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# Short-term carbon dioxide emission under contrasting soil disturbance levels and organic amendments

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ABSTRACT

Agriculture can be either a source or sink of atmospheric $CO_2$ depending on soil management. The application of swine slurry in conventional tilled soils could enhance soil $CO_2$ emission depleting soil organic C stocks. However, the use of recalcitrant C-rich organic fertilizers in no-till soils can offset soil $CO_2$ emission promoting soil C sequestration. This hypothesis was tested by evaluating short-term $CO_2$-C emissions from a Rhodic Nitisol under contrasting soil disturbance levels (disturbed (DS) and undisturbed soil (US)) top-dressed with mineral or organic fertilizers (urea (UR), raw swine slurry (RS), anaerobically digested swine slurry (ADS), and composted swine slurry (CS)). Soil $CO_2$ emission was evaluated for 64 days using static chambers where gas samples were collected and analysed by photoacoustic infrared spectroscopy. Soil water-filled pore space (WFPS), temperature and meteorological data were concomitantly registered and a first-order exponential decay model was used to assess the decomposition of organic fertilizers and $CO_2$ emissions induced by soil disturbance. Soil $CO_2$-C emission was correlated with soil temperature, while limiting soil aeration impaired $CO_2$-C efflux when WFPS $>0.6\ cm^3\ cm^{-3}$. Disturbance increased soil $CO_2$-C efflux ($36.3 \pm 2.2$ kg $CO_2$-C $ha^{-1}\ day^{-1}$) in relation to US ($33.3 \pm 1.6$ kg $CO_2$-C $ha^{-1}\ day^{-1}$). Extra labile C input through RS amendment induced an increased soil $CO_2$-C efflux for a longer period ($t_{1/2} = 16.9$ and 9.6 days in DS and US treatments, respectively), resulting in higher $CO_2$-C emissions than soil amended with other fertilizers. The recalcitrant C input by ADS and CS had limited effect on soil $CO_2$-C emissions. CS presented a genuine potential for substantial soil organic C accumulation while offsetting increased $CO_2$-C emissions in comparison to RS amended soils.

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## 1. Introduction

Brazil is the fourth largest swine producer and exporter in the world, with a herd of 38.6 million heads in 2013 (USDA-FAS, 2014). The annual swine slurry production in Brazil was estimated as 122 million cubic meters containing approximately $3.4 \times 10^5$ Mg of N, $2.9 \times 10^5$ Mg of $P_2O_5$, and $1.8 \times 10^5$ Mg of $K_2O$ and accounts for 9.4, 6.8, and 3.7% of the demand for these nutrients by Brazilian agriculture, respectively (Aita et al., 2014a). The use of swine slurry as fertilizer in agricultural soils has been the usual fate of this waste in Brazil (Kunz et al., 2009) and is an important strategy for sustainable concentrated animal feeding operations (Kunz et al., 2005) that supply lower cost nutrients for crop production instead of mineral fertilizers.

Although incorporation (Rochette et al., 2009) or injection (Aita et al., 2014b) of ammonia-rich swine slurry into the soil would be preferable to prevent $NH_3$-N volatilization, swine slurry topdressing remains the usual practice in Brazilian no-till system. These practices can impact soil C and N dynamics by affecting soil $CO_2$ emissions (Aita et al., 2012). Increased soil $CO_2$ emission can be observed after soil tillage operations which incorporate crop residues into soil (Reicosky and Lindstrom, 1993; Reicosky et al., 1997). Soil amendment with organic residues or mineral fertilizers can also impact C and N dynamics and promote increases in soil $CO_2$ emissions (Chantigny et al., 2001, 2002; Aita et al., 2012). However, studies assessing the contribution of organic and mineral amendments on soil $CO_2$ emission present contrasting results in

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the literature. While some studies reported increased mineralization of crop residues-C and enhanced soil $CO_2$ emissions (Chantigny et al., 2001; Muhammad et al., 2011), others reported no synergistic effect when crop residues are incorporated (Giacomini and Aita, 2008; Aita et al., 2012). When N is limiting, swine slurry amendment could enhance crop residue decomposition, however, this effect would not be expected if the original concentrations of soil mineral N or the mineralization of soil organic N are sufficient to support the decomposition of crop residues (Aita et al., 2012).

Modifications of swine slurry organic matter quality via anaerobic digestion or composting (Vivan et al., 2010; Angnes et al., 2013) could also impact C and N dynamics and potentially decrease $CO_2$ emissions from soils amended with these materials (Bertora et al., 2008; Giacomini and Aita, 2008; Marcato et al., 2009; Yang et al., 2002). Soil $CO_2$ emission peaks are promoted by the presence of carbonates in the swine slurry which can be released when applied to acidic soils (Chantigny et al., 2002) and also by the rapid mineralization of volatile fatty acids (labile C) found in swine slurry (Kirchmann and Lundvall, 1993). Labile C forms are promptly consumed during swine slurry treatment (Vivan et al., 2010; Angnes et al., 2013) resulting in recalcitrant C-rich organic fertilizers. However, literature results are still inconclusive regarding $CO_2$ emission from soils amended with swine slurry treated by anaerobic digestion or composting; this is important since these are emerging manure treatment technologies in Brazil (Kunz et al., 2009).

Although some studies reported lower $CO_2$ emission from soils amended with composted or anaerobically digested swine slurry in comparison to raw swine slurry (Yang et al., 2002; Marcato et al., 2009), others found no differences in emissions between composted and raw swine slurry amendments in conventional or no-till systems (Giacomini and Aita, 2008) or between anaerobically digested and raw swine slurry in soil incubation experiments (Bertora et al., 2008). Nonetheless, soil amendment with composted organic residues in no-tillage system is generally reported to substantially increase soil organic C stocks by offsetting soil $CO_2$-C emissions (Gulde et al., 2008; Lal, 2009; Nicoloso, 2009; Powlson et al., 2012). Anaerobic digestion and composting could also offset $CH_4$ emission in relation to conventional swine slurry management and storage (Kunz et al., 2009; Zhong et al., 2013) and mitigate soil $N_2O$ emission in relation to other organic residues (Zhong et al., 2013).

