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EFFECTS OF ABIOTIC VARIABLES AND ROOT BIOMASS ON CO_2 EVOLUTION AND CARBON BALANCE AFTER BURNING IN A SEMI-ARID GRASSLAND ECOSYSTEM

V. Meenakshi Sundaravalli & Kailash Paliwal*

Department of Plant Sciences, School of Biological Sciences, Madurai Kamaraj University, Madurai - 625 021, India

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SUNDARAVALLI, V.M. & PALIWAL, K. 1998. Effects of abiotic variables and root biomass on CO_2 evolution and carbon balance after burning in a semi-arid grassland ecosystem. Soil respiration rates and carbon balance were estimated in a semi-arid grassland ecosystem at Madurai, India. The alkali absorption method was used to measure carbon dioxide evolution rates from the soil. Annual carbon balance was estimated on the basis of litter production, litter disappearance and CO_2- C output. Maximum soil respiration rates were 120 mg CO_2 m^{-2} h^{-1} in the burned and 183 mg CO_2 m^{-2} h^{-1} in the unburned grasslands. Positive correlations were observed between CO_2 rates and soil temperature, litter moisture and soil moisture. Among the three variables, significant positive correlation ($p< 0.001$, $n=12$) was observed between soil moisture and soil respiration rates in both the grasslands. Multiple regression analysis revealed that 73 to 85 % variability in soil respiration rates was due to the combined effect of soil moisture, litter moisture and soil temperature. Mean annual carbon output from the soil was 252 and 310 g cm^{-2} y^{1} in the burned and unburned grasslands respectively. CO_2- C output by soil respiration exceeded the input of carbon through litter production by 2.76 to 8.27 % and was 3.09 to 9.49 % higher than the estimated loss of carbon through litter disappearance.

Key words: Soil respiration - soil moisture - litter disappearance - carbon balance - tropical grassland - semi-arid region - Madurai - India

SUNDARAVALLI, V.M. & PALIWAL, K. 1998. Kesan pembolehubah abiotik dan biojisim akar terhadap evolusi CO_2 dan keseimbangan karbon selepas pembakaran dalam ekosistem padang rumput separuh gersang. Kadar respirasi tanah dan keseimbangan karbon ditaksirkan dalam ekosistem padang rumput separuh gersang di Madurai, India. Kaedah penyerapan alkali digunakan untuk mengukur kadar evolusi karbon dioksid dari tanah. Keseimbangan karbon tahunan disukat berdasarkan pengeluaran sarap, kehilangan sarap dan output CO_2- C. Kadar respirasi tanah maksimum ialah 120 mg CO_2 m^{-2} h^{-1} di padang rumput yang telah dibakar dan 183 mg CO_2 m^{-2} h^{-1} di padang rumput yang tidak dibakar. Korelasi positif dicerap di antara kadar CO_2 dengan suhu tanah, kelembapan sarap dan kelembapan tanah. Di antara ketiga-tiga pemboleh ubah, korelasi positif bererti ($p< 0.001$, $n=12$) dicerap di antara kadar kelembapan tanah dan kadar respirasi tanah di kedua-dua padang rumput. Analisis regresi berganda menunjukkan bahawa 73 hingga 85% kebolehubahan dalam kadar respirasi tanah adalah disebabkan oleh gabungan kesan-kesan kelembapan tanah, kelembapan sarap dan suhu tanah. Purata output karbon tahunan daripada tanah tersebut masing-masing adalah 252 dan 310 g cm^{-2} y^{1} di padang rumput yang dibakar dan padang rumput yang tidak dibakar. Output CO_2- C oleh respirasi tanah

**Author for correspondence.*

melebihi input karbon melalui pengeluaran sarap sebanyak 2.76 hingga 8.27% dan 3.09% hingga 9.49% lebih tinggi daripada anggaran kehilangan karbon melalui kehilangan sarap.

