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Effect of tillage on short-term CO₂ emissions from a loam soil in semiarid Aragon (NE Spain)

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SUMMARY – Adoption of conservation tillage in rainfed agricultural systems can reduce soil CO₂ emissions to the atmosphere thus minimizing soil organic carbon losses and mitigating the greenhouse effect. In this study we evaluate the influence of conventional and conservation tillage (reduced tillage and no-tillage) systems on short-term CO₂ fluxes from a loam soil under both continuous cropping and cereal-fallow rotation. The study has been conducted as part of a long-term conservation tillage experiment established in 1989 in semiarid Central Aragón (NE Spain). CO₂ emissions measured just after primary tillage operations were greater under continuous cropping than under cereal-fallow rotation. For both cropping systems, CO₂ fluxes were significantly higher under conventional tillage than under reduced tillage and no-tillage. First results indicate that conservation tillage can reduce CO₂ fluxes from semiarid soils in Aragón.

Key words: Soil CO₂ flux, conservation tillage, conventional tillage, soil organic carbon, dryland cropping.

RÉSUMÉ – "Effet du labour sur les émissions de CO₂ à court terme provenant d'un sol de texture moyenne dans les zones semi-arides de l'Aragon (nord-est de l'Espagne)". L'adoption du labour de conservation dans les systèmes de culture sèche peut réduire les émissions de CO₂ du sol dans l'atmosphère et, par conséquent, minimiser les pertes de carbone organique du sol et atténuer l'effet de serre. Dans la présente étude, nous évaluons l'influence des systèmes de labour conventionnel et de labour de conservation (labour réduit et non-labour) sur les flux de CO₂ à court terme provenant d'un sol de texture moyenne en deux régimes de culture : continue et rotation céréales-jachère. L'étude menée faisait partie d'une expérience à long terme de labour de conservation mise en place en 1989 dans une zone semiaride du centre de l'Aragon (NE de l'Espagne). Pour les deux systèmes de culture, les flux de CO₂ du sol mesurés immédiatement après les opérations de labourage étaient significativement supérieurs en labour conventionnel par rapport au labour réduit et au non-labour. Ces premiers résultats suggèrent que le labour de conservation pourrait être considéré comme une stratégie efficace pour réduire les émissions de CO₂ provenant des sols agricoles dans les zones semiarides de l'Aragon.

Mots-clés : Flux de CO₂ du sol, labour de conservation, labour conventionnel, carbone organique du sol, systèmes de culture de zones semiarides.

Introduction

Cultivated soils contain nearly 12% of the worldwide soil organic C pool (Flach *et al.*, 1997). This content is the result of historical losses of soil organic carbon (SOC) due to the conversion of grass and forest lands to croplands and changes in agricultural management practices (Flach *et al.* 1997). Tillage, especially when including mouldboard ploughing, can be one of the dominant causes of soil organic carbon reductions (Reicosky *et al.*, 1995). With the adoption of sustainable management practices, such as conservation tillage, agricultural soils can increase the amount of SOC and contribute to mitigate carbon dioxide (CO₂) emissions (Paustian *et al.*, 2000). However, the magnitude of conservation tillage response can considerably vary depending on soil and climate conditions.

In semiarid Aragón (NE Spain), where long-fallowing and mouldboard ploughing are common agricultural practices, rainfed farming systems are characterized by low crop yields and low soil organic matter content (López *et al.*, 1996). The objective of this study was to evaluate the effect of conventional and conservation tillage practices on short-term soil CO₂ emissions from a rainfed agricultural soil of semiarid Aragón.

Materials and methods

The study was carried out during November 2002 and March 2003 at the dryland experimental farm of the Estación Experimental de Aula Dei (CSIC) in Peñaflo, province of Zaragoza (41°44'N, 0°46'W). The soil is a loam (fine-loamy, mixed, thermic Xerollic Calciorthid) according to the USDA soil classification (Soil Survey Staff, 1995) and the climate semiarid, with an average annual rainfall of 340 mm and an average annual air temperature of 14.7 °C.

