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Soil Respiration Rates under Different Land Uses in Northeastern Mexico

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Abstract
Determinations of CO_2 efflux, soil temperature and soil water content were monitored between July 3, 2001 and January 29, 2002. At each sampling date, two daily measurements (at 08:00 and 14:00 h local time, named as morning and afternoon, respectively) were carried out. A dynamic closed chamber with a portable system EGM employing a infrared gas analyzer (IRGA) and a soil chamber (SRC-1) was used to assess soil CO_2 efflux throughout the experimental period in vertisols under different land uses in northeastern Mexico: Pasture (*Dichanthium annulatum*), *Leucaena leucocephala* in an alley cropping system, a native and undisturbed shrubland plot, *Eucalyptus microtheca* plantation, and a *Sorghum bicolor* field.
During the studied period, average morning soil respiration rates for all land uses ranged from 0.7 to 8.4 μmol CO_2 m^{-2} s^{-1} (in Oct. and y Aug., respectively), while afternoon soil respiration rates ranged from 0.6 to 14.4 μmol CO_2 m^{-2} s^{-1} throughout the experiment. Average morning and afternoon soil respiration rates showed the following decreasing CO_2 efflux order among the five investigated land uses Pasture>Shrubland>Leucaena>Eucalytus>Sorghum, indicating that pasture plot showed the highest average morning and afternoon soil respiration rates 3.5 and 5.0 μmol CO_2 m^{-2} s^{-1}, respectively. In contrast Sorghum shows the lowest average morning and afternoon soil respiration rates 1.9 and 2.5 μmol CO_2 m^{-2} s^{-1}, respectively.

Introduction

Soil respiration is an important component of the terrestrial carbon budget and is considered the second-largest factor in the flux of carbon between the earth's ecosystems and the atmosphere (Bohn 1982, Eswaran *et al.*, 1993, 1995). It has been pointed out that any increase in soil CO_2 emissions in response to environmental change have the potential to substantially increase atmospheric CO_2 levels and to provide a positive effect to global warming (Schleser, 1982; Jenkinson *et al.*, 1991; Kirschbaum, 1995). Soil respiration is widely accepted as the most representative manifestation of the biological activity in the soil, and a good understanding of the variation occurring in the CO_2 fluxes due to land use changes, could help interpret the soil fluxes of other biogenic gases such as N_2O, NO, CO, CH_4. Identifying the environmental factors that control soil CO_2 emissions and their effects on emission rates, is a fundamental aspect in assessing the potential impacts of environmental change. Soil respiration rates vary significantly among major biome type, suggesting that vegetation type influences the rate of soil respiration,

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soil microclimate and structure, the quantity and quality of detritus supplied to the soil, and the overall rate of root respiration (Raich and Tufekcioglu, 2000). Recent studies have indicated that the terrestrial biosphere is acting as a carbon sink (Valentini *et al.*, 2000; Schimel *et al.*, 2001), attenuating the potential global warming by anthropogenic gases emissions (mostly CO_2 and CH_4). It has been well documented that rates of soil respiration are dependent upon soil temperature and soil-water content (Carlyle and Than, 1988; Raich and Tufekcioglu, 2000) and land uses (Raich and Tufekcioglu, 2000). Other soil factors potentially influencing rates of soil respiration *in situ* include the availability of C substrates for microorganisms (Seto and Yanagiya, 1983), plant root densities and activities (Ben-Asher *et al.*, 1994), soil organism population levels (Singh and Shukla, 1977; Rai and Srivastava, 1981), soil physical and chemical properties (Boudot *et al.*, 1986;) and soil drainage (Moore and Knowles 1989; Freeman *et al.*, 1993).According to the above mentioned and focusing on the importance of the increasing anthropogenic emissions of greenhouse gases in northeastern Mexico and to understand the contribution of different land uses in CO_2 efflux in predominant vertisols type soils in this region.

Material and Methods

Research site description

The present study was carried out at the Experimental Research Station of the Faculty of Forest Sciences of the Autonomous University of Nuevo Leon (24º47' N; 99º32' W; 350 m elevation) located 8 km south of Linares county, in Nuevo Leon state of Mexico. The climate is typically subtropical and semi-arid with a warm summer. Mean monthly air temperature ranges from 14.7^{o}C in January to 22.3^{o}C in August, although daily high temperatures of 45^{o}C are common during the summer. Average annual precipitation is 805 mm with a bimodal distribution. Peak rainfall months are May, June and September. Annual potential evapotranspiration is 2200 mm. The native Shrubland vegetation is known as the Tamaulipan Thornscrub or subtropical Thornscrub woodlands (SPP-INEGI, 1986). The dominant soils are deep, dark gray, lime gray, lime clay vertisols, with montmorillonite, which shrink and swell noticeably in response to changes in soil moisture content. These soils are the result of alluvial processes.

