Indian Journal of Science and Technology, *Vol 11(40), DOI: 10.17485/ijst/2018/v11i40/130132, October 2018*

ISSN (Print): 0974-6846
ISSN (Online): 0974-5645

Soil Respiration for Four Vegetation uses in the University of Sucre - Colombia

Euriel Millan-Romero[1]*, Luis Salcedo-Martínez[2] and Carlos Millan-Paramo[1]

[1]Faculty of Engineering, University of Sucre, Sincelejo, Colombia;
euriel.millan@unisucre.edu.co, carlos.millan@unisucre.edu.co
[2]University of Sucre, Sincelejo, Colombia; luis.salcedo@uniscre.edu.co

Abstract

Objectives: To determine the annual rate of Soil Respiration (SR) in different vegetation uses in the University of Sucre, analyzing its relationship with temperature, soil moisture and some properties of soils. **Methods/Analysis**: It includes the selection of the sampled areas, the location of the plots and the measurement of the SR, temperature and soil moisture in each one over a year. The determination of some properties of soils and the use of statistical software that allows comparing data between each of the soils and determining the existence of relationship between the measured variables. **Findings**: The organic matter in the soil turned out to be the main limiting factor of the SR, greater amount of organic matter favors the SR. The SR was not related to the soil temperature but to the soil moisture where ranges were formed that optimizes or limits the SR. The area with the greatest diversity of plant species (native vegetation) had the highest SR average (46.42 µmol CO_2/m^2s), followed by Hura crepitans (42.04 µmol CO_2/m^2s), Pasture (41.66 µmol CO_2/m^2s) and Tectona grandis (40.65 µmol CO_2/m^2s), these differences were due to the characteristics of each soil and the sun exposure of each one. **Novelty/Improvement**: The accumulated Soil Respiration ASR resulted to have a direct linear relationship with respect to time. Based on this, the annual SR rate was estimated between 49.3 and 49.4 mol CO_2/m^2 in the area with native vegetation, 47.5 and 47.6 mol CO_2/m^2 in H. crepitans, 44.8 and 44.9 mol CO_2/m^2 in pasture and 44.3 and 44.4 mol CO_2/m^2 in T. grandis.

Keywords: Organic Matter, Soil Moisture, Soil Respiration, Soil Uses, Temperature

1. Introduction

Soil Respiration (SR) is one of the oldest parameters to quantify microbial activity, representing the total flow of CO_2 produced by metabolic processes of organisms, including heterotrophic and autotrophic respiration[1,2]. There are different processes to microbial respiration that cause the soil to release CO_2 as the fermentative and anaerobic processes that use NO_3 and SO_4 as electron acceptors[3].

SR is one of the components that contributes the most CO_2 to the total respiration of the global ecosystem[1,4], emitting approximately 80.4 Pg CO_2-C (1 Pg = 10^{15} g) which represents 10% of the total atmospheric carbon[5]. The measure of this reflects the quantity and quality of carbon sources present in the soil, which reflects an index of the potential of the microbiota to degrade organic matter[6]. However, due to the presence of microorganisms is related to the amount of organic component present in the soil, like the microbial biomass, the measurement of the rate of respiration in the soil is a sensitive indicator that allows assessing the response of ecosystems to external factors[3].

Respiration rates depend mainly on the locality; in general, they are higher in areas of warm climate and can vary from place to place due to temperature, pH, moisture content, availability of nitrogen, amount of organic matter[7]; amount of leaf litter, Carbon[8]; porosity, texture and bulk density of the soil[9]. These characteristics vary when there is a change in the use of the soil and with this, the amount of CO_2 emitted from the same is directly affected[10,11]. Additionally, it has been shown that

Author for correspondence

the variations of temperature and moisture present in soil can be related to the variation in the SR exponentially[12,13] or directly[14]; although in other cases no relation has been found[15,16].

In this study, the annual rate of Soil Respiration was determined in four vegetation uses, in an anthropized soil inside the University of Sucre (Puerta Roja), evaluating the variations that occur in temperature, moisture and SR during a year, in the same way comparing the effects that have the use of the soil on such annual rate and estimating if the properties of each soil can influence the SR.

2. Materials and Methods

2.1 Study Area

The research was conducted from June 2015 until May 2016 at the University of Sucre (Puerta Roja) in the municipality of Sincelejo (Sucre - Colombia), which is located at 09°19'01" of North latitude and 75°23'16.39" of West longitude. It has an area of approximately 235490.7 m^2 and is framed in a tropical dry forest life zone, with an altitude of 182 meters above sea level and climate of warm thermal with a temperature ranging between 25.5°C-28.7°C and an average relative humidity of 60-80%[17,18].

Inside the university campus are soils with different degrees of anthropization, among which four anthropized areas with different soil uses were selected: An area with the presence of plants native to the region (from now on "Native vegetation") with an area of 0.7 ha in which the families Fabaceae, Euphorbiaceae, Malvaceae, Acanthaceae, Asteraceae and Anacardiaceae predominate and in a lesser proportion Amaranthaceae, Boraginaceae and Solanaceae according to the Herbarium of the University of Sucre (HEUS). A space of 0.5 ha is covered with pasture and other herbaceous plants (hereinafter "Pasture"); and two areas with monoculture plantations, one with Teak (Tectona grandis) of 0.5 ha; and another with "Ceiba de Leche" (Hura crepitans) of 0.6 ha.

