SOIL CO_2 EMISSION AS RELATED TO INCORPORATION OF SUGARCANE CROP RESIDUES AND AGGREGATE BREAKING AFTER ROTARY TILLER

LUIS G. TEIXEIRA[1], ADRIAN FUKUDA[2], ALAN R. PANOSSO[3], AFONSO LOPES[4], NEWTON LA SCALA JR.[5]

ABSTRACT: Soil tillage is a process that accelerates soil organic matter decomposition transferring carbon to atmosphere, mainly in the CO_2 form. In this study, the effect of rotary tillage on soil CO_2 emission was investigated, including the presence of crop residues on the surface.Emissions were evaluated during 15 days after tillage in 3 plots: 1) non-tilled and without crop residues on soil surface (NTwo), 2) rotary tiller without the presence of crop residues on soil surface (RTwo), and 3) rotary tiller with the presence of crop residues in soil surface (RTw). Emissions from the RTw plot were higher than the other plots, (0.777 g CO_2 m^{-2} h^{-1}), with the lowest emissions recorded in the NTwo plot (0.414 g CO_2 m^{-2} h^{-1}). Total emission indicates that the difference of C-CO_2 emitted to atmosphere corresponds to 3% of the total additional carbon in the crop residues in the RTw plot compared to RTwo. The increase in the RTwo emission in comparison to NTwo was followed by changes in the aggregate size distribution, especially those with average diameter lower than 2 mm. The increase in emission from the RTw plot in relation to RTwo was related to a decrease in crop residue mass on the surface, and its higher fragmentation and incorporation in soil. When the linear correlation between soil CO_2 emission, and soil temperature and soil moisture is considered, only the RTw treatment showed significant correlation ($p<0.05$) with soil moisture.

KEYWORDS: soil respiration, soil tillage, carbon dioxide, temporal variability of soil CO_2 emission.

EMISSÃO DE CO_2 DO SOLO EM FUNÇÃO DA INCORPORAÇÃO DE PALHA DE CANA-DE-AÇÚCAR E QUEBRA DE AGREGADOS APÓS PREPARO COM ENXADA ROTATIVA

RESUMO: O preparo do solo é um dos processos que aceleram a decomposição da matéria orgânica, transferindo carbono para atmosfera, principalmente na forma de CO_2. Neste trabalho, investigou-se o efeito do preparo com enxada rotativa sobre as emissões de CO_2 do solo durante 02 semanas após o preparo do solo, incluindo-se a presença de resíduos vegetais sobre a superfície. As emissões foram avaliadas por 15 dias após preparo em 3 parcelas: 1) sem preparo e sem palha superficial (SPs); 2) preparo com enxada rotativa sem a presença de palha na superfície (ERs), e 3) preparo com enxada rotativa com a presença de palha superficial (ERc). As emissões provenientes da ERc foram superiores às demais (0,777 g CO_2 m^{-2} h^{-1}), sendo as menores emissões registradas na parcela SPs (0,414 g CO_2 m^{-2} h^{-1}). As emissões totais indicaram que a diferença de C-CO_2 emitida à atmosfera corresponde a 3% do total de carbono adicional presente na palha, na parcela ERc, quando comparado à parcela ERs. O aumento da emissão da parcela SPs para ERs foi acompanhado de uma modificação na distribuição do tamanho de agregados, especialmente aqueles com diâmetro médio inferior a 2 mm. O aumento da emissão da parcela ERs para ERc esteve relacionado a uma diminuição da massa de palha na superfície, com fragmentação e incorporação da mesma no interior do solo. Quando se analisa a correlação linear entre emissão de CO_2 versus temperatura e umidade do solo, somente a emissão da ERc foi significativamente correlacionada ($p<0,05$) à umidade do solo.

PALAVRAS-CHAVE: respiração do solo, preparo do solo, dióxido de carbono, variabilidade temporal da emissão de CO_2 do solo.