Land uses experimental plots

Five experimental plots with different land uses were selected at the research site to evaluate the contribution of CO_2 efflux: Pasture (*Dichanthium annulatum*), *Leucaena leucocephala* in an alley cropping system, a native and undisturbed shrubland plot, *Eucalyptus microtheca* plantation, and a *Sorghum bicolor* field.

Soil respiration measurements

The closed chamber method for measuring soil respiration was described by Parkinson (1981), where a chamber of known volume is placed on the soil and the rate of increase in CO_2 within the chamber is monitored. Thus, soil CO_2 efflux in each plot was obtained by means of a dynamic closed chamber which is a portable system EGM (PP-Systems, U.K.), employing infrared gas analyzer (IRGA) and a soil chamber (SRC-1), equipped with a fan. With this system, the air is continuously sampled in a closed circuit through the EGM, and the soil respiration rate is calculated, displayed and recorded by the analyzer.

Sampling procedures

Determinations of CO_2 efflux in each plot were made twice a week between July 3, 2001 and January 29, 2002. At each sampling date, two daily measurements (at 08:00 and 14:00 h local time, named herein as morning and afternoon sampling time, respectively) were carried out. At each sampling time, four (replications) randomly measurements of soil CO_2 efflux (μmol CO_2 m^{-2} s^{-1}) were taken. Simultaneously, soil temperature (^{o}C) and soil water content (%, dry mass basis) were registered. It is important to mention that soil respiration in *Sorghum* and *Leucaena* plots, was measured between plant rows.

Environmental data

Air temperature (^oC) and precipitation data (mm) were obtained from a meteorological station located 100 m from the study site. Gravimetric soil water content on each sampling date was determined in soil cores at depths of 0-20 cm by using a soil sampling tube (Soil Moisture Equipment Corp.). Soil water content was determined by drying soil samples in an oven at 105^oC for 72 h, and was expressed on a dry mass soil basis. Soil temperature was measured by means of a geothermometer (Fisher Scientific) at 10-15 cm soil depth.

Results and Discussion

Environmental conditions during the experimental period

Seasonal trends of monthly mean, minimum and maximum air temperatures, and total precipitation are shown in Fig. 1. During the experimental period mean maximum air temperatures ranged from 18.8^oC (January, 2002) to 36.4^oC (July, 2001), whereas mean minimum air temperatures varied between 6.3^oC (January, 2002) and 24.3^oC (July, 2001). Total rainfall registered at the study site was 592 mm (Fig. 1).

