Available online at www.sciencedirect.com
ScienceDirect
Soil & Tillage Research 91 (2006) 244–248
Soil & Tillage Research
www.elsevier.com/locate/still

Short communication

Short-term soil CO_2 emission after conventional and reduced tillage of a no-till sugar cane area in southern Brazil

N. La Scala Jr.*, D. Bolonhezi, G.T. Pereira

FCAV-UNESP, Via de Acesso Prof. Paulo Donato Castellane s/n, 14884-900 Jaboticabal, SP, Brazil

Received 10 January 2005; received in revised form 22 November 2005; accepted 23 November 2005

Abstract

The impact of tillage systems on soil CO_2 emission is a complex issue as different soil types are managed in various ways, from no-till to intensive land preparation. In southern Brazil, the adoption of a new management option has arisen most recently, with no-tillage as well as no burning of crops residues left on soil surface after harvesting, especially in sugar cane areas. Although such practice has helped to restore soil carbon, the tillage impact on soil carbon loss in such areas has not been widely investigated. This study evaluated the effect of moldboard plowing followed by offset disk harrow and chisel plowing on clay oxisol CO_2 emission in a sugar cane field treated with no-tillage and high crop residues input in the last 6 years. Emissions after tillage were compared to undisturbed soil CO_2 emissions during a 4-week period by using an LI-6400 system coupled to a portable soil chamber. Conventional tillage caused the highest emission during almost the whole period studied, except for the efflux immediately following tillage, when the reduced plot produced the highest peak. The lowest emissions were recorded 7 days after tillage, at the end of a dry period, when soil moisture reached its lowest rate. A linear regression between soil CO_2 effluxes and soil moisture in the no-till and conventional plots corroborate the fact that moisture, and not soil temperature, was a controlling factor. Total soil CO_2 loss was huge and indicates that the adoption of reduced tillage would considerably decrease soil carbon dioxide emission in our region, particularly during the summer season and when growers leave large amounts of crop residues on the soil surface. Although it is known that crop residues are important for restoring soil carbon, our result indicates that an amount equivalent to approximately 30% of annual crop carbon residues could be transferred to the atmosphere, in a period of 4 weeks only, when conventional tillage is applied on no-tilled soils.

Keywords: Soil CO_2 emission; Soil respiration; Soil tillage; No-tillage

1. Introduction

In São Paulo State, southern Brazil, 3.5 million hectares are currently cropped with sugar cane and the burning of crops and surface residues prior to harvesting is still practiced; however, strategies for soil carbon restoration on agricultural lands have also expanded. Nowadays, 350 000 ha are already converted to no-tillage associated with cropping system practices, with the addition of large amounts of crop residues on the soil surface every year (Ripoli and Ripoli, 2004). Such conversion has altered soils significantly by increasing the amount of lost organic matter and helping the mitigation of the greenhouse effect, as predicted and already observed in tropical agrosystems (Bayer et al., 2000; Lal and Logan, 1995). Projections of carbon sequestration potential for southern Brazil have indicated approximately 90 g C m^{-2} $year^{-1}$ in the first 40 cm of soil layer (Sá et al., 2001) and results from studies performed around the world, when summarized to various climates and soil types, support that an

* Corresponding author. Tel.: +55 16 3209 2625; fax: +55 16 3202 4275.
E-mail address: lascala@fcav.unesp.br (N. La Scala Jr.).

0167-1987/$ – see front matter
doi:10.1016/j.still.2005.11.012

additional soil carbon input from 34 to 57 g C m^{-2} $year^{-1}$ could be reached in the first years following the change from conventional to no-tillage agricultural practices (Marland et al., 2003; West and Post, 2002). Although these projections are based on the influence of tillage practices on soil carbon transfer to the atmosphere (La Scala et al., 2001; Bayer et al., 2000; Prior et al., 2000; Rochette and Angers, 1999; Reicosky and Lindstrom, 1993), few works have focused on the extent to which tillage enhances soil CO_2 emission in sugar cane areas with large amounts of surface matter on its soil surface. Additionally, it is important to consider that, on average, a first plant crop is followed by approximately five ratoon crops in our region, until production declines significantly. Therefore, tillage is also applied in areas where conservation practices are conducted in order to promote ratoon renovation, either with reduced or conventional tillage practices.

