Article

Soil respiration in four land use systems

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Abstract:

Soil respiration (Sr), or carbon dioxide (CO_2) emission, is considered to be the second most important factor in the flux of carbon. Land use change has altered the global carbon cycle; this can aggravate global warming. The objective was to evaluate CO_2 efflux variation on a daily and a seasonal basis in Vertisol under four land use systems —thornscrub, grassland, agricultural and *Eucalyptus* spp. plantation—, through weekly measurements in morning and afternoon samplings during one year, using a portable EGM-4 analyzer; the soil temperature and soil moisture were also measured. The Sr for morning was 3.21 μmol CO_2 m^{-2} s^{-1} (agricultural), 3.86 μmol CO_2 m^{-2} s^{-1} (plantation), 4.61 μmol CO_2 m^{-2} s^{-1} (grassland) and 6.17 μmol CO_2 m^{-2} s^{-1} (thornscrub); the values of the afternoon Sr increased for all land use systems. Significant differences ($P \leq 0.05$) in land use and sampling time were determined. The soil temperature ranged between 12 °C and 35.4 °C, and the soil moisture, between 6.9 % and 47 %. In Vertisols, CO_2 efflux varies according their use, being higher in afternoon and in correlation with the moisture. Scrubs and grassland systems, which are more common in the northeast Mexico, showed the highest values for Sr.

Keywords: Global warming, CO_2 efflux, *Tamaulipas* thornscrub, soil respiration, land use systems, Vertisol.

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Introduction

Soil respiration (Sr), or CO_2 efflux, is an important component of the carbon cycle and is considered the second largest flow of carbon between the soil and the atmosphere (Cantú *et al.*, 2010; Srivastava *et al*., 2012). CO_2 soil production is a result of biological processes (Moitinho *et al.*, 2015), such as the respiration of roots and soil organisms, as well as of the decomposition of organic matter (Millard *et al.*, 2008) and, to a lesser extent, of the chemical oxidation of carbon compounds (Lloyd and Taylor, 1994). The speed at which soil carbon is emitted in the form of CO_2 determines the net flow between the soil and the atmosphere (Schwendenmann *et al*., 2007). Small changes in the respiration of the soil affect the global dynamics of carbon (Wei *et al.*, 2014).

The soils are the largest carbon reservoir (1500 PgC) (Lal, 2008), since they store 80 % of the global terrestrial carbon (Nielsen *et al*., 2011), and can act as a source or sink of the atmospheric CO_2 and influence the global climate change processes (Goudde *et al.*, 2016). The carbon stored in the soils is a major component, as the carbon content of these is higher than that of the atmosphere and biosphere (Mishra *et al.*, 2009). The overall rate of carbon efflux from the ecosystems to the atmosphere is approximately 75 to 100 PgC yr^{-1}, which is 10 times more than the amount emitted by fossil fuels (Buczko *et al.*, 2015).

The main factors that regulate soil the respiration of the soil are its temperature and humidity (Davidson *et al.*, 1998), the precipitation (Hussain *et al.*, 2011) and the type of vegetation (Scholze *et al.*, 2003); these are of interest due to their effect on the increases in soil respiration, given the uncertain global climate change scenario.

Carbon emissions resulting from changes in land use represent the second largest anthropogenic source of carbon dioxide efflux into the atmosphere and are the component with the highest level of uncertainty in the global carbon cycle

(Scharlemann *et al.*, 2014), as they lead to loss of soil carbon (Smith *et al.*, 2016).

Soils occupy 8.3 % of the national territory, are considered to be the most productive in the country (Torres *et al.*, 2016). In northeastern Mexico, their surface holds agricultural or livestock production activities and supports the native vegetation of regional economic importance (Llorente, 2004). The name Vertisol comes from the Latin *vertere* (turn), which refers to the constant internal recycling of soil material (IUSS, 2007); these are clay soils that tend to clump together easily when moist (Ghosh *et al.*, 2011).

The objectives of this study were to evaluate the diurnal and seasonal variations of CO_2 efflux in a Vertisol under four land use systems in northeastern Mexico and their relationship with the environmental variables, in order to compare the emission of CO_2 in the various land use systems.

Materials and Methods

Study area

The research was conducted in the municipality of *Linares*, *Nuevo León*, in northeastern Mexico, on the campus of the Faculty of Forest Sciences at the Autonomous University of *Nuevo León* (*Universidad Autónoma de Nuevo León*), which is located at the coordinates 24°47'51.22'' N and 99°32'29.71'' W, at an altitude of 380 m (Figure 1). The climate is tropical and semi-arid with a warm summer and an average monthly temperature ranging from 14.7 °C in January to 22.3°C in August. The average annual precipitation is 805 mm, with a bimodal distribution (González *et al.*, 2010). The predominant soil type is Vertisol, which is characterized by its depth, its dark-gray color, its fine clayey-loamy texture and its high content of montmorillonite, which contracts and expands notably in response to changes in the moisture content of the soil (Woerner, 1991). Table 1 shows some of the physical and chemical characteristics of Vertisol for a depth of 0-30 cm in each of the land use systems.

