rates in grassland may be the soil microclimatic conditions and structure, the quantity and quality of detritus supplied to the soil and the overall rate of root respiration. On contrary to our results, Dong *et al.* (2005) showed increased CO_2 emissions during summer and decreased CO_2 emissions during winter in four grassland types. Following rainy season-II, due to water availability, a more suitable environment is provided as a high season for a better plant growth as far as the grassland of semi-arid ecosystem is concerned. With the strengthening of root system growth and soil microorganism activity, soil CO_2 efflux reaches a peak value. Winter season is characterized by apparently no rain. However, the measurements evident for soil CO_2 emissions. During this season, the growth of the grass reaches to the flowering stage and the grassland is still alive with root respiration associated with the respiration of microorganism in the soil that led to CO_2 emissions. This is again contrary to the results observed by Dong *et al.* (2005). The decreased soil respiration rates during the summer are probably due to the absence of precipitation when the soil temperature was higher than the previous seasons. The grassland became dry due to greater plant evapotranspiration and soil water evaporation. This in turn induced lower soil water content (almost completely dry soil) restraining the respiration of root system and microorganism. Conant *et al.* (2000), observed similar results in that, soil respiration in semi-arid ecosystems increases with C pool size and mean annual precipitation, but decreases with increase in mean annual temperature.

Effect of moisture on soil CO_2 efflux: A strong relationship between soil CO_2 efflux and soil moisture was observed in our study. A sharp increase in soil CO_2 efflux was observed both in the control and in grassland immediately after rain (rainy season-II). It was obvious from our study that drying and successive rewetting affects the soil CO_2 efflux. The effect of summer drought became apparent as soil moisture fell below 3%. The limiting effect of soil moisture on soil respiration was clear as soil respiration responded quickly and sharply to each rain event, reaching its highest values and then decreasing to pre-rain values. Soil moisture after the rainfall may limit soil respiration in two ways; either by limiting aeration and thus the diffusivity of air when it is high, or by stressing the soil microbial communities and root respiration when it is low. This view is supported by our previous studies in various plantation sites

(Gnaana Saraswathi *et al.*, 2008). Our results are in agreement with Holt *et al.* (1990), who observed 3-fold increase in soil respiration immediately after heavy rains. Maximum soil temperatures coincided with minimum water content in the summer and minimum soil temperatures were recorded during the rainy season-II, when soil moisture was maximum influencing soil respiration. Slight showers during rainy season-I did not have much influence on SR in a significant way in both the sites. However, the dry soil of the summer when followed by slight showers may partly stimulated the soil respiration from the displacement of air rich in CO_2 from within soil and from the activity of microbes that oxidize the carbon dissolved in water.

Effect of soil temperature on soil CO_2 efflux: Many of the long-term global modeling studies considered soil temperature as the sole variable for determining soil respiration. However, studies from Mediterranean and semi-arid ecosystems, including our past and the present study, in general, reveal that the soil respiration fluxes are highly sensitive and largely controlled by soil moisture (Kaye and Hart, 1998; Gnaana Saraswathi *et al.*, 2008).

The poor relationship between soil CO_2 efflux and soil temperature frequently occurred when soil moisture was low. The poor relationship must be a response of both plant and soil microbial metabolism to water stress (Malhi and Grace, 2000). The increased soil temperature due to water stress conditions increases the hydraulic resistance, restricting transpiration and thus causes stomatal closure and a reduction in photosynthesis. As a result, the population of microbes in the rhizosphere and the fine-root production diminishes. The drying effect due to high soil temperature thus reduces soil efflux (Sotta *et al.*, 2004).

The interactive effects of soil temperature and soil moisture on soil respiration suggest a decline in the net CO_2 efflux with the forecasted increasing temperature. It can be concluded from our results that the control (barren land) and grassland of semi-arid ecosystem were more sensitive to the seasonal distribution of rainfall and moisture than temperature and this active portion of the year will have much influence to affect the total soil respiration. Our data suggest that the grassland is likely to become a net source of CO_2 during rainy and winter season. However, during other season, due to increased soil temperature and low soil moisture content, the grassland acts as a sink for carbon.

Acknowledgments

Authors are thankful to Department of Biotechnology, Government of India, for financial support (grant no: 102/IFD/SAN/1018/2002-2003). Our thanks are also to Prof. Dr. P. Gunasekaran, Head and Coordinator, UGC-NRCBS, School of Biological Sciences, Madurai Kamaraj University, Madurai for providing Li-Cor 6400-09 Soil CO_2 flux Chamber. Our thanks are due to Regional Meteorological Centre, Government of India, for providing us the rainfall data for the study period. Assistance in the field by Mr. C. Lalrammawia is greatly acknowledged.