2.2 Field Work

In each of the areas, three permanent plots were established during a year with an area of 200 m^2 and dimensions of 10 x 20 m. The location and distance between the plots were adapted to the conditions of the respective work areas covering the largest possible area. PVC "necklaces" with a diameter of 10.5 cm, a height of 10 cm and a depth of 8 cm inside the ground were installed in the corners of the plots, in order to reduce disturbance in the soil. In total 48 necklaces were located taking into account the four soil uses. The measurements and samplings were made every 4 weeks between 08:00 and 18:00 hours of the day; each plot was visited at a different time between samplings to take into account the environmental variation in relation to the position of the sun at the end of the day.

2.3 Respiration, Temperature and Moisture of the Soil

For the SR an equipment was used EGM-4 (PP-Systems) together with a Soil Respiration chamber SRC-1 (PP-Systems). This instrument is of the category dynamic closed chambers and has an infrared gas analyzer or IRGA (Infra-Red Gases Analyzer) where the CO_2 flow is determined by the increase of the concentration in the chamber in a determined time[19]. In addition, this equipment has a sensor that measures the temperature of the soil simultaneously with the SR.

As the equipment gives the value of the SR in units of ppm, the SR was calculated as a flow of CO_2 using the followingequation[20]:

$$FCO_2\left(\mu mol/m^2s\right)= \Delta CO_2\left[\mu mol/m^3\right]V\left[m^3\right]/\left(\Delta t[s].A\left[m^2\right]\right) \quad (1)$$

For soil moisture measurement, a kit ML3 Theta Kit brand Delta-T Devices was used, which has a humidity meter HH2 for instant reading and an insertion tool to penetrate hard soils.

2.4 Physical-chemical Soil Analysis

For soil analysis, four subsamples were taken per plot at random points until reaching a 1 Kg sample for each area (12 sub-samples in total for each soil use). For each sub-sampling, the layer of vegetation and surface of the soil was removed and then a hole was made in the shape of a "V" with a depth of 10 cm. A slice of the soil 2-3 cm thick was cut from the hole wall, from which the part that was between 3 and 8 cm deep was taken, then homogenized and was delivered to the laboratory[21].

The homogeneous soil sample was used of 0.5 Kg to do physical-chemical tests, following the indications and methodologies exposed by Geographic Institute (IGAC) (Table 1)[22–24].

Table 1. Methods to determine the edaphic characteristics

Determination	Methodology or Equation
Bulk density	Clod of paraffined soil
Organic Matter	Indirect method, Organic carbon[22]
pH	Potentiometric 1:1 NTC 5264 [23,24]
Porosity	P = 1- (ρa/ρr) ρb: Bulk density. ρp: Particle density.
Texture	Bouyoucos

2.5 Statistical Analysis

The statistical program R version 3.4.1 was used to evaluate the normality of the data obtained with the Shapiro-Wilk and Kolmogorov-Smirnov tests. The Kruskal Wallis test was used for differences between treatments and subsequently two versions of the Mann-Whitney U test were performed, one normal and the other by inequalities of the Tukey test to determine the difference between the means of the values of each one of the soil uses. In addition, a Spearman and/or Pearson correlation coefficient analysis was carried out when the data allowed it, to determine the relationship of the SR with the temperature, with the moisture and with the properties of the soils.

3. Results and Discussion

3.1 Variation of the Temperature

The temperature of the soils inside the University had an average between 29°C and 31°C, being similar to the average of the environmental temperature that the IDEAM manages for the department of Sucre (27-34°C IDEAM). The highest value was registered in the soil of T. grandis, with 36°C in February and the lowest value was 26°C in the soil with native vegetation in September. Figure 1 shows that the soil with T. grandis had higher temperatures than the rest of soil uses in six months, the months of February, March, April and May were the highest temperatures and in June, July, August, September and October were the lowest temperatures.

The temperature in the soil uses was organized in the following way, the largest was in the soil with T. grandis (31°C), followed by the pasture (30.42°C), H. crepitans (29.92°C) and finally that of native vegetation (29.83°C). Taking into account that the heating of the soil depends directly on the amount of radiation that reaches its surface[25], in the soil with T. grandis, the highest temperature records were found, due to the characteristics of this area and the species. The soil has a free surface of another plant species, that combined with T. grandis physiognomic characteristics such as the cylindrical shaft and lack of branches until the first 20 or 25 m, which do not expand beyond 3 or 4 meters in circumference[26], make the soil is exposed to the sun much of the time and in a greater percentage of area. In addition, this is a deciduous specie[26], which means that it loses its leaves in the summer months (such as January, February, March) and with it there would be a total exposure of the soil to the sun, which would increase the temperature considerably.

In the Kruskal Wallis test a p-value of 0.335 (>0.05) was obtained, so we can infer that there were no significant differences between the temperatures of one soil and another throughout the year. This behavior of the temperature with differences between months, but no differences between annual averages of the land uses can be due to the proximity of the areas, exposed to the same monthly fluctuations of environmental temperature.