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[1] Engº Agrônomo, Mestrando do Programa de Pós-Graduação em Agronomia (Produção Vegetal) da FCAV/UNESP, Departamento de Ciências Exatas, Jaboticabal -SP, lgteixeira@ymail.com.
[2] Aluno de graduação em Agronomia, IC CNPQ, Departamento de Ciências Exatas, FCAV/UNESP, adrianfukuda@hotmail.com.
[3] Engº Agrônomo, Doutorando em Agronomia (Produção Vegetal), Departamento de Ciências Exatas, FCAV/UNESP, Jaboticabal -SP, arpanosso@hotmail.com.
[4] Engº Agrícola, Co-orientador, Prof. Adjunto II, Departamento de Engenharia Rural, FCAV/UNESP, afonso@fcav.unesp.br.
[5] Físico, Orientador, Prof. Dr., Departamento de Ciências Exatas, FCAV/UNESP, lascala@fcav.unesp.br.
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INTRODUCTION

Carbon dioxide (CO_2) is the gas that contributed the most with additional greenhouse effect, which prevailed in recent decades (IPCC, 2007). According to IPCC publications (Intergovernmental Panel on Climate Change), CO_2 emissions in different sectors should be reduced, among which the agriculture sector stands out.

More specifically, when considering the case of sugarcane crop management, especially in southeastern Brazil, there are reports of two contrasting situations: the sugarcane harvesting system with and without burning. Currently, Brazil is the world's largest producer of sugarcane with 612 million tons harvested in 2009, with an area of approximately 7.5 million hectares (CONAB, 2009). About 50% of the total area is harvested without burning of the crop residue, and by the year 2014 the harvest of sugarcane in the state of São Paulo should be completely without burning. The traditional technique of sugarcane harvesting involves the burning of leaves and crop debris to facilitate the harvesting work. In contrast, mechanical harvesting does not require burning, and this sole fact represents an important contribution to reduce greenhouse gas emissions and, additionally, since crop residues are left on the soil, it allows a possible increase of organic matter content in the soil (CERRI et al., 2007).

WEST & POST (2002) estimated that the change in soil management practices, from conventional to reduced sequestration could result in a rate of 57 ± 14 g of carbon per square meter per year in agricultural areas in the first 5 to 10 year of conversion. This result is corroborated by several short-term studies in which the emission is examined, showing that after soil preparation, carbon loss via CO_2 to the atmosphere also increases (LA SCALA et al., 2006). Emissions as high as several tons of CO_2 in a few weeks have been recorded in plots where tillage was conducted in addition to that portion without disturbance (CHAVEZ et al., 2009; LA SCALA et al., 2006).

The rotary tiller is one of the most used tillage implements in Brazil, especially in horticulture. The number of blades per rotor, the knife rotation, the position of the impact plate, and work speed are adjustment variables that influence the process of soil fragmentation, thus providing better conditions for crop development. The disruption of soil aggregates, as evidenced by the reduction of its diameter, exposes the organic matter in the soil, leading to rapid oxidation and flow of CO_2 into the atmosphere (BALOTA et al., 2004).

Soil preparation is one of the agricultural activities that most influence carbon loss in the soil via CO_2 emissions into the atmosphere (LAL, 2007; JACINTHE & LAL, 2005). The influence of soil preparation on the immediate or almost immediate emissions of CO_2 into the atmosphere has been intensively studied by varying tillage systems and soil types. The vast majority of experimental results indicate an increase in the emission induced by tillage, which lasts for hours, sometimes weeks, after preparation. This increase has been attributed to two main factors: a) the breaking of the aggregates, exposing organic matter that was previously protected from microbial activity, b) soil decompaction and subsequent increase of the decay constant of labile organic matter (constant k), especially via increase in oxygenation and gas transport into the soil (GRANDY & ROBERTSON, 2007; DE GRYZE et al., 2006). Soil preparation may cause a third additional effect on emissions when it incorporates fragments and organic material debris from previous crops into the soil, such as sugarcane residues. Thus, rationalization of agricultural activities could assist in mitigating global warming through carbon sequestration in the soil (CERRI et al. 2007; LAL, 2007), such as soil preparation, as the effect on losses of soil carbon have been studied by several other authors (BAYER et al., 2006; SARTORI et al., 2006; LA SCALA et al. 2005).