References

Adachi, M., Y.S. Bekku, W. Rashidah, T. Okuda and H. Koizumi: Differences in soil respiration between different tropical ecosystems. *Appl. Soil. Ecol.,* **34**, 258-265 (2006).

Conant, R.T., J.M. Klopatek and C.C. Klopatek: Environmental factors controlling soil respiration in three semi-arid ecosystems. *Soil Sci. Soc. Am. J.,* **64**, 383-390 (2000).

Dong, Y., Y. Qi, J. Liu, Y. Geng, M. Domroes, X. Yang and L. Liu: Variation characteristics of soil respiration effluxes in four types of grassland communities under different precipitation intensity. *Chi. Sci. Bull.,* **50**, 583-591 (2005).

Gnaana Saraswathi, S., C. Lalrammawia and Kailash Paliwal: Seasonal variability in soil-surface CO_2 efflux in selected young tree plantations in semi-arid eco-climate of Madurai. *Curr. Sci.,* **95**, 94-99 (2008).

Han, G., G. Zhou, Z. Xu, Y. Yang, J. Liu and K. Shi: Biotic and abiotic factors controlling spatial and temporal variation of soil respiration in an agricultural ecosystem. *Soil Bio. Biochem.,* **39**, 418-425 (2007).

Holt, J.A., M.J. Hodgen and D. Lamb: Soil respiration in the seasonally dry tropics near Townville, Northern Queensland. *Aust. J. Soil Res.,* **28**, 737-745 (1990).

Huxman, T.E., M.D. Smith, P.A. Fay, A.K. Knapp, M.R. Shaw and M.E. Loik: Convergence across biomes to a common rain-use efficiency. *Nature,* **429**, 651-654 (2004).

Kaye, J.P. and S.C. Hart: Restoration and canopy type effects on soil respiration in a ponderosa pine - Bunchgrass ecosystem. *Soil Sci. Soc. Am. J.,* **62**, 1062-1072 (1998).

Lenton, T.M.: Land and ocean carbon cycle feedback effects on global warming in a simple earth system model. *Tellus,* **52B**, 1159-1188 (2000).

Li, L.H. and Z.Z. Chen: Soil respiration in grassland communities in the world. *Chin. J. Ecol.,* **17**, 45-51 (1998).

Li, Y.L., D. Otieno, K. Owen, Y. Zhang, J. Tenhunen, X.Q. Rao and Y.B. Lin: Temporal variability in soil CO_2 emission in an orchard forest ecosystem. *Pedosphere,* **18**, 273-283 (2008).

Loik, M.E., D.D. Breshears, W.K. Lauenroth and J. Belnap: A multi-scale perspective of water pulses in dry land ecosystems: Climatology and ecohydrology of the western USA. *Oecologia,* **141**, 269-281 (2004).

Lou, Y., Z. Li and T. Zhang: Carbon dioxide efflux in a subtropical agricultural soil of China. *Wat. Air Soil Pollut.,* **149**, 281-293 (2003).

Malhi, Y. and J. Grace: Tropical forests and atmospheric carbon dioxide. *Trees,* **15**, 332-337 (2000).

Mielnick, P.C. and W.A. Dugas: Soil CO_2 efflux in a tallgrass prairie. *Soil Biol. Biochem.,* **32**, 221-228 (2000).

Raich, J.W. and A. Tufekcioglu: Vegetation and soil respiration: Correlations and controls. *Biogeochemistry,* **48**, 71-90 (2000).

Reynolds, J.F.: Desertification. *In:* Encyclopedia of Biodiversity (*Eds.*: S.A. Levin). Academic Press, San Diego. pp. 61-78 (2001).

Reynolds, J.F., P.R. Kemp, K. Ogle and R.J. Fernandez: Modifying the 'pulse-reserve' paradigm for deserts in North America: Precipitation pulses, soil water and plant responses. *Oecologia,* **141**, 194-210 (2004).

Sotta, E.D., M. Meir, Y. Malhi, A.D. Nobre, M. Hodnett and J. Grace: Spatial heterogeneity of soil respiration and related properties at the plant scale. *Global Change Biol.,* **10**, 601-617 (2004).

Yi, Z., S. Fu, W. Yi, G. Zhou, J. Mo, D. Zhang, M. Ding, X. Wang and L. Zhou: Partitioning soil respiration of subtropical forests within different successional stages in south China. *For. Ecol. Management,* **243**, 178-186 (2007).

Zhang, X.S.: The eco-economic functions of the grassland and its pattern. *Sci. Technol. Rev.,* **8**, 3-5 (2000).

Zhao, J., Q. Yu-chan and D. Yun-she: Diurnal and seasonal dynamics of soil respiration in desert shrub land of *Artemisia ordosica* on Ordos plateau of inner Mongolia. China. *J. For. Res.,* **18**, 231-235 (2007).