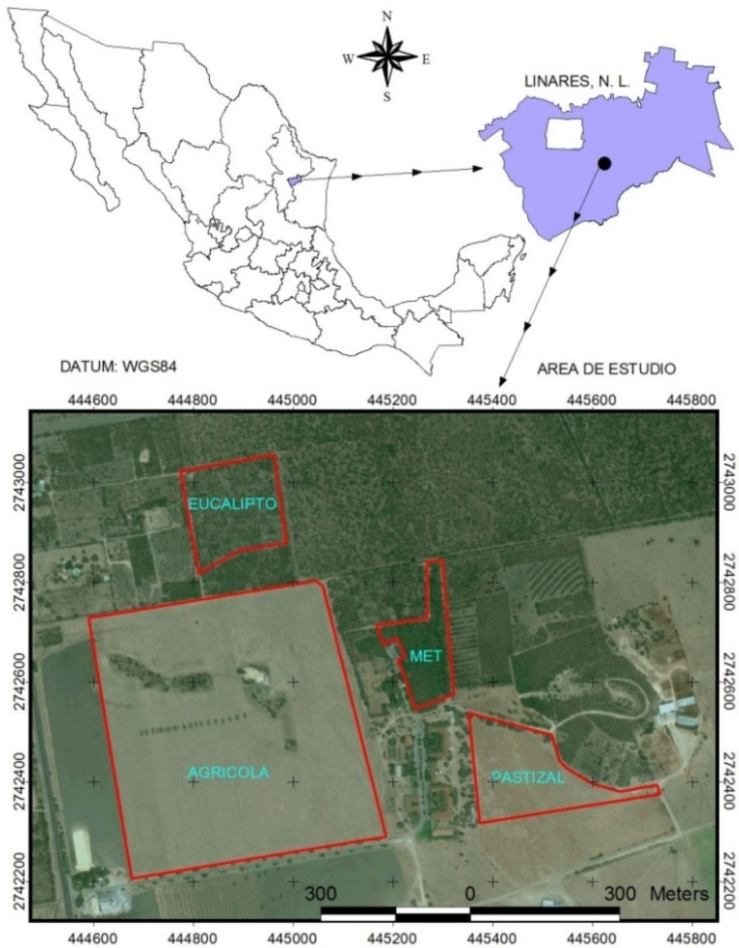


Figure 1. Location of the study area.

Table 1. Chemical and physical properties of the Vertisols (0-30 cm) for each land use system.

Soil properties	Land use systems			
	Thornscrub	Grassland	Plantation	Agricultural
pH	7.60	7.61	7.64	7.72
Bulk density (g cm^{-3})	0.9	1.3	1.1	1.1
Sand (%)	17.8	16.2	18.8	9.4
Silt (%)	41.2	38.9	40.2	40.9
Clay (%)	41.0	44.9	41.0	49.7
Electrical conductivity (dS m-1)	0.14	0.14	0.10	0.09
Organic matter (%)	6.1	4.6	3.5	2.3
Cation Exchange Capacity (cmol kg-1)	46.7	44.9	38.1	36.1

Experimental plots

Four land use systems were located: 1) *Tamaulipas* thornscrub (MET), which corresponds to the native arboreal vegetation, characterized by the predominance of thorny species —*Celtis pallida* Torr., *Acacia rigidula* Benth., *Randia aculeata* L., *Condalia lycioides* (A.Gray) Weberb., *C. obovata* Hook., *Bernardia myricaefolia* Benth. & Hook.f., *Forestiera angustifolia* Torr., and *Karwinskia humboldtiana* (Schult.) Zucc., among others (Inegi, 2009) —; 2) grassland area, integrated by an intensive livestock system and rotation of paddocks with *Dichanthium annulatum* (Forssk.) Stapf; 3) agricultural area, crop rotation, planting *Sorghum bicolor* (L.) Moench. and *Triticum* spp., under a system of zero tillage with criteria of sustainable production; and 4) eucalyptus plantation, composed of *Eucalyptus* *camaldulensis* Dehnh. and *E. microtheca* F.Muell., established in 1983 for research purposes and initially planted under a Taungya system (Cantú *et al.*, 2010).

Measurements of CO_2 efflux, temperature and soil moisture

Soil respiration was determined *in situ*, using the *Parkinson* closed dynamic chamber (1981), with a portable EGM-4 analyzer. This system is equipped with a non-dispersive infrared gas (IRGA) and a soil respiration chamber (SCR-1) to measure the CO_2 efflux (EGM-4 PP Systems, Massachusetts, USA). Weekly measurements were taken from March 13, 2015, to March 07, 2016, twice a day (at 8:00 and 14:00 h, i.e. morning and afternoon). Readings were carried out for each system, with four random repetitions at a minimum distance of 5 m between them for the grassland, thornscrub and plantation systems, while on the agricultural area a total of 32 measurements were taken per date between rows of plants. The camera was placed directly on the ground, and the duration of the measurements was approximately 120 seconds, depending on the rate of increase of the CO_2 concentrations in the chamber.

The flow of CO_2 was estimated in micromoles of carbon dioxide per square meter per second (μmol CO_2 m^{-2} s^{-1}). The soil temperature was measured in conjunction with the breathing, by means of a sensor (STP-1) built into the soil respiration chamber. The moisture content was determined through gravimetry using the NOM-021 RECNAT-2000 AS-5 method (Semarnat, 2002) at a depth of 0-15 cm.

Environmental Conditions

The precipitation (mm) and the air temperature (°C) were registered daily using a portable DAVIS VANTAGE PRO2 PLUS Precision Weather Station (PWS) located at a distance of 100 m from the study area (Figure 2). During the experimental period, a total precipitation of 695 mm occurred, and the temperature ranged between 6.6 °C (in January 2016) and 36.5 °C (in August 2015).

