A LABORATORY STUDY OF SOIL CARBON DIOXIDE EMISSIONS IN A VERTISOL AND AN ALFISOL DUE TO INCORPORATING CORN RESIDUES AND SIMULATING TILLAGE

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Abstract

Soil organic carbon (SOC) is reduced in annual horticultural systems due to accelerated CO_2 emission from the frequent and intensive tillage required to prepare beds and manage pests. Conversely, crop residue incorporation has the potential to counteract the loss of SOC. We hypothesised that vegetable systems could be made more resistant to SOC loss by including a high-residue grain crop such as sweet corn (*Zea mays* var. *rugosa* L.) in the rotation. We incubated two Australian soils, an Alfisol and a Vertisol, in plant-free sealed chambers with a ± corn residue treatment and soils either sieved/disturbed or not to simulate tillage. Carbon dioxide-carbon (CO_2-C) flux was measured using air samples collected at 24 hours before , and 1, 120, 240 and 360 h after simulated tillage. Residue incorporation had a larger effect on CO_2-C flux than tillage for both soil types. The tillage x residue interaction accounted for 40% of CO_2-C flux; the effect of residue was highly significant but tillage alone was not significant. The effect of simulated tillage on residue incorporated soil was most stimulatory and the treatment without residue or without simulated tillage was the least stimulatory to CO_2 emission. Residue effects were 22% higher in the Alfisol compared with the Vertisol whilst tillage effects were 26% higher in the Vertisol than in the Alfisol. The Vertisol was more resistant to CO_2 losses than the Alfisol after disturbance as the gas fluxes stabilised more rapidly following soil disturbance. In summary, residue incorporation and tillage interactions were a function of soil type, and fine-textured soils such as the Vertisol may be less prone to CO_2 losses than lighter-textured soils.

Keywords: soil organic carbon, organic vegetable, mechanical weed control, soil disturbance.

Introduction

Annual horticultural systems commonly rely on frequent and intensive tillage to prepare beds and manage weeds and insects. Tillage stimulates the loss of soil organic carbon (SOC) through accelerated CO_2 emission brought about by improvement in soil aeration and soil and crop residue contact (Angers *et al.* 1993) and disruption of soil aggregates exposing the physically protected soil organic matter (SOM) to decomposition (Six *et al.* 2000; Mikha and Rice 2004). However, some vegetable farmers use green manures, organic inputs (e.g. compost, mulch) and crop residues to perform various functions including increasing SOM. Crop residue management systems that maintain organic materials in situ can benefit SOM (Liu *et al.* 2009; van Groenigen *et al.* 2011).

The effects of tillage and crop residue management can have opposing influences on SOC and may be difficult to isolate (Liu *et al.* 2009, Dong *et al.* 2009; Dalal *et al.* 2011). For practical assessment, quantification of effect of each of the two practices individually is desirable to enable evaluation of their contributions separately (Liu *et al.* 2009). Luo *et al.* (2010) summarised the data from 39 published papers for Australian conditions on the interaction of stubble retention and/or conservation tillage on soil C change in the surface 0.1 m of soil. They have shown that the synergistic effect of combining stubble retention and conservation tillage increased SOC content by 16.37% as compared with stubble burning and conventional tillage.

The SOC pool in the soil is the balance of C inputs in the form of crop residue and biomass, and C outputs such as CO_2 emissions and other losses. The CO_2 fixed in plant biomass by photosynthesis is returned to soil forming SOM, some of which is lost due to tillage (Jarecki and Lal 2003; Johnson *et al.* 2007). Vegetable systems are especially vulnerable to rapid SOC losses because of a heavy reliance on intensive tillage. We hypothesised that SOC losses from soils in such systems could be reduced by including a high-residue grain crop like sweet corn (*Zea mays* var. *rugosa* L.) in the rotation. The subsequent corn stover input in the soil could balance the expected loss of SOC due to tillage.

