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Soil respiration and distribution of aggregates in modified agroforestry systems of coffee and avocados in Huatusco, Veracruz, Mexico

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Abstract

Coffee agroforestry systems (CAFS) in Veracruz, Mexico, are being altered by introduction of avocado trees, which is currently introduced among the coffee. This practice could change the soil organic carbon (SOC) content, soil structure, biological activity, and CO_2 emissions. The objective of this work was to evaluate the variation of soil respiration (SR) and aggregate size in modified CAFS with avocados. Three CAFS, an avocado–coffee system (ACS), and an avocado monoculture (AMC) were compared. Three plots were delimited in each system, where soil samples were extracted at three soil depths. Before incubation, soil pH, bulk density (Mg m^{-3}), soil organic matter (SOM, %), and SOC (mg C g^{-1}) contents were determined. The distribution of soil aggregates was quantified in dry soil and the weighted minimum diameter (WMD) was determined. Incubation allowed to determine the potential CO_2 flux generated by SR for 30 days; the residual SOC was determined after incubations, whose difference with the initial SOC allowed to perform a balance of C, calculating a SOC degradation rate constant (K_t). ANOVA ($p < 0.05$) and means comparison with the Tukey's test was performed. In the ACS a lower range average (0.6 a 0.8 mm) of WMD was found at the three soil depths, the lowest SR (150 kg CO_2-C ha^{-1} h^{-1}), a positive balance of SOC, having a negative K_t constant were recorded. Subsequently, the introduction of avocados contributes to the storage of SOC and the reduction of CO_2 emissions.

Keywords: Bioconcentration, ectomycorrhiza, heavy metals, millet, soil, translocation

Introduction

Agroforestry systems (AFS) have been recognized for their potential to sequester large amounts of C in the soil (Soto-Pinto *et al*., 2010), and for generating less CO_2 emission than a forest (Yago *et al*., 2019). In Veracruz, México, coffee agroforestry systems (CAFS) are dominant and classified as coffee traditional polyculture systems (CTPS), which are characterized by their high diversity of species that fulfill the functions of providing shade and food for self-consumption (Moguel y Toledo, 1999). This high diversity in the system allows a diversified production of litter which can accelerate the decomposition of organic residues (OR) through the diversity of microorganisms and detritivores, as well as transfer of nitrogen between soil horizons (Handa *et al*., 2014), contributing to build up the reserves of C and N in the soil (Fornara y Tilman, 2008; Lange *et al*., 2015).

The activity of these organisms can be affected by the floristic composition of agroforestry systems, due to the quantity and quality of such residues. The production of leaf litter from avocado plantations reports on average 2.8 t ha^{-1} $year^{-1}$ in dry matter (Bernal-Estrada, 2020), which impacts the decomposition and mineralization processes (Villavicencio-Enríquez, 2012). Therefore, changes in diversity and management in a system could alter the balance of the CO_2 flow and modify the capacity of the systems to store or sequester C (Tilman *et al*., 2006).

The CTPS are currently being displaced by avocado cultivation in Veracruz (Mexico), due to the fluctuating coffee prices in the market (Jaffe *et al*., 2008). The introduction of avocados in coffee plantations has generated the loss of floristic diversity, which could have a negative impact on biodiversity and environmental services (Escamilla, 2016). This change in floristic vegetation could

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influence the variation of CO_2 emissions generated by soil respiration (SR), due to such modification of OR quantity and quality entering in soil. This could change the micro-environments, where the microorganisms release CO_2 to the atmosphere, affecting its concentration, as well as the C sequestration potential of the soil (Iqbal *et al*., 2010; Sanderman & Baldock, 2010; Chapman & Newman, 2010). The modification of floristic composition in a system alters the quantity and quality of the OR, which, if the soil microbial activity is hampered, could drive to a SOM accumulation (Gallardo, 2017).

Variation in SOM concentrations changes the state of soil aggregation; this aggregation can generate macro-aggregates (>2.0 mm) that improve the structural state of the soil, allowing an increase in porosity, the development of the biological activity, and higher CO_2 emissions (Chattterjee *et al*., 2020). Opposite, if the aggregate size decreases can indicate OR would be recalcitrant, undergoing slow decomposition in soils and, therefore, increasing the potential to store SOC in the long term, but resulting in a deficient soil biological-activity (Chattterjee *et al*., 2020).

Soil respiration (SR) is an important indicator of edaphic activity and soil quality (Vallejo, 2013), due to its sensitivity to variation or loss of plant diversity, since vegetation is essential for regulating the SOC content (Chen & Chen, 2018) through litter production. This production may increase with the diversity and heterogeneity of species due to the availability of abundant OR generated in rich or productive ecosystems (Hooper *et al*., 2005; Zhang *et al*., 2012).

The aim of this work was to evaluate the variation of soil respiration (SR) and aggregate size in modified CAFS by the introduction of avocados in the region of Huatusco, Veracruz (Mexico).