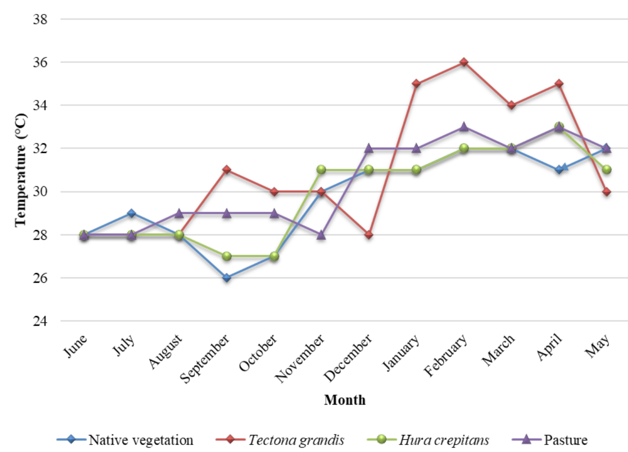

Figure 1. Variation of soil temperature over 12 months in four vegetation uses within the University of Sucre.

3.2 Moisture Variation

Regarding the moisture present in the soil, according to Figure 2, a pattern of moisture can be presumed throughout the year, being higher between the months of July to November but, when December arrives until May it decreases progressively to increase again in June.

The moisture in the four soil uses ranged between 30%-40%. However, moisture values between 5% and 9% were registered in the months of April, March and

February in the soil with T. grandis. In contrast, the highest values were in the soil with native vegetation, with values of 58% and 52% in the months of September and August respectively.

The averages of annual moisture in each use of the soils were given as follows: Native vegetation (42.4%), H. crepitans (39.58%), pasture (38.0%) and finally T. grandis (20.17%); in this case, the Kruskal Wallis test showed a p-value of 5.225 e^{-16} (<0.05), demonstrating the existence of significant differences in the moisture of the four soil uses.

The moisture content in the soil with T. grandis was lower, compared to the other three soil uses due to the same characteristics for which it has a higher average temperature. Then, an increase in temperature and a direct exposure to the sun makes the water retained inside evaporate more easily and quickly, which leads to a low moisture content.

In contrast, the soil of the area with native vegetation had lower average temperature and higher percentage of moisture throughout the year, a fact that has been register for the greener zones[27], because they have characteristics contrary to the soil of T. grandis. In this area, the soil is more cover by large trees as well as various shrub and herbaceous plant species that remain always green throughout the year, preventing the sun from reaching directly to the surface of the ground almost entirely. The temperature may vary less and moisture may be maintained[28], which, accompanied by a greater amount of organic matter and lower porosity compared to the other three soils, favors the retention of a greater amount of water inside the soil[29,30].

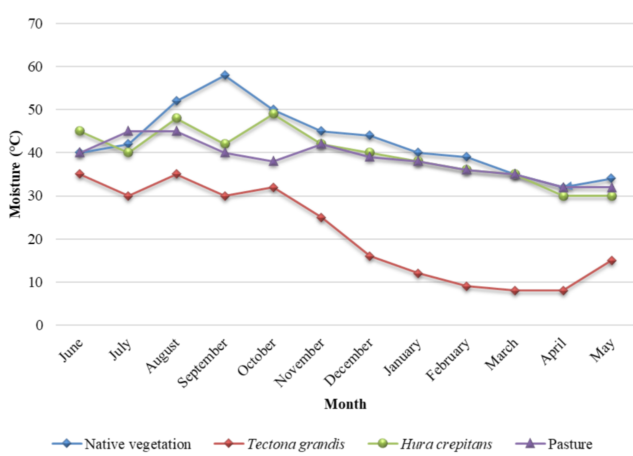

Figure 2. Variation of soil moisture over 12 months in four vegetation uses within the University of Sucre.

3.3 Variation of Soil Respiration

The SR had a similar pattern in the four soil uses in the university campus (Figure 3); in the rainy months (months of June to October), the SR is higher after the first rains in June, due to the activation of the metabolic processes of the bacteria present in the soil[31]. However, as the rains continue, the temperature reaches the lowest values, the moisture the highest and the RS decreases, which is similar to that found in other studies where the emission of CO_2 from the ground was reduced in winter times, which would be in our ecosystem during the rainy months[32]. In the dry months (months of January to April) where the temperature is higher and the moisture becomes lower, the SR was significantly reduced in relation to the values of rainy months, coinciding with other investigations, given that in drought activities inside the soil are reduced due to lack of water or moisture[33–36]. After the dry season, it was noted that the SR increased after a rain event (month of May), this has been observed in other investigations[16,37], this fact is explained because when it rains, the water helps activate the metabolic processes in roots and bacteria within the soil[37]. Additionally, it causes the gas stored in the pores of the soil and comes out to the surface (known as degassing), causing an increase in SR[35].

The Figure 3 shows that SR values with native vegetation and H. crepitans are above the values obtained in soils with T. grandis and pasture in most of the time. This was confirmed by observing the average values of SR per month in the four study areas, native vegetation with 46.42 µmol CO_2/m^2s, followed by H. crepitans with 42.04 µmol CO_2/m^2s, pasture with 41.66 µmol CO_2/m^2s and T. grandis with 40.65 µmol CO_2/m^2s. Within the records, the lowest value was 27.32 µmol CO_2/m^2s in the soil with T. grandis, while the highest value was found in the soil with native vegetation with 66.26 µmol CO_2/m^2s. All these SR values obtained were higher than those reported in Canada[38], China[13.33,39,40,41], Slovakia[42], Spain[15,27,37,43], Hungary[32,34,44], Mexico[35], USA[8,12,16,45–47] and the data presented for Colombia[48–50]. Perhaps, because in the ecosystems of warm or tropical climates, like those of this investigation, SR increases in comparison with soils of cold and temperate climate[7], being affected by the altitude of the ground, being higher in low altitudes like the present investigation and minors in high latitudes as in the soils of the works mentioned[14,37]. In addition to the climatic characteristics, the measurement method can have effects on the results[19]. Research has shown that SR in situ is greater than expected by samples in laboratories[12,51,52] or estimated by mathematical models[1,53].

