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CARBON FRONTIERS

CO_2 MITIGATION STRATEGIES BASED ON SOIL RESPIRATION

ESTRATEGIAS DE MITIGACIÓN DE CO_2 A PARTIR DE LA RESPIRACIÓN DEL SUELO

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Abstract

Soil, in addition to storing, provides CO_2 to the atmosphere emitted by soil respiration, mainly due to biotic and abiotic factors, as well as soil management. The objective of the research was to evaluate soil respiration in different uses and quantify its CO_2 emissions at two different times of the year, as well as estimate its storage to make a balance to establish strategies that allow with the climate change mitigation. The CO_2 emission was measured every 30 min by using a closed dynamic chamber placed on the soil and integrated with an infrared gas analyzer, as well as temperature and moisture of the soil with sensors. Three land uses (agroforestry, forestry and agricultural) and two seasons of the year (summer and winter) were analyzed for 24 continuous hours at each site. Positive correlation between environmental temperature and soil respiration was found. The agricultural system stores low carbon content in the soil (50.31 t C ha^{-1}) and emits 9.28 t of C ha^{-1} in the highest temperature season, in contrast to a natural system that emits 3.98 t of C ha^{-1} and stores 198.90 t of C ha^{-1}. The balance sheet reflects the need to know $CO2$ emissions to the atmosphere from soils and not just storages. Having scientific support from the ground to the atmosphere is an important step in decision-making that will contribute to climate change mitigation.

Keywords: Agricultural, C storage, land use change, agroforestry, forestry.

Resumen

El suelo, además de almacenar es fuente de CO_2 a la atmósfera emitido por la respiración del suelo, principalmente por factores bióticos y abióticos, así como del manejo del suelo. El objetivo de la investigación fue evaluar la respiración del suelo en diferentes usos y cuantificar las emisiones de CO_2 en dos momentos diferentes del año, así como estimar el almacén de este para hacer un balance que permita establecer estrategias que ayuden con la mitigación del cambio climático. Mediante una cámara dinámica cerrada colocada en el suelo e integrada con un analizador de gas infrarrojo se midió la emisión de CO_2 cada 30 min, así como la temperatura y la humedad del suelo con sensores. Se analizaron tres usos del suelo (agroforestal, forestal y agrícola) y dos temporadas del año (verano e invierno) durante 24 horas continuas en cada en sitio. Se encontró que existe correlación positiva entre la temperatura ambiental y la respiración del suelo. El sistema agrícola almacena bajo contenido de carbono en el suelo (50,31 t C ha^{-1}) y libera hasta 9,28 t de C ha^{-1} en la temporada de mayor temperatura, en contraste con un sistema natural que emite 3,98 t de C ha^{-1} y almacena 198,90 t de C ha^{-1}. El balance refleja la necesidad de conocer las emisiones de CO_2 a la atmósfera por los suelos y no sólo los almacenes. Contar con soporte científico desde la respiración del suelo a la atmosfera es un paso importante para la toma de decisiones que contribuyan a la mitigación del cambio climático.

Palabras clave: Agrícola, almacén de C, cambio de uso de suelo, agroforestería, forestal.

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1 Introduction

The soil can act as a source and sink of atmospheric carbon dioxide (CO_2) (Sainju et al., 2008). The constant increase in CO_2 to the atmosphere is the main factor of climate change, as well as the increase in temperatures and change in precipitation patterns (Liebermann et al., 2020). One of the main sources of CO_2 emissions is soil, also known as soil respiration (SR), which is also one of the crucial components within the carbon cycle in terrestrial ecosystems (Murcia-Rodríguez and Ochoa-Reyes, 2008). It is well known that small changes in SR can influence the concentration of atmospheric carbon and caloric balance (Kane et al., 2005; Murcia-Rodríguez and Ochoa-Reyes, 2008). Understanding SR is an important step, as it helps determine whether an ecosystem behaves as a source of carbon or CO_2 sink ((Burbano, 2018; Singh et al., 2015). Unfortunately, the change in land use, which is defined as the change from soil cover to other use, and changes in management practices can have important C balance ratios, which is an important precursor to the increase in SR (Francioni et al., 2019; Wang et al., 2013).

