CO_2 soil emission under different methods of oil palm replanting

Emisiones de CO_2 de suelo bajo diferentes métodos de renovación en palma de aceite

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Abstract. *Colombian oil palm plantations have started a large-scale replanting phase. The replanting process has an effect on the disposal of biomass, plant health management, and agro-ecological conditions due to the disturbance that is generated. This document addresses soil respiration (CO_2 flux) as a response variable of crop replanting. Seven renovation methods used in Colombia were tested. The measurements were taken over time after the disturbance and planting of the new crop. This study was carried out in the municipality of Tumaco between August of 2009 and June of 2011 using 7 methods of renovation and 4 stages of crop development. The CO_2 flow was measured at 12 points in each plot. There were no significant differences for the CO_2 emission among the replanting methods. The average value for respiration was 929 mg CO_2 m^{-2} h^{-1} (± 270.3); however, significant differences were found over time. This response was not related to fluctuations of soil temperature and moisture; therefore, there should be an associated response to biotic factors (microbial organisms) not established in this study. The values suggested that the soil of the plots under a replanting process emitted considerable quantities of carbon into the atmosphere, but the emissions declined over time and, in turn, were offset by the photosynthesis of the new crop (14 μ CO_2 $m^{-2}s^{-1}$ ± 1.4, data not shown), creating an overall positive carbon balance.*

Key words. Biomass decomposition, *CO_2* flux, *Elaeis guineensis*, soil disturbance.

Resumen. *La palmicultura colombiana comenzó una fase a gran escala de renovación de cultivo; diversos aspectos influyen en esta situación, dentro de los más relevantes está la disposición de la biomasa y su impacto en el área fitosanitaria, y la condición agroecológica debido al disturbio generado. En este documento se abordó la respiración del suelo (flujo de CO_2) como variable respuesta a la renovacion del cultivo. El trabajo se llevó a cabo en el municipio de Tumaco, entre agosto de 2009 y junio de 2011, en 7 métodos de renovación y en 4 fases de desarrollo del cultivo se midió el flujo de CO_2 en 12 puntos de cada parcela. Dentro de los métodos no se evidenciaron diferencias de emisión de CO_2. El valor promedio fue de 929 mg CO_2 m^{-2} h^{-1} (± 270,3), sin embargo a través del tiempo se encontraron diferencias significativas, esta respuesta no está relacionada con las fluctuaciones de temperatura y humedad del suelo, por lo tanto debe existir una respuesta asociada a factores bióticos (microbiota) no establecida en este trabajo. Los valores sugieren que desde el suelo de lotes en proceso de renovación se emiten cantidades considerables de carbono hacia la atmósfera, pero que van disminuyendo a través del tiempo y a su vez son ampliamente niveladas con la fotosíntesis del nuevo cultivo (14 μ CO_2 $m^{-2}s^{-1}$ ± 1,4 datos no mostrados), generando un balance positivo en estado global del carbono.*

Palabras claves. Descomposición de biomasa, flujo de *CO_2*, *Elaeis guineensis*, disturbios del suelo.

Replanting, in the case of oil palm, is regarded as a process that, in addition to being costly, affects the financial aspects of companies. Oil palm replanting criteria cover aspects in addition to the chronological ones, including palm height (difficult to harvest), reduced yield, plant health issues, economic reasons, and technical issues, etc. (Celis, 2000; Nazeeb, 1998).

Whatever the reason, in the replanting process, the biomass that is left in the field (stems and fronds) is about 90 t of dry matter per hectare (25-plus year-old palms) (Khalid *et al*., 2000; Castilla, 2004). In the Tumaco area, an average of 34,000 ha are being replanted and approximately 2.7 million t of gradually decomposing biomass will be produced in the short-term. This would pose a high risk to the development of the new crop, because this biomass could become a major source of pest and disease problems (Avila *et al.,* 2014).

In the agro-ecological context, soil is the largest carbon sink-pool on earth (Raich *et al*., 2002; Jiang *et al*., 2015; Shi *et al*., 2011), with an important participation in

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the carbon cycle with respiration or a CO_2 flux (Jiang *et al*., 2015; Kurth *et al*., 2014; Zhang *et al*., 2013). This component is associated with root respiration, soil microorganisms and organic matter decomposition. Therefore, its evaluation has been aimed at the study of microbial activity, nutrient recycling, and soil carbon flux, etc (Anderson, 2011; Wang *et al*., 2011; Yan *et al*., 2011).