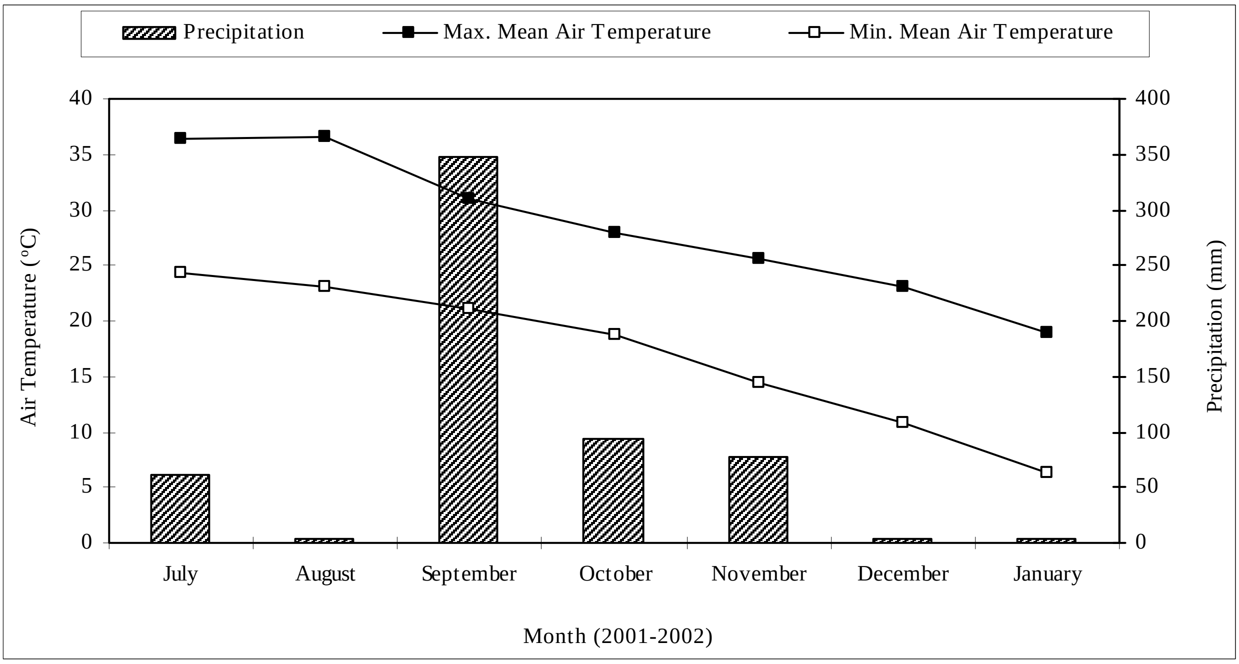
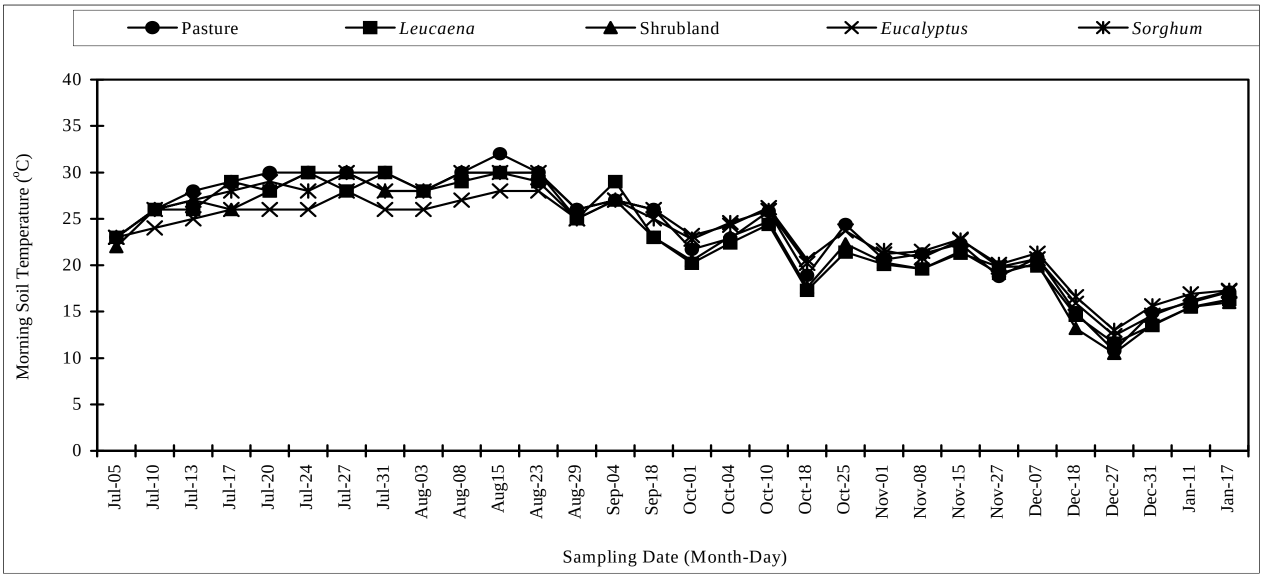
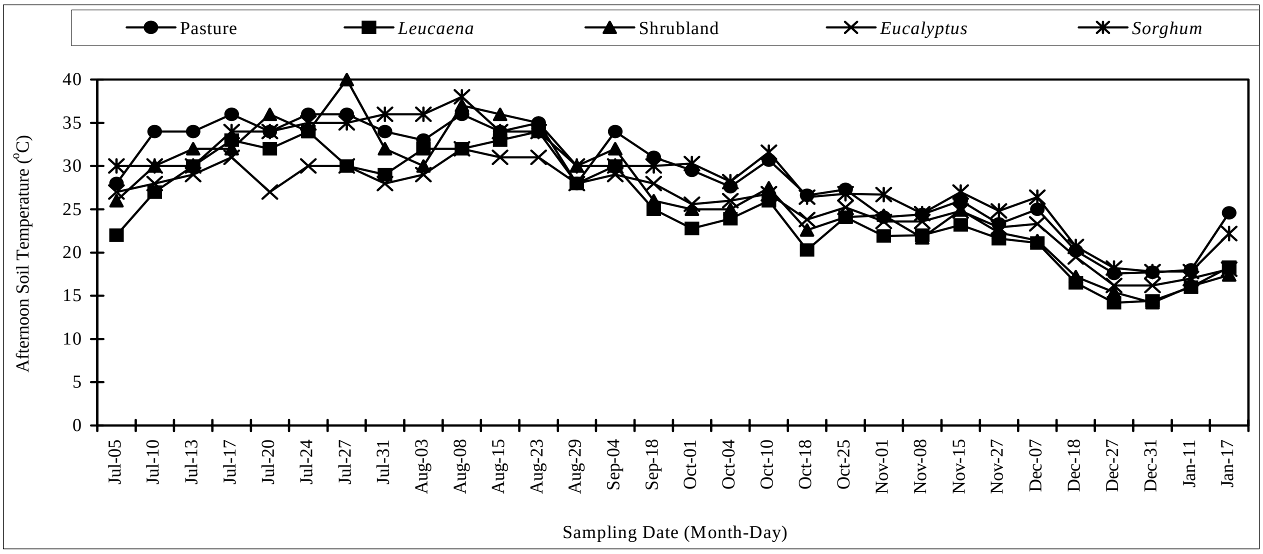