Materials and Methods

The experiment was carried out in the community of Tlaxopa, Municipality of Huatusco de Chicuellar, Veracruz (19° 10’ 25’’ NL y 96° 57’ 30’’WL, Mexico), at an average of 1,300 masl. In the study area, the climate is humid semi-warm, with an average annual temperature at 16.4 °C and characterized by abundant rainfall, mean precipitation being 2,018 mm yr^{-1} (INEGI, 2019).

The dominant soils are *Andosol*, which, according to the WRB (2009) classification, are characterized by the dark color, fine texture, strong acidity, and high SOM content. The orography of the site is hilly with slope ranged between 15 to 30% and plantation design was according to contour lines.

The types of CAFS were selected as:
a) three coffee traditional polycultures (CTPS) according to the classification of Moguel & Toledo (1999) for coffee plantations in Mexico; b) an avocado and coffee system (ACS); and c) a monoculture of avocado (MCA). The five sites selected were 21 years old and they were modified during the time elapsed with different plant densities, agronomic management and the introduction of avocados.

1) The coffee traditional polyculture with renewal (CPR): It is 21 yrs old, with a density of 4,000 coffee plants ha^{-1} of which 2,000 were of the Typica and Bourbon varieties, and other 2,000 of Geysha, Mundo Novo and Costa Rica varieties renewed in 2014. Shade trees were *Junglas* spp, *Inga* spp, and *Grevillea robusta*, at a density of 60 trees ha^{-1};
2) Coffee traditional polyculture with severe pruning and cleaning (CPC): It is 21 yrs old and managed since 12 yrs with a density of 2,400 coffee plants ha^{-1} of the varieties Typica and Bourbon. Shade trees of *Grevillea robusta* were distributed at a density of 40 trees ha^{-1}. Weeds were managed with the hoe and reintegrated into the soil;
3) Coffee traditional polyculture abandoned (CPA): It is 21 yrs old and managed since 12 yrs with a density of 2,400 coffee plants ha^{-1} of the varieties Typica. The shade tree species are *Junglas* spp, *Inga* spp. and *Grevillea robusta*, at a density of 60 trees ha^{-1}, in addition to banana (*Musa paradisiaca*) plants, variety Velillo, with a density of 40 plants ha^{-1}. Weeds are removed by hand with the hoe and reintegrated into the soil;
4) Agroforestry system of avocado and coffee (ACS): It is 21 yrs old and managed since 8 yrs with a density of 100 *Hass* avocado trees ha^{-1} and 1,800 coffee plants ha^{-1} of Costa Rica variety. Weeds were managed with the brush cutter and reintegrated into the soil; and
5) Monoculture of avocado (MCA): It is 21 yrs old and managed since 8 yrs with a density of 210 *Hass* avocado trees ha^{-1}. The weeds were controlled with authorized herbicides.

The experimental design was a factorial design of 5X3 (five systems by three depths). In each of the five systems, random sampling points were located, and an excavation in the soil was carried out. The samples were collected at three depths: 0-10, 10-20 and 20-30 cm. In each one, samples were taken, in triplicate, to determine the bulk density (BD), weighted minimum diameter of aggregates (WMD), chemical characteristics, soil respiration, and SOC contents. The soil sampling was carried out in October 2019; physical and chemical characterizations were carried out in November 2019, and soil respiration *in vitro* in January 2020.

Soil analyses were performed according to the following methods: a) the pH using a potentiometer (1:1 water-soil ratio); b) the BD (Mg m^{-3}) was carried out with the cylinder method (Page *et al*., 1982); c) Aggregate determination in the soil was carried out with the methodology of Le Bissonnais (1996), using the following sieves: 6.35, 4.76, 3.36, 2, 1, 0.5, 0.25 and <0.25 mm; the resulting information was used to determine the WMD; d) SOC and soil inorganic carbon (SIC) before and after incubation were determined on TOC-V CPN *Shimadzu* C analyzer; and e) the soil biological activity was evaluated through soil respiration (SR): Ten grams of soil samples were weighed, in triplicate, and then incubated in plastic containers of 18 cm of diameter with hermetic lids at a dry moisture content of 50%, over 30 days, at room temperature in the soil laboratory of *Colegio de Postgraduados* (Texcoco, Mexico); the moisture content was monitored daily at weight difference and replaced with the help of a micropipette. The EGM-4 equipment was used to measure the CO_2 emission flow, which is based on the dynamic camera method proposed by Parkinson (1981). The CO_2 flow per unit area and time were used to calculate the soil respiration with the following formula:

Table 1: General characteristics of the soils of each studied system

System	Soil pH			BD (Mg m^{-3})			SOC (Mg C ha^{-1})		
	0- 10 cm	10-20 cm	20-30 cm	0- 10 cm	10-20 cm	20-30 cm	0- 10 cm	10-20 cm	20-30 cm
ACS	4.8 ±0.31 a	4.7 ±0.24 a	4.6 ±0.27 a	0.49±0.03 b	0.55±0.04 ab	0.55±0.04 ab	75±2.4 a	64 ±2.4 a	58 ±1.7 a
MCA	4.8 ±0.31 a	4.4 ±0.24 a	4.4 ±0.27 a	0.48±0.03 b	0.49±0.04 b	0.47±0.04 b	56±2.4 b	46 ±2.4 b	31 ±1.7 b
CPR	3.7 ±0.31 a	3.7 ±0.24 a	3.8 ±0.27 a	0.66±0.03 a	0.67±0.04 ab	0.69±0.04 a	32±2.4 c	35 ±2.4 c	18 ±1.7 c
CPC	4.0 ±0.31 a	3.7 ±0.24 a	3.7 ±0.27 a	0.65±0.03 a	0.71±0.04 a	0.70±0.04 a	35±2.4 c	20±2.4 c	19 ±1.7 c
CPA	3.7 ±0.31 a	3.6 ±0.24 a	3.7 ±0.27 a	0.67±0.03 a	0.67±0.04 ab	0.66±0.04 a	35±0.4 c	25 ±2.4 c	18 ±1.7 c
P-Value	0.0676	0.0331	0.1179	0.0012	0.0155	0.0053	<0.0001	<0.0001	<0.0001
DMS	1.437	1.119	1.264	0.137	0.192	0.172	1.12	1.11	0.78

BD: Soil bulk density, ACS: Avocado-coffee system, MCA: Monoculture of avocados, CPR: Coffee traditional polyculture with renewal, CPC: Coffee traditional polyculture with pruning and severe cleaning, CPA: Coffee traditional polyculture abandoned. Tukey test ($p \leq 0.05$); different letters indicate significant statistical differences. *p*-Value: Probability value; DMS: Minimal significant difference.

$$R = b * \frac{P}{1000} * \frac{273}{273 + Ta} * \frac{40.01}{22.41} * \frac{V}{A}$$

Where: R = CO_2 flow g m^{-2} h^{-1}; b = CO_2 concentration in mg L^{-1}; V = System volume in m^3; A = Camera area in m^2; P = Atmospheric pressure in mb; Ta= System volume temperature in °C.

Data obtained were used to perform the C balance using the methodology proposed by Rahman (2013) which consists of calculating the difference between the C inputs and outputs in the soil, where the inputs correspond to SOC before incubation and the outputs SOC after 30 days of incubation.

The SOC degradation rate constant (K_t) was calculated according to the kinetic model proposed by Tanvea *et al*. (2008), modified according to the formula:

$$\mathrm{Ln}(C_f/C_i) \times 100 = -K_t$$

Where: K_t is the degradation rate constant; C_f and C_i corresponds to the final and initial C contents, respectively; t is the time, either day or year.

Statistical analysis was related to an analysis of variance (ANOVA) with a $p < 0.05$ and a comparison of Tukey's HSD means were applied. Agroforestry systems of coffee traditional polycultures and those associated with avocado with their respective depths, were the classifying variables, and the rest of the variables were independent. The statistical program InfoStat version 2018-I was used; means of soil biological activity and WMD were compared using a double-axis diagram, for analyzing the interactions between them.

Results and Discussion

General characteristics of the soil of each system are shown in Table 1.

Soil pH varied from 3.6 to 4.8 in the soils of all the systems and in the three depths, a range that corresponds to highly acidic and hyper-acidic soils. The low BD values correspond to typical *Andosol* soils, ranging between 0.48 to 0.70 Mg m^{-3}, increasing values in soil depth. The highest BD found at the depth of 0-10 and 20-30 cm corresponds to CTPS; however, at the intermediate depth (10-20 cm) these presented similar values to those that the CPR and CPA to the ACS. The BD results confirm that CTPS have less soil porosity (73.2-75.4%) for the development of soil activity than the systems associated with avocado (73.9-82.3%) in the three depths (real density of 2.65 g cm^{-3} was considered).

The CTPS showed an average of 72.8% of aggregates with diameters higher than 1.0 mm, in the depth of 0-10 cm (Fig. 1a); 69.9% in 10-20 cm depth (Fig. 1b) and 62.7% in 20-30 cm depth (Fig. 1c). meanwhile the other system associated with avocados (ACS) reported an average of 74.2 % of aggregates in diameters smaller than 1.0 mm for the