Thus, the objective of this study was to characterize soil emissions of CO_2 induced by tillage with rotary tiller in terms of incorporation of sugarcane residues. The interest was to differentiate the effects of tillage on additional emissions, distinguishing the contribution of aggregate breaking from the residues incorporated into the soil.

MATERIAL AND METHODS

The study was carried out at Usina São Martinho (Pradópolis - SP), in the ranch Fazenda Barrinha located in the municipality of Barrinha - SP (21°13'29" S; 48° 6'49" W, WGS84). The experiments were performed between 12 and 27 of July, 2008.

The local climate is classified according to Köeppen as Cwa subtropical with average annual temperature of 21° C. The average annual rainfall is 1,380 mm, with a concentrated distribution in the period from October to March, while the months between April and September are relatively dry. Throughout the experimental period and the whole month of July there was no rain, with the previous incidents recorded on 01 and 21 of June with 3 and 4 mm, respectively.

The experimental area is characterized as with Dusky Red Latosol (Oxisol) soil of clayey texture and a flat terrain (slope = 0.5%) (EMBRAPA, 2006).Compound soil samples (0.00 to 0.20 m) were collected in the area and submitted to chemical and physical analyses, which indicated pH in $CaCl_2$ of 5 , featuring an acidic reaction condition of the soil, organic matter content of 311 g dm^{-3}, which equals to approximately 181 g dm^{-3} total organic carbon, calcium, magnesium and potassium of 19.1, 6.9 and 1.1 $mmol_c dm^{-3}$, respectively, cation exchange capacity (CEC) of 61 $mmol_c dm^{-3}$, base saturation (V%) of 44% and content of clay, silt and sand of 64.42%, 16.55% and 19.03% respectively. The average soil density found in recent studies was 1.25 ± 0.02 g cm^{-3} (PANOSSO et al., 2011).

It is noteworthy that the site had history of more than 15 years of sugarcane cropping, with harvesting system without burning, reduced tillage and mineral fertilization with formula containing nitrogen and potassium.

At the time of defining the experimental plots, there was a mass of 15 Mg ha^{-1} of sugarcane straw on the soil surface, with a C:N ratio close to 125:1, as residues of previous *Saccharum sp* crops.

Three plots, with dimensions of 10 × 2 m each (length and width, respectively) were established, and the following treatments were applied: preparation with rotary tiller in the presence of residue (RTw); preparation with rotary tiller without residue (RTwo) and plot without preparation and without residue on the surface (NTwo).

To prepare the soil for RTw and RTwo treatments, a Massey Ferguson 290 4×2 TDA with motor power of 77.3 kW, with work speed of 2.5 km h^{-1} was used. The rotary tiller worked with the impact plate down, a rotor speed of 153 rpm and 32 type C knives, passing three times in each treatment (to enhance the breakdown and incorporation of the soil organic residue into the soil) at an average work depth of 8 cm. A machine to bunching the crop residue was used during the operation to remove the residues in the treatments RTwo and NTwo.

After preparing the soil, six PVC rings (diameter = 0.1 m) were distributed diagonally in the plot and orderly inserted 3 cm into the soil, with 1.7 m distance between them, to support the equipment used to measure soil respiration. The emission of CO_2 from the soil was computed using a LI-8100 LI-COR system (Nebraska, USA) (HEALY et at., 1996). During measurement, the LI-8100 system monitors changes in CO_2 concentration inside the camera by using infrared spectroscopy (IRGA Infrared Gas Analyzer). The soil camera, with an internal volume of 854.2 cm^3, with a contact area of 83.7 cm^2, was placed on PCV rings previously inserted into the soil.