The objectives of this study were to quantify the effect of common soil tillage treatments (conventional and reduced) on intermediate CO_2 emissions in a sugar cane plantation with surface crop residues input and understand their differences in terms of the relation to soil moisture and soil temperature.

2. Materials and methods

2.1. Studied site

The field experiment was established on an oxisol (Psamitic Eutroferric red latosol in the Brazilian systems of soil classification, EMBRAPA; 1999) with pH 5.2 and a total organic matter level of 32 g kg^{-1} (0–20 cm) and located at APTA, Ribeirão Preto, São Paulo state in southern Brazil. The mean particle size distribution for the surface layer comprised 57% clay, 32% silt and 11% sand. The site had been explored with sugar cane crops in the last 6 years and no-tillage had been applied during that time. In the course of the previous 6-year period, crop residues (mainly leaves) had been left by annual harvests in a rate of 17 tonnes of dry mass per year. As based in literature, we supposed carbon concentration of such residues is approximately 40% of dry mass (Ball-Coelho et al., 1993; De Oliveira et al., 1999).

The climate of the investigated area is subtropical with an average annual temperature of 21.6 °C with a mean annual precipitation around 1454 mm. Rainfall is concentrated in the period from October to March (around 1100 mm), and the climate is relatively dry from April to September (around 230 mm). An amount of 17 tonnes of dry mass per hectare was measured on soil surface a week before the experiment started, left by previous harvesting. On December 11, 2003, three neighboring plots of 40 m × 100 m were established (each on the same soil type and altitude), and three different treatments were applied, one on each plot as follows: (1) conventional tillage (CT, moldboard plowing followed by a two applications of offset disk harrows), and (2) reduced tillage (RT, chisel plowing). Conventional and reduced tillage disturbed the soil to 30 and 40 cm in depth, respectively. The third treatment was a non-disturbed control, non-tilled (NT), in which the plot was left unaltered with crop residues on its surface.

2.2. Measurement of CO_2 emissions

After tillage was finished, 10 PVC plastic rings (10 cm in diameter) were scattered on each of the three plots. CO_2 measurements were initiated a few minutes after tillage and were performed on December 11, 12, 13, 14, 15, 16, 17, 18, 19, 22, 23 and 30, once a day, as well as on January 6, 2004, the last day investigated.

Emissions were measured using a 6400–09 soil CO_2 flux chamber built by LI-COR, USA (Healy et al., 1996). It was placed on the top of the plastic rings and coupled to an LI-6400 photosynthesis system that computes the emissions coming from the soil to the chamber. Following each measurement, the flux was calculated by computing several CO_2 flux measurements from the soil to the chamber in each studied point (La Scala et al., 2000). The system operation prevents CO_2 excessive pressure inside the chamber by operating between maximum and minimum CO_2 concentrations (390 and 370 ppmv, respectively). The rate of increase in CO_2 concentration inside the chamber was monitored and soil CO_2 emission was computed when CO_2 concentration in the chamber was equal to that on the soil surface in the open (380 ppmv). In all measurements, a short sampling period of 1.5 min at each measurement point was used to complete the sampling from all the 30 points as quickly as possible and to prevent soil temperature variation in the studied plots during that period. Soil temperature from 0 to 20 cm in depth was measured using an LI-6400 soil temperature probe (LI-COR, USA) and soil moisture (0–12 cm) was monitored on all days and in all the studied points by using a portable hydrosense system (TDR probe, Campbell, USA) that estimates the percentage of moisture in soil volume (% H_2O in soil volume). The CO_2 emission data were submitted to one-way analysis of variance and mean separation procedure.