Figure 1. Monthly mean, minimum and maximum air temperatures, and monthly precipitation between July, 2001 and January, 2002 at the research site. Precipitation (▨); Mean Maximum Air Temperature (■); Mean Minimum Air Temperature (☐).

The seasonal trend of morning and afternoon soil temperature during the studied period are shown in Fig. 2. Maximum morning soil temperature values ranged between 28^oC (*Eucalyptus*) to 32^oC (Pasture), whereas minimum morning soil temperature varied from 10.5^oC in Shrubland to 13^oC in *Sorghum* (Fig. 2(a)). Maximum afternoon soil temperature ranged from 40^oC (Shrubland) to 32^oC (*Eucalyptus*), while minimum afternoon soil temperature varied between 17.8 ^oC (*Sorghum*) and 14.2 ^oC (*Eucalyptus*) (Fig. 2(b)).



a)



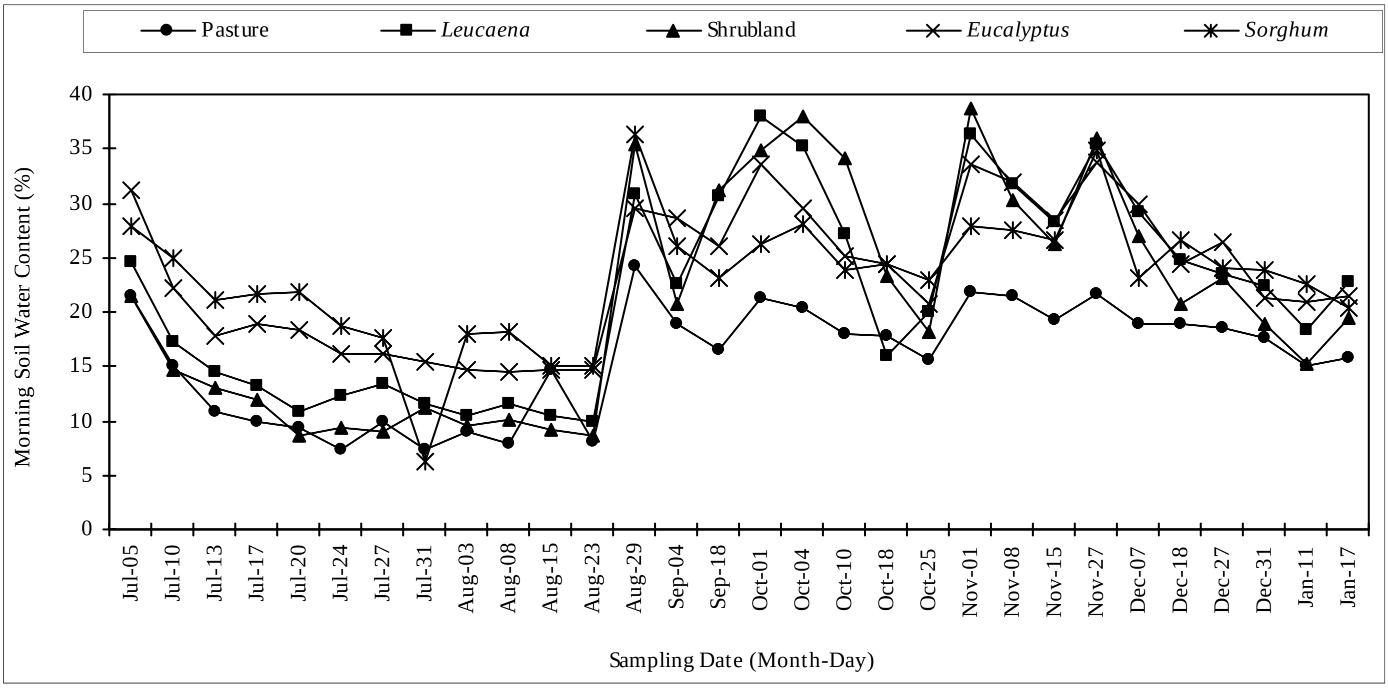
b)

Figure 2. Seasonal variation in morning (a) and afternoon (b) soil temperature at five different land uses. Pasture (•); Leucaena (■); Shrubland (▲); Eucalyptus (×) and Sorghum (∗).