Introduction

Soil respiration measures the rate of carbon dioxide evolution from the soil-litter system due to aerobic respiration of micro-organisms, soil fauna and living roots (Wiegert *et al.* 1970). Soil respiration is a useful parameter for studying soil biological activity, carbon cycling and energy flow in an ecosystem (Singh & Gupta 1977) and is also considered an important index of the decomposition subsystem. Relationship between soil respiration and organic matter input in the soil has been used to calculate carbon balance (Coleman 1973). Large amounts of carbon are released to the atmosphere as CO_2 during decomposition of litter and added to soil from above-ground and below-ground sources and additional CO_2 is released by respirations of living roots. Raich and Schlesinger (1992) estimate that global soil respiration by terrestrial ecosystem is 68 giga tonnes y^1, an order of magnitude greater than the 5.7 giga tonnes y^1 released through fossil fuel combustion plus industrial sources (Watson *et al.* 1990).

The studies on soil respiration in terrestrial ecosystem have been reviewed by Singh and Gupta (1977) and Medina *et al.* (1980). Singh and Ambasht (1980) and Gupta and Singh (1981, 1982) studied soil respiration in tropical and sub-tropical ecosystems.

The objectives of the present study were (i) to measure the rate of carbon dioxide evolution from the soil in a semi-arid grassland, (ii) to study the effect of soil moisture, litter moisture and soil temperature on CO_2 rates, and (iii) to analyse the carbon balance of the system on the basis of litter production, litter disappearance and CO_2 - C output in a tropical grassland ecosystem in the semi-arid region of Madurai, India.

Materials and methods

Study site

The study site was a 12-y-old protected grassland located at Madurai (10° 00'N, 78° 10' E) at an altitude of about 132 m above mean sea-level. The eco-climate of Madurai is semi-arid. The mean maximum temperature ranged between 28.2 and 37.4 °C and the mean minimum temperature ranged between 21 and 28 °C. The annual rainfall during the study period was 986 mm, and the rainy season was from July to November. The maximum rainfall was 340 mm recorded during the month of November. The relative humidity ranged between 33 and 79% during the study period (Figure 1).

The soil is reddish-brown and laterite sandy loam. The pH of the soil ranged from 7.0 to 8.5. The grassland was dominated by *Heteropogon contortus.* The other species present were *Aristida adscensionies, Lepidogathis pungens, Indigofera aspalathoides* and *Tephrosia purpurea.* About 0.2-ha area of the grassland was intentionaly burned on May 25, 1993 for this study. The adjacent unburned grassland of 0.3 ha was taken as control.

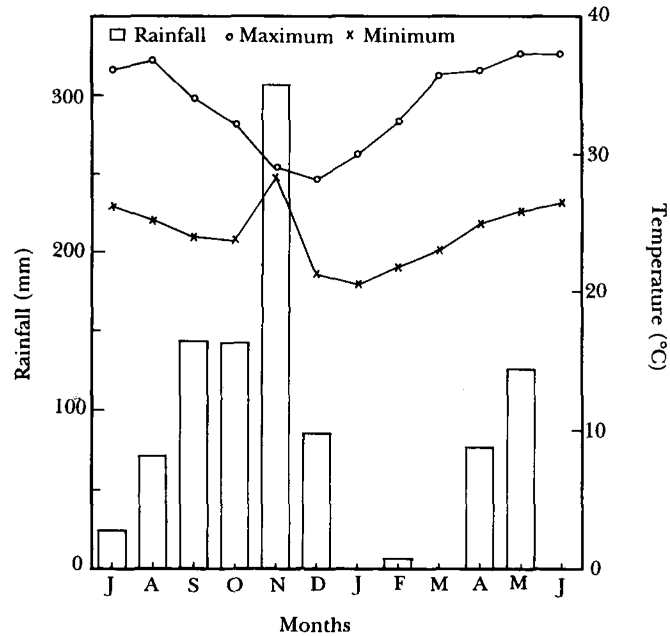

Figure 1. Ombrothermic diagram of the study sites during July 1993 - June 1994

Measurement of soil respiration rates

Soil respiration was measured using an alkali absorption method (Gupta & Singh 1977). The measurements were made at 15-day intervals from July 1993 to June 1994. Ten beakers containing 50 ml of 0.25 N NaOH solution were placed at 10 m spacing on both the burned and unburned grasslands. Closed, air tight plastic chambers (diameter 13 cm, height 15 cm) were inverted over each beaker and embedded 5 cm deep in the soil. Two similar chambers were placed on the wooden platform lined by a layer of polythene sheets at each site to serve as blank. The chambers were left in the field for 24 h after which they were removed and the beakers containing NaOH were immediately sealed. The amount of CO_2 absorbed by the alkali was determined by precipitating with 5 ml 10 % barium chloride solution and titrating against standardised 0.25 N HCL using phenophthalein as an indicator. The data were converted to mg $m^{-2} h^{-1}$ of CO_2 evolved (Anderson *et al.* 1983). The mean blank value was substracted from each titrated value.