In the Kruskal Wallis test a p-value 0.01718 (<0.05) was obtained, suggesting the existence of significant differences between the SR of the four soil uses. When comparing SR data between them, statistical differences were found only between the soil of native vegetation and T. grandis with a p-value of 0.038 (<0.05). Which may indicate that by anthropizing or changing soil uses in the study area, to plant species such as T. grandis can affect the processes that occur in the soil, and one of them is RS. It known that the vegetation types present alter the amount of CO_2 emission[13]. In the native vegetation and in H. crepitans, the average SR remained above the other soil uses due to a greater protection of the soil by the presence of trees, shrubs, herbaceous and litter leaves[10,11], which at the same time increases the microbial biomass and root biomass, favoring the SR[8]. Therefore, in this case, it is evident that more conserved forest soils always showed higher SR when compared with pastures and bare soils, as well as other works[8,15,53].

The four areas selected in the study have undergone changes within the university due to man, but the fact that the SR has been greater in the area with greater coverage and diversity of native plants is of great interest when making changes in the soil use. For example, the deforestation of forests to plant T. grandis as an economic activity and the reforestations of areas with only one species are not an activity that helps the conservation of an ecosystem. The presence of a greater number of native species in an area can lead to better soil conservation, as well as the balance of biogeochemical cycles and therefore a conservation of the other components of biodiversity.

SR is considered as a measure of the activity of microorganisms[7], such as the amount of available carbon and the quality of soil[6], so it is inferred that the soil with native vegetation and H. crepitans were found to be in better condition and more preserved that the pastures soils and T. grandis.

3.4 Relationship between Soil Respiration, Temperature and Moisture in the Soil

Table 2 shows the values of the correlation between the SR with the temperature and soil moisture, as well as the p-values of each correlation coefficient. It can be deduced

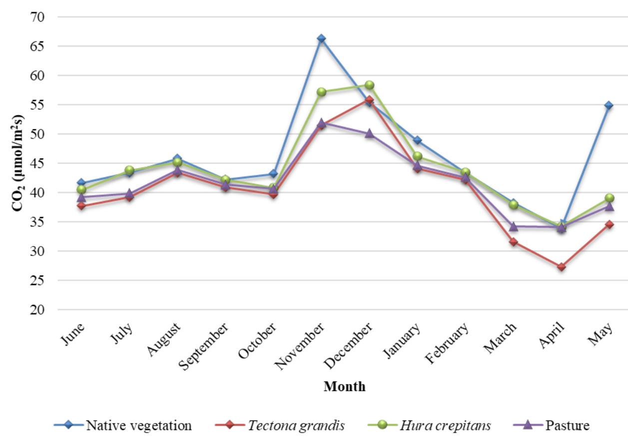

Figure 3. Variation of Soil Respiration over 12 months in four vegetation uses within the University of Sucre.

that in the four land uses there was no significant relationship between the SR and the temperature but there was a significant relationship between the SR and the moisture, similar to other reports[12,46]. The temperature was not significant in this work due to the proximity of the areas in the literature there are reports where the relationship between the SR and the soil temperature was always higher[38,44]. In addition to this, it is stated that in soils with a hot climate, as in this case, the SR is more related to moisture than to other factors[36].

Figure 4 shows the curves that relate moisture to Soil Respiration for each of the soil uses. In the native vegetation the SR was favored when the moisture stayed in a range between 40% and 50%, in T. grandis in the range between 15% and 32%, in H. crepitans in a range between 35% and 48% and in pasture between 25% and 42%. When the moisture values were outside these ranges, the SR was reduced. It can be said that an optimum moisture range and another limiting range for the SR were formed. These ranges can be related to the field capacity of each soil use, because when the soil has a moisture at field capacity the SR increases, but when it is lower or higher the SR is reduced[31,38]. Therefore, it can be considered that moisture is one of the main factors that limit and determine the amount of SR in each type of soil[54].

Table 2. Results of Spearman correlation tests of Soil Respiration (SR) values with the Temperature (T) and Moisture (M) present in each of the soil uses

Variables	Correlation	Native Vegetation	T. grandis	H. crepitans	Pasture
SR–T SOIL	Spearman	-0.1146	-0.2476	-0.1913	-0.2115
	P-value correlation	0.5058	0.1454	0.2637	0.2156
SR–M SOIL	Spearman	0,3509	0,3528	0,3975	0,5841
	P-value correlation	0.0359	0.0348	0.0164	0.0002

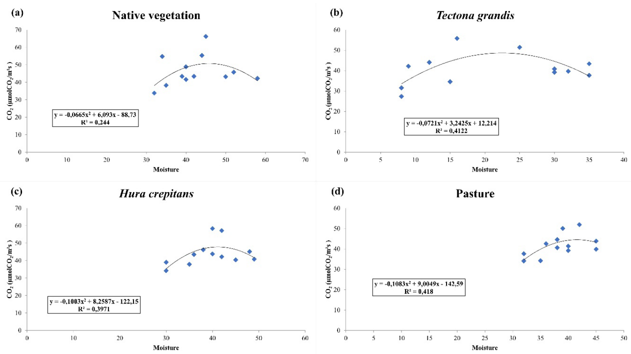

Figure 4. Polynomial regressions between soil moisture and Soil Respiration for each soil use: (a) Native vegetation; (b) T. grandis; (c) H. crepitans; (d) Pasture.