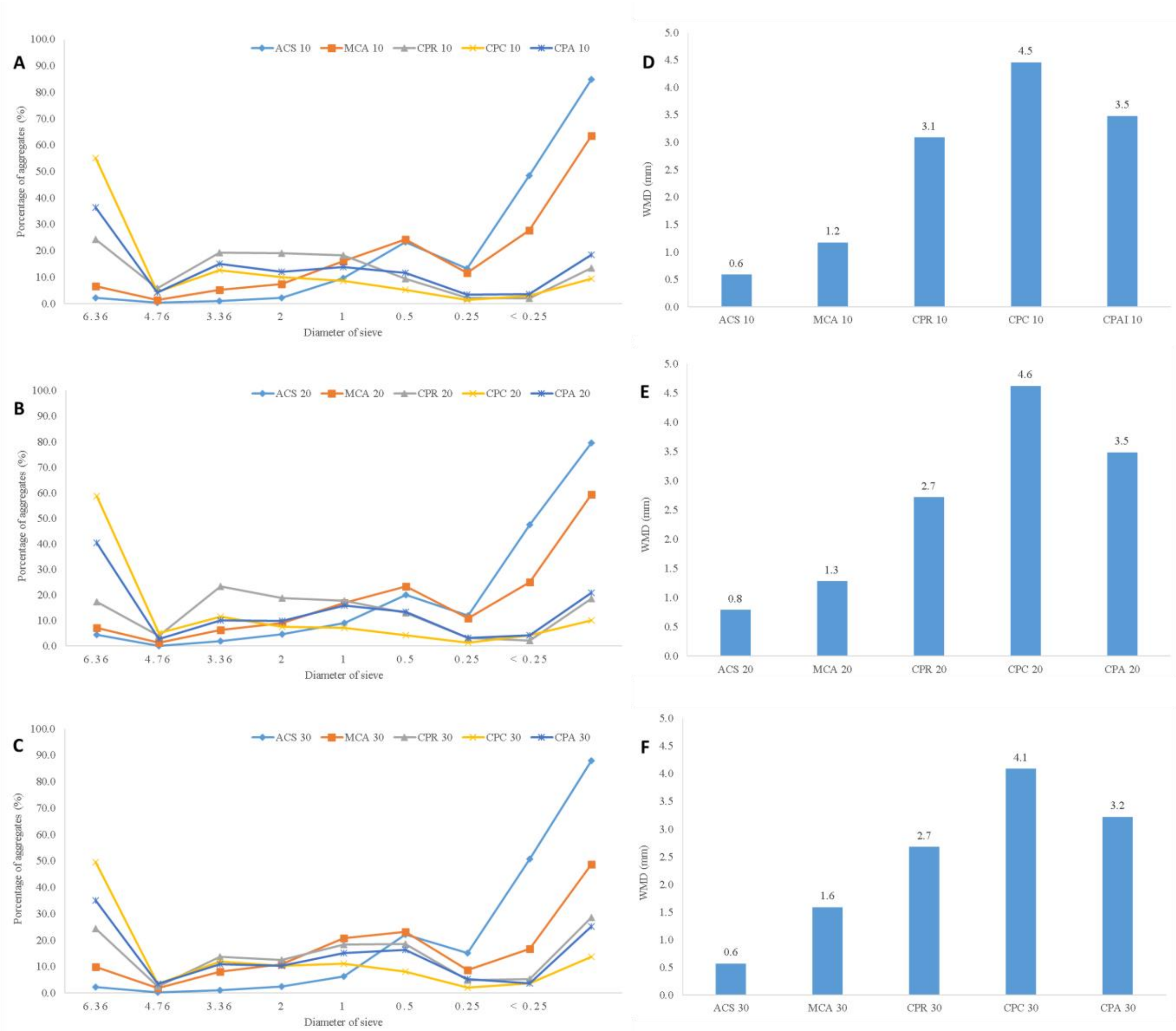

Figure 1: Average distribution of soil aggregates

A: Percentage of aggregates by sieve size at the depth of 0-10 cm; B: Percentage of aggregates by sieve size at the depth of 10-20 cm; C: Percentage of aggregates by sieve size at the depth of 20-30 cm; D: WMD per system in the depth of 0-10 cm; E: WMD per system in the depth of 10-20 cm; F: WMD per system in the depth of 20-30 cm. ACS: Avocado-coffee system. MCA: Monoculture avocado. CPR: Coffee traditional polyculture with renewal. CPC: Coffee traditional polyculture with pruning and severe cleaning. CPA: Coffee traditional polyculture abandoned.

depth of 0-10 cm, 69.4% depth of 10-20 cm and 62.5% in the depth of 20-30 cm. These distributions of aggregates show, corresponding to WMD values, that CTPS have aggregates of 3.7 mm, meanwhile ACS and MCA systems of 0.9 mm on average, at a depth of 0-10 cm (Fig. 2 e and f). The accumulated WMD (0-30 cm depth) is 3.5 mm on average for CTPS and 1.0 mm for systems associated with avocado (ACS and MCA).These values exhibited differentiate the soils in CTPS (that have structure with very low risk of runoff and diffuse erosion) from those of ACS and MCA (having moderately stable structure and risk of runoff and diffuse erosion), according to the climatology and topography factors (Bissonnais, 1996); furthermore, aggregates in CTPS are 250% larger than in the modified systems with avocados. The distribution of aggregates smaller than 1.0 mm in the ACS is attributed to the introduction of avocados in the system; occurring significant higher BD values in the systems with presence of avocados. The lower value of WMD in the ACS are influenced by the high content of SOM, a relationship that should be directly