3. Results and discussion

Table 1 presents soil CO_2 emission means in the plots on each of the studied days. Shortly after tillage was applied, emissions were as high as 2.41 and 2.18 g of CO_2 m^{-2} h^{-1} in the reduced (RT) and conventional plots (CT), respectively, and as low as 1.11 g of CO_2 m^{-2} h^{-1} in the non-tilled (NT) plot. These values are quite low when compared to those provided by Rochette and Angers (1999) and Reicosky and Lindstrom (1993), who studied the early burst of carbon dioxide after moldboard- and chisel-plowed soils, but are similar to those by Alvarez et al. (2001), who studied the increase of soil respiration rates shortly following plow tillage in Argentine Rolling Pampas. Differently from the first day, on the second day, CT soil emission was higher than that in RT, which was due to a sharp decrease in reduced plot emissions during the first 24 h. As tillage disturbance strongly contributes to the first 24 h emission, the results indicate that the impact of chisel plowing on the immediate soil CO_2 release was as high as that caused by moldboard plowing followed by offset disk harrow on our soil. This is different from the effect reported by Reicosky and Lindstrom (1993), where moldboard was responsible for the highest initial CO_2 flux, when compared to chisel just after plowing a clay loam soil.

The F-test analysis of variance showed a significant interaction ($p < 0.01$) between tillage and time, indicating that time after tillage should be considered when assessing the treatment effect on soil CO_2 emission, soil temperature and soil moisture. The mean separation procedure indicates that comparing the differences between emissions on each studied day is not a simple task, as this changes from day to day. The mean separation procedure (Tukey test, Table 1) showed that emission from the NT plot significantly differed ($p < 0.05$) from that of RT only on the first day studied and, apart from that, no significant differences were observed between these two treatments until the last day. Also, significant differences between RT and CT were dependent on the day observed, with no differences between them within the first 24 h. From the 2nd to the 4th day, differences persisted, but on the 5th day studied, once again, the emissions from RT and CT showed no significant differences. Mean separation procedure for soil temperature and moisture indicates that soil temperature were mainly different when plots are compared but soil moisture shows a more complex relationship between plots. Results in Table 1 indicate that moisture were always superior in the NT plot when compared to the other ones, but RT plot moisture starts lower than in CT plot just after tillage, getting higher as experiment runs and raindrop events occurred in site. In day 5 soil moisture in CT and RT plots were not significantly different from each other until the end of the experiment.

Time changes occurring in soil CO_2 emission can be better seen in Fig. 1. Emissions of tilled surfaces exhibited similar temporal trends as reported by others (La Scala et al., 2001; Rochette and Angers, 1999; Reicosky and Lindstrom, 1993) with a decrease on the first days after tillage. This decrease was predominant even with a rainfall event of 10.4 mm, which occurred on the 3rd experimental day. From day 1 to day 8, emissions in all plots showed a quasi monotonic decrease and reached their lowest values of 0.47, 0.74

Table 1
Mean CO_2 emission soil temperature and soil moisture over the period studied

Tillage systems	Days												
	1	2	3	4	5	6	7	8	9	12	13	20	27
FCO_2													
NT	1.11 a	0.92 a	0.70 a	0.74 a	0.86 a	0.87 a	0.60 a	0.47 a	0.57 a	0.86 a	0.79 a	1.05 a	0.77 a
RT	2.41 b	1.44 a	1.17 a	1.35 a	1.23 ab	1.25 ab	1.18 a	0.74 a	1.10 ab	1.28 ab	1.18 ab	2.00 ab	1.22 a
CT	2.18 b	2.19 b	2.01 b	2.10 b	1.88 b	1.97 b	1.29 a	1.29 b	1.50 b	1.71 b	1.57 b	2.90 b	2.83 b
T_{soil}													
NT	25.4 a	24.4 a	25.3 a	26.1 a	25.5 a	25.5 a	25.7 a	25.2 a	25.3 a	25.3 a	25.2 a	25.8 a	24.4 a
RT	25.6 a	24.7 a	26.9 b	27.2 b	26.6 b	29.3 b	28.3 b	25.7 a	26.4 b	26.6 b	26.5 b	27.5 b	25.3 b
CT	27.1 b	25.1 b	28.0 c	28.8 c	27.2 b	27.5 c	30.1 c	27.6 b	28.3 c	28.0 c	27.8 c	29.8 c	26.6 c
SM_{soil}													
NT	48.0 a	52.1 a	48.0 a	44.5 a	40.8 a	39.4 a	36.4 a	38.4 a	28.6 a	49.7 a	43.8 a	42.8 a	47.3 a
RT	13.0 b	24.8 b	21.0 b	18.2 b	15.2 b	13.2 b	21.7 b	17.5 b	16.3 b	20.5 b	19.4 b	19.6 b	37.6 b
CT	20.0 c	26.3 b	23.0 c	18.0 c	14.5 b	15.4 b	17.3 b	13.5 b	14.9 b	16.5 b	13.9 b	16.2 b	28.6 b