This laboratory study was conducted to separate the effects of residue incorporation and tillage in an associated field trial where sweet corn stover incorporation in a corn-cabbage (*Brassica oleracea* L.) rotation had a positive effect on SOC, but no differences in SOC for organic and conventional soil management systems. Organic vegetable systems rely on tillage for mechanical weed control, whereas conventional systems rely on herbicides. This paper is an extended version of a conference paper presented at the Fifth World Congress in Conservation Agriculture (Bajgai *et al.* 2011).

Materials and methods

Soils from 0-0.1 m depth were collected from two contrasting cropping sites: a self-mulching black clayey Vertisol and sandy brown Alfisol (Soil Survey Staff, 2010) from the Armidale area of New South Wales, Australia (latitude 30.48°S, longitude 151.65°E, elevation 1063 m). Selected properties for the two soils are presented in Table 1. The soil samples were air-dried, sieved through <2 mm sieve, plant debris removed and homogenised by mixing. We used plant-free examples of an Australian Alfisol and a Vertisol in our experiment. Five hundred (Vertisol) and 600 (Alfisol) grams of soil (oven-dried basis) were weighed into 0.86 m diameter polythene pots to a depth of ~0.1 m.

Table 1. Selected soil properties for 0-0.1 m depth with means (n = 4).

Soil property	Alfisol	Vertisol
Carbon (g $100g^{-1}$)	1.28	2.47
Nitrogen (g $100g^{-1}$)	0.12	0.21
pH (H_20) 1:5	6	5.8
Bulk density (Mg m^{-3})	1.47	1.22
Sand content (g $100g^{-1}$)	72.4	24.4
Silt content (g $100g^{-1}$)	11.3	13.9
Clay content (g $100g^{-1}$)	16.3	61.7

A three-way factorial design: (1) ground (<4-mm) stover incorporation (+RES or -RES), (2) simulated tillage (+Till or –Till), and (3) soil type (Vertisol or Alfisol) was used with four replicates in a completely randomised layout. The –RES –Till treatment was considered analogous to a conventional soil management system and the +RES +Till treatment was considered analogous to an organic soil management system. The +RES treatment was amended with 15 tonnes ha^{-1} (dry weight basis) of stover with an average carbon:nitrogen ratio of 34:1, and pre-incubated at 25°C for four months to allow decomposition of the applied residue.

During pre-incubation, water was applied once in two weeks for Vertisol and once every six days for Alfisol to bring soil moisture levels from wilting point (-1500 kPa) to field capacity (-33 kPa). At the end of pre-incubation, i.e., when treated soils dried closer to wilting point, the soils were sieved to simulate tillage (Calderon *et al.* 2000; Kristensen *et al.* 2003) through a <4-mm mesh. A pictorial summary of the methodology adopted is shown in Figure 1.

The sieved soil was then repacked into the pots and the pots were placed in sealed PVC tubes for headspace air sampling. The air samples were drawn through a rubber septum inserted on the cover using a surgical needle mounted on a syringe. The air samples were taken before covering and 30 minutes after covering, and the difference in concentrations was calculated as the flux of CO_2. The air samples were stored in evacuated vials and analysed with a gas chromatograph. Air samples were collected 24 hours (h) before the simulated tillage treatment, and 1, 120, 240 and 360 h after the tillage treatment.

Analysis of variance was used to assess the effects of residue, simulated tillage, soil type and time of sampling on CO_2-C flux using the statistical package R version 2.9.1 (R Development Core Team 2010). The data were log transformed to stabilise variances. *P*-values ≤ 0.05 were considered significant.