In Mexico, (SEMARNAT-INECC, 2018), from 1990 to 2015 the increase in CO_2e was 208%, whereas in 2015 net emissions amounted to 503 473.80 Gg of CO_2e, of which 11 340 Gg of CO_2e correspond to deforestation for new farmland. Although soil processes play a key role in carbon flows in ecosystems, there is still little information on soil breathing dynamics. It is important to understand the impact of environmental changes on ecosystems and to identify the factors that control CO_2 emissions from the soil and their effects on emission rates (Ramírez and Moreno, 2008). The determination of SR can contribute to the development of better mitigation tools. In addition, it provides detailed information to promote co-activities between climate change mitigation and adaptation strategies, and will be based on soil management and conservation (Serrano et al., 2017).

For example, Araújo de Santos et al. (2019) reported that a crop of corn emits 0.99 μmol CO_2 m^{-2} s^{-1} and corn cropped with bean 1.00 μmol CO_2 m^{-2} s^{-1}. In addition, the application of different types and concentrations of fertilizer influence SR (Chi et al., 2020). Soil management influences SR, as according to Zsolt et al. (2020), conventional plowing methods favor the increase of SR. In turn, Costa et al. (2018) evaluated soil respiration in a preserved forest and cocoa SAF with and without management, finding that the first emits 45.03 mg CO_2-C m^{-2} h^{-1}, while SAF without management emits up to 125 mg CO_2-C m^{-2} h^{-1} and with management 41.8 mg CO_2-C m^{-2} h^{-1}. On the other hand, in a pine forest (*Pinus palustris Mill.*) the annual SR was evaluated in stands from 5 to 21 years old, 12.0 Mg C ha^{-1} and 13.9 Mg C ha^{-1}, respectively (ArchMiller and Samuelson, 2016). Tang et al. (2006) report SR in different mixed and pine forests 450.5±22.3, 381.8±18.2 and 250.9±20.2 mg CO_2-C m^{-2} h^{-1}, respectively, where they also report that it correlated with soil temperature and humidity. Hence, SR can be predicted in combination with soil temperature and water content; and the effects of Ts and Hs on soil respiration will vary depending on the location of the sampling (Zhao et al., 2013).

Therefore, the aim of this study was to evaluate soil respiration in different uses and quantify CO_2 emissions at two different times of the year, as well as to estimate the carbon store to establish balances to formulate strategies that contribute to climate change mitigation.

2 Materials and methods

2.1 Description of the area

2.1.1 Agroforestry and agricultural systems

Both systems cover an area of 0.05 ha (10 × 50 m) and are located between coordinates $19°49'N$ and $98°89'W$. They are located at 2250 masl in a predominantly temperate subhumid climate with summer rainfall, with an average annual temperature of $16.4°C$ and average annual precipitation of 618 mm. The floors are Vertisoles type. The systems belong to a farm that integrates various technologies and have an organic and agroecological production of vegetables, fruit and meat, such as fish, rabbit and sheep for approximately 20 years.

The agroforestry system (AS) consists of technology of crops in alleys with fruit trees of *Prunus persica* (peach), Pyrus communis (pears) and *Malus domestica* (apples) in the tree formation. The separation between tree and tree is 2.5 m. Annually planted interspersed vegetables (*Beta vulgaris sp.* (chard), *Lactuca sativa* (lettuce) and *Cucurbita pepo* (pumpkin), (Ruta graveolens and *Avena sativa* (for grazing). The agricultural system of monoculture (ASM) consists of maize (*Zea mays*) planted in rows and with irrigation system. To start the growing cycle, the soil is tilled and periodically weeded manually.

2.1.2 Temperate forestry system

The temperate forest system (TFS) covers an area of 1640.48 ha, and it is located between coordinates $19°15'N$ and $98°37'O$ (Chávez-Salcedo et al., 2018).The dominant climates are semi-cold in the parts of higher altitude and temperate in the areas nearby; the average annual precipitation ranges from 800 mm to 1200 mm, the average annual temperature ranges from $6°C$ in the highest altitude areas to $14°C$ (Lomas-Barrié et al., 2005).