In addition to CO_2 emissions, temperature (0.0 - 0.2 m) and volumetric soil moisture content (0.00 to 0.12 m) near the rings were measured daily. The temperature sensor was accompanied with the LI-8100 system, and soil moisture was measured using a TDR (*Time Domain Reflectometry*) called *Hydrosense System* (Campbell Scientific, Utah, USA). Measurements of CO_2 flow, temperature and humidity occurred from 12 until 19 July 2008 at intervals of 24 hours between measurements. As of July 19, the interval between measurements was 48 hours, until the last day of measurement, July 27, 2008. Twelve evaluations were conducted in fifteen days of study. The time established for measuring the emission of CO_2, humidity and temperature was in the morning, starting at 7.30 am.

Three soil samples were taken from each treatment in the depth between 0.0 an 0.2 m, to assess the stability of aggregates with the method described by KEMPER & CHEPIL (1965). The material was first air dried and strained with a 7.93 mm mesh. The set of sieves used was composed of 4; 2; 1; 0.5; 0.250 and 0.125 mm meshes. In each set, 50 g soil sub-samples were placed on the sieve with largest mesh (4 mm) and moistened with alcohol. Then the set of sieves was placed in a tank with water and subjected to slow vertical agitation for 15 min. The soil retained on each sieve was transferred to vials with the aid of water jets and was subsequently placed into an oven at 105 ºC, being then weighed, thus indicating the distribution of aggregates retained on each sieve differentiated diameter. From the results obtained the mean geometric diameter (MGD) was calculated and used as an index of stability, according to MAZURACK (1950).

The results were analyzed using descriptive statistics and graphic linear regression analysis with SAS (SAS version 9, SAS Institute, Cary, NC, USA) and Origin (Origin Lab Corporation, Northampton, MA, USA) software, respectively.

RESULTS AND DISCUSSION

Figure 1 shows CO_2 emissions (with half average standard error bar) after preparing the soil in the plots studied. Immediately after tillage, the largest emissions reached 1.365 g CO_2 m^{-2} h^{-1} and the lowest was 0.829 g CO_2 m^{-2} h^{-1}in the RTw and NTwo plots, respectively. The emissions of the RTwo plot showed intermediate values for almost the entire study period, below the RTw and above NTwo emissions. Similar emission values were reached on the 15th day after soil preparation, close to 0.42 g CO_2 m^{-2} h^{-1}, as indicated by the overlapping mean standard error bars.

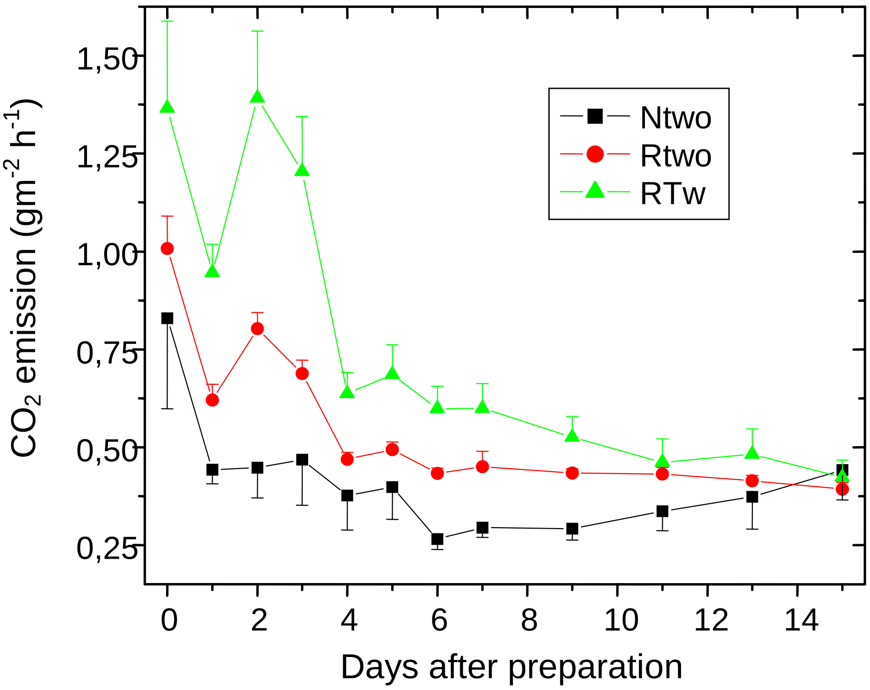

FIGURA 1. Mean soil CO_2 emission (with half of standard error) in NTwo=No tillage, without crop residues, RTwo= After Rotary Tillage, without crop residues and RTw= After Rotary Tillage, with crop residues.