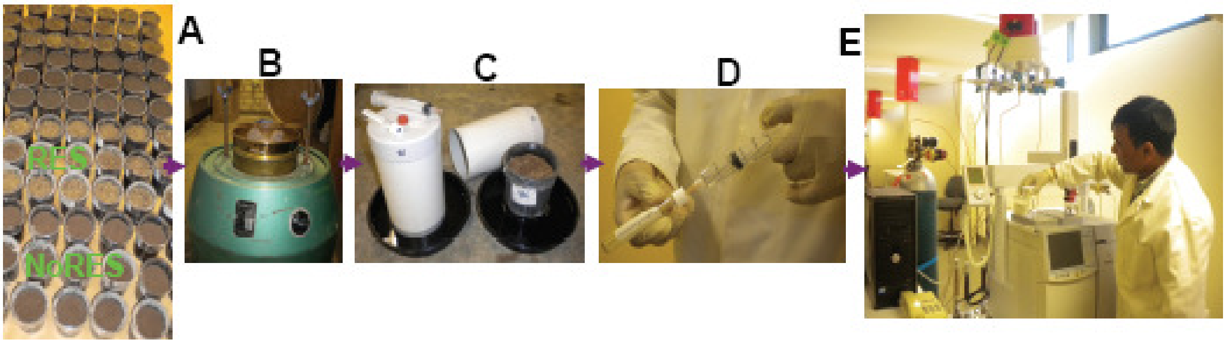

Figure 1. Summary of the methodology: (A) treatments prepared, (B) < 4 mm sieve mounted on sieve-shaker to simulate tillage, (C) sealed chamber used for headspace gas sampling, (D) samples in evacuated vials and (E) sample analysis by gas chromatograph.

Results and discussion

The analysis of variance indicated that CO_2-C flux varied significantly over time and residue treatment ($P < 0.001$) Tillage treatment and soil type were not significant ($P \geq 0.28$). The following interactions were significant: soil type x time, soil type x residue incorporation and residue incorporation x tillage ($P \leq 0.014$). Initial CO_2-C flux levels at -24 h were largely not significant across soil types and treatments (average ~11 mg $m^{-2}h^{-1}$), with large increases at 1 h to ~ 76 mg $m^{-2}h^{-1}$ on average, followed by a decline to pre-tillage levels (slightly higher in Alfisol) at 120, 240 and 360 h. The +RES+Till treatment was most sensitive to flux of CO_2-C followed +RES-Till treatment in both soil types in first 1 h after the tillage treatment. Figure 2 demonstrates that the CO_2-C flux was highest for the +RES+Till treatment and was least for the -RES-Till treatment.