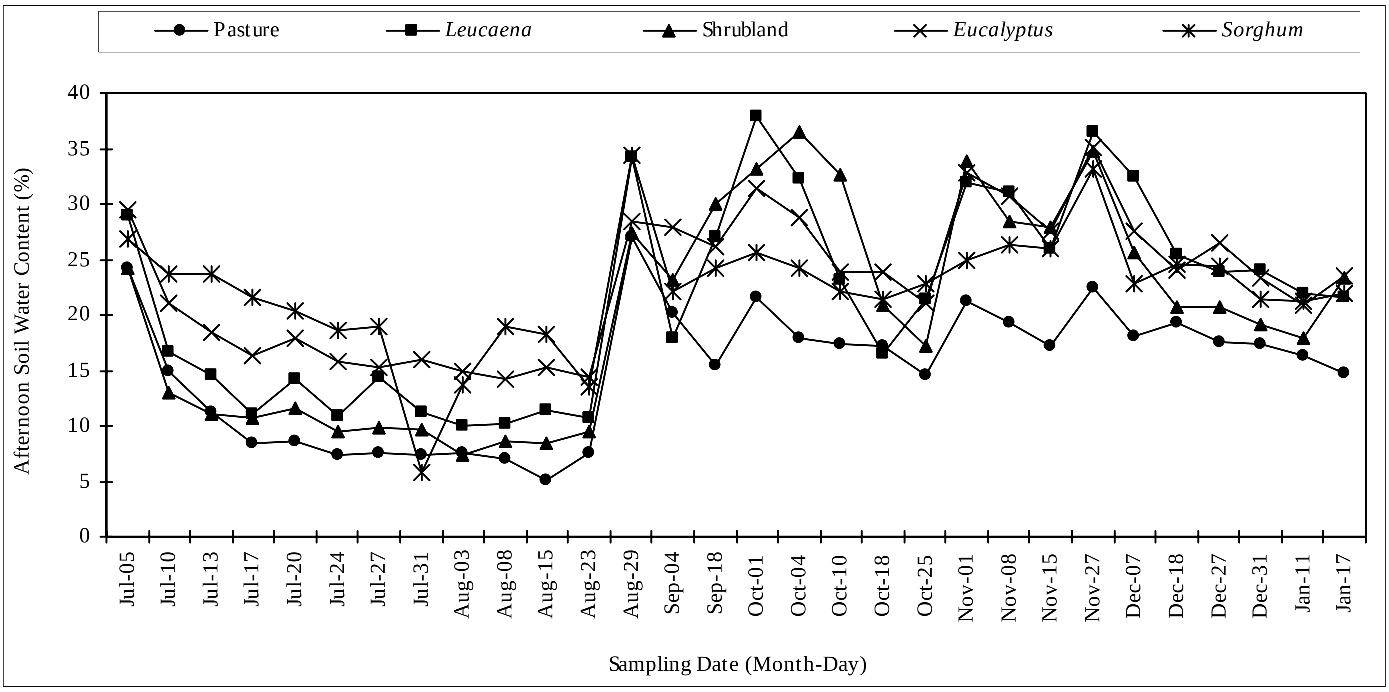
Seasonal soil water content trends at each land use were similar between morning (Fig. 3(a)) and afternoon (Fig. 3(b)) sampling times.

Seasonal variation in soil respiration

The seasonal variation in morning and afternoon soil respiration rate at each land uses is shown in Figs. 4 (a) and (b), respectively. During the studied period, average morning soil respiration rates ranged from 0.01 (Shrubland and *Sorghum*) to 8.46 (*Leucaena*) μmol CO_2 m^{-2} s^{-1}. With respect to afternoon soil respiration rates values ranged from 0.01 (Pasture, *Eucalyptus* and *Sorghum*) to 14.4 (*Leucaena*) μmol CO_2 m^{-2} s^{-1} throughout the experimental period. In general, average morning and afternoon soil respiration rates showed the following decreasing CO_2 efflux order among the five investigated land uses Pasture>Shrubland>*Leucaena*>*Eucalyptus*>*Sorghum*,



a)