On day zero, immediately after preparation, soil disturbance effect was observed especially in the NTwo treatment, due to residue removal and insertion of the PVC ring in the soil.

Emissions were also noticed to show exponential decay over time (Figure 1), being this behavior typical of this type of emission after tillage (TEIXEIRA et al., 2010; LA SCALA et al., 2006, LA SCALA et al., 2005, AL-KAISI & YIN, 2005). The characteristic exponential decay in the emission over time after preparation comes from, according to ELLERT & JANZEN (1999), the kinetics of decay of the labile soil carbon, released by the tillage, as described by an equation of decay of the emission of the first order over the time.

A significant correlation (p<0.05) in the soil CO_2 emission with time after tillage was observed in RTw and RTwo, as shown in Figure 2. The coefficient of determination (R^2) in the figures below, between Ln (FCO_2) and time were 74 and 66% in the treatments RTw and RTwo, respectively, indicating exponential decay of the emission over time after tillage. The low values of the coefficient of determination could be explained because the time dependence of the emission of CO_2 from the soil to climate variables, in addition to soil temperature and moisture. LA SCALA et al. (2003) studied temporal variations of soil CO_2 emission in an Oxisol in Jaboticabal, and concluded that these variations can be modeled from the daily variations of air temperature, relative humidity, solar radiation, atmospheric pressure and water evaporation.

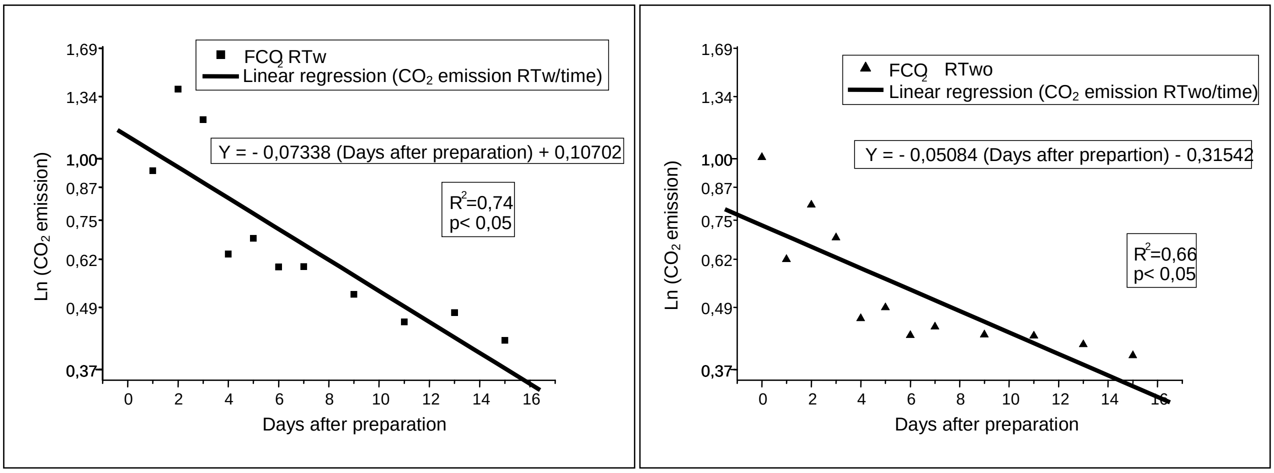

FIGURA 2. CO_2 Emissions against time after tillage, treatments RTw = Rotary Tillage, with crop residues and RTwo = Rotary Tillage, without crop residues.