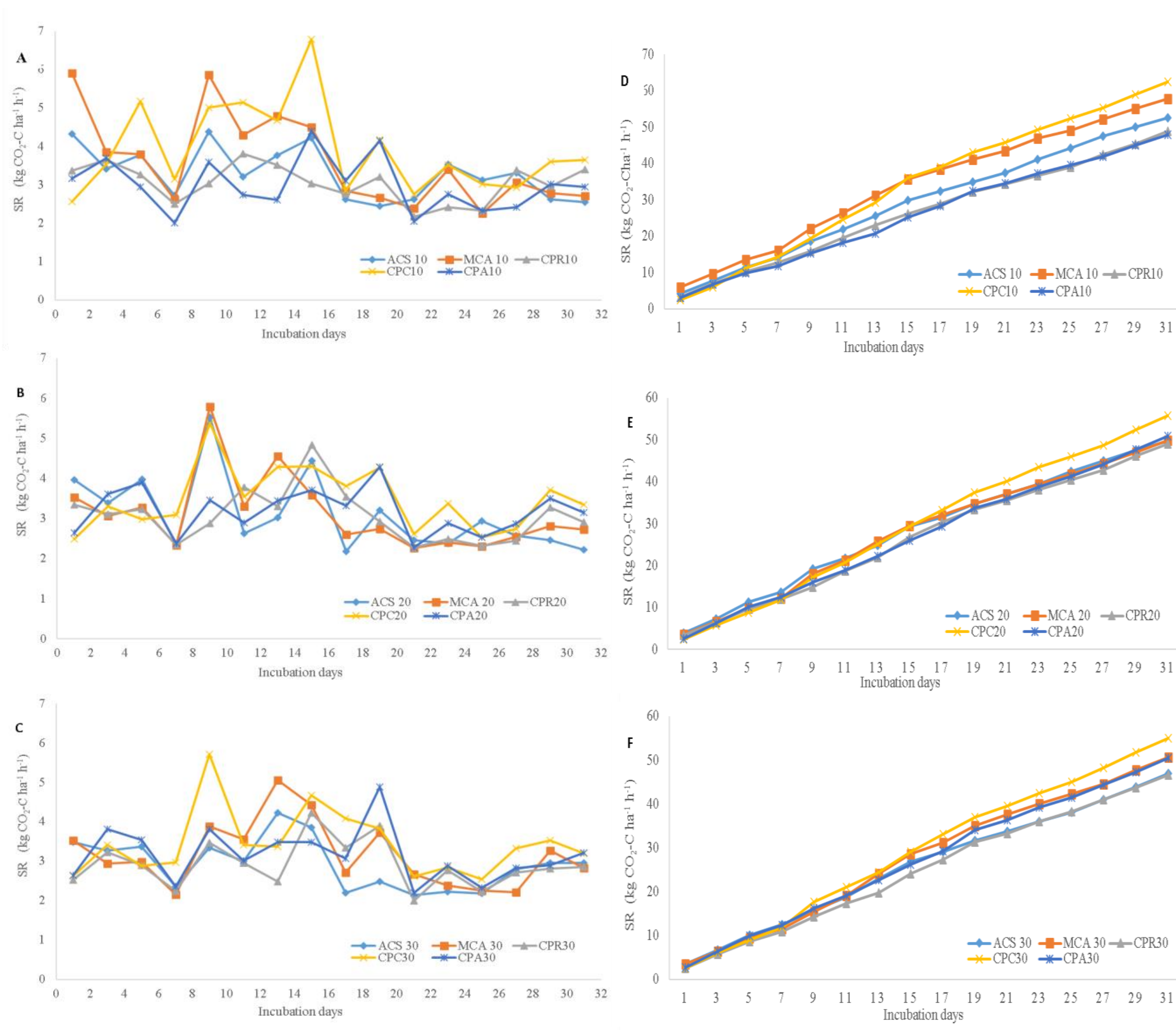

Figure 2: CO_2 emission from soil respiration in each system

Legend: A; Soil respiration at the depth of 0-10 cm, B; Soil respiration at the depth of 10-20 cm, C; SR at the depth of 20-30 cm, D; Accumulated SR at the depth of 0-10 cm, E; Accumulated SR at the depth of 10-20 cm, F; Accumulated SR at the depth of 20-30 cm. ACS: Avocado-coffee system. MCA: Monoculture avocado. CPR: Coffee traditional polyculture with renewal. CPC: Coffee traditional polyculture with pruning and severe cleaning. CPA: Coffee traditional polyculture abandoned.

proportional; however, in this case, it is opposite. This behavior can be attributed to the active fraction of SOM which is stimulated by deposition of OR (avocado leaves), which humified more quickly (SR is higher when avocados are introduced) because their higher N content (lower C/N ratio) than the OR produced by coffee plantations (different chemical composition; Munguía et al., 2004; Medina et al., 2017). However, intensive pruning management contributes to a WMD 3.7 times higher than the WMD of the MCA system. Nevertheless, the BD values for the systems are lower than the reported average (0.82 Mg m^{-3}) by Siavoch *et al*. (2000) for CTPS, with smaller aggregates of WMD (varying between 0.6 to 0.8 mm), a range that confirms the high potential to store carbon in the long term, but deficient to generate soil activity, i.e., such as evidenced by the lower CO_2 emission (Chattterjee *et al*., 2020).