Means with the same letter are not significantly different by the Tukey test at 5% of probability. $N = 10$, daily and total means (g of CO_2 m^{-2} h^{-1}, °C and in vol.% for soil emission, soil temperature and soil moisture, respectively). NT: no-tillage; RT: reduced tillage; CT: conventional tillage.

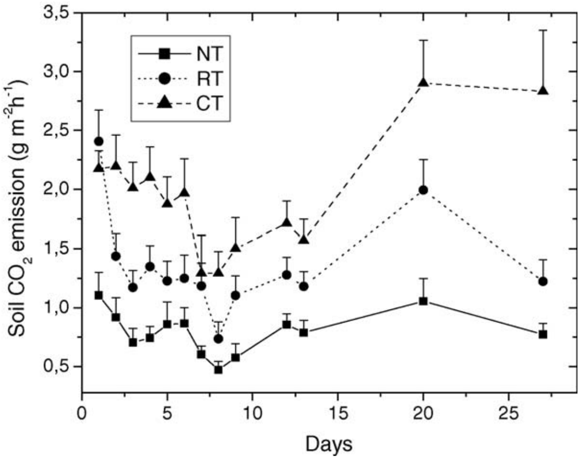

Fig. 1. Soil CO_2 emission (g of CO_2 m^{-2} h^{-1}) and half of standard error (vertical bars) for the studied treatments.

and 1.29 g of CO_2 m^{-2} h^{-1} in NT, RT and CT plots, respectively, on the 8th day studied. It was also on this day that the lowest soil moisture and temperature were recorded, 13.5% of soil moisture in the CT plot and 25 °C of soil temperature in the NT plot. From day 8 until the last week studied, emission increase was probably mostly due to changes in soil temperature and soil moisture, as around 100 mm of rain precipitation occurred in the site.

A linear regression between soil CO_2 emission and soil moisture in the CT and NT plots ($p < 0.05$) supports the fact that soil moisture is a controlling factor. Fig. 2 presents the linear regressions between emission and moisture in CT and NT tillage systems only, as no significant regression was found between such variables in the RT plot. As seen in this figure and also in equations, soil moisture varied in both plots during the experiment, but in the NT plot moisture was always kept much higher than in CT. Angular coefficients of regressions inserted in Fig. 2 indicate that CO_2 emission sensitivity to soil moisture was higher in the CT plot than in the NT plot. Such effect could be related to the fact that water percolation in a tilled plot is easier when compared to that in no-till plot, especially when the presence of crop residues on the surface and a more compact soil condition in undisturbed tillage conditions are taken into account.

Multiple regression equations relating flux to both soil moisture and soil temperature also confirm that soil moisture is the most important factor describing the temporal variability in NT and CT plots. Table 2 presents the results of multiple regressions in each tillage systems. As can be seen just soil moisture was related to CO_2 emissions at a significant level ($p < 0.05$). Despite the coefficient of determination (R^2) of this analysis is higher than in the individual equation involving soil moisture only (inserted in Fig. 2), in this study no linear correlation was found between emissions and soil temperature, even in linear regressions or multiple regressions, and this was probably due to the fact that during the course of the experiment, soil temperature was always around an optimal condition for microbial activity (around 26.5 °C). On the other hand, soil moisture changed much more during that period and also between plots. On the last day studied soil CO_2 emission returned to