2.2 Soil respiration

SR was measured with a 8100A LICOR portable equipment and two cameras, one fixed and one quick tap (LI-COR Biosciences, 2015). The chambers are closed and have 20 cm of diameter, and are placed on PVC collars inserted into the floor at 3 cm depth at least 24 hours in advance (López-Teloxa et al., 2020). The experimental design consisted of installing two separate chambers at 5 m to achieve two simultaneous observations every half hour. The 8100A LICOR monitors changes in CO_2 concentration over time within the chamber through optical absorption spectroscopy in the infrared region (IRGA infrared gas analyzer). The camera measures for 90 seconds the concentration of CO_2 of which the first 30 seconds are deadband to stabilize and are not considered. Atmospheric CO_2 accumulated in the chamber is measured as CO_2 flow in micromoles per square meter per second (μmol m^{-2} s^{-1}) of dry air, which are subsequently converted to grams per hour (g CO_2 m^{-2} h^{-1}). The reported CO_2 flow is the result of soil CO_2 emission by autotrophic (plant roots) and heterotrophic (microorganisms) (Moitinho et al., 2015). The camera has sensors (model p/n8150-203 Soil Temperature Probe and 8100-204 Theta Soil Soil Soil Probe soil) that also allow to record soil temperature and humidity (St and Sh, respectively).

2.3 Organic carbon stored

To determine soil organic carbon (SOC) a total of 9 soil samples were analyzed for each of the 3 sites, having a total of 27 per season. Each sample was collected by the method of unchanged samples at three depths, 0-10, 10-20 and 20-30 cm with a drill composed of two radio rings 2.6 cm and a height of 2.9 cm, so the floor volume calculated by each ring is 63.98 cm^3 (Etchevers Barra et al., 2005). The collected samples were dried at room temperature and sifted with a 100 mm sieve. To obtain the DAP, the complete (dry) soil sample was weighed and stones and roots were separated and weighed. The percentage of organic carbon was determined with a total organic carbon analyzer (TOC-V, Shimadzu Labs) equipped with a solid sample module (model SSM-5000, Shimadzu Labs).

2.4 Experimental design

SR was determined in three land uses (TFS, AS and ASM) and in two seasons of the year, summer and winter. SR was determined for 24 hours at each site, thus having 3 sites, 144 h and 576 measurements per season. Daily meteorological registers [environmental temperature (Tamb) and precipitation (Prec)] were obtained with a portable weather station (The Crosse Technology Mod.C86234) placed at 1.5 m height and 1 m away from the measuring and sampling chamber. In addition, the data were corroborated with weather stations near the sampling sites: Estación Chapingo and Estación Avila Camacho operated by Cuenca Aguas del Valle de México Agency (OCAVM) and Estación Altzomoni operated by Sistema Monitor Nacional (https://smn.cna.gob.mx/es/estaciones-meteorologicas-automaticas-3), Mexico state.

2.5 Statistical analysis

The statistical analysis was done in 2 moments: 1) The variance analysis (ANDEVA) and the Tukey test were used to identify statistically significant differences ($p < 0.05$) in the values of respiration, temperature and soil humidity between the two seasons and the three uses of the soil. For more accuracy and reduced potential errors, the data was first standardized. 2) Pearson correlation analysis was used to identify correlation between soil respiration from the three soil uses and climatic variables (St, Sh, Tamb and Prec).

3 Results

3.1 Area description

SR in all three land uses and both seasons are presented in Figure 1. SR in TFS fluctuates from 0.20 to 0.40 g CO_2 m^{-2} h^{-1}, in AS from 0.41 to 0.61 g CO_2 m^{-2} h^{-1} and in ASM from 0.67 to 0.99 g CO_2 m^{-2} h^{-1} in summer. Increases are seen at 08:00 hours, reaching maximums between 13:00 and 15:00 hours. SR in ASM is 35% higher compared to AS. SR in a natural system such as TFS is 50% lower compared to agricultural management, since this is mainly due to the mineralization of organic carbon in the soil that increases its decomposition rate by farming and soil structure is altered, increasing CO_2 as reported by Baah-Acheamfour et al. (2016). On the other hand, during winter, TFS fluctuates from 0.15 to 0.24 g CO_2 m^{-2} h^{-1}, in AS from 0.19 to 0.62 g CO_2 m^{-2} h^{-1} and in ASM from 0.23 to 0.60 g CO_2 m^{-2} h^{-1}. SR in natural systems is mainly due to the joint action of biotic and abiotic factors such as: type and age of vegetation, soil type and climatic variations (Hu et al., 2018).