Measurement of soil moisture, litter moisture and soil temperature

On each date of measurement of soil respiration, soil moisture was determined by taking three soil samples (15 × 15 × 30 cm) from the areas adjacent to the soil respiration measurement chambers using a pickaxe. Soil samples were oven dried at 105 ± 5 °C to constant weight. Soil moisture was determined by gravimetric method. Litter moisture was determined by collecting the litter in polythene bags and oven drying at 60° C for 24 h. Litter moisture percentage was determined using the formula

$$\text{Litter moisture percentage} = \frac{\text{loss of wt. on drying} \times 100}{\text{dry wt. of litter}}$$

Soil temperature was recorded using a digital soil thermometer (CT 804, Century, India).

Estimation of root biomass

On each sampling date, five soil monoliths (25 × 25 × 30 cm) were excavated randomly using a pickaxe from the places adjacent to the soil respiration measurement chambers. The roots were separated by washing the soil with tap water using a 2-mm sieve. Then the samples were oven dried at 80 °C to constant weight and the dry weight was recorded.

Statistical analysis

Student *t*-test was used to find out whether there were any significant differences between the sites. Least-square linear regression analysis was used to correlate soil respiration with soil moisture, litter moisture, soil temperature and root biomass. Multiple regression analysis was used to study the combined effect of the above abiotic variables on soil respiration rates.

Results

The monthly variations in soil moisture, litter moisture and soil temperature at the study sites are given in Figures 2a and 2b. Soil moisture and litter moisture were higher during the rainy season (September to December 1993) and lower during the dry period (January to April 1994) in both the study sites. The soil moisture content ranged from 10 to 16 % in the unburned grassland and 9 to 14 % in the burned grassland while litter moisture ranged from 7 to 30 % and from 6 to 14% in the unburned and burned grasslands respectively. Soil temperature (0-10 cm) fluctuated throughout the study period.

Seasonal and site differences in CO_2 evolution rates

Greater CO_2 evolution in the soil occurred from September to December. The CO_2 evolution rates for the two grassland sites ranged from 48 to 183 mg CO_2 m^{-2} h^{-1}. CO_2 evolution rates were low at the time of low moisture from January to March (Figure 3). The CO_2 evolution rates were significantly higher in the unburned grassland when compared to the burned grassland ($p<0.05$).

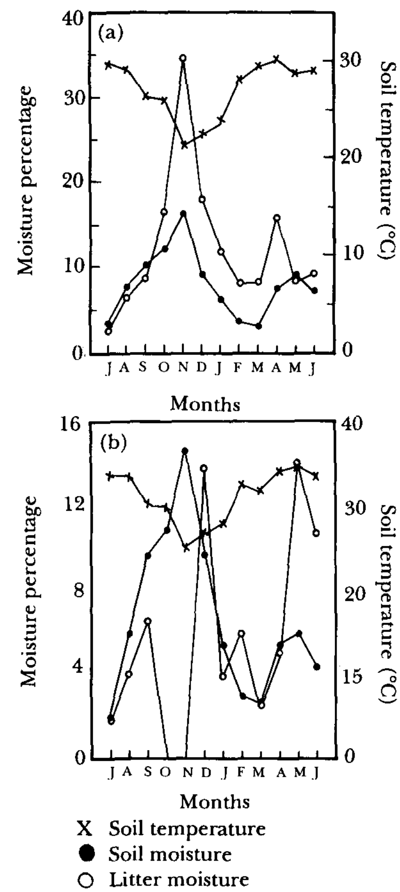

Figure 2. Monthly changes in soil moisture, litter moisture and soil temperature in the (a) unburned, and (b) burned grasslands

CO_2 evolution rates and abiotic variables

The CO_2 evolution rates for the two grassland sites were related to their corresponding soil moisture, litter moisture and soil temperature. Correlation and regression analysis showed that more variation in soil respiration rates could be attributed to soil moisture (64 to 79%) than to litter moisture (27 to 41 %). In the unburned site the respiration rates showed significant correlation with litter moisture ($r = 0.64$, $n = 12$) whereas it was insignificant in the burned site ($r= 0.52$, $n = 12$). Soil temperature showed positive correlation with respiration rates. To assess the combined effect of various abiotic variables ($n = 12$ for each variable) on CO_2 evolution rates, a multiple regression equation was developed.