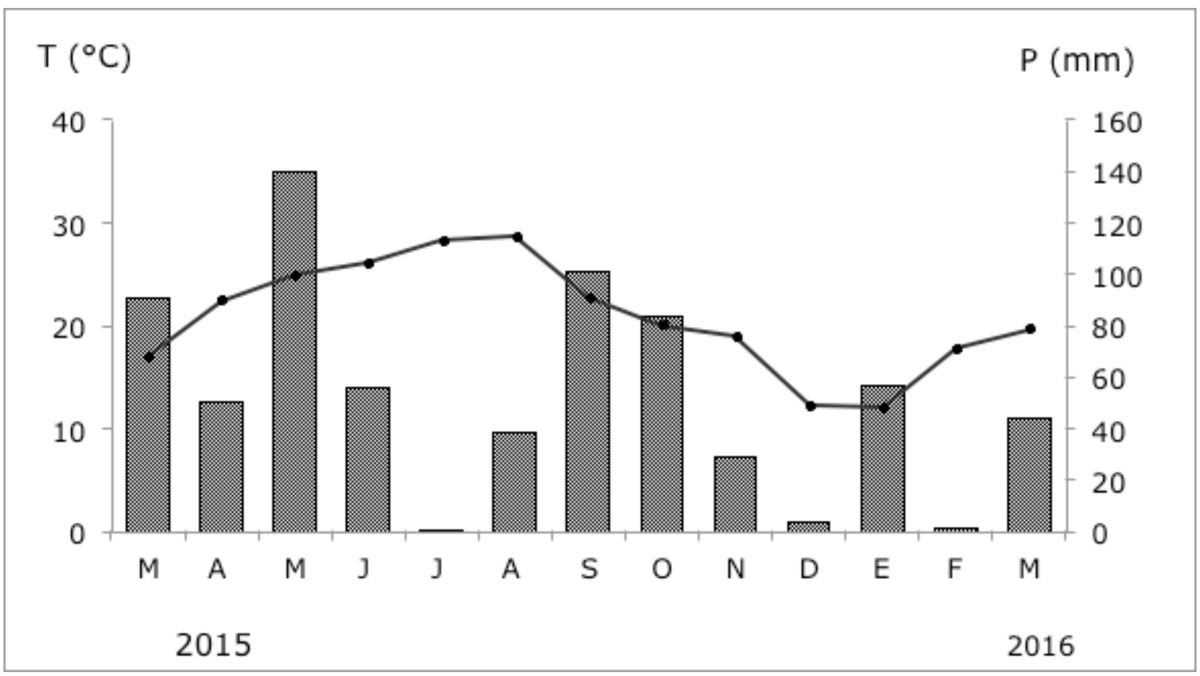


Figure 2. Climate diagram with monthly values for ambient air temperature (°C) and precipitation (mm) at the study site, from March 2015 to March 2016.

Statistical Analyses

The variance analysis was utilized to assess the effect on the CO_2 flows by land use (U factor) and sampling time (T factor), and also according to their interaction (U*T) for each date and for all the observations. The CO_2 efflux data were subjected to a logarithmic transformation in order to meet the normality assumptions and variance homogeneity. A Tukey's test was applied in order to establish the statistically significant differences ($P \leq 0.05$) in soil respiration between the land use systems in the morning and in the afternoon. Spearman's correlation analysis was utilized to relate soil respiration to the environmental variables, which did not meet the normality assumptions. All the statistical analyses were carried out with the Statistical Package for Social Sciences (SPSS) for Windows, standard version 13.0 (SPSS Inc., Chicago, IL).

Results and Discussion

The total CO_2 efflux interval ranged between 0.06 and 48.7 μmol CO_2 m^{-2} s^{-1}. According to the variance analysis, differences ($P \leq 0.05$) were found in the soil respiration, temperature and soil moisture for the land use factor (UF); there were no differences in soil moisture for the sampling time factor (TF), and no significant differences were found in any of the studied variables for the UF*TF interaction (Table 2). The Sr is highest in the morning samplings carried out in the thornscrub (6.17 μmol CO_2 m^{-2} s^{-1}) and differs from that of the other land uses, followed by the grassland (4.61 μmol CO_2 m^{-2} s^{-1}), the plantation (3.86 μmol CO_2 m^{-2} s^{-1}) and the agricultural area (3.21 μmol CO_2 m^{-2} s^{-1}). The values increased to 4.23, 4.33, 5.93 and 8.40 μmol CO_2 m^{-2} s^{-1}, respectively, for the afternoon measurements. A thronscrub>grassland>plantation>agricultural area behavior was observed both in the morning and in the afternoon.