Descriptive statistics of the emission of CO_2, temperature and soil moisture over the studied period are presented in Table 1. As already noted in Figure 1, the RTw treatment was higher than the average emission, 0.777 g CO_2 m^{-2} h^{-1}, whilst the lowest average emission was recorded in the NTwo plot, 0.414 g CO_2 m^{-2} h^{-1}. Analyses of maximum, minimum values, standard deviation and standard errors also indicate that the major changes occurred in the RTw plot, that such values had daily average ranging from 1.391 to 0.423 g CO_2 m^{-2} h^{-1}. The NTwo treatment showed lower temperatures compared to other plots, with daily averages ranging from 11.2 to 41.1 ^{o}C. Between the treatments with tillage, the plot RTwo showed lower temperature values in relation to the RTw plot, with minimum 13.3 and maximum 38.9 °C, while RTw ranged between 14.8 and 42.4 °C of minimum and maximum, respectively.

Soil moisture was low in the three treatments (when compared with field capacity of the soil under study) during the whole period of the experiment, with the highest values observed in the plot NTwo, with extremes of 15.5 and 9.5% in first and last day of the experiment, respectively. Assuming that soil preparation provided better aeration conditions in the plots RTwo and RTw, it facilitated gas exchanges to the atmosphere, and consequently reduced further soil moisture. Similar results were also reported by LA SCALA et al. (2006), where soil moisture in plots after tillage was significantly reduced in comparison to plots without disruption, with this reduction persisted over at least 3 weeks after preparation. Thus, humidity remained higher in the NTwo plot compared with those prepared with rotary tiller.

TABLE 1. Descriptive statistics of CO_2 emission, temperature and soil moisture through the 15 days studied.

	Average	Standard deviation	Standard Error	Minimum	Maximum
			CO_2 Emission (g m^{-2} h^{-1})		
NTwo	0,414	0,147	0,043	0,265	0,829
RTwo	0,553	0,191	0,055	0,393	1,007
RTw	0,777	0,357	0,103	0,423	1,391
			Soil temperature (^oC)		
NTwo	20,6	10,1	2,9	11,2	41,1
RTwo	24,8	8,7	2,5	13,3	38,9
RTw	30,3	7,5	2,2	14,8	42,4
			Soil moisture (% volume)		
NTwo	13,1	1,7	0,5	9,5	15,5
RTwo	8,5	1,4	0,4	6,5	11,2
RTw	10,4	1,5	0,4	8,0	12,7

N=6.

By analyzing the linear correlation between emission of CO_2, temperature and soil moisture (data not shown), it was noted that the NTwo and RTwo treatments showed no significant correlation (p>0.05). However, the emission of the RTw treatment was significantly correlated (r=0.84, p<0.05) with soil moisture, however, it did not show a significant linear correlation with soil temperature. Soil moisture is related to variations in CO_2 emissions when, overall, this is a limiting factor, which controls especially the temporal variability of the emission (EPRON et al., 2004; KANG et al., 2003). In the tropics, a more significant relationship is commonly observed with the soil moisture, and not with temperature that has, in general, values close to the optimal conditions for microbial activity (HASHIMOTO et al., 2004).

Supposedly, the increase in CO_2 emission in the plots NTwo and RTwo is associated with increased decay constant, the k factor, and also the introduction of labile carbon in the process of decay in the plot RTwo due to aggregate breaking and exposure to microbial activity (GRANDY & ROBERTSON, 2007; DE GRYZE et al., 2006). Additional recent studies on CO_2 emissions after soil preparation, by contrasting plots without disturbance, modeled the assumptions described above (LA SCALA et al. 2009; LA SCALA et al. 2009a, LA SCALA et al., 2008).