Unburned: $y = 213.95 + 7.38\ x_1 - 1.62\ x_2 - 4.04\ x_3$; $R^2 = 0.73$
Burned: $y' = 134.27 + 8.13\ x_1' + 1.59\ x_2' - 2.97\ x_3'$; $R^2 = 0.85$

where x_1, x_1' = soil moisture, x_2, x_2' = litter moisture, x_3, x_3'= soil temperature, y_1, y_1' = soil respiration. This equation means that about 73 to 85 % variability in soil respiration rates was due to variation in the soil moisture, litter moisture and soil temperature.

The root biomass was comparatively higher in the unburned site than in the burned site (Figure 4). The root biomass increased during the rainy season (September to December 1993). The maximum root biomass occurred in the month of December in the unburned (400.5 g m^{-2}) and in November in the burned sites (393.73 g m^{-2}). The minimum was observed in July and March in the unburned and burned sites respectively.

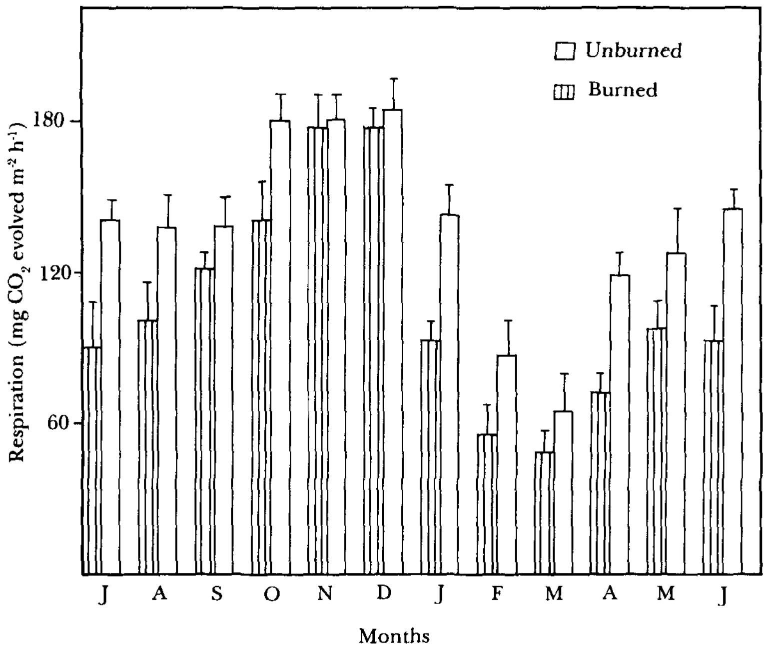

Figure 3. Changes in soil respiration rates during the study period (Bars represent ± se)

Carbon balance

Monthly CO_2- C output was calculated from the measurement of soil respiration rates on various sampling dates (Table 1). The maximum CO_2- C output was observed during the months of September to December (24 to 37 g cm^{-2}) and the minimum in the month of March (10 to 13 g cm^{-2}) in both sites. Annual carbon outputs of the study sites were 252 g cm^{-2} in the burned and 310 g cm^{-2} in the unburned sites.