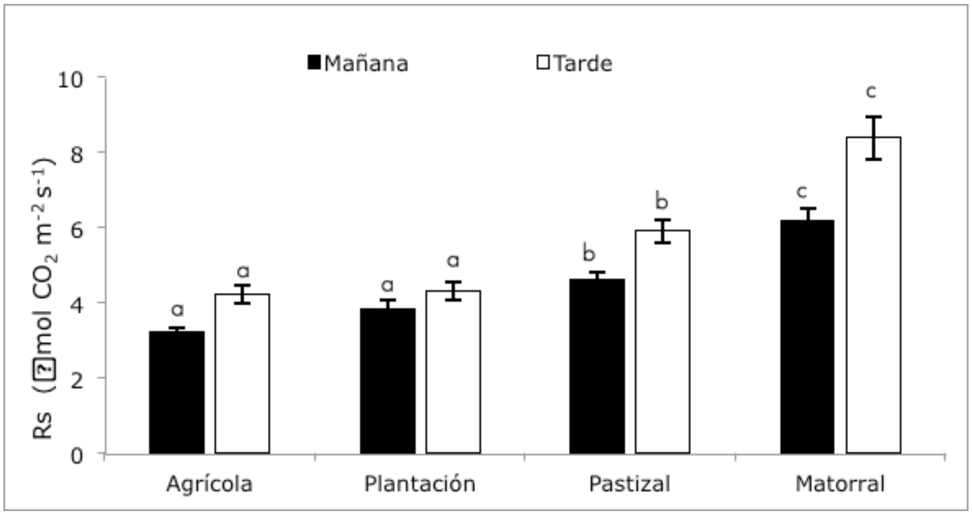
Tukey's test (P≤0.05) evidenced statistically significant differences in the Sr (P≤0.05) for the morning and afternoon samplings between the various land use systems (Figure 3). No differences were found between the thronscrub and the plantation in either sampling schedule. Thus, while the agricultural system has the lowest levels of CO_2 emission, it is not statistically different from the emissions of the eucalyptus plantations. Schwendenmann *et al*. (2007) cite no differences in the Sr between a forest and a grassland, with values of 5.7 and 5.2 μmol CO_2 m^{-2} s^{-1}, respectively, and they ascribe the high production of underground biomass to the grassland.

Table 2. Variance analysis of soil respiration, moisture and temperature for the model with two classification criteria (land use and sampling time) and Levene contrast.

Variable	**Model** $F_{(7, 1656)}$	**UF**[(a)] $F_{(3,1656)}$	**TF**[(b)] $F_{(1, 1656)}$	**UF*TF** $F_{(3, 1656)}$	Levene test(c) $F_{(7, 1656)}$	$\mathbf{R^2}$ **Adjusted**
Respiration	19.381 (0.000)	38.716 (0.000)	19.257 (0.000)	0.086 (0.968)	1.178 (0.312)	0.072
Moisture	19.116 (0.000)	42.443 (0.000)	1.619 (0.203)	1.621 (0.183)	17.160 (0.000)	0.071
Temperature	19.681 (0.000)	19.554 (0.000)	34.804 (0.000)	0.768 (0.512)	2.434 (0.018)	0.051

UF[(a)] = Land use; TF[(b)] = sampling time; [(c)] = Contrasting the null hypothesis of variance homogeneity.

Values between parentheses show the p value (P≤0.05).



Bars with different letters at the same sampling time differ significantly at P≤0.05.

Figure 3. Mean (n=52) soil respiration values (μmol CO_2 $m^{-2}s^{-1}$) in the morning and in the afternoon in the four land uses with standard error bars.

The values of the Sr were observed to be higher in the measurements taken in the months of April and May, and in September and October; in these, the thornscrub reached a maximum with 37 μmol de CO_2 m ^{2} s^{-1}, on May 18, 2015, unlike in July-August and December-February, when the soil respiration was less than 10 μmol de CO_2 m^{-2} s^{-1}. These results show the variability of the Sr throughout a year (Figures 4 and 5), which indicates that different levels of CO_2 emissions can be found in the same soil type according to the use of the land and is influenced by the interaction of the soil moisture. Vallejo *et al*. (2005) point out that the changes in the land use and management indicate changes in the carbon contents that are consistent with the organic matter contents registered in the present study. The same tendency to an increase in soil respiration with larger amounts of organic matter is observed for the various land uses. According to

Vásquez *et al*. (2013), low contents of organic matter reflect a reduced microbial activity, resulting in a lower CO_2 emission. On their part, Scharlemann *et al*. (2014) report losses of 25 to 50 % organic carbon due to disturbances that alter the physical-chemical characteristics of the soils and thus modify the carbon reserves (Weissert *et al*., 2016).

Cantú *et al*. (2010) assessed the CO_2 flows in 2001 under similar conditions in five land use systems for Vertisol. The morning Sr rate ranged between 0.7 and 8.4 μmol CO_2 m^{-2} s^{-1}, and the afternoon rate, between 0.6 and 14.4 μmol CO_2 m^{-2} s^{-1}. These results are consistent with the fact that the agricultural area had the lowest CO_2 efflux (1.9 and 2.5 μmol CO_2 m^{-2} s^{-1} in the morning and in the afternoon, respectively). Nevertheless, they differ in that the grassland had the highest emission (3.5 μmol CO_2 m^{-2} s^{-1} in the morning, and 5 in the afternoon).