Determining soil respiration from croplands is necessary for evaluating the global terrestrial carbon budget and how it is altered in future climates (Zhang *et al*., 2013). In recent years, there have been investigations to establish CO_2 soil emissions in crops or ecosystems (Belfon *et al*., 2014; Jiang *et al*., 2015; Shen *et al*., 2015). Considering that Oil palm cultivation has been expanding and it is one of the fastest developing agricultural crops in tropical regions (Tan *et al*., 2012), it is very important to evaluate emissions from this crop; however, there is little information on oil palm in terms of soil respiration (Adachi *et al*., 2005; Frazão *et al*., 2014; Tan *et al*., 2012). Therefore, this study aimed to determine changes in soil respiration considering the humidity and temperature of the soil under different replanting methods and to analyze the behavior and impact associated with the disturbance created and CO_2 emissions.

MATERIALS AND METHODS

Study area. The experiment was established at Palmeiras SA, an oil palm plantation located in the municipality of Tumaco, Nariño (1°27´6.12" N y 78°41´55.93" W). The average rainfall in this region is 2,950 mm and it has a temperature of 28°C. The texture of the soil in which the essay was established was clay loam; there were acidic soils, with an intermediate organic matter content (2 to 4%), low aluminum saturation (<27%), and low content of phosphorus (<5 mg kg^{-1}). Other characteristics of the soil included calcium saturation (>50%), potassium saturation (5.21%) and magnesium saturation (18.4%).

Between the years 2009 and 2011, seven renovation methods (treatments), based on a combination of the method of eradication of the old palms and the disposal of the residues of eradicated palms, were tested (Table 1). A randomized complete block design was used for the treatment distribution with four replicates per treatment and a total of 28 experimental units, each one with 23 palms. The total study area was 11 hectares. The genetic material used as the new crop was the interspecific hybrid *E. guineensis* x *E. oleifera* (Coari x La Me).

Table 1. Replanting treatments implemented in the experiment, established at Palmeiras SA, Tumaco Colombia. Oil palm interspecific hybrids (*Elaeis oleifera* H.B.K. Cortes vs. *Elaeis guineensis* Jacq.).

No.	Treatment	Description
T1	Herbicides	Application of herbicides to standing palms which are left to decompose over time.
T2	Stacking	Cut down the palms and place them every two rows of the new hybrid palms.
T3	Chipping and stacking	Felling, chipping and stacking the palms every two rows of the new hybrid palm.
T4	Chipping, spreading and incorporating	Felling and chipping the palms and spreading the chips throughout the plot and incorporating them using mechanical equipment.
T5	Removal	Felling and removing the palms from experimental plot.
T6	Stacking in ditches	Felling the palms and stacking them in open ditches every two rows of the new hybrid palms and covering them with soil.
T7	Carbonize	Felling and chipping the palms, followed by carbonization in stacks of biomass made up mainly of stem chips.

Measurement of soil respiration. The soil respiration was measured using an automated soil CO_2 flux system (LI-8100, LI-COR, USA) equipped with a portable camera (Model 8100-103), PVC cylinders (20.3 cm diameter and 10 cm high); this was a closed system and air was circulated from a chamber to an infrared gas analyzer

(IRGA) and, then, sent back to the chamber. Flux is estimated from the rate of CO_2 concentration increments inside the chamber, which has been deployed on soil surfaces for a short period of time. The measurements were taken between 9:00 and 11:00 hours, the time that has the highest flux rate (information not shown). We measured the soil temperature and moisture simultaneously during each measurement period. The soil temperature at the 10 cm depth was measured with a soil temperature probe connected to a Li-Cor 8100. The volumetric soil moisture content at the 0–10 cm depth was measured with a portable HH2 meter and SM200 moisture sensor (Delta-T, England). The soil samplings were taken on August of 2009 and June of 2011 in four growth stages of the crop (one day before the replanting of the new crop, 62 days after the planting of the new crop, 519 days after the replanting of the new crop, which corresponded to beginning of flowering, and 670 days after replanting of the new crop which corresponded to the beginning of bunch production).