3.5 Physical and Chemical Properties of the Soil

Table 3 shows the physical and chemical properties of the soil for each of the uses. It is observed that in all samples the texture is similar (clayey soil). Furthermore, three of the land uses studied have a slightly alkaline pH (H. crepitans, native vegetation and pasture) while the soil with T. grandis is slightly acidic. In terms of organic matter, mean values were obtained in the sample of soil with native vegetation, low in the H. crepitans and pasture samples, and very low values for T. grandis. This is basically because the replacement of this in monocultures is deficient in comparison to soils with a variety of vegetation due to the specialization of the soil and the non-rotation of the use.

3.6 Relationship between Soil Respiration and Physical Properties

Like moisture, the amount of CO_2 emitted from the ground is related to physical characteristics of the soil. To establish the existence of a relationship between SR and the characteristics of each soil use, the average SR values were used and the Pearson correlation test was carried out (Table 4). The highest correlation coefficient was between the SR and the organic matter (0.8263), this being the only soil property that has a significant relationship with the SR. Given that it has a greater coefficient than those obtained in relation to temperature and moisture, it can be inferred that the presence of organic matter was the main factor that conditioned the amount of CO_2 emitted by the four study areas. The SR increases when there is more organic material, due to the percentage of organic matter increases the production and decomposition by the microbial element in the soil[7,15,44].

Although organic matter has been the only property with a significant relationship with SR, it is necessary to consider other characters that work together in the soil to optimize or limit the emission of CO_2 into the atmosphere. This indicates that, although porosity, pH, bulk density and cation exchange capacity have had small values in their correlation indexes, these may be exerting some effect on the RS in conjunction with the other factors. Besides those evaluated here, it can also be related to soil biomass[32,53], root biomass[13], organic C content[54], among others.

Table 4. Results of Pearson correlation tests between the physical-chemical characteristics and the SR of each soil use

Variables	Pearson Correlation	P-values correlation
SR – Bulk density	0.1325	0.7545
SR – pH	0.5703	0.1399
SR –Total porosity	-0.4704	0.2395
SR – Orgánic Matter	0.8263	0.0115
SR - CEC	0.4612	0.2501

CEC: Cation exchange capacity

3.7 Determination of the Annual Rate of Soil Respiration in the Four uses of Vegetation

Accumulated Soil Respiration (ASR) or also called annual RS rate is directly related to time, through a linear

Table 3. Physical and chemical properties of the soil in four vegetation uses

Determination	Native vegetation	T. grandis	H. crepitans	Pasture
Bulk density (g cm-3)	1.60	1.64	1.35	1.27
pH	7.57	6.05	7.69	7.80
Texture	Clayey	Clayey	Clayey	Clay loam
Porosity (%)	30.63	38.11	49.05	52.07
Orgánic matter (%)	2.45	0.45	2.00	1.91
CEC (meq/100g soil)	24.00	21.50	29.00	23.50

regression model (Figure 5). It can be seen that in the native vegetation and H. crepitans the highest values of SRA were obtained.

To calculate the ASR in the four soils with different use, the following equations (Figure 5) were used:

- Native vegetation: ASR = 1.5857D-8.4619.
- T. grandis: ASR = 1.4126D-3.1289.
- H. crepitans: ASR = 1.5195D-4.8808.
- Pasture: ASR = 1.429D-3.0461.

Where D is the elapsed time in days.

The annual rate of SR for each soil use was as follows: 1. Native vegetation: 49.28 and 49.41 mol CO_2/m^2 per year; 2. T. grandis: 44.27 and 44.4 mol CO_2/m^2 per year; 3. H. crepitans: 47.5 and 47.62 mol CO_2/m^2 per year; 4. Pasture: 44.8 and 44.93 mol CO_2/m^2 per year. The annual rate of respiration of the soil with native vegetation is higher than that of the other land uses, this is due to the conserved characteristics of the soil and the non-erosion due to the amount of plants present, helping to conserve a good content of matter organic and to keep active and in balance the metabolic processes of the organisms, bacteria, fungi and roots present in the soil. According to[5], forested areas have a higher rate of Soil Respiration than any other type, being the zone with natural vegetation the most similar to a small fragment of forest. The change in the use of the soil can directly affect the respiration of this and with it the balance of the ecosystems, for that reason the use and the changes that are being made inside the campus of the university and in all the regions should be reconsidered.

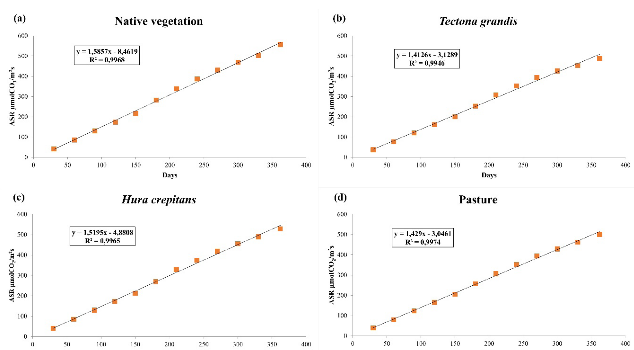

Figure 5. Accumulated Soil Respiration (ASR) in the four soil uses in the 360 days of research: (a) Native vegetation; (b) T. grandis; (c) H. crepitans; (d) Pasture.