Three tillage treatments for both fall and spring tillage were compared: conventional tillage (CT), with mouldboard ploughing to 35-40 cm depth as primary tillage; reduced tillage (RT), with chisel ploughing to 25-30 cm depth; and no-tillage (NT). Fall tillage is applied in the fallow period of the continuous cropping (CC) system before barley sowing, whereas spring tillage is performed within the fallow period of the cereal-fallow (CF) rotation. In both cropping systems, mouldboard ploughing in the CT plots was followed by a pass of a tractor-mounted scrubber as a traditional practice to break down large clods. In the fall tillage, a secondary tillage operation to a depth of 10-15 cm was applied with a sweep cultivator in the CT and RT plots. More details about site and soil characteristics, crop management practices and experimental design are found in López *et al.* (1996).

Soil surface CO₂ emissions were measured over a period of 12-22 days immediately after primary tillage operations, using an open chamber with a diameter of 21 cm (model CFX-1, PPSystems) connected to an infrared gas analyser (model EGM-4, PPSystems). On the same sampling dates, soil temperature at 10 cm measured with a hand-held probe (model STP-1, PPSystems), and gravimetric soil water content (0-10 cm) were also determined. In September 2002, soil samples (0-5 cm) were collected in both cropping systems for total organic carbon content by the Walkley and Black method (MAPA, 1986).

Results and discussion

Soil surface CO₂ fluxes ranged from 0.061 to 0.926 g CO₂/m²/h during the period of fall tillage operations (CC system) and from 0.058 to 0.378 g CO₂/m²/h during the period of spring tillage (CF rotation) (Fig. 1). These values are within the range found in the literature for agricultural soils in other semiarid regions (Ellert and Janzen, 1999).

The lowest values of soil CO₂ flux corresponded to the NT plots in both fall and spring tillage periods. NT fluxes were slightly greater than zero for the entire monitoring periods (0.058 and 0.088 g CO₂/m²/h in fall and spring tillage, respectively). Fluxes measured prior to primary tillage were low and similar under the three tillage systems. Immediately after tillage, CO₂ fluxes were largest in CT, with average values of 0.93 g CO₂/m²/h and 0.38 g CO₂/m²/h for the fall and spring periods, respectively. Fluxes from RT plots were significantly lower than from CT plots (0.19 and 0.17 g CO₂/m²/h in fall and spring, respectively). Greater short-term CO₂ emissions from CT plots immediately after a tillage event have also been observed by other authors (Reicosky and Lindstrom, 1993; Reicosky *et al.*, 1997; Ellert and Janzen, 1999). Reicosky *et al.* (1997) concluded that this rapid increase in the CO₂ flux resulted from a physical release of CO₂ stored in soil pores from previous microbial activity. Regression analyses were made to study the possible contribution of soil temperature and soil moisture to CO₂ flux. However, no significant correlations were found between soil CO₂ flux and these factors (data not shown). This would indicate that in our conditions soil CO₂ flux immediately after tillage is due to a physical release rather than to an increase in actual microbial activity. In that sense, differences between CT and RT could be explained by the different soil disturbance produced by mouldboard and chisel ploughs. In our study, while mouldboard plough worked until a depth of 35-40 cm with soil-inverting action, in the case of chisel plough, without inversion of soil profile, the maximum tillage depth was 30 cm.

Under both cropping systems, the large initial CO₂ fluxes observed immediately after mouldboard ploughing rapidly decreased within the next 24 h (Fig. 1). However, CO₂ fluxes measured 24 and 48 h after primary tillage were higher in CT than in NT, with significant differences after spring tillage. This result is similar to that reported by Rochette and Angers (1999) who concluded that the CO₂ emissions following tillage are due to the stimulation effect of tillage on soil organic matter and residue decomposition.