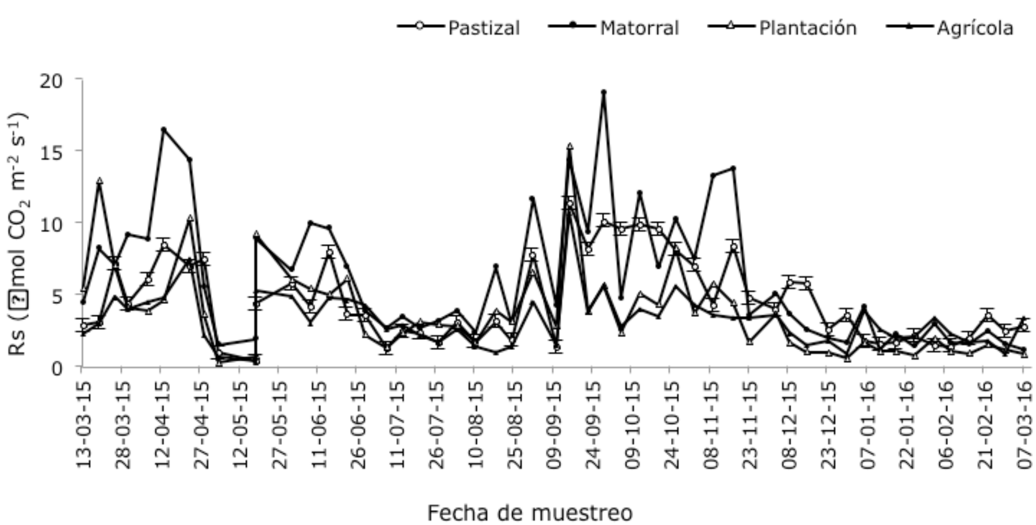


Figure 4. CO_2 efflux (μmol CO_2 m^{-2} s^{-1}) in the morning samples during the study period for the four land uses.

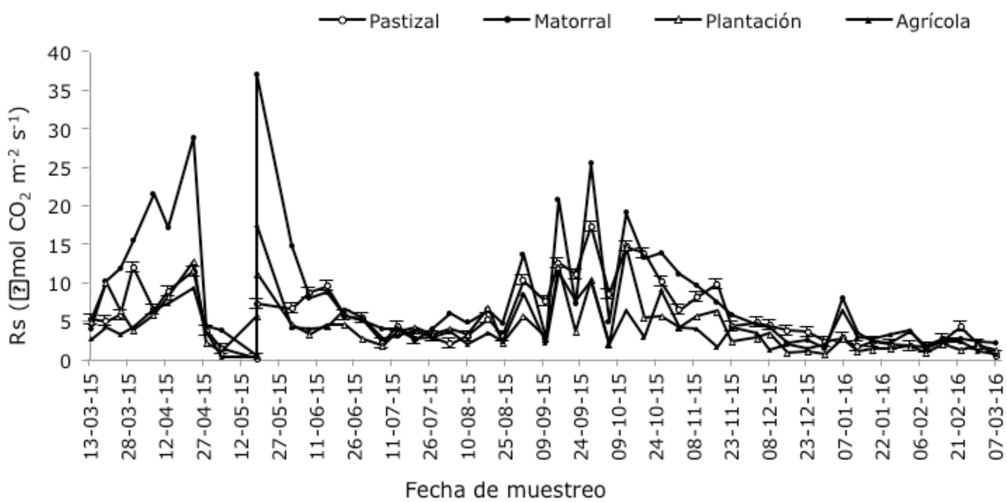


Figure 5. CO_2 efflux (μmol CO_2 m^{-2} s^{-1}) in the afternoon samples during the study period for the four land uses.

Table 3 summarizes the results of the two-way variance analysis of the Sr by sampling site for the land use (UF) and the sampling time (TF) factors and their interaction (UF*TF). Based on the 52 samples that were carried out, significant differences (P≤0.05) were determined in the soil respiration on 41 dates by land use; differences (P≤0.05) were found on 18 dates between the morning and the afternoon Sr. As for the UF*TF interaction, significant differences (P≤0.05) occurred in 13 of the 52 samplings.

Table 3. ANOVA of soil respiration by land use (U), sampling time (T) and their interaction by sampling date.

Sampling date	Land use (UF)		Sampling time (TF)		Interaction (UF*TF)		R2 Adjusted
	F Value	P Value	F Value	P Value	F Value	P Value	
Mar-13-15	6.53	0.002	0.69	0.412	2.31	0.101	0.395

Mar-19-15	23.50	0.237	1.83	0.188	1.51	0.237	0.693
Mar-25-15	9.59	< 0.001	0.03	0.844	3.30	0.037	0.506
Mar-30-15	33.22	< 0.001	18.02	< 0.001	7.91	0.001	0.813
Apr-07-15	15.65	< 0.001	8.75	0.007	1.91	0.154	0.637
Apr-13-15	25.58	< 0.001	8.42	0.008	1.67	0.199	0.729
Apr-23-15	12.60	< 0.001	12.32	0.002	1.17	0.342	0.601
Apr-28-15	4.09	0.018	3.11	0.090	0.64	0.596	0.250
May-04-15	12.29	< 0.001	6.20	0.020	3.33	0.036	0.598
May-18-15	12.26	< 0.001	0.05	0.823	6.17	0.003	0.609
May-25-15	15.24	< 0.001	45.57	< 0.001	6.39	0.002	0.769
Jun-01-15	8.41	0.001	1.31	0.263	5.14	0.007	0.530
Jun-08-15	13.37	< 0.001	0.21	0.645	5.57	0.005	0.618
Jun-15-15	11.50	< 0.001	0.31	0.582	0.65	0.587	0.490
Jun-22-15	1.04	0.392	0.38	0.540	1.54	0.229	0.036
Jun-29-15	8.57	< 0.001	7.31	0.012	0.17	0.912	0.461
Jul-07-15	4.68	0.010	1.68	0.206	0.73	0.539	0.261
Jul-13-15	0.76	0.525	2.13	0.157	0.09	0.964	0.080
Jul-20-15	0.75	0.533	1.50	0.232	0.99	0.414	- 0.009
Jul-27-15	2.76	0.064	2.99	0.096	0.14	0.935	0.132
Aug-03-15	1.95	0.147	0.68	0.416	0.99	0.412	0.076
Aug-10-15	3.53	0.030	11.76	0.002	0.02	0.995	0.333
Aug-18-15	5.70	0.004	4.79	0.039	2.15	0.120	0.408
Aug-24-15	2.39	0.093	1.74	0.199	1.29	0.300	0.157