4. Conclusions

The main conclusions of the study may be summarized as follows:

- The variation of the SR in the year depended on the type of vegetation and the degree of anthropization that each of the soils had, always presenting an average of higher SR in the soils that have a greater diversity of vegetation species (Native vegetation).
- Plantations of T. grandis can have possible negative effects on soil properties, such as pH (producing acidification) and the retention capacity of organic matter, and at the same time produce an imbalance in the exchange of CO_2 from soils.
- The main limiting factor of the SR was the organic matter present in the soil. The higher the percentage of organic matter, the greater the respiration of the soil. This is due to the increase in the number and activity of microorganisms and every organism present in the soil.
- Moisture was the second factor limiting the respiration of the soil, forming optimal humidity ranges, within which the RS is favored and outside of them decreases. These optimization ranges will depend directly on the type of vegetation that is given to the soil.

5. References

1. Ryan M, Law B. Interpreting, measuring and modelling Soil Respiration. Biogeochemestry. 2005; 73:3–27. https://doi.org/10.1007/s10533-004-5167-7.
2. Vargas R, Detto M, Baldocchi D, Allen M. Multiscale analysis of temporal variability of soil CO_2 production as influenced by weather and vegetation. Global Change Biology. 2010; 16(5):1589–605. https://doi.org/10.1111/j.1365-2486.2009.02111.x.
3. Medina M. Caracterizacion bioquímica y microbiologica de un suelo de pradera de «Dactylis glomerata» y «Medicago sativa» bajo diferentes proporciones de siembra. Ediciones Universidad de Salamanca: Espa-a. 2012.
4. Rey A, Pegoraro E, Tedeschi V, De Parri I, Jarvis P, Valentini R. Annual variation in Soil Respiration and its components in a coppice oak forest in Central Italy. Global Change Biology. 2002; 8(9):851–66. https://doi.org/10.1046/j.1365-2486.2002.00521.x.
5. Raich J, Potter C, Bhagawati D. Interannual variability in global Soil Respiration, 1980-94. Global Change Biology. 2002; 8:800–12. https://doi.org/10.1046/j.1365-2486.2002.00511.x.
6. Kennedy A, Papendick R. Microbial characteristics of soil quality. Journal of Soil and Water Conservation. 1995; 50(3): 243–8.
7. Krebs L. Respiracion del suelo como herramienta para evaluar calidad de fondos en acuicultura. I. Desarrollo de un protocolo estándar para medir dioxido de carbono.

Tesis de Grado, Escuela superior politécnica del litoral; Guayaquil, Ecuador. 2003. p. 1–67.