Regarding temperature and humidity, Oertel et al. (2016) mention that these vary significantly with the depth and characteristics of the area, for example, exposure to light, shadow and wind. During summer, in the AS and ASM the environment temperature showed variation from 13.5 to 23.9°C and zero millimeters of rain reported. While in the forest, the variation was 6.9 to 13.3°C and 2.6 mm of rain throughout the day. AS and ASM present similar values and behaviors in SR throughout the season from 15.7 to 24.8°C and 15.3 to 23.5°C, respectively, with highs between 12:00 and 14:00 hours, time in which respiration has its peaks. On the other hand, in the TFS, SR ranged from 8.12 to 11.97°C. In relation to Sh, in the AS it ranged from 0.16 to 0.20 m^3 m^{-3}, while the humidity in the SAM and SFT is similar, 0.36 to 0.40 m^3 m^{-3} and 0.37 to 0.53 m^3 m^{-3}, respectively. In ASM the increase of Sh is mainly due to the system being irrigated, which is carried out every day from 10:00 to 12:00 hour.

During winter, the environment temperature values are lower as expected, in AS and ASM the environment temperature ranged from 3.4 to 23.9°C and zero millimeters of rain. While in TFS the temperature ranged from 2.2 to 13.3°C and 1 mm of rain throughout the day. AS and ASM presented similar values and behaviors in the St throughout the day, from 3.1 to 20.3°C and 2.6 to 20.6°C, respectively, with highs between 13:00 and 14:00 hours. Unlike the first season, AS and TFS humidity records are similar 0.25 to 0.27m^3 m^{-3} and 0.22 to 0.23m^3 m^{-3}, respectively. Due to a fallow period, Sh in ASM presented the lowest recorded values of 0.15 to 0.16m^3 m^{-3}, along with the fact of the lack of precipitation during the period evaluated. In agricultural crops, SR correlates with physical characteristics of soil, soil temperature and humidity (Araújo de Santos et al., 2019).

Soil respiration had higher emissions in higher temperature periods, so it can be ensured that it is mostly correlated with it (Figure 1). On the other hand, due to irrigation, SR increases in dry soils by increasing microbial activities (Sainju et al., 2008). As for the COS, 198.9, 89.97 and 58.55 t ha^{-1} concentrations were found for TFS, AS and ASM, respectively, for summer, while for the following season the first two cases decreased their concentration to 171.36 and 76.50 t ha^{-1}, while ASM increased to 65 t ha^{-1}. However, the following order of concentration is generally presented for summer and winter ASM >AS >TFS, similar to López-Teloxa et al. (2017), who claimed that land use and management significantly influences the content of COS.

3.2 Statistical analysis

Table 1 summarizes the average SR, SOC, St and Sh values per season (summer and winter) and land uses (TFS, AS, and ASM). ANDEVA was performed following the three factors of the sampling protocol to determine the variability of soil parameters between the factors (season, land use and sampling time) of the area (Table 2). SR and St values showed significant differences in season, land use and sampling time, as well as in their interactions. Hence, the variation in environmental temperature in each season, as well as soil disturbance due to different uses significantly influence the SR and St (Baah-Acheamfour et al., 2016; Murcia-Rodríguez