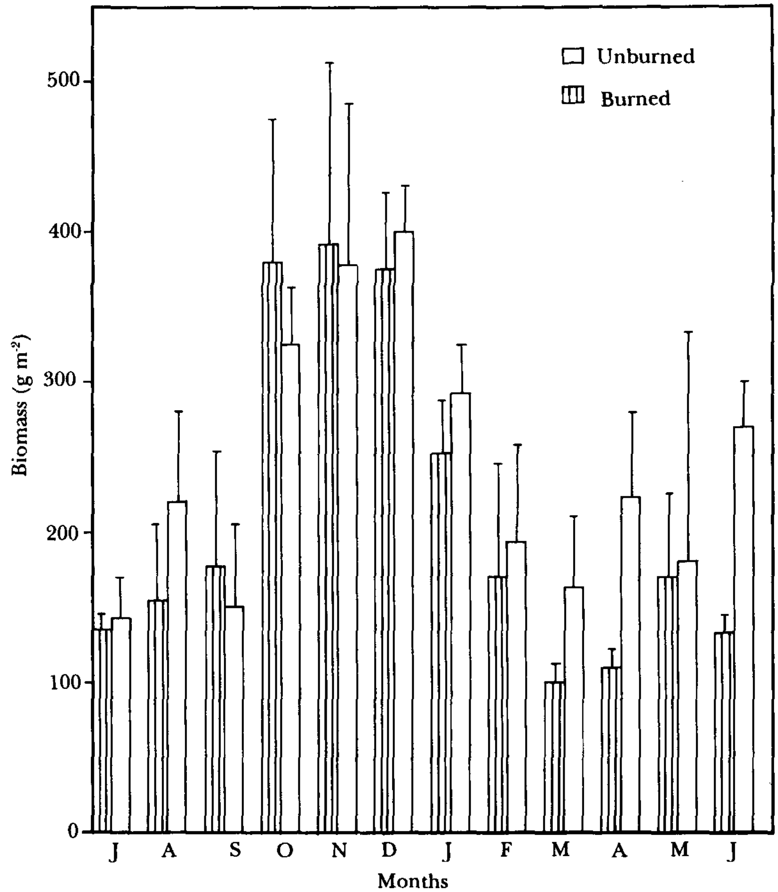

Figure 4. Changes in root biomass in the unburned and burned grasslands (Bars represent ± se)

Table 1. Monthly CO_2- C output from the soil litter system in the burned and unburned grasslands of the semi-arid region at Madurai

Month	CO_2- C output (g C m^{-2} $month^{-1}$)	
	Burned	Unburned
July	18.21	19.60
August	20.31	28.71
September	23.72	25.70
October	28.58	27.98
November	34.56	35.12
December	35.68	37.09
January	18.91	28.71
February	10.12	15.84
March	9.80	13.30
April	14.23	23.04
May	18.90	29.39
June	18.97	25.11
	251.99	309.59

The annual carbon balances of the grassland sites are presented in Table 2. Carbon input is taken in terms of litter production. CO_2 evolved from the soil is taken as carbon output. Litter disappearance which is estimated from the total litter production and weight loss was also taken as another output parameter (Sims & Singh 1978). For the dry matter values of litter production and litter disappearance, carbon weight was calculated on the assumption that carbon content is 0.45 of the dry matter (Coleman 1973, Reichle *et al.* 1973, Woodwell *et al.* 1978). The weight of carbon (CO_2- C) from carbon dioxide was estimated by using a factor of 3.67 (Coleman 1973). The loss of carbon through respiration was 2.76 and 8.27 times higher than the input of carbon in litter production in the unburned and burned grasslands respectively. The carbon outputs through soil respiration were also 3.09 times higher in the unburned and 9.49 times higher in the burned grasslands, than the estimated total losses of carbon in litter disappearance. It is interesting to note that loss of carbon in litter disappearance and carbon input in litter production were nearly equal in each site.

Table 2. Total annual carbon input and output in the burned and unburned grasslands of the semi-arid region at Madurai (in g m^{-2} y^{-1})

	Parameter	Burned	Unburned
Input	Litter production (L)	30.47	112.32
Output	Litter disappearance (LD)	26.54	100.07
Output	Soil respiration (CO_2 output)	251.99	309.59
Output/Input ratio	LD/L	0.87	0.89
	CO_2 output/L	8.27	2.76
	CO_2 output / LD	9.49	3.09

Discussion

The soil respiration values obtained in the present study ranged from 48 to 183 mg CO_2 m^{-2} h^{-1} which are comparable with the respiration rates reported by Ilangovan (1993) in a tropical grazingland in Madurai, and Medina and Zelwer (1972) in a semi-arid forest ecosystem in Venezuela. The observed values were lower, when compared to the reported values of other tropical and temperate grassland ecosystems (Table 3). The CO_2 evolution from the soil showed maximum rates during the rainy season (September to December). This is attributed to the favourable soil moisture and optimum temperature which provide a suitable micro-climate for the enhanced CO_2 output from the soil due to increased microbial activity (Rout & Gupta 1989). Lower rates of CO_2 evolution during the dry period (February and March) are due to the low moisture and dry conditions of the soil. A similar effect of seasonality on soil respiration has been reported in several other studies (Gupta & Singh 1981, Rajvanshi & Gupta 1986). Under tropical conditions, CO_2 evolution rates have been reported to be high during warm wet periods and low during hot dry months (Kucera & Kirkham 1971).