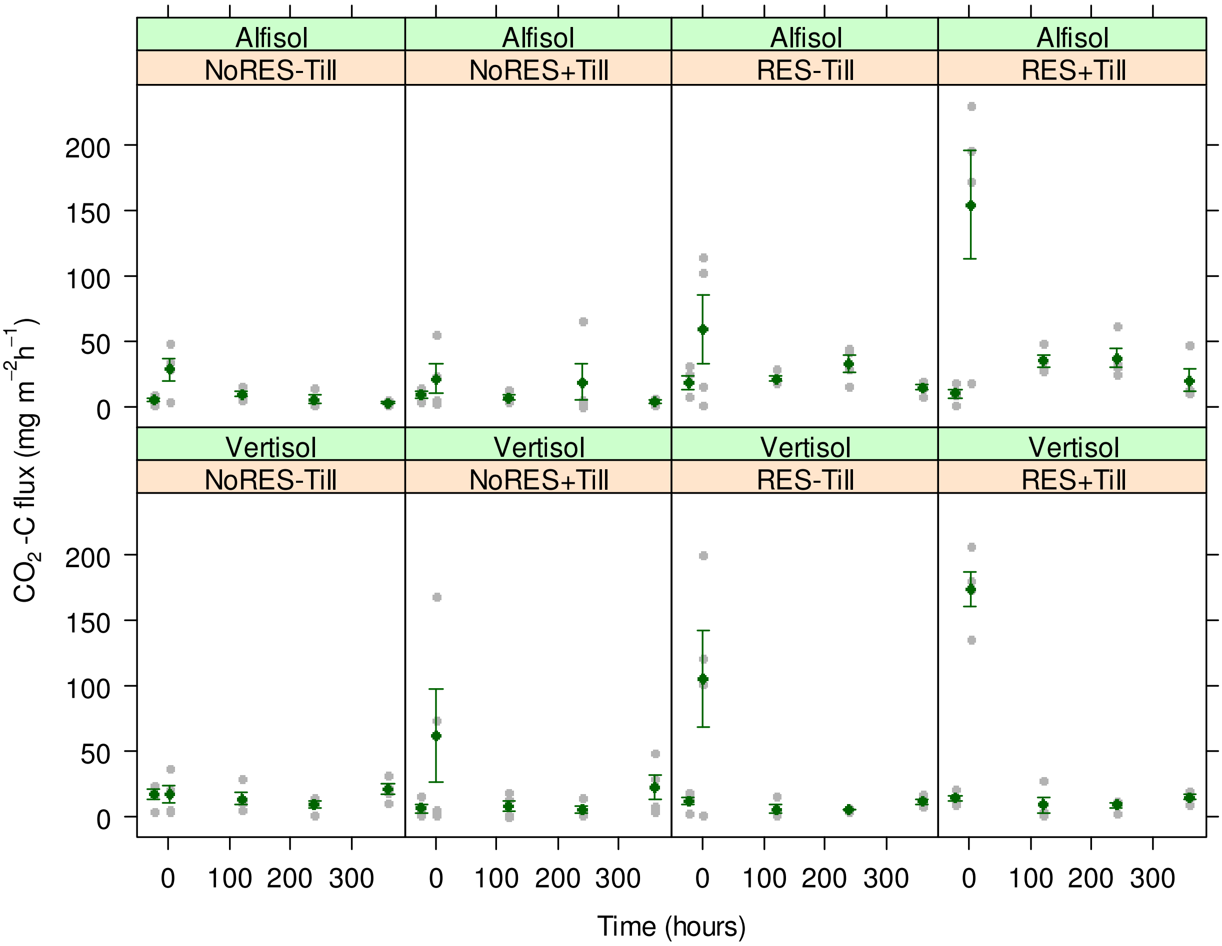

Figure 2. CO_2-C flux for four treatments in Alfisol and Vertisol soils after simulated tillage. The grey dots are raw data points and the vertical bars are standard errors of means.

The soil type x residue interaction was highly significant due to +RES producing 73% and 48% more flux for Alfisol and Vertisol, respectively, in comparison to –RES, indicating a higher rate of residue mineralisation in the Alfisol, presumably due to increased O_2 and CO_2 exchange (Wuest *et al.* 2003) in the sandier soil. When the effect of the tillage and residue was isolated, the residue treatment was highly significant mainly due to residue-derived flux (Kuzyakov 2006) but the simulated tillage was insignificant. Greater fluxes at 120 and 240 h in Alfisol than Vertisol are also likely to be due to greater porosity allowing more gas exchange in the non-swelling sandy soil. The higher flux at 360 h for Vertisol was possibly due to increased porosity (shrinking in response to drying) and/or delayed stimulation of microbial respiration (Wuest *et al.* 2003).

The residue x tillage interaction was based on a lack of tillage effects in –RES, but 40% more CO_2-C flux in +RES for +Till than -Till as soil disturbance facilitates better in soil aeration and soil and crop residue contact for C mineralisation (Angers *et al.* 1993). This is because of the improved availability of O_2 and the exposure of more decomposition surfaces, thereby stimulating increased microbial activity (Beare *et al.* 1994). Compared with –RES-Till, tillage alone increased flux by 16%, less than the effect of residue alone (52% increase in flux). The -RES-Till treatment (scenario of conventional vegetable) emitted 70% less CO_2-C flux than +RES+Till (organic scenario), indicating that the effects of tillage and residue alone were largely additive. These trends are corroborated by findings for laboratory (Calderon *et al.* 2000; Wuest *et al.* 2003) and field trials (Ellert and Janzen 1999; La Scala *et al.* 2006; Gesch *et al.* 2007) in terms of CO_2-C flux peaking within hours after disturbance and dropping down later, irrespective of residues being applied or not. Roberts and Chan (1990) had shown similar results for Australian Alfisol. The cumulative proportional CO_2-C flux (Figure 3) shows the strong initial effect of +RES in the Vertisol compared with the Alfisol.