Sep-01-15	8.79	< 0.001	4.64	0.041	2.01	0.139	0.492
Sep-10-15	3.28	0.038	2.76	0.110	5.53	0.005	0.417
Sep-15-15	6.90	0.002	1.07	0.311	2.77	0.063	0.427
Sep-22-15	6.63	0.002	0.80	0.378	2.59	0.076	0.409
Sep-28-15	10.01	< 0.001	9.52	0.005	0.45	0.717	0.523
Oct-05-15	34.65	< 0.001	1.68	0.207	0.31	0.812	0.763
Oct-12-15	18.93	< 0.001	26.72	< 0.001	1.56	0.224	0.724
Oct-19-15	43.31	< 0.001	8.50	0.008	3.55	0.029	0.821
Oct-26-15	3.50	0.031	1.41	0.246	2.16	0.118	0.269
Nov-02-15	12.86	< 0.001	0.48	0.494	0.79	0.510	0.526
Nov-09-15	12.51	< 0.001	0.41	0.526	3.11	0.045	0.565
Nov-17-15	22.39	< 0.001	1.24	0.275	2.31	0.102	0.688
Nov-23-15	9.52	< 0.001	2.61	0.119	1.11	0.364	0.470
Dec-03-15	1.73	0.186	0.04	0.838	0.54	0.655	- 0.003
Dec-08-15	11.20	< 0.001	0.03	0.855	2.24	0.109	0.518
Dec-15-15	23.11	< 0.001	0.87	0.358	1.05	0.385	0.682
Dec-23-15	13.62	< 0.001	0.50	0.482	1.15	0.349	0.550
Dec-30-15	29.44	< 0.001	0.70	0.411	4.83	0.009	0.757
Jan-06-16	39.40	< 0.001	37.09	< 0.001	0.26	0.850	0.828
Jan-12-16	11.35	< 0.001	7.36	0.012	4.61	0.011	0.609
Jan-18-16	5.93	0.004	3.43	0.076	0.08	0.966	0.319
Jan-25-16	7.62	0.001	7.36	0.012	1.41	0.263	0.470
Feb-02-16	10.01	< 0.001	1.05	0.314	0.63	0.598	0.456

Feb-08-16	1.92	0.153	1.20	0.283	1.23	0.319	0.106
Feb-15-16	2.40	0.092	13.25	0.001	0.49	0.690	0.326
Feb-22-16	5.88	0.004	0.47	0.499	0.54	0.657	0.292
Feb-29-16	6.42	0.002	2.04	0.165	0.56	0.646	0.341
Mar-07-16	1.77	0.178	4.89	0.037	6.43	0.002	0.421

Relationships between the Sr and environmental variables

The relationship between the morning and afternoon Sr rates and the environmental variables soil temperature, soil moisture, relative air moisture, maximum and minimum ambient air temperatures, and monthly precipitation for each land use system was determined based on Spearman*'s* correlation ($P \leq 0.05$) (Table 4). No correlation was observed between Sr and the soil temperature for the morning samplings in the grassland and agricultural systems, or in the afternoon samplings for the agricultural area. These observations may respond to the fact that the vegetal cover moderates the microclimate conditions by maintaining the soil moisture (Gomes *et al.,* 2016). The soil temperature interval ranged between 12.3 °C (thronscrub) and 33.1 °C (plantation) for measurements taken in the morning, and between 13.7 °C (thornscrub) and 35.4 °C (plantation) for those taken in the afternoon (Figure 6). There is little temperature variation between the land use systems to indicate a clear tendency in regard to Sr. Studies prove that temperature is an important factor because of its effect on the soil biota (Iglesias *et al.*, 2010).

Table 4. Spearman's correlation coefficient, Rho values for the soil respiration in the morning and afternoon samplings, according to the various land uses and environmental variables (n=52).

Environmental Variables	**Land use**			
	Grassland	**Scrubland**	**Plantation**	**Agricultural**
	Morning soil respiration			
Soil temperature	0.104	0.281*	0.297*	0.047
Moisture content of the soil	0.344*	0.574**	0.606**	0.538**
Air temperature	0.068	0.127	0.104	0.007
Relative moisture	0.346*	0.293	0.363*	0.157
Maximum air temperature	0.021	0.083	0.097	0.090
Minimum air temperature	0.049	0.201	0.253	0.015
Monthly precipitation	0.282*	0.254	0.229	0.118
	Afternoon soil respiration			
Soil temperature	0.302*	0.273*	0.365**	0.171
Moisture content of the soil	0.304*	0.588**	0.499**	0.414**
Air temperature	0.080	0.025	0.057	0.116
Relative moisture	0.468**	0.467**	0.635**	0.384*
Maximum air temperature	0.158	0.132	0.207	0.089
Minimum air temperature	0.169	0.212	0.363**	0.128
Monthly precipitation	0.254	0.163	0.226	0.184

* Indicates that there is a significant difference (P≤0.05) and that a correlation between the variables exists; * * Indicate that there is a significant difference (P≤0.01) and that a correlation between the variables exists.