MCA and ACS at the depth of 0-10 cm (Fig. 2a) during the first 13 days of incubation provided the highest amount of CO_2 emissions with a maximum on day 9.0 (2.2

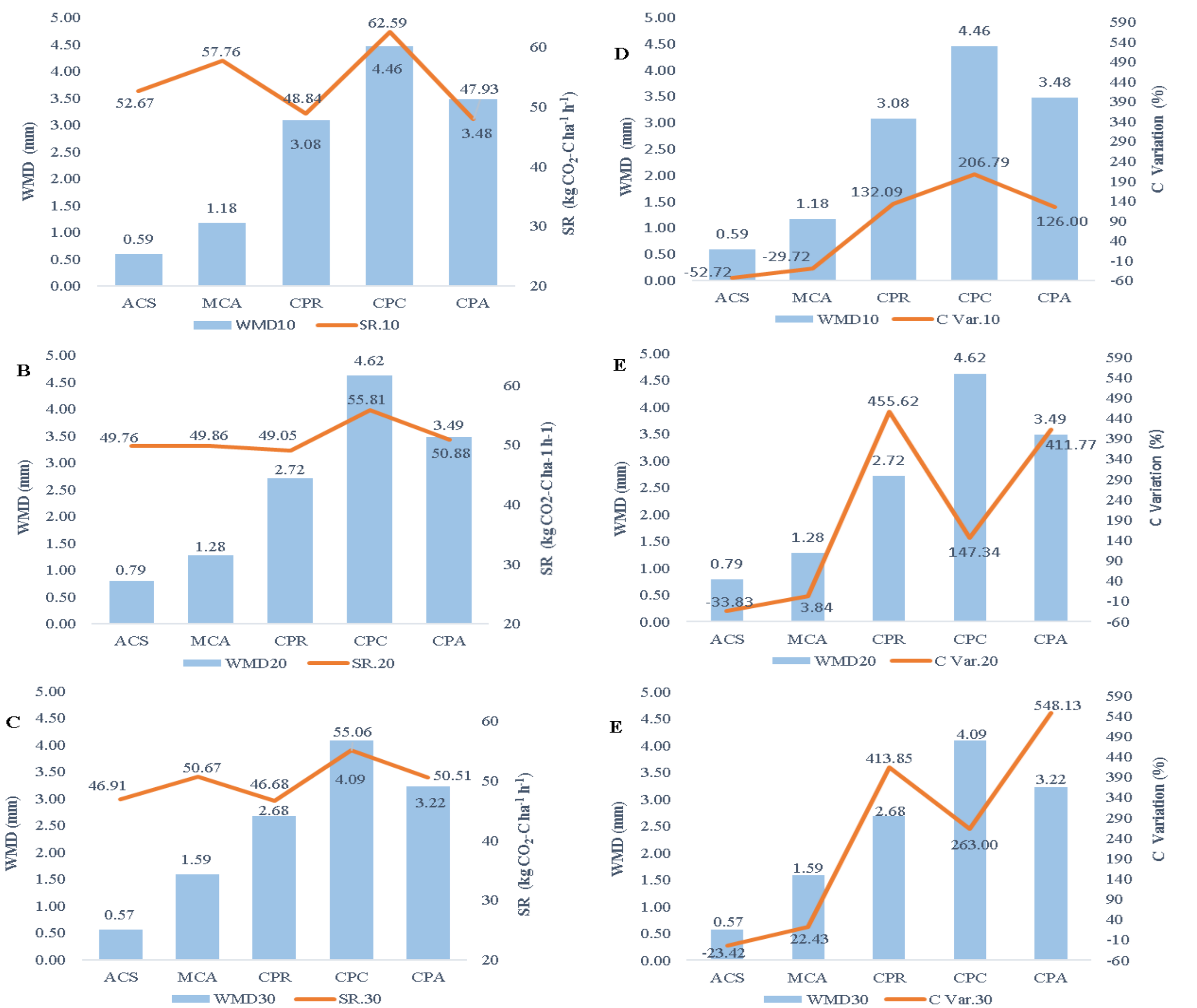

Figure 3: Relationship between the weighted minimum diameter (WMD) and the variation of C (Var.)