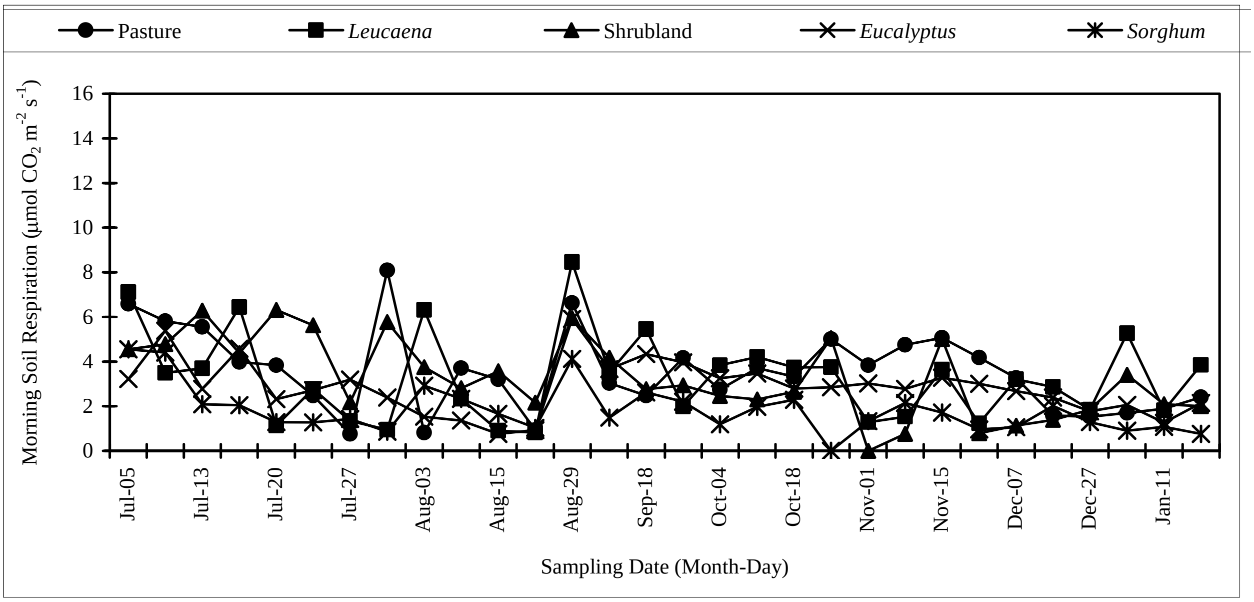


b)

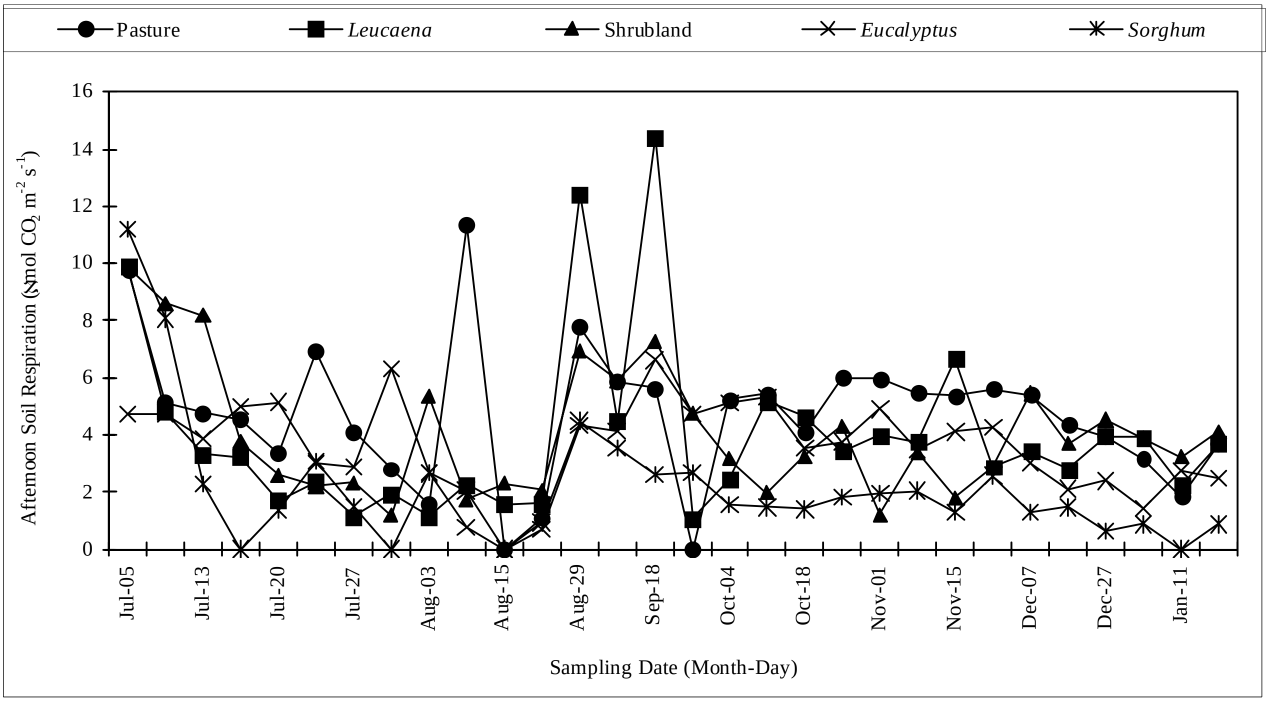
Figure 3. Seasonal variation in morning (a) and afternoon (b) soil water content (%) at 20 cm soil profile depths at five different land uses. Pasture (•); Leucaena (■); Shrubland (▲); Eucalyptus (×) and Sorghum (✳).