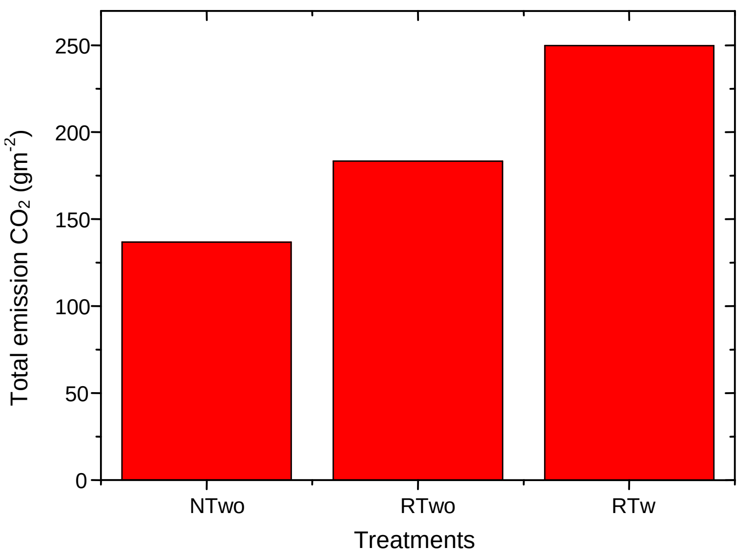

FIGURA 3. Total soil CO_2 emission through the 15 days in the studied plots.

The total emissions of CO_2 from the soil in the plots NTwo, RTwo and RTw within 15 days of preparation were 136.84, 183.37 and 249 74 g CO_2 m^{-2}, respectively (Figure 3). These figures reinforce the hypothesis that both the breakdown of aggregates and the introduction of labile carbon in soils through crop residues accelerate emissions. The first increase occurred in the NTwo for RTwo plots is due to the effect of increasing the constant k and the introduction of labile carbon, which was previously protected from the decay process via aggregate breakdown. The first increase corresponds to 46.53 g CO_2 m^{-2}, an increase of 34% emissions in the NTwo plot. The second increase, observed from RTwo to RTw, is only due to the introduction of labile carbon present in the residue in the decay process, since the effect of tillage on the increase of the constant k and the breakdown of aggregates is the same in both plots (RTwo and RTw), due to the application of the same tillage system (rotary tiller) under the same conditions. This increase corresponds to 66.37 g CO_2 m^{-2}, or 36% increase in emissions over that of the RTwo plot.

The difference of emission between plots, when converted into C-CO_2 indicates that during the two weeks 37.32, 50.01 and 68.11 grams of C-CO_2 m^{-2} were issued in the NTwo, RTwo and RTw plots, respectively. Thus, the observed increase was 18.1 g C-CO_2m^{-2} of RTwo in relation to RTw, supposedly, from the mass of incorporated residue. This loss corresponds to 181 kg C-CO_2 per hectare, which is little, if we consider that the residue mass present on the soil surface at the time of tillage was 15 tons per hectare, or 6 tons of carbon equivalents per hectare, 40% of the sugarcane straw mass (DE OLIVEIRA et al., 1999). Therefore, approximately 3% of total carbon present in the residue mass was transferred to the atmosphere within 15 days after tillage, due to the incorporation and fragmentation promoted by the rotary tiller.

The crop residues usually present in their composition various compartments of carbon, of which there are fractions that are rapidly metabolized by soil microorganisms (THORBURN et al., 2001). This fraction was directly related to the increase in emissions due to the presence of residue at the time of tillage and throughout the fifteen-day study.