Statistical analysis. To examine the effect of the renovation method and sampling period, a repeated measure analysis of variance (ANOVA) was performed using the general linear model (GLM) procedure. A Duncan's multiple range test was used to compare the different means of soil respiration between the renovation methods within each period. We used Statistical Analysis with SAS/STAT® Software (SAS Institute Inc. North Carolina, USA) for all of the statistical analyses.

RESULTS AND DISCUSSION

Soil respiration. According to the methods of renovation (eradication-replanting) used, no statistically significant differences were found between them ($P>0.05$; $n=12$), indicating that the decomposing organic matter and the disturbance did not significantly affect the CO_2 flux in the different plots (Figure 1). However, significant differences were found over time. This response was not strange although it was difficult to draw any definitive

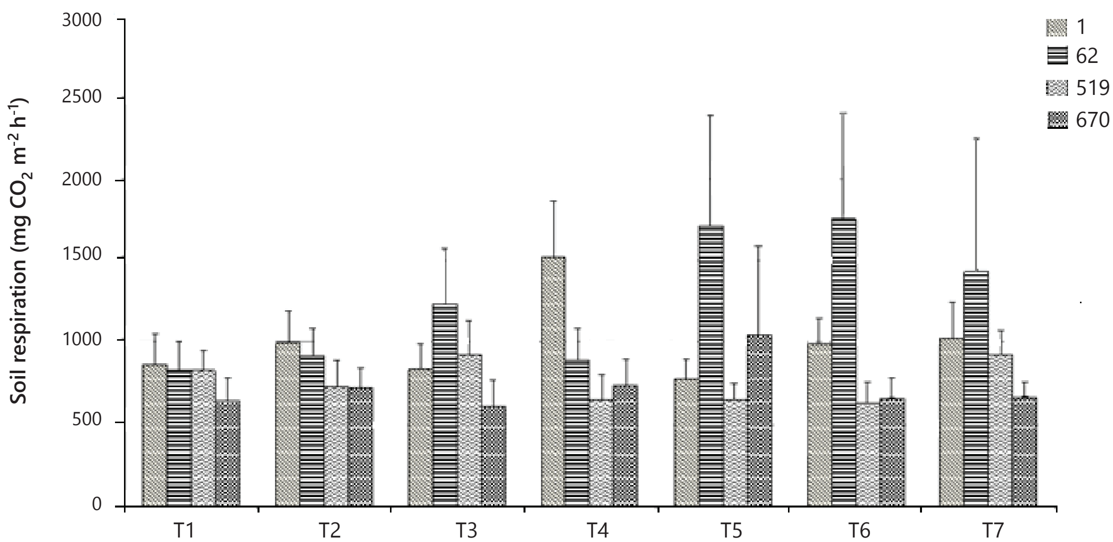

Figure 1. Soil respiration rates under different replanting methods and during the establishment of the new crop. 1: One day before felling the palms. 62: 62 days after planting the new crop. 519: 519 days after planting the new crop, beginning of flowering. 670: 670 days after planting the new crop, start of bunch production.

conclusions about the general effect of the elevated CO_2 on the respiratory processes. The relevant literature is somewhat contradictory. For example, a total soil respiration decrease under elevated CO_2 has been reported (Callaway *et al*., 1994); in other studies, increments in the total soil respiration have been recorded (Lin *et al.*, 1999) and there are even some reports in which the total soil respiration did not change (den Hertog *et al*., 1993). Our results showed that, in the case of oil palm, the eradication-replanting methods used did not significantly affect the rate of CO_2 emissions into the environment; on the contrary, the emissions declined significantly over time. Similarly, it was observed that the soil moisture and temperature did not affect the soil respiration rates; therefore, it is plausible that the vegetation cover played an important role in protecting the soil from direct solar radiation, preventing wide fluctuations in the soil temperature and moisture content. It is necessary to continue assessing soil respiration rates over time, as associated with nutrients and soil microorganism populations, which have a direct effect on soil respiration rates.

On day 62, the highest respiration rate was reached with an average of 1,253 mg CO_2 m^{-2} h^{-1} and the lowest respiration rate with an average of 723 mg CO_2 m^{-2} h^{-1} was reached on day 670. This high value on day 62 could have been related to the biomass decomposing and nutrient cycling, possibly similar to what happens in grasslands where it has been observed that the nutrient content directly affects the soil microbiota and soil respiration (Balogh *et al*., 2011). Similarly and synergically, the increased root mass of the new crop was a factor that may have affected the soil respiration rates. For example, Li *et al.* (2006) found that rootlet respiration rates in secondary forests accounted for 69% of soil respiration in Puerto Rico.