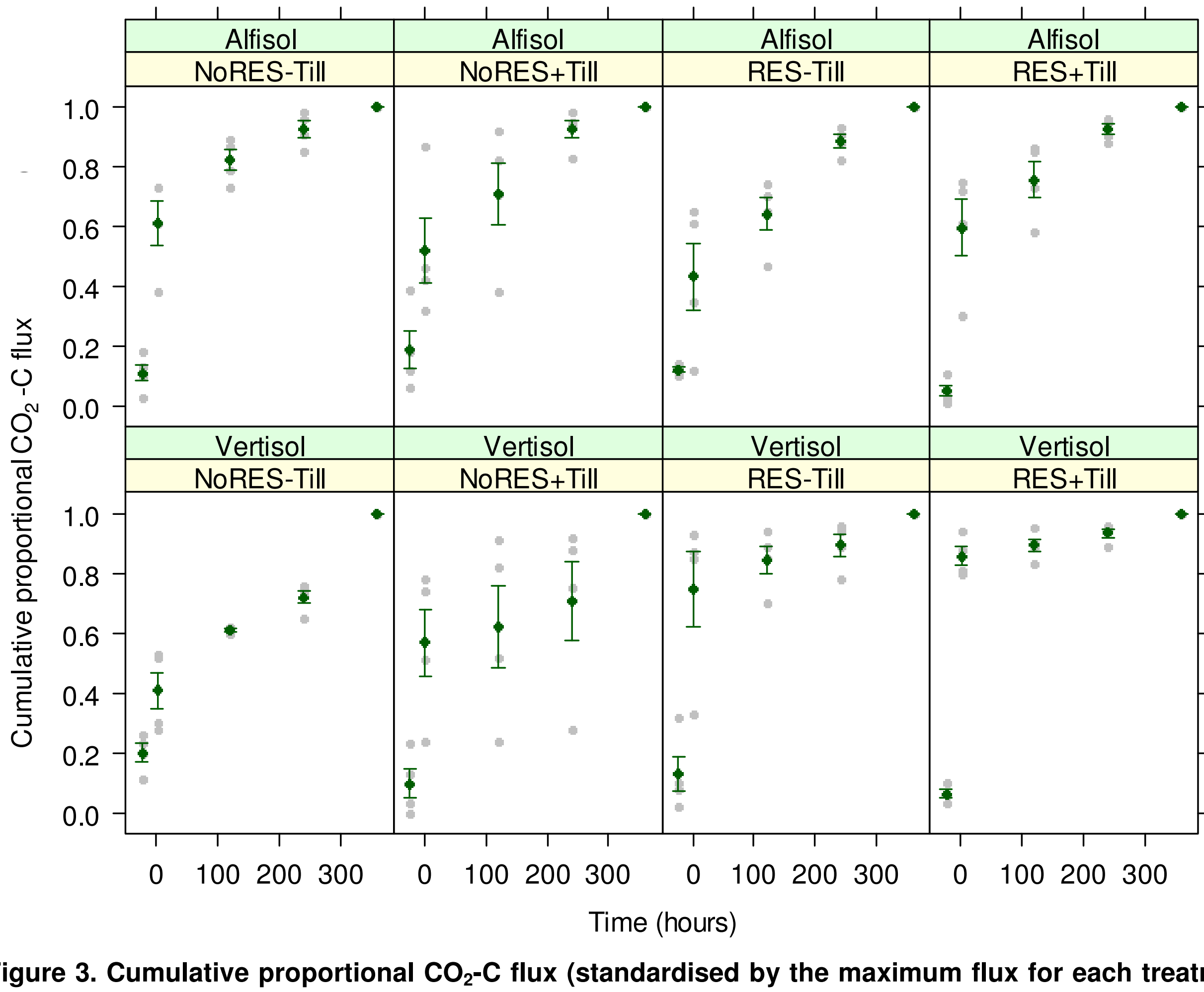

Figure 3. Cumulative proportional CO_2-C flux (standardised by the maximum flux for each treatment combination) for four treatments in Alfisol and Vertisol soils after simulated tillage. The grey dots are raw data points and the vertical bars are standard errors of means.

However, we could not directly compare the magnitude of our CO_2-C fluxes as we were using cultivated soil with or without residue incorporation, and used a different intensity of simulated tillage than in the cited literature. A portion of the added C is lost as CO_2, especially with tillage, but SOC will still be higher than -RES treatments (van Groenigen *et al.* 2011) due to remains from the incorporated residue. Cumulative CO_2-

C fluxes were generally in order of NoRES-Till < NoRES+Till < RES-Till < RES+Till for both soil types (Figure 4). Residue effects were 22% higher in Alfisol compared to Vertisol whilst tillage effects were 26% higher in Vertisol compared to Alfisol.