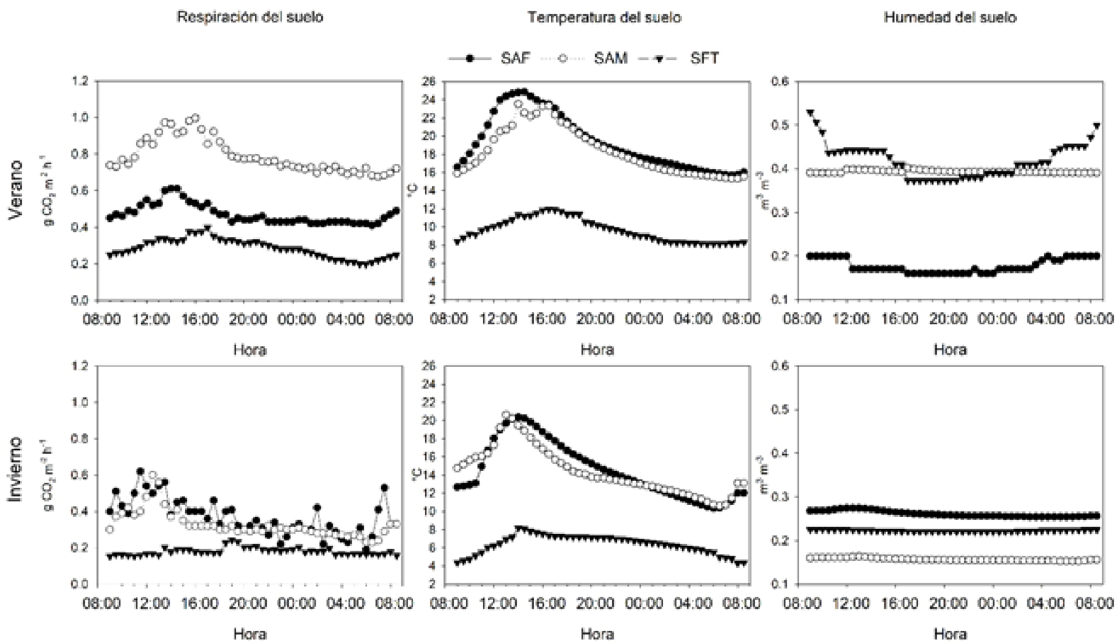

Figure 1. Variation of SR, St and Sh throughout the day in Summer and Winter.

and Ochoa-Reyes, 2008). In addition to the above, management practices significantly affect SR (Sainju et al., 2014). Despite the fact that environmental conditions such as temperature and precipitation normally have a dominant influence on the amount of SOC in the soil (López-Teloxa et al., 2017), no statistical differences were observed according to sampling seasons ($p = 0.40$), but they are observed according to the uses ($p<0.05$). Sampling seasons, land uses, measurement time and seasonal interaction with land use influence the variation of Sh ($p<0.05$).

Several studies have shown that there is correlation with SR and environmental variables as well as with their combined effect (Figure 2) (Murcia-Rodríguez et al., 2012; Ramírez and Moreno, 2008). As is the case of AS and ASM, where St and Tamb, have high positive correlation in SR ($p<0.05$), but there is inconclusive evidence on significance in TFS ($p>0.05$). In addition to the low temperatures in the TFS, the system is preserved with little or no soil disturbance unlike the AS and ASM. On the other hand, Sh presents positive correlation in ASM and TFS, this is consistent with other studies where it was reported that the values of SR increases after precipitation or irrigation events (La Scala et al., 2001; Moitinho et al., 2015; Panosso et al., 2009), while it is negative for AS in all three cases $p<0.05$. The relationship between temperature and humidity content with SR results in complex interactions that depend on the relative limitation of these two variables on microbial and root activity, as well as on the diffusion of gases (Ramírez and Moreno, 2008). Since no precipitation data was reported during AS and ASM sampling for both seasons, Pearson's correlation is zero. While in the TFS the correlation is positive with the precipitation ($p<0.05$). SOC has a negative influence, i.e. it decreases by increasing SR, this occurs for AS and TFS while it is positive for ASM, the latter could be due to fertilizer in the area (Sainju et al., 2008). In short, SR is mostly influenced by environmental and soil variables, with soil temperature being most influential (Mukumbuta et al., 2019). This information is consistent with ArchMiller and Samuelson (2016); Han et al. (2018), Wang et al. (2013), and Wang et al. (2013), who say that SR increases exponentially with the increase in St.

Table 1. Respiration and CO_2 storing by land use and season of the year.