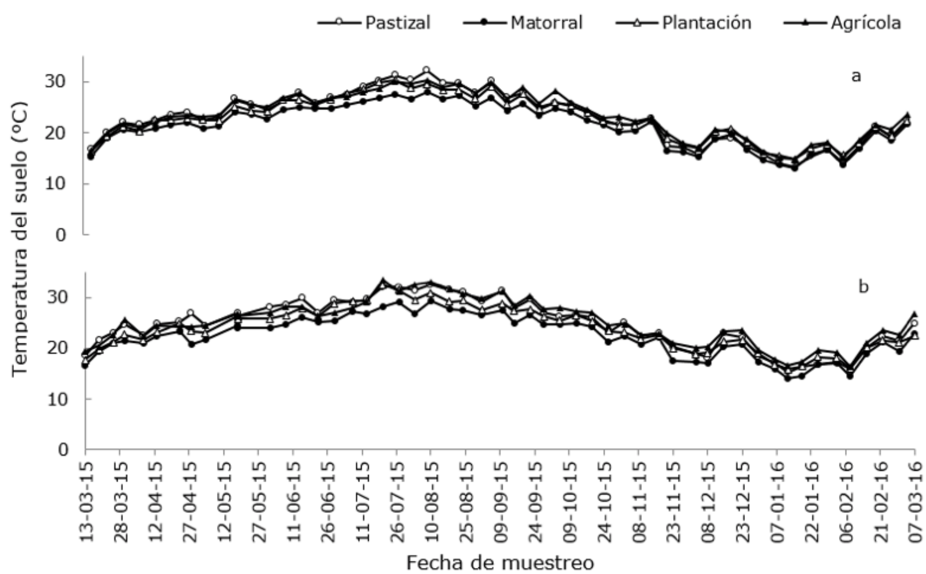


Figure 6. Soil temperature (°C) for the four land uses in the morning (a) and afternoon (b) samplings carried out during the study period.

A high, positive correlation was estimated for the soil moisture variable in all the systems in both the morning and afternoon measurements. The average soil moisture content was 18.9, 21.1, 21.5 and 23.7 % for plantation, grassland, thornscrub and agricultural area, respectively, in the morning samplings, and 18.7, 20.9, 21.6 and 22.6 % in the afternoon samplings (Figure 7). In this respect, according to Millard *et al*. (2008), the overall respiration rate decreases is limited in sites with 5 to 12 % moisture contents; on the other hand, Rosík *et al*. (2013) register a soil moisture threshold of 12 to 19 % when the CO_2 begins to dissociate from the changes in temperature. Furthermore, Cantú *et al*. (2010) point out that it is important to research the CO_2 efflux for Vertisols with gravimetric contents below 15 % due to the cracks in the structure of Vertisols, which cause measurement errors. In this regard, a notable reduction of the Sr to values under 5 μmol CO_2 m^{-2} s^{-1} was observed with moisture contents below 15 %. Srivastava *et al*. (2012) prove that the factors that most influence the CO_2 efflux are the soil moisture and the soil temperature.

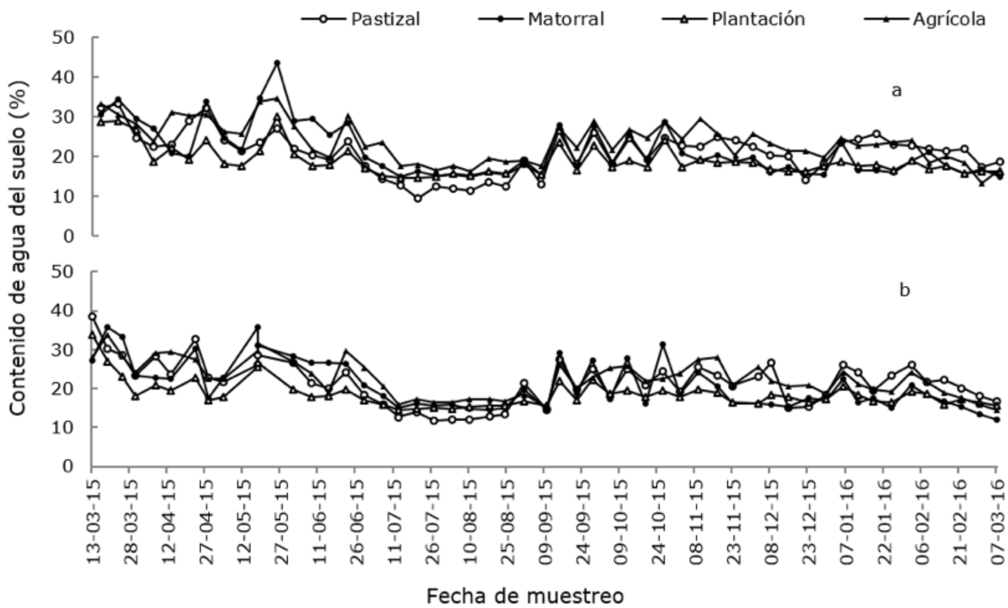


Figure 7. Water content of the soil (°C) in the morning (a) and afternoon (b) samplings during the study period for the four land uses.

In this study, the soil moisture was observed to be the variable with the highest correlation with CO_2 efflux for both the morning and the afternoon samplings, since soil respiration increases with higher moisture contents in response to the microbial activity of the soil (Davidson *et al*., 2006). Likewise, the changes in cover in the various land use systems regulate the soil temperature and moisture; these changes in the vegetation have an impact on the CO_2 exchange (Scholze *et al*., 2003), particularly in dry regions, where moisture is the most limiting factor for the activity of desert organisms (Bowling *et al.,* 2011).