The soil respiration recorded in our research showed fluctuations, with an average of 929 mg CO_2 m^{-2} h^{-1} (± 270.3); this is similar to the results of Adachi *et al.* (2006), who found an average of 965 mg CO_2 m^{-2} h^{-1} (± 557.7) for a 25-year-old plantation in Malaysia. On the other hand, these values differed a little from those reported by Henson (1994) for a 9-year-old plantation in Malaysia, where the values recorded were between 20 and 40% lower than those in this study, evidence of how difficult it is to compare the information obtained on soil respiration in different studies and how the methods may affect the values obtained.

Table 2 shows the soil respiration rates in different ecosystems and by different authors. All studies used the same measuring method (IRGA). A significant contribution of carbon dioxide by the oil palm plantation can be observed, with 50% more emissions than primary or secondary forests, but lower than those reported for grasslands (Fernandes *et al*., 2002; Balogh *et al*., 2011).

Table 2. Soil respiration in different types of vegetation and different regions

Soil respiration (mg CO_2 m^{-2} h^{-1})	Vegetation/Location/Seasons	References
929	Oil palm plantation / Colombia /Dry and rainy seasons	This study
799	Oil palm plantation / Malaysia / No information	Henson (1994)
966	Oil palm plantation / Malaysia / Rainy seasons	Adachi *et al.* (2006)
667	Primary forest / Colombia / Dry and rainy seasons	Ramirez and Moreno (2008)
667	Secondary forest / Colombia/ Dry and rainy seasons	Ramirez and Moreno (2008)
183 - 1162	Grassland / Brazil / Dry and rainy seasons	Fernandes *et al*. (2002)

Response of soil respiration to soil temperature and soil water content. Various studies have shown that soil moisture and temperature affect soil respiration. This is mainly due to soil physical properties that trigger variable responses to changes in solar radiation and rainfall, promoting or inhibiting root respiration and creating changes in soil microorganism populations, both closely related to the CO_2 flux (Shi *et al*., 2011; Yan *et al*., 2011). However, in this study, the fluctuation in soil respiration could not be explained by variations in the soil temperature (regression R^2= 0.05; P>0.05). This behavior may have been due to the fact that the temperature changes did not show strong variations as reported in other studies. For example, Wang *et al.* (2011) mentioned a direct incidence of temperature in soil respiration, as the temperature variation was 25°C, 5 times higher than that reported in this study, where the maximum variation was 5°C (Figure 2).

The low variation in the soil temperature might have been related to the vegetation cover, which, in the case of oil palm, plays an important role in protecting the soil against radiation and loss of water through evaporation. As a good agronomic practice, the new planting must have a well-established vegetation cover. This was probably the reason why the temperature variations were so low and, therefore, there was not a conditioned response of the CO_2 flux.

The soil moisture, unlike the soil temperature, ranged widely from 15% to 70% of gravimetric moisture, influenced by dry and rainy seasons (Figure 3). However, moisture did not explain the variation in soil respiration over time (regression R^2= 0.01). This report differed from that found in other crops, such as eucalyptus (Chen *et al.,* 2011), where a clear relationship was demonstrated between soil moisture and soil respiration.