A; WMD and accumulated soil respiration at depth of 0-10 cm, B; WMD and accumulated soil respiration at depth of 10-20 cm, C; WMD and accumulated soil respiration at depth of 20-30 cm, D; WMD and Var. in the depth of 0-10 cm, E; WMD and Var. in the depth of 10-20 cm, F; WMD and Var. in the depth of 20-30 cm. ACS: Avocado-coffee system. MCA: Monoculture avocado. CPR: Coffee traditional polyculture with renewal. CPC: Coffee traditional polyculture with pruning and severe cleaning. CPA: Coffee traditional polyculture abandoned and 3.0 kg CO_2-C ha^{-1} h^{-1}, respectively). The CPC and CPA systems showed the same trend with 2.8, and 3.2 kg CO_2-C ha^{-1} h^{-1}, respectively, and the CPC system had its highest emission on day 13. At the depth of 10-20 cm (Fig. 2b), the maximum emissions for ACS occurred on day 13 with 2.7 kg CO_2-C ha^{-1} h^{-1} on average, for MCA on day 11 with 2.1 kg CO_2-C ha^{-1} h^{-1} and for CTPS on day 15 with an average range of 2.5-3.0 kg CO_2-C ha^{-1} h^{-1}. While at a depth of 20-30 cm (Fig. 2c), the systems associated with avocados showed their maximum emission (2.7 kg CO_2-C ha^{-1} h^{-1}) in a shorter period (9 days) than CPR (2.5 kg CO_2-C ha^{-1} h^{-1} on the 15th day), CPC and CPA with 2.5 kg CO_2-C ha^{-1} h^{-1} on average on the 19th day.

Table 2: CO_2 emission generated from soil respiration

System	CO_2 emission (kg CO_2 -C ha^{-1} h^{-1}) 0- 10 cm		10-20 cm		20-30 cm	
ACS	53 ±1.95	bc	50 ±2.32	a	47 ±1.25	b
MCA	58 ±1.95	ab	50 ±2.32	a	51 ±1.25	ab
CPR	49 ±1.95	bc	49 ±2.32	a	47 ±1.25	b
CPC	63 ±1.95	a	56 ±2.32	a	55 ±1.25	a
CPA	48 ±1.95	c	51 ±2.32	a	51 ±1.25	ab
P-Value	<0.05		0.31		<0.05	
DMS	9.09		10.79		5.82	

ACS: Avocado-coffee system; MCA: monoculture avocado; CPR: Coffee traditional polyculture with renewal; CPC: Coffee traditional polyculture with pruning and severe cleaning. CPA: Coffee traditional polyculture abandoned; DMS: Minimal significant difference; *P-Value*: Probability value; Tukey test ($p \leq 0.05$).

Table 3: SOC balance and degradation rate constant (K_t)

System	SOC balance (Mg C ha^{-1}) 0- 10 cm		10-20 cm		20-30 cm		Degradation rate constant (K_t) day^{-1} 0- 10 cm		10-20 cm		20-30 cm	
ACS	26±4.6	a	15±5.1	a	9±3.1	a	-2.3±0.3	b	-1.24±0.39	c	-0.77±0.29	d
MCA	9±4.6	a	-1±5.1	a	-5±3.1	a	-1.03±0.3	b	0.15±0.39	c	0.76±0. 29	c
CPR	-38±4.6	b	-78±5.1	b	-63±3.1	c	2.8±0.3	a	5.56±0.39	a	5.32±0. 29	ab
CPC	-61±4.6	c	-37±5.1	c	-44±3.1	b	3.6±0.3	a	2.91±0.39	b	4.19±0. 29	b
CPA	-37±4.6	b	-87±5.1	c	-81±3.1	d	2.7±0.3	a	5.31±0.39	a	6.08±0. 29	a
P-Value	<0.0001		<0.0001		<0.0001		<0.0001		<0.0001		<0.0001	
DMS	21.193		23.641		14.202		1.38		1.8		1.36	

ACS: Avocado-coffee system. MCA: Monoculture avocado. CPR: Coffee traditional polyculture with renewal. CPC: Coffee traditional polyculture with pruning and severe cleaning. CPA: Coffee traditional polyculture abandoned. Tukey test ($p \leq 0,05$); different letters indicate significant statistical differences. *P*-Value: Probability value, DMS: Minimal significant difference.

The accumulated respiration varied between 46.7 and 62.6 kg CO_2-C ha^{-1} h^{-1} in all systems and depths (Table 2). The CPC system associated with pruning and severe cleaning was the one that reported the highest SR in the first depth (0-10 cm); the same was observed in the depth of 20-30 cm; while in the intermediate depth (10-20 cm), no significant differences were found between systems. The ACS showed 18.8% less emissions than CPC but emitted 9.9% more CO_2 than the abandoned CTPS (CPA) at the depth of 0-10 cm (Fig. 2e). In the 10-20 cm there were no significant statistical differences, and at 20-30 cm depth (Fig. 2f) it resembles the system with lower respiration (CPR); this system corresponds to the renewed coffee plantation, that is, with a high density of young coffee plants.