The assessment of short-term $CO_2$ emissions (8–90 days) is useful to estimate emissions from tillage operations during the mineralization of organic carbon in soil as well as from the decomposition of crop and other organic residues (La Scala et al., 2006; Aita et al., 2008; Drewitt et al., 2009; Pes et al., 2011; Aita et al., 2012). Thus, in this study $CO_2$ emission from a Nitisol in southern Brazil was assessed for over 64 days in order to infer impacts of contrasting soil disturbance levels on the decomposition of organic fertilizers. We also hypothesized that application of recalcitrant C-rich organic fertilizers (anaerobically digested or composted swine slurry) on undisturbed soils (no-till) can decrease soil $CO_2$-C emission in relation to disturbed soils (conventional tillage) amended with raw swine slurry or urea thereby promoting soil C sequestration.

## 2. Materials and methods

### *2.1. Field experiment*

The experiment was initiated in January 2013 on a Rhodic Nitisol (FAO, 1998) located in Concordia-SC, Brazil (27°18′53″S, 51°59′25″O). The site had been cultivated with maize and wheat crops under no-tillage. The soil characteristics (0–0.10 m soil layer) were: clay, silt and sand content of 250, 460, and 290 g kg$^{-1}$, respectively, pH-$H_2O_{(1:1)}$ 5.3, pH-SMP 5.8, SOM 39.0 g kg$^{-1}$, $P_{\text{Mehlich-I}}$ 6.6 mg dm$^{-3}$, $K_{\text{Mehlich-I}}$ 249.6 mg dm$^{-3}$, Ca 7.5 cmol$_c$ dm$^{-3}$, Mg 3.3 cmol$_c$ dm$^{-3}$, CTC 11.8 cmol$_c$ dm$^{-3}$ and base saturation 68%. The local climate is humid subtropical (Cfa) based on the Köppen classification system (EMBRAPA, 2004).

The experiment had a split-plot design with two soil disturbance levels as the main plots (1 m × 5 m) and five fertilization treatments as the subplots (1 m × 1 m). All treatments were replicated four times. The buffer rows measured 1 m between replication blocks and 0.4 m among plots and subplots. Existing plant residues were manually removed and 4 Mg ha$^{-1}$ of wheat straw (*Triticum aestivum* (L.)) was placed on the soil surface of each subplot (January 23rd: day 0). The soil disturbance treatments were: undisturbed (US) and disturbed soil (DS). In the DS treatment, the wheat straw was incorporated in the 0–0.10 m layer manually with a shovel, ensuring that no aggregates >2 cm remained intact (January 25th: day 2). In the US treatment, the wheat straw was maintained at the soil surface with no disturbance. On day 5 (January 28th) the subplot fertilization treatments were established by manual surface application of 140 kg total-N ha$^{-1}$ as either urea (UR), raw swine slurry (RS), anaerobically digested swine slurry (ADS), or composted swine slurry (CS); control treatment (CTR) received no fertilizer. The nitrogen fertilization rate followed the CQFS RS/SC (2004) guidelines with a goal of 9 Mg ha$^{-1}$ of maize grain yield. Varying C inputs among treatments were related to composition variation of organic fertilizers used in this study; material was obtained from a fattening swine farm at Embrapa Swine and Poultry Research Center (Table 1). The RS was collected from deep storage tanks, while the ADS was collected from an anaerobic lagoon composed of effluent from a covered lagoon biodigestor used to treat swine slurry (Vivan et al., 2010). The CS consisted of a mixture of swine slurry with sawdust and wood shavings (bulking agents) which was composted for 150 days as reported by Angnes et al., 2013. Samples of wheat straw, RS,

**Table 1**
Application rate and characteristics of the wheat straw and organic fertilizers used in this study.

| Material | Characteristics | | | | | | | | Application rate | TOC input | TN input |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | DM | VS | TOC | TN | Org-N | $NH_4$-N | $NO_3$-N | C/N | | | |
| | % | kg m$^{-3}$ | | | | | | | m$^3$ ha$^{-1}$ | kg ha$^{-1}$ | kg ha$^{-1}$ |
| RS[a] | 7.4 | 45.9 | 29.0 | 4.4 | 1.7 | 2.7 | ND | 6.6 | 31.7 | 919 | 140 |
| ADS[a] | 6.5 | 38.4 | 17.7 | 5.2 | 2.6 | 2.6 | ND | 3.4 | 27.1 | 480 | 140 |
| | | g kg$^{-1}$ | | | | | | | Mg ha$^{-1}$ | | |
| CS[b] | 29.1 | ND | 317.0 | 16.6 | 15.1 | 1.2 | 0.3 | 19.1 | 29.0 | 2,675 | 140 |
| WS[b] | 90.0 | ND | 428.7 | 12.2 | ND | ND | ND | 35.1 | 4.0 | 1,543 | 44 |

RS: raw swine slurry; ADS: anaerobically digested swine slurry; CS: composted swine slurry; WS: wheat straw; ND: not determined; DM: dry matter; VS: volatile solids; TOC: total organic carbon; TN: total nitrogen; Org-N: organic nitrogen; $NH_4$-N: ammonium-nitrogen; $NO_3$-N: nitrate-nitrogen; C/N: total organic carbon/total nitrogen ratio.
[a] Results are expressed on a fresh matter basis.
[b] Results are expressed on a dry matter basis.

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