8. McCulley R, Boutton T, Archer S. Soil Respiration in a subtropical Savanna Parkland: Response to water additions. Soil Science Society of America Journal. 2007; 7(3):820–8. https://doi.org/10.2136/sssaj2006.0303.
9. Vargas R, Baldocchi D, Allen M, Bahn M, Black T, Collins S, Curiel J, Hirano T, Jassal R, Pumpanen J, Tang J. Looking deeper into the soil: Biophysical controls and seasonal lags of soil CO_2 production and efflux. Ecological Applications. 2010; 20(6):1569–82. PMid: 20945760. https://doi.org/10.1890/09-0693.1.
10. Arevalo C, Chang S, Bhatti J, Sidders D. Mineralization potential and temperature sensitivity of soil organic carbon under different land uses in the Parkland region of Alberta, Canada. Soil Science Society of America Journal. 2012; 76(1):241–51. https://doi.org/10.2136/sssaj2011.0126.
11. Liu Y, Liu S, Wang J, Zhu X, Zhang Y, Liu X. Variation in Soil Respiration under the tree canopy in a temperate mixed forest, central China, under different soil water conditions. Ecological Research. 2014; 29(2):133–42. https://doi.org/10.1007/s11284-013-1110-5.
12. Curiel J, Baldocchi D, Gershnson A, Goldstein A, Misson L, Wong S. Microbial Soil Respiration and its dependency on carbon inputs, soil temperature and moisture. Global Change Biology. 2007; 13(9):1–18. https://doi.org/10.1111/j.1365-2486.2007.01415.x.
13. Han G, Xing Q, Luo Y, Rafique R, Yu J, Mikle N. Vegetation types alter Soil Respiration and its temperature sensitivity at the field scale in an Estuary Wetland. PLoS One. 2014; 9(3): e91182. PMid: 24608636 PMCid: PMC3946705. https://doi.org/10.1371/journal.pone.0091182.
14. Luo S, Liu G, Li Z, Hu C, Gong L, Wang M, Hu H. Soil Respiration along an altitudinal gradient in a subalpine secondary forest in China. Forest - Biogeosciences and Forestry. 2015; 8(4):526–32.
15. Martinez T, Gonzalez L, Delgado J. Respiración del suelo en zonas riparias. Efecto de la materia orgánica, de la vegetación herbácea y de la biomasa de raíces. En: Los sistemas forrajeros: entre la producción y el paisaje. Actas de la XLVI Reunión científica de la SEEP. Ed. Neiker; Vitoria. 2007. p. 665–70.
16. Borkhuu B, Peckham S, Ewers B, Norton U, Pendall E. Does Soil Respiration decline following bark beetle induced forest mortality? Evidence from a lodgepole pine forest. Agricultural and Forest Meteorology. 2015; 214–215:201–7. https://doi.org/10.1016/j.agrformet.2015.08.258.
17. Aguilera M. La Economia del Departamento de Sucre: Ganaderia y Sector Publico. Documento de Trabajo sobre Economía Regional. Banco de la Republica: Centro de Estudios Economicos CEE; 2005, 63.
18. Gaceta Departamental de Sucre. Plan vial departamental de Sucre. Gobernacion de Sucre; Sucre, Colombia. 2010.
19. Pumpanen J, Kolari P, Ilvesniemi H, Minkkinen K, Vesala T, Niinisto S, Lohila A, Larmola T, Morero M, Pihlatie M, Janssens I, Curiel J, Grünzweig J, Reth S, Subke J, Savage K, Kutsch W, Østreng G, Ziegler W, Anthoni P, Lindroth A, Hari P. Comparison of different chamber techniques for measuring soil CO_2 efflux. Agricultural and Forest Meteorology. 2004; 123:159–76. https://doi.org/10.1016/j.agrformet.2003.12.001.
20. Oviedo L. Medicion de la respiracion del suelo en ecosistemas mediterraneos con sistemas de camaras y analizadores tipo IRGA. [Tesis de Maestria]. Universidad de Granada: Espa-a; 2007. p. 1–32.
21. Bernier R. Tecnicas de muestreo de suelo para análisis de fertilidad. En: Bernier, R. curso de capacitación para operadores del programa de recuperación de suelos degradados INDAP, décima región. Centro regional de investigacion Remehue; Chile. 1999. p. 2–14.
22. Walkley A, Black I. An examination of Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. Soil Science. 1934; 37(1):29–38. https://doi.org/10.1097/00010694-193401000-00003.
23. Willard H, Merrit L, Dean J. Instrumental methods of analysis. 5th Ed. New York: D. Van Nostrand; 1974. p. 1–860.
24. Bates R. Determination of pH; theory and practice. 2nd Ed. New York: Wiley; 1973.
25. Allen R, Pereira L, Raes D, Smith M. Crop evapotranspiration. Guidelines for computing crop wáter requirements. FAO. Irrigation and drenaige paper. FAO: Roma. 2000.
26. SEPHU (Sociedad Espa-ola de Productos Humicos). El cultivo de la Teca. Noticias SEPHU, Sociedad espa-ola de productos húmicos S. A.: Zaragoza, Espa-a. 2009.
27. Mendiara S. Efecto de los usos del suelo en la emisión de Dioxido de carbono del suelo a la atmosfera en un agroecosistema semiarido del Valle del Ebro. Tesis para especializacion en Industrias Agrarias y Alimentarias. Universidad de VIC, Escuela Politecnica Superior: Espa-a. 2012.
28. Ferreras L, Costa J, García F. Temperatura y contenido hídrico del suelo en la superficie durante el cultivo de trigo bajo dos sistemas de labranza. Ciencia del Suelo. 1999; 17(2):39–45.
29. Liebig M, Tanaka D, Wienhold B. Tillage and cropping effects on soil quality indicators in northern Great Plains. Soil and Tillage Research. 2004; 78(2):131–41. https://doi.org/10.1016/j.still.2004.02.002.
30. Salcedo E, Galvis A, Hernandez T, Rodriguez R, Zamora F, Bugarin R, Carrillo R. La humedad aprovechable y su

relacion con la materia organica y superficie específica del suelo. Terra Latinoamericana. 2007; 25(4):419–25.