The systems with intensive management (MCA) had a WMD 50% larger than in ACS and therefore exceeds 50% values of soil respiration (Fig. 3a). Similarly, in the CTPS higher respiration is reported in the CTPS with pruning and severe cleaning (CPC), attributed to the presence of aggregates with a WMD that exceeds 44.8% in size to the CPR systems and in 28.2% at CPA. However, intensive pruning management contributes to a WMD 3.7 times higher than the WMD of the MCA system. This relationship is also observed in the other depths (Fig. 3b, 3c).

The modification of the CTPS generated less soil activity that can be attributed to the systems ACS (avocado and coffee system) and MCA (monoculture) composed with fewer species, less diversified than the CTPS (Xi *et al*., 2012); however, the accumulated emissions are similar to the average (147 kg CO_2-C ha^{-1} h^{-1}) reported by Hergoualc´h *et al*. (2008) for the coffee system in *Andosols*. While in the CTPS the greater diversity of species within their composition contributes to the biological activity of the soil and, therefore, there is an increase in CO_2 emissions (Chen & Chen, 2019), also such agroforestry systems provide diversified organic residues, Sheng *et al*. (2010), promoting soil respiration and SR in the CTPS is higher than in systems with intensive management, Siavosh *et al*. (2000).

The SOC balance was positive for ACS and reported the highest average range (9-26 Mg C ha^{-1}) in all depths. The MCA showed a positive balance in the first -10 cm depth (Table 3), while the rest showed a negative balance; however, the three depths showed statistical similarities to the ACS system. The CTPS generated a negative balance to store SOC at all depths.

The variation of the SOC contents in the depth of 0-10 cm (Fig. 3d) indicates that SOC before incubation is higher than after incubation in systems ACS and MCA, where the WMD is smaller. While all the CTPS show an increase in SOC greater than 100%, the CPR (132%), and CPC (207%) had the highest WMD and SOC values. However, CPA despite having a higher WMD than CPR (132%), generated a lower increase in the SOC content. At depths of 10-20 and 20-30 cm (Fig. 3e), the variation in SOC content has the same trend as in the first depth for systems associated with avocados, CPC reduced its increase in SOC, CPR, and CPA were the ones that generated the greatest increases in SOC generated later by SR, in both systems they represent more than 400% increase. The difference between the time of maximum CO_2 emissions in the systems can be attributed to the modification of the CTPS, since in the systems associated with avocados different ORs are produced (data are not shown), which modify the biological activity (Paolini, 2018).

The SOC degradation rate constant (K_t) was negative for the ACS system at all depths and positive for the rest of the systems. The CPA system had the accumulated highest K_t in all depths, which allows the following order: CPA = CPR > CPC > MCA > ACS.

According to their ability to degrade OR, this relationship allows an inverse balance. The positive SOC balance in the modified systems with avocados (MCA and ACS) indicates the capacity of the systems to generate conditions that inhibit the biological activity of the soil and therefore, showing less CO_2 emissions. This produced modification of systems with avocados generating less C output which had a positive impact on mineralization processes of labile SOM (Le Noë *et al*., 2019), while the CTPS generated a negative balance, producing higher concentrations of residual C due to the biological activity of the soil.

The capacity of the systems to promote C deposits and reduce emissions generated by soil activity is related to their capacity to degrade SOM, which was negative for the avocado coffee system (ACS) and less than one for the monoculture avocado (MCA), according to the results of Kt, suggests the modified systems have a low soil activity, Beer (1988) who found in agroforestry systems of coffee with shade trees (producing between 5,000 to 10,000 kg ha^{-1} $year^{-1}$ of organic material), allows to explain high rates of soil respiration and positive values of Kt (2.7 and 6.08) in the agroforestry systems not modified (CPA, CPR, CPC). Similarly, the diversified floristic composition of coffee agroforestry systems produces a higher amount of organic residues, changing the rate of decomposition, Villavicencio-Enríquez (2012). The low values of CO_2 emissions accumulated during incubation contribute to maintaining the soil C reserve. This response showed a low degradation capacity of SAC reducing soil respiration (Zimmermann *et al*., 2009).

Results allow the group the coffee systems without modification and avocado diversity of tree species, the density of coffee plants and management with severe pruning which in turn, generated higher soil respiration and could be attributed to litter produced under agroforestry systems (Beer, 1988) with positive values of K_t and highest values in WMD.

Conclusion

In conclusion, the lowest WMD generated in the two systems associated with avocados had a lower microbial activity, giving a positive SOC balance and a negative SOC degradation rate constant (K_t). The ACS system generated the lowest concentration of accumulated CO_2 emissions. The introduction of avocados to the coffee traditional SAF contributes to the storage of SOC and the reduction of CO_2.

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