Table 3. Soil respiration rates (mg CO_2 m^{-2} h^{-1}) in some grassland ecosystems

Grassland ecosystems	Place	Soil respiration	Source
Temperate grasslands			
Agropyron - Koeleria grassland	Canada	135 - 150	Redmann (1974)
Andropogon grassland	USA	47 - 332	Coleman (1973)
Tropical grasslands			
Sesbania bispinosa	India	49 - 358	Gupta & Singh (1981)
Mixed grassland	India	55 - 378	Gupta & Singh (1981)
Desmostachya bipinnata	India	60 - 448	Gupta & Singh (1981)
Heteropogon contortus	India	50 - 162	Ilangovan (1993)
Heteropogon contortus	India	48 - 183	Present study

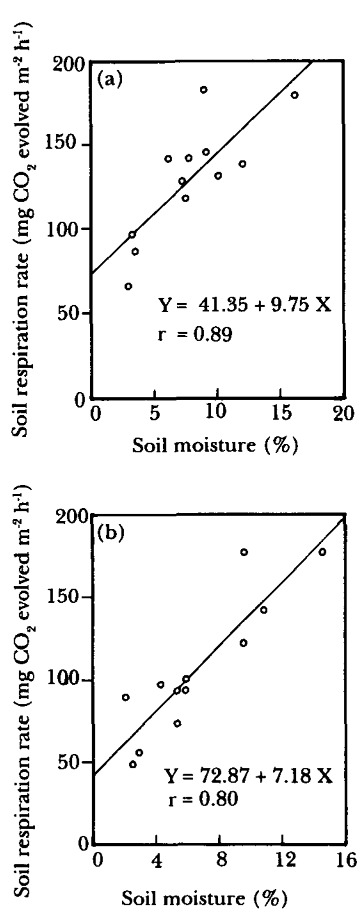

Figure 5. Relationship between soil respiration and soil moisture in the (a) unburned, and (b) burned grasslands

Among the three abiotic variables, soil moisture plays an important role in controlling the soil respiration rates, because soil moisture showed a highly significant ($p < 0.001, n = 12$) positive correlation with respiration rates compared to soil temperature and litter moisture (Figure 5). Similarly, Gupta and Singh (1981) and Rajvanshi and Gupta (1986) observed better correlation of CO_2 evolution rates with soil water than temperature in grassland and forest ecosystems respectively. Bunnell *et al.* (1977) also reported that soil moisture was of greater importance than temperature in controlling CO_2 evolution from soil.

Between the two sites, the CO_2 evolution rates were significantly higher in the unburned grassland than in the burned one. The differences in the CO_2 evolution rates between the two sites could be attributed to differences in litter accumulation and root biomass. The effect of habitat differences on CO_2 evolution rates under similar climatic conditions has been reported by Tewary *et al.* (1982), Gupta and Singh (1981) and Medina *et al.* (1980).

The carbon balance showed that the carbon output due to soil respiration was higher in the unburned than in the burned grasslands. The higher carbon output in soil respiration could be attributed to the contribution of root respiration. Medina *et al.* (1980) reported that the contribution of roots to total CO_2 output might be as high as 67 - 82 % for root mats in an Amazonian forest. Kucera and Kirkham (1971) observed increasing rates of CO_2 evolution with increasing root biomass. Edwards and Sollins (1973) also found maximum CO_2 production from the plots having the highest root biomass.

In this study, the carbon dynamics showed that about 11 to 13 % of carbon was accumulated in the grassland soil. Thus, the greater accumulation of carbon shows the seral nature of the grassland in the semi-arid ecoclimate where soil moisture plays a significant role in the regeneration of grassland. The carbon accumulated in the present system is comparable with the value of 20 % reported by Singh and Yadava (1974), but is at variance with the value of 38% reported by Behera and Pati (1986), for a tropical grassland in both studies.

Thus, the present study reveals that the rate of soil respiration in the grasslands varied due to differences in the soil moisture, litter moisture, soil temperature and root biomass. Burning reduces the rate of soil respiration which could be attributed to the lower root biomass and lower litter accumulation.

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