31. Gunti-as M. Influencia de la temperatura y de la humedad en la dinamica de la materia organica en los suelos de Galicia y su relacion con el cambio climatico. [Tesis doctoral]. Universidad de Santiago de Compostela, Espa-a. 2009. p. 1–749.
32. Koncz P, Balogh J, Papp M, Hidy D, Pinter K, Foti S, Klumpp K, Nagy Z. Higher Soil Respiration under mowing than under grazing explained by biomass differences. Nutrient Cycling in Agroecosystems. 2015; 103(2):201–15. https://doi.org/10.1007/s10705-015-9732-3.
33. Han T, Huang W, Liu J, Zhou G, Xiao Y. Different Soil Respiration responses to litter manipulation in three subtropical successional forests. Scientific Reports. 2015; 5:18166. PMid:26656136 PMCid:PMC4676067. https://doi.org/10.1038/srep18166.
34. Balogh J, Papp M, Pinter K, Foti S, Posta K, Eugster W, Nagy Z. Autotrophic component of Soil Respiration is repressed by drought more than the heterotrophic one in a dry grassland. Biogeosciences Discussions. 2015; 12(12): 16885–911. https://doi.org/10.5194/bgd-12-16885-2015.
35. Cueva A, Yepez E, Garatuza J, Watts C, Rodriguez J. Dise-o y uso de un sistema portátil para medir la respiracion del suelo en ecosistemas. Terra Latinoamericana. 2012; 30(4):327–36.
36. Tucker C, Reed S. Low soil moisture during hot periods drives apparent negative temperature sensitivity of Soil Respiration in a dryland ecosystem: A multi-model comparison. Biogeochemistry. 2016; 128(1-2):155–69. https://doi.org/10.1007/s10533-016-0200-1.
37. Mara-on S, Castro J, Kowalski A, Serrano P, Sanchez E, Zamora R. Efecto de los tratamientos forestales post-incendio sobre los flujos de CO2 de respiración del suelo. 5° congreso Forestal Espa-ol. Sociedad espa-ola de Ciencias Forestales: Espa-a. 2009.
38. Gaumont D, Black T, Riffis T, Barr A, Jassal R, Nesic Z. Interpreting the dependence of Soil Respiration on soil temperature and water content in a boreal aspen stand. Agricultural and Forest Meteorology. 2006; 140(1-4):220–35. https://doi.org/10.1016/j.agrformet.2006.08.003.
39. Fan L, Yang M, Han W. Soil Respiration under different land uses in Eastern China. PLoS ONE. 2015; 10(4):e0124198. PMid: 25875998 PMCid: PMC4395438. https://doi.org/10.1371/journal.pone.0124198.
40. He X, Lv G, Qin L, Chang S, Yang M, Yang J, Yang X. Effects of simulated nitrogen deposition on Soil Respiration in a populus euphratica community in the Ebinur Lake Area, a Desert Ecosystem of Northwestern China. PLoS ONE. 2015; 10(9):e0137827. PMid: 26379186 PMCid: PMC4575029. https://doi.org/10.1371/journal.pone.0137827.
41. Chang S, Shi Z, Thomas B. Soil Respiration and its temperature sensitivity in agricultural and afforested poplar plantation systems in northern Alberta. Biology and Fertility of Soils. 2016; 52(5):629–41. https://doi.org/10.1007/s00374-016-1104-x.
42. Gafrikova J, Hanajík P. Soil Respiration, microbial abundance, organic matter and C, H, N, S contents among recovering wind throw sites in Tatra National Park. Phytopedon (Bratislava). 2015; 14(1):7–14.
43. Barba J, Curiel J, Poyatos R, Janssens I, Lloret F. Strong resilience of Soil Respiration components to drought-induced die-off resulting in forest secondary succession. Oecologia. 2016; 182(1):27–41. PMid: 26879544. https://doi.org/10.1007/s00442-016-3567-8.
44. Kotroczo Z, Veres Z, Biro B, Attila J, Feketec I. Influence of temperature and organic matter content on Soil Respiration in a deciduous oak forest. Eurasian Journal of Soil Science. 2014; 3:303–10. https://doi.org/10.18393/ejss.87903.
45. Pacific V, McGlynn B, Riveros D, Welsch D, Epstein, H. Landscape structure, groundwater dynamics and soil water content influence Soil Respiration across riparian-hillslope transitions in the Tenderfoot Creek Experimental Forest, Montana. Hydrological Processes. 2011; 25(5):811–27. https://doi.org/10.1002/hyp.7870.
46. Berryman E, Barnard H, Adams H, Burns M, Gallo E, Brooks P. Complex terrain alters temperature and moisture limitations of forest Soil Respiration across a semiarid to subalpine gradient. Journal of Geophysical Research: Biogeosciences. 2015; 120(4):707–23. https://doi.org/10.1002/2014JG002802.
47. Decina S, Hutyra L, Gately C, Getson J, Reinmann A, Short A, Templer P. Soil Respiration contributes substantially to urban carbon fluxes in the greater Boston area. Environmental Pollution. 2016; 212:433–9. PMid: 26914093. https://doi.org/10.1016/j.envpol.2016.01.012.
48. Murcia M, Ochoa M. Respiracion del suelo en una comunidad sucesional de pastizal del bosque altoandino en la cuenca del rio Pamplonita, Colombia. Caldasia. 2008; 30(2):337–53.
49. Ramirez A, Moreno F. Respiracion microbial y de raices en suelos de bosques tropicales primarios y secundarios (Porce, Colombia). Revista Facultad Nacional de Agronomía, Medellín. 2008; 61(1):4381–93.
50. Murcia M, Ochoa M, Poveda E. Respiracion del suelo y caída de hojarasca en el matorral del bosque altoandino (cuenca del río Pamplonita, Colombia). Caldasia. 2012; 34(1):165–85.
51. Kang S, Doh S, Lee D, Lee D, Jin V, Kimball J. Topographic and climatic controls on Soil Respiration in six temperature mixed-hardwood forest slopes, Korea. Global Change

Biology. 2003; 9(10):1427–37. https://doi.org/10.1046/j.1365-2486.2003.00668.x.

52. Guerrero P, Quintero R, Espinoza V, Benedicto G, Sanchez M. Respiracion de CO_2 como indicador de la actividad microbiana en abonos orgánicos de Lupinus. Terra Latinoamerica. 2012; 30(4):355–62.
53. Bosch A, Dorfera C, He J, Schmidt K, Scholten T. Predicting Soil Respiration for the Qinghai-Tibet Plateau: An empirical comparison of regression models. Pedobiologia. 2016; 59(1-2):41–9.https://doi.org/10.1016/j.pedobi.2016.01.002.
54. Shi B, Jin G. Variability of Soil Respiration at different spatial scales in temperate forests. Biology and Fertility of Soils. 2016; 52(4):561–71. https://doi.org/10.1007/s00374-016-1100-1.