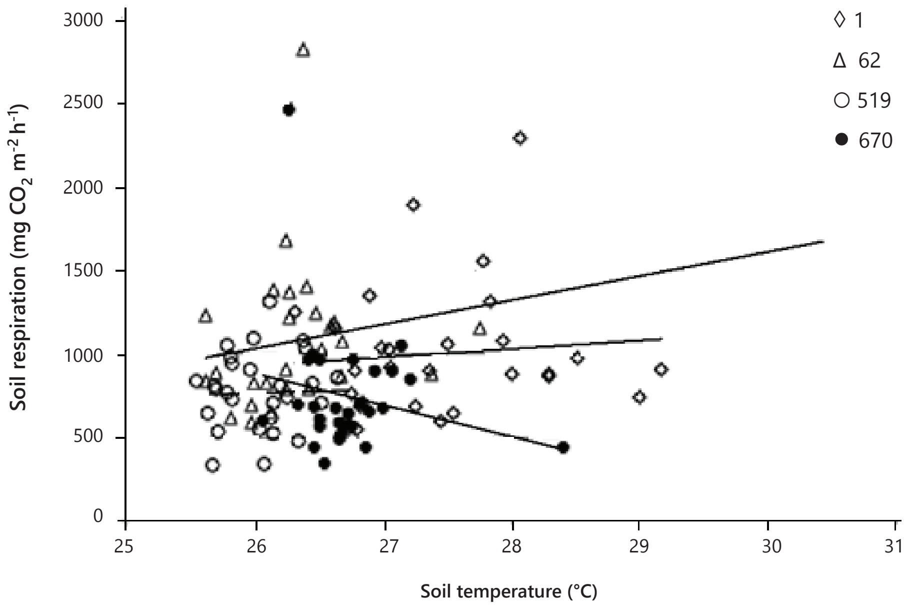

Figure 2. Relationship between the soil respiration and soil temperature. (n=28) at different days after the renovation. 1: One day before felling the palms. 62: 62 days after planting the new crop. 519: 519 days after planting the new crop, beginning of flowering. 670: 670 days after planting the new crop, start of bunch production.

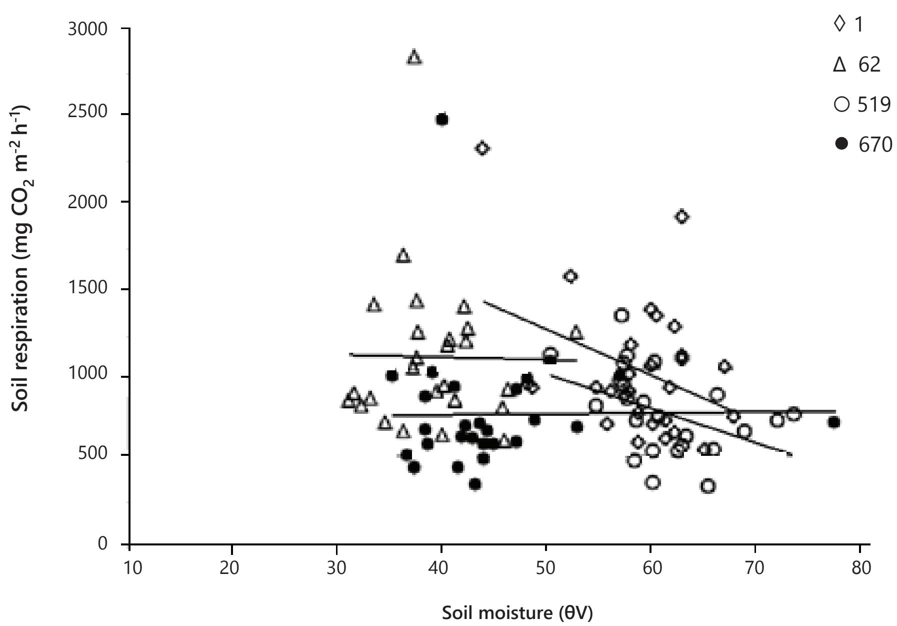

Figure 3. Relationship between the soil respiration and volumetric water (n=28) at different days after the renovation. 1: One day before felling the palms. 62: 62 days after the planting of the new crop. 519: 519 days after planting the new crop, beginning of flowering. 670: 670 days after planting the new crop, start of bunch production.

Since soil moisture, together with some physical soil characteristics, affects soil microorganism populations, there may be more or less respiration depending on the season (Shi *et al*., 2011; Yan *et al*., 2011). Similarly, soil moisture thresholds may be associated with soil temperature for the soil respiration to be affected by these two variables (Lellei-Kovács *et al*., 2011).

CONCLUSIONS

During this investigation, no differences in the total soil respiration among the methods of replanting were found. Although biomass can play an important role in soil respiration increase, the differences in the accumulated biomass in the field were not as significant as those of the soil respiration, as the time between the beginning of the renovation process and the biomass decomposition and nutrient cycling. The maximum soil respiration value was 1600 mg CO_2 m^{-2} h^{-1} at the beginning of the replanting and the minimum value was 650 mg CO_2 m^{-2} h^{-1} at the time of the beginning of bunch harvesting, 670 days after the beginning of the renovation process. Although a direct relationship between soil respiration and soil temperature or soil moisture was not found, it is important to work with oil palm to integrate other components associated with CO_2 emissions.

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