indicating that pasture plot showed the highest average morning and afternoon soil respiration rates 3.5 and 5.0 μmol CO_2 m^{-2} s^{-1}, respectively. In contrast, *Sorghum* shows the lowest average morning and afternoon soil respiration rates 1.9 and 2.5 μmol CO_2 m^{-2} s^{-1}, respectively.

Conversely, *Leucaena* showed the absolute maximum morning and afternoon CO_2 efflux rate during the study period; 8.4 µmol CO_2 m^{-2} s^{-1} and 14.4 µmol CO_2 m^{-2} s^{-1}, respectively.



a)



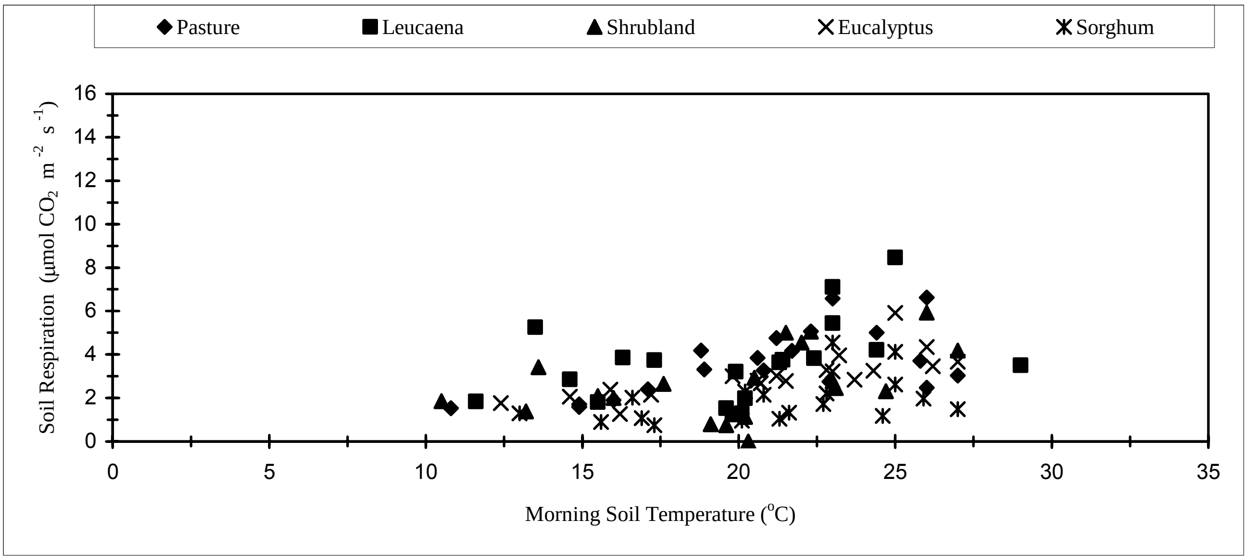
b)

Figure 4. Seasonal variation in morning (a) and afternoon (b) soil respiration rate at five different land uses. Pasture (•); Leucaena (■); Shrubland (▲); Eucalyptus (×) and Sorghum (✳).