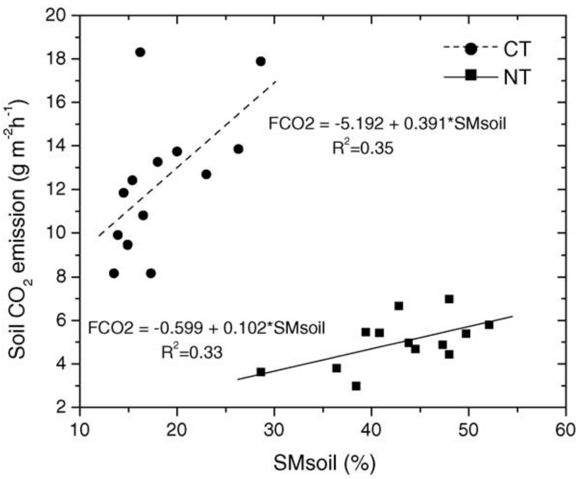

Fig. 2. Soil CO_2 emission (g of CO_2 m^{-2} h^{-1}) against soil moisture (vol.%) for the CT and NT treatments. Solid lines represents the best linear regression fits ($p < 0.05$). Best linear regression equation and determination coefficient (R^2) are also inserted in figure.

Table 2
Multiple linear regression models between soil CO_2 emission (FCO_2) and soil temperature (T_{soil}) and soil moisture (SM_{soil}) for studied treatments

Tillage treatment	Multiple linear regression ($FCO_2 = A + B \times T_{soil} + C \times SM_{soil}$)	R^2
NT	A = −15.95 ± 17.68 B = 0.62 ± 0.66 C = 0.12 ± 0.05**	0.38
RT	A = 21.00 ± 20.37 B = −0.39 ± 0.71 C = −0.11 ± 0.14	0.06
CT	A = −6.19 ± 22.36 B = 0.37 ± 0.73 C = 0.44 ± 0.20**	0.36

R^2: determination coefficient. A: g CO_2 m^{-2} h^{-1}; B: g CO_2 m^{-2} h^{-1} (°C)$^{-1}$; C: g CO_2 m^{-2} h^{-1} (vol.%)$^{-1}$.
** $p < 0.05$.

values close to those recorded on the first day, 1 month after tillage, and differently from similar works performed in the dry winter period in our region, the significant differences between emissions persisted (La Scala et al., 2000). Total soil CO_2 emission in the studied period was estimated by taking into account the area under the curves of Fig. 1 (integration method). Results were 523.5, 894.9 and 1361.8 g of CO_2 m^{-2} for the NT, RT and CT plots, respectively. Total emission indicated an increase of 160 and 71% in soil CO_2 efflux at the end of a 4-week period when soils were prepared with conventional and reduced tillage as compared to no-till, respectively. Such values confirm that in longer terms a moldboard plow tillage system would cause higher emissions than chisel plowing, as reported by others (Reicosky and Lindstrom, 1993), but the results also showed that CT total emission was higher than that in NT in at a rate of 840 g of CO_2 m^{-2}, or 230 g of carbon-CO_2 m^{-2} (or 2300 kg of carbon-CO_2 per hectare). As 17 tonnes of dry mass were initially on the soil surface when tillage was applied, from the initial 6800 kg of carbon per hectare contained in residues (since approximately 40% of it is carbon) roughly 30% was transferred back to the atmosphere in soil respiration after conventional tillage as compared to no-till, in 1 month only. Due to the huge values of total soil respiration after tillage found here, we believe that attempts to restore soil carbon in agricultural areas should take into account the impact of each tillage system with especial care to places where no-till is already conducted and crop residues are annually left in soil surface after harvest. This is particularly important in tropical regions, and in rainy seasons, where soil moisture and soil temperature are more adequate to microbial activity and land is mechanically prepared.