USE OF THE SOIL	SEASON	SR $g\ m^{-2}\ h^{-1}$	SOC t ha^{-1}	St $^{\circ}C$	Sh $m^3\ m^{-3}$
SFT	Summer	0.29±0.05a	198.9±31.4a	9.65±1.30a	0.42±0.04a
	Winter	0.18±0.02b	171.36±19.7a	6.36±1.04b	0.22±0.00b
SAF	Summer	0.47±0.05a	86.97±7.96a	19.32±3.05a	0.18±0.01a
	Winter	0.38±0.11b	76.5±7.78a	14.60±3.14b	0.26±0.007b
SAM	Summer	0.79±0.09a	58.55±11.65a	18.34±2.61a	0.39±0.002a
	Winter	0.32±0.07b	65.00±14.1a	14.40±2.64b	0.16±0.003b

Letters a and b indicate significant differences (Tukey test).
TFS-Temperate Forest System, AS-Agroforestry System, ASM-Agricultural Monoculture System.

Table 2. P-values resulting from multivariate variance analysis at a 95% confidence level.

Factor	Variable			
	SR	SOC	St	Sh
Season	0.00	0.40	0.00	0.00
Soil use	0.00	0.00	0.00	0.00
Measurement time	0.00	N.D.	0.00	0.04
Season*Soil use	0.00	0.49	0.00	0.00
Season * Measurement time	0.00	N.D.	0.00	1.00
Soil use * Measurement time	0.01	N.D.	0.00	0.92

4 Discussion

As expected in a forest, lower emissions were observed compared to an agricultural system of up to 50% less. Data is similar to that found by Campos (2014), who reports that up to 89.6 mg C m^2 h^1 is emitted in a cloud forest while in an agricultural system with corn-potato-corn rotation 128.1 mg C m^2 h^1 is emitted. Regarding the differences between summer and winter, a similar behavior is found, although ASM reduces its emission to a level similar to AS, but retains the tendency to be more emitting, since altered systems have higher CO_2 emissions especially in summer (Abdalla et al., 2018). The results of this study focus on the importance of soil respiration analysis in different uses, in order to offer multifunctional systems that ensure food security and diversity of environmental benefits.

Soil use and management practices can affect CO_2 emission into the atmosphere by modifying soil temperature and water content (Baah-Acheamfour et al., 2016). A commonly used practice in agricultural systems is tilling, which can make the soil dry; hence, it increases the temperature due to soil disturbance and decreases waste on the soil surface, which is consistent with Nouchi and Yonemura (2005) in a rice paddy with tillage, where the annual emission is 2845 g CO_2 m^{-2} per year while without tillage is 2198 g CO_2 m^{-2} per year.

The results obtained here show that there is a positive correlation between environmental temperature and CO_2 or SR emissions, which is consistent with Wang et al. (2013), who say that SR is lower at low temperatures. On the other hand, irrigation in soils that have remained directly exposed to the sun's rays for a long period of time increases SR, due to microbial breathing that is limited by water stress (Curtin et al., 2000)

The system and type of crop, as is the case with AS and ASM, differ in terms of SR, St and Sh, since there is greater soil coverage in AS than in a monoculture, in addition to fallow periods that affect the intensity of shadow and evapotranspiration (Sainju et al., 2008). Management practices, such as farming, can increase soil CO_2 emission by altering soil aggregates, reducing plant residues and oxidizing soil organic C by more than 47% in 5 years, and zero farming practices and reduced crop intensity can increase SOC (Patiño-Zúñiga et al., 2009). This is a limitation of our results but they frame future research work to conduct further respiration studies in different uses and soil management.

When it comes to carbon storing, the behavior is as expected, i.e., TFS retains more than ASM, while there are no differences for seasons. This is similar to López-Teloxa et al. (2017) where SOC concentration is higher in a forest with secondary vegetation in contrast to temporary agriculture, 28.44 and 20.42 t ha^{-1}, respectively. Once the emission and storage of C was quantified, it allowed to raise a balance sheet (table 3). As found by Mukumbuta et al. (2019) who reported a balance of 1.2 t C ha^{-1} (SOC of 8 t C ha^{-1} and SR of 6.8 t C ha^{-1}) in pasture.