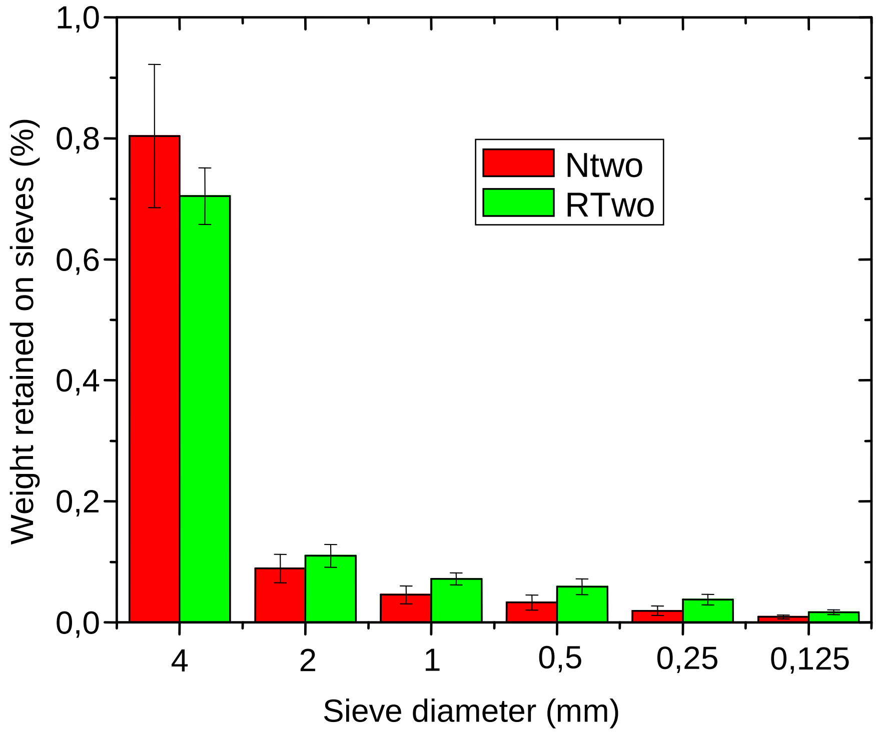

FIGURA 4. Aggregate weight distribution retained in the siege with different diameters, from soils collected in NTwo and RTwo plots. (N=3).

Figures 4 and 5 show evidence of the main processes responsible for additional emissions when comparing NTwo and RTwo as well as between the RTwo and RTw plots. The percentage of aggregate mass retained on the sieves of different diameters (Figure 4) in the treatments NTwo and RTwo indicates that the soil had a different aggregate distribution after preparation with rotary tiller. These results indicate a decrease of aggregates with diameters smaller than 4 mm and an increase in the distribution of aggregates with diameter below this value, especially between 2 to 0.125 mm. In percentage terms, the sieves with 0.5 and 0.25 mm mesh had the highest weight gain, retaining 79 and 95%, respectively. Supposedly, the reduction in aggregates that equal to or are greater than 4 mm was responsible for the availability of additional labile carbon to microbial activity, which carbon was previously trapped inside or between soil aggregates.

Figure 5 shows two photographs of the RTw plot before and after soil tillage for comparison. It can be noticed that a significant portion of the residue mass initially present on the soil surface was incorporated due to the preparation effect using rotary tiller (Figure 5A). It is also noticeable the decrease in residue size due to the fragmentation effect promoted by the rotary tiller, which has been described by several authors (BALOTA et al., 2004). Residue fragmentation and its incorporation in the soil are factors favorable to the decomposition promoted by microbial activity and subsequent emission of CO_2 to the atmosphere (Figure 5B).

A B

FIGURE 5. A) RTw plot before tillage was applied, with huge crop residue amount and having higher crop residue sizes when compared to Figure5B; B) RTw plot after rotary tillage, smaller amount of crop residues in soil surface with smaller size, when compared to Figure5A.

CONCLUSIONS

CO_2 emissions that are induced by tillage were affected by the presence of crop residue on the soil, leading to an increase in emissions of C-CO_2 equivalent to 3% of total carbon equivalent of the residue. The emission in the RTw plot (with residue) was 40.5 and 88.7% higher than the RTwo and NTwo treatments (both without residue), respectively. There was a change in size distribution of soil aggregates, induced by soil preparation with rotary tiller, especially aggregates with diameters smaller than 2 mm. Tillage decreased CO_2 emissions almost exponentially over time after soil preparation, which may be related to the exposure of labile carbon available to microbial degradation due to aggregate breaking and the incorporation of crop residue in the soil.

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