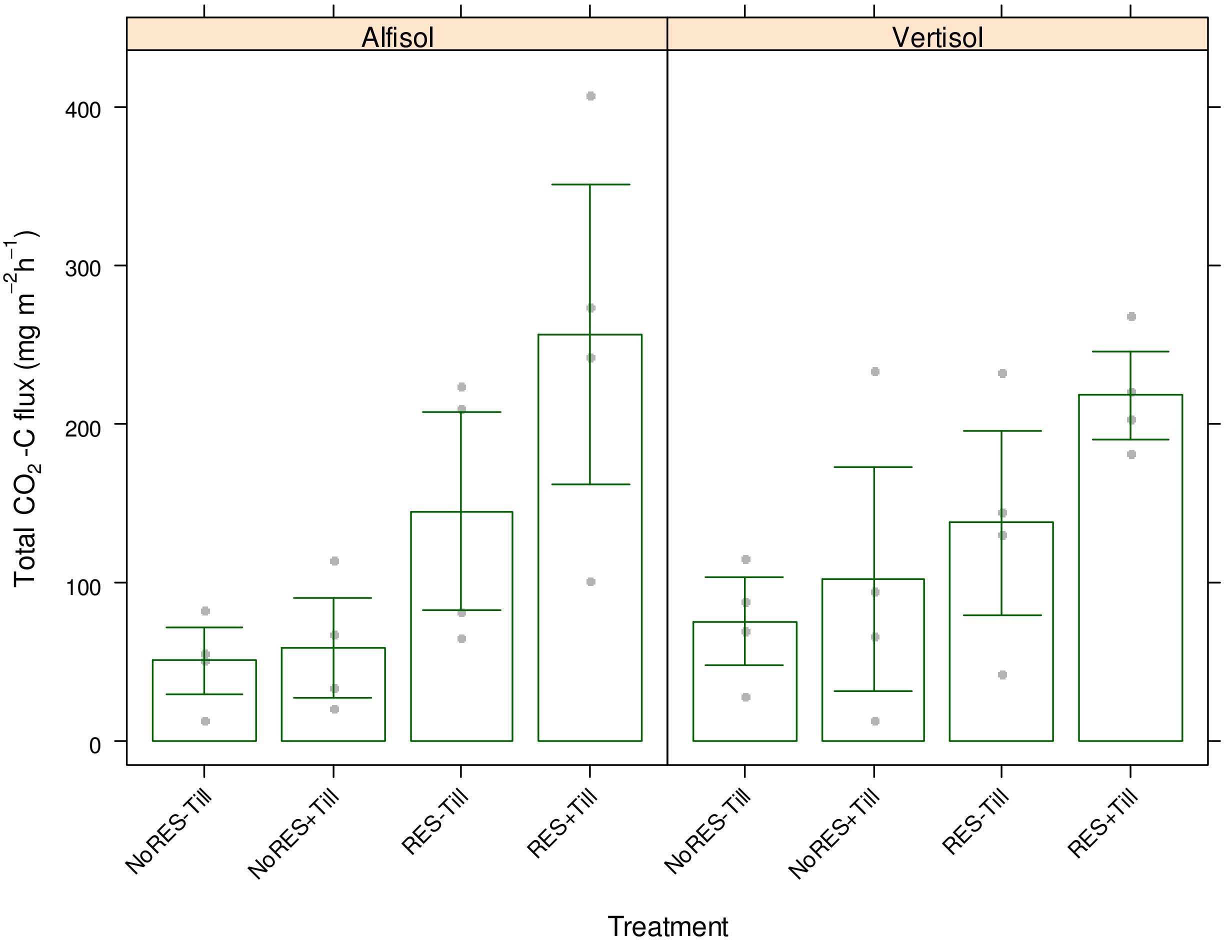

Figure 4. Total CO_2-C flux for Alfisol and Vertisol soils. The grey dots are raw data points and the vertical bars are standard errors of means.

The variation in fluxes in Figure 3 and Figure 4 demonstrate two advantages of not disturbing soil. Firstly, the +RES+Till treatment evolved a significantly higher flux of C than the +RES-Till treatment and so soil in the +RES-Till treatment may act as sink of CO_2, but soil in the +RES+Till treatment acts as a source. The cumulative plot clearly demonstrates the statistical differences between disturbed and undisturbed soil where residue had been incorporated. Secondly, the treatments without corn residue and without simulated tillage will have more soil carbon compared to the treatments without residue but tilled because less is CO_2 being released from the same baseline level. It is easy to visualise this fact by plotting the extra CO_2-C flux over the –RES-Till (control here) treatment (Mondini *et al.* 2007). The extra CO_2-fluxes to show that Vertisol is more resistant to SOC losses after disturbance than the Alfisol as the downward trend of flux over the measurement time, whilst the Alfisol show an upward trend, indicating its lower resistance being sandy and porous to gas exchanges facilitating microbial respiration.

Some of the shortcomings of this research are related to the frequency and duration of data sampling with respect to time after stimulated tillage. We measured flux at -24, 1, 120, 240 and 360 h after the tillage treatment and were not able to capture the rate of decrease of flux between 1 and 120 h after simulated tillage, where maximum activity from the peaks to almost stable levels occurred (Figure 2).

Conclusions

Residue incorporation had a larger effect on CO_2-C flux than tillage for both soil types, suggesting that C availability and form can be more important than disturbance in cropping soils. The interaction of tillage x residue contributed 40% of CO_2-C flux, however, when the effect of the tillage and residue was isolated, the residue treatment was highly significant mainly due to residue-derived flux (Kuzyakov 2006) but the simulated tillage was insignificant. The +RES+Till treatment had a significantly higher flux of C than the +RES-Till treatment, with the former treatment acting as a CO_2 sink and the latter acting as a CO_2 source. The residue effects were more pronounced in the Alfisol whilst tillage effects were more pronounced in Vertisol. The Vertisol soil was found to be more resistant to SOC losses than the Alfisol after disturbance as the gas fluxes stabilised more quickly. The Alfisol soil was less resistant to SOC losses based on its sandy and porous characteristics for gas exchanges, facilitating increased microbial respiration and subsequent CO_2 losses from the soil. In summary, residue incorporation and tillage interacted differently in the different soil types, and fine-textured soils such as the Vertisol may be less prone CO_2 losses than lighter soils

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