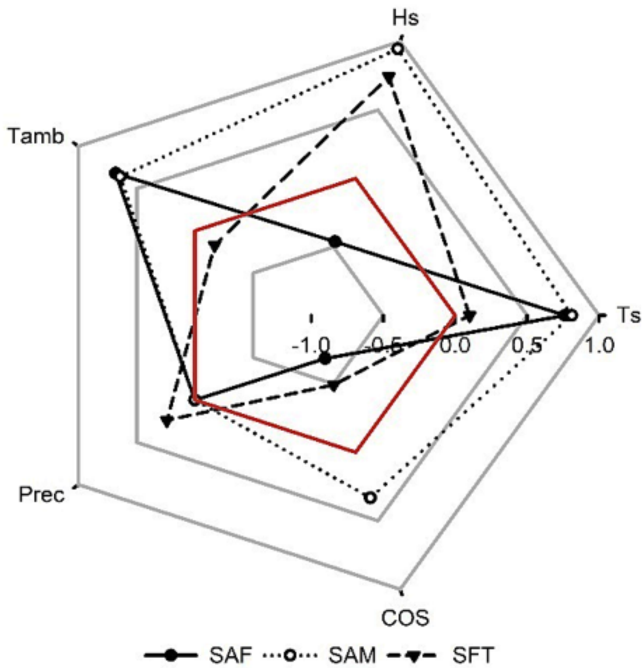

Figure 2. Correlation with environmental and SOC variables according to SR. Note: Variables close to the red line have no correlation.

An important factor that helps to understand the integral C balance of an agroecosystem is the close relationship between SR and SOC (Alberti et al., 2010). It is clear that an agricultural system preserves lower amounts of carbon in the soil, releasing up to 9.28 t of C ha^{-1} in the highest temperature season, in contrast to a natural system (3.98 t of C ha^{-1}). Therefore, agroforestry systems (table 3) are intermediate points that allow to ensure food and preserve as much possible). According to various authors such as Baah-Acheamfour et al. (2016) and Kwak et al. (2019) it is a land-use practice that, in addition to introducing trees and shrubs to farmland or livestock, helps to potentially mitigate CO_2 emissions from agricultural systems.

Finally, it should be remembered that according to IPCC (2013) the increase in temperature is unequivocal and an increase in temperature is expected worldwide (UNFCCC, 2015). Hence, soil can contribute to climate change mitigation as land use is systemized and the organic carbon of land is conserved (Burbano, 2018), adapting management and irrigation practices in different seasons of the year (Francioni et al., 2019; Chi et al., 2020). The actions carried out and adapted to each system offer beneficial solutions to face multiple environmental and social challenges (Tschora and Cherubini, 2020). Thus, the following studies should focus on the different soil management practices, seasons of the year and growing cycles, in order to deepen on the balance of SR and SOC.

Table 3. Balance of carbon emitted and stored from the soil.

USE OF THE SOIL	SEASON	C emitted t ha^{-1}	C stored t ha^{-1}			
			Depth (cm)			Total
			0 - 10	10 - 20	20 -30	
TFS	Summer	3.98	77.21	64.54	57.14	198.90
	Winter	1.91	66.59	58.30	46.46	171.36
AS	Summer	5.55	29.24	28.74	23.36	81.34
	Winter	4.36	25.88	24.41	20.85	71.14
ASM	Summer	9.28	14.94	14.99	20.39	50.31
	Winter	3.86	21.42	21.32	24.04	66.78

TFS=Temperate forestry system, AS=Agroforestry system, ASM=Agricultural system of monoculture.

5 Conclusiones

Studying storage-carbon emission dynamics in terrestrial ecosystems underpins the understanding of the problem and helps in the definition of better policies and care programs. The change in land use that increases soil organic carbon losses mainly in CO_2 should be avoided while promoting, for example, natural coverage or agroforestry production systems.

The increase in global temperature has impacted the carbon cycle, especially on its soil, which is exacerbated by deforestation and openness to new agricultural areas. It is believed that it is important to improve the knowledge of various multifunctional production systems that contribute to the reduction of CO_2 emissions and increase carbon stored in the soil.

This study made it possible to evaluate land uses that mostly contribute to mitigating the effects of climate change with the incorporation of agroforestry systems into the production system; in addition to the importance of year-round soil coverage, as fallow periods can be detrimental to both soil and CO_2 contribution to the atmosphere. It should be noted that the data obtained are the first reported from the evaluated areas, so it is important to continue the measurements throughout the year to characterize the behavior in SR of agroforestry systems. Having scientific support from SR (CO_2 emission) to the atmosphere is an important step in decision-making that will contribute to climate change mitigation.

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