4. Conclusions

Soil CO_2 emission in agricultural areas is an important aspect that should be addressed in a quantitative way and this work showed that conventional and reduced tillage systems differently and significantly affected short-term CO_2 emissions, when compared to undisturbed no-till soil conditions. Changes in soil moisture were more related to changes in soil CO_2 emissions in CT and NT plots during the 4-week period after tillage. Total emission was huge and a significant amount of carbon mass was additionally produced especially from the conventional tillage plot when compared to the no-till plot and also to the reduced tillage plot. Results of this work suggest that 30% of soil carbon input in crop residues could be lost after plowing tropical soils, when compared to the no-till plot emissions, in 1-month period after tillage.

Acknowledgements

The authors are grateful to FAPESP, FUNDUNESP and CNPq for financial support.

References

Ball-Coelho, B., Tiessen, H., Stewart, J.W.B., Salcedo, I.H., Sampaio, E.V.S.B., 1993. Residue management effects on sugarcane yield and soil properties in northeastern Brazil. Agron. J. 85, 1004–1008.

Bayer, C., Mielniczuk, J., Amado, T.J.C., Martin-Neto, L., Fernandes, S.V., 2000. Organic matter storage in a sandy clay loam Acrisol affected by tillage and cropping systems in southern Brazil. Soil Till. Res. 54, 101–109.

De Oliveira, M.W., Trivelin, P.C.O., Penatti, C.P., Piccolo, M.C., 1999. Field decomposition and release of sugar cane trash nutrients. Pesq. Agropec. Bras. 34, 2359–2362.

Healy, R.W., Striegl, R.G., Russel, T.F., Hutchinson, G.L., Livingston, G.P., 1996. Numerical evaluation of static-chamber measurements of soil–atmosphere gas exchange: identification of physical processes. Soil Sci. Soc. Am. J. 60, 740–747.

Lal, R., Logan, T.J., 1995. Agricultural activities and greenhouse gas emissions from soils of the tropics. In: Lal, R., Kimble, J., Levine, E., Stewart, B.A. (Eds.), Soil Management and Greenhouse Effect. Lewis Publishers, Boca Raton, USA, pp. 293–307.

La Scala Jr., N., Marques Júnior, J., Pereira, G.T., Corá, J.E., 2000. Short-term temporal changes in the spatial variability model of CO_2 emissions from a Brazilian bare soil. Soil Biol. Biochem. 32, 1459–1462.

La Scala Jr., N., Lopes, A., Marques Júnior, J., Pereira, G.T., 2001. Carbon dioxide emissions after application of tillage systems for a dark red latossol in southern Brazil. Soil Tillage Res. 62, 163–166.

Marland, G., West, T.O., Schlamadinger, B., Canella, L., 2003. Managing soil organic carbon in agriculture: the net effect on greenhouse gas emissions. Tellus Series B: Chem. Phys. Meteorol. 55, 613–621.

Prior, S.A., Reicosky, D.C., Reeves, D.W., Runion, G.B., Raper, R.L., 2000. Residue and tillage effects on planting implement-induced short-term CO_2 and water loss from a loamy sand soil in Alabama. Soil Tillage Res. 54, 197–199.

Reicosky, D.C., Lindstrom, M.J., 1993. Fall tillage method: effect on short-term carbon dioxide flux from soil. Agron. J. 85, 1237–1243.

Ripoli, T.C.C., Ripoli, M.L.C., 2004. Biomassa de cana-de-açúcar: colheita, energia e ambiente. Barros Marques Editoração Eletrônica, Piracicaba 302.

Rochette, P., Angers, D.A., 1999. Soil surface carbon dioxide fluxes induced by spring, summer and fall moldboard plowing in a sandy loam. Soil Sci. Soc. Am. J. 63, 621–628.

Sá, J.C.D., Cerri, C.C., Dick, W.A., Lal, R., Venske, S.P., Piccolo, M.C., Feigl, B.E., 2001. Organic matter dynamics and carbon sequestration rates for a tillage chronosequence in a Brazilian oxisol. Soil Sci. Soc. Am. J. 65, 1486–1499.

West, T.O., Post, W.M., 2002. Soil organic carbon sequestration rates by tillage and crop rotation: a global data analysis. Soil Sci. Soc. Am. J. 66, 1930–1946.