According to Riveros-Iregui *et al*. (2007), the moisture content is the factor that controls soil respiration because it inhibits the diffusion of CO_2.

As for precipitation, the Sr was correlated with the data for rainfall at the time when the measurements were taken; therefore, correlation with the Sr was obtained only for mornings in the grassland. However, it is a major factor, given the variation in precipitations forecasted by climate change projections (IPCC, 2007). Various studies have demonstrated that the dynamics of precipitation and the availability of water in the soils will affect the global carbon balance (Hussain *et al.,* 2011). Campos (2014) points out that global warming may have a negative effect on the water availability of the soil and thereby reduce soil respiration. This tendency of the Sr to augment with increased precipitation results from the fact that the amount of water that enters the porous space of the soil eliminates the edaphic CO_2 (Moitinho *et al*., 2015), as shown in Figure 8, where a rising tendency of soil respiration is observed after rainfall both in the morning and in the afternoon, as a result of a phenomenon known as the Birch effect (Johnson *et al.,* 2013).

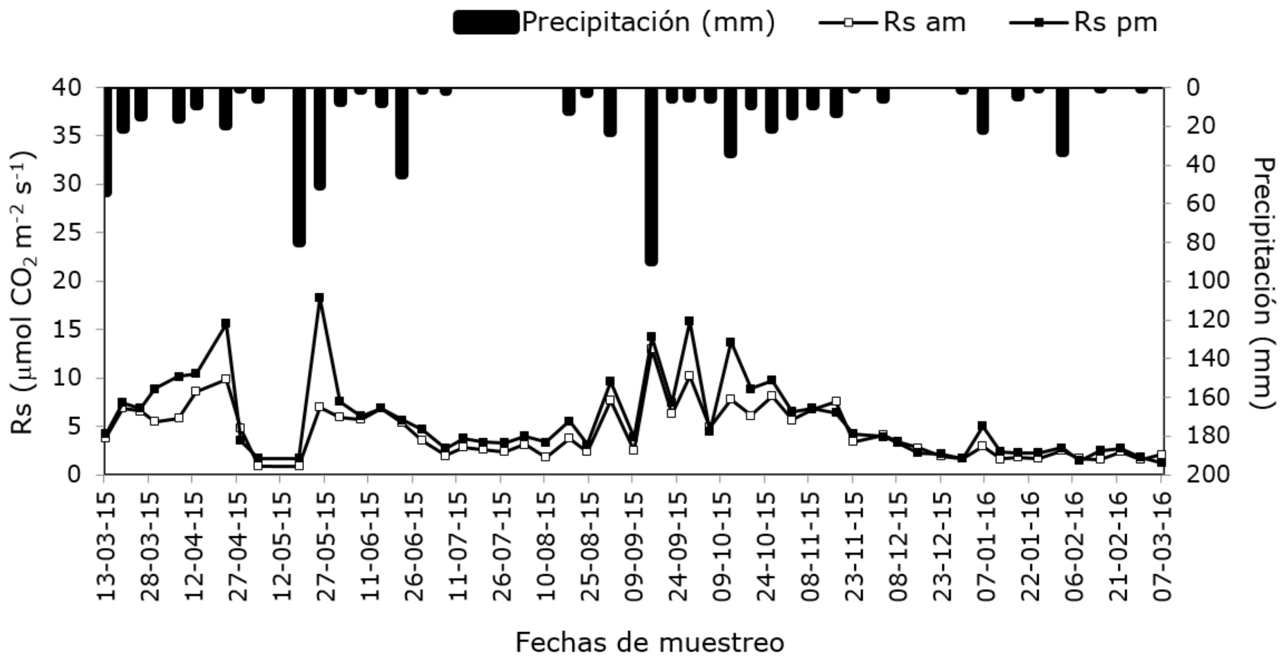


Figure 8. Precipitation distribution and average CO_2 flows of the four land use systems during the study period.

Conclusions

Analyses of Vertisol under four land use systems show differences in soil respiration. Thornscrub is the system with the highest CO_2 emission, followed by the grassland; these two are the most common land uses in northeastern Mexico. The agricultural area and *Eucalyptus* plantation are the systems with the lowest CO_2 emission. There is a high, positive correlation between Sr and soil moisture in all land use systems, while no relation is found between soil temperature and Sr in the agricultural or grassland systems. Likewise, soil respiration rates vary considerably at the daily and seasonal scales: the highest is for the afternoon in autumn and in spring, when the precipitation is heaviest. CO_2 flows follow this order: thornscrub>grassland>plantation>agricultural. Semi-arid regions are sensitive to the variability of precipitation. Thus, increased CO_2 emission in

Vertisols in response to environmental changes may have implications on the global carbon balance.

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Conflict of interest

The authors declare that they have no conflict of interest.

Contribution by author

María Inés Yáñez Díaz: research development, structure and design of the manuscript; Israel Cantú Silva: design of the manuscript and interpretation of the results and editing of the document; Humberto González Rodríguez: site selection, support in the results and revision of the manuscript; José G. Marmolejo Monsiváis: climate data, environmental correlations, revision of the manuscript; Enrique Jurado: contribution to the drafting of the abstract, discussion and conclusions, and revision of the manuscript; Marco V. Gómez Meza: statistical analyses and editing of the document.