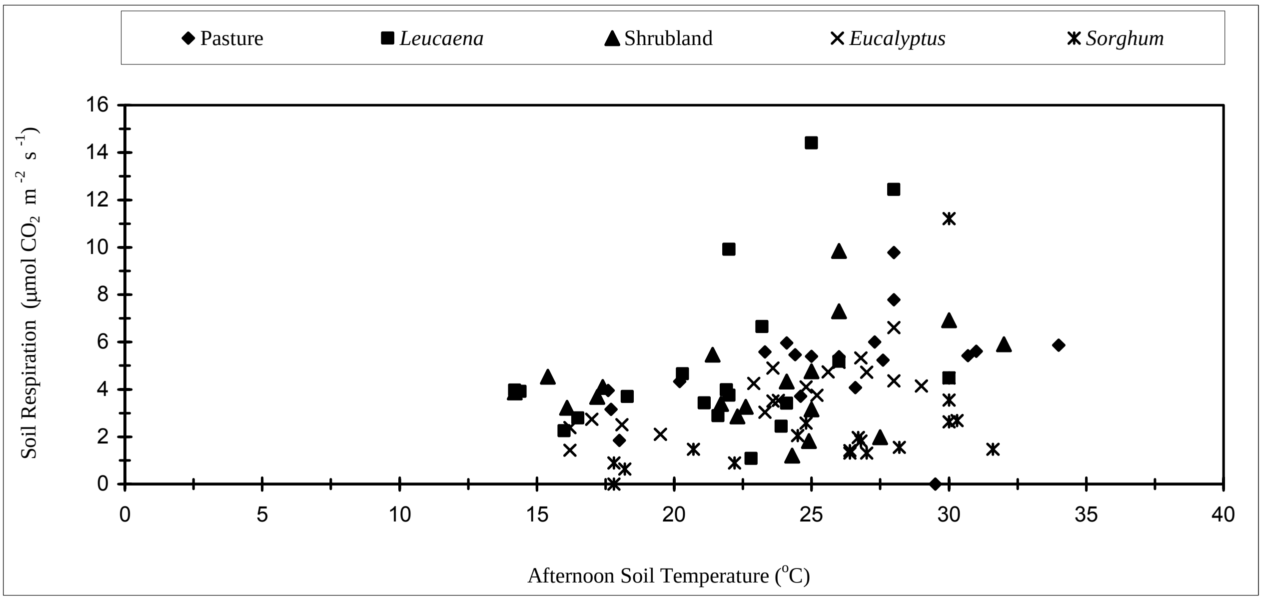
Soil temperature and soil respiration relationships

The relationship between soil respiration rate and soil temperature for all land uses at each sampling time is illustrated in Fig. 5. Factors such as temperature, moisture availability, and substrate properties that simultaneously influence the production and consumption of organic matter are more important in controlling the overall rate of soil respiration than vegetation type in most cases. However, coniferous forests had ~10% lower rates of soil respiration than did adjacent broad-leaved forests growing on the same soil type, and grasslands had, on average,

~20% higher soil respiration rates than did comparable forest stands, demonstrating that vegetation type does in some cases significantly affect rates of soil respiration (Raich and Tufekcioglu, 2000). Morning soil respiration rates during the studied period ranged from 0.7 to 8.4 µmol CO_2 m^{-2} s^{-1}, while in the afternoon increased the range from 0.6 to 14.4 µmol CO_2 m^{-2} s^{-1}, showing the *Leucaena* and Pasture the absolute maximum CO_2 efflux rates. Higher afternoon soil temperatures were observed during the studied period in Sorghum and Pasture plots, such results may be related to the low vegetative density of these land uses, due the lack of radiation interception, compared with others land uses involving trees (i.e. *Leucaena* and Eucalyptus) that showed lower soil temperatures. However the trend of morning soil temperature during the studied period was similar in the five land uses. Although Pasture and Sorghum showed higher afternoon soil temperatures, only Pasture showed higher soil respiration rate, while Sorghum presented the lowest soil respiration rates.



a)



b)

Figure 5. Relationship between soil respiration and soil temperature in morning sampling (a) and afternoon (b). Data are from all land uses and selected sampling dates (SWC>15%) during the studied period.

Soil moisture and soil respiration relationships

The exact relationship between SWC and the soil CO_2 efflux rate differs from one soil type to another (Howard and Howard, 1993), and is also likely to depend on adaptations by the soil microbial communities to local climatic conditions. Severe soil CO_2 efflux limitations in more arid ecosystems, for example, do not occur until the SWC drops below about 0.1 $m^3 m^{-3}$ (Carlyle and Than, 1988; Janssens et al., 2000, 2003). It seems to be that SWC during the dry period (Jul.-10 to Aug.-23) did not affect the soil respiration rate significantly. Since Pasture and Shrubland, which showed the lowest SWC (<10%) during this dry period (Fig. 3(a) and (b)), also obtained highest respiration rates in comparison with Eucalyptus and Sorghum which presented the highest SWC (>15%). However, the dry period has relevant influence in the verstisol structure, since the soil shrink and swell noticeably in response to low soil moisture content and that affect the reliability of the CO_2 efflux measurement by the close dynamic chamber. This results show the need of research efforts in SWC of vertisols in dry periods, specially when the SWC drops below 15%, in order to understand the dynamics of the CO_2 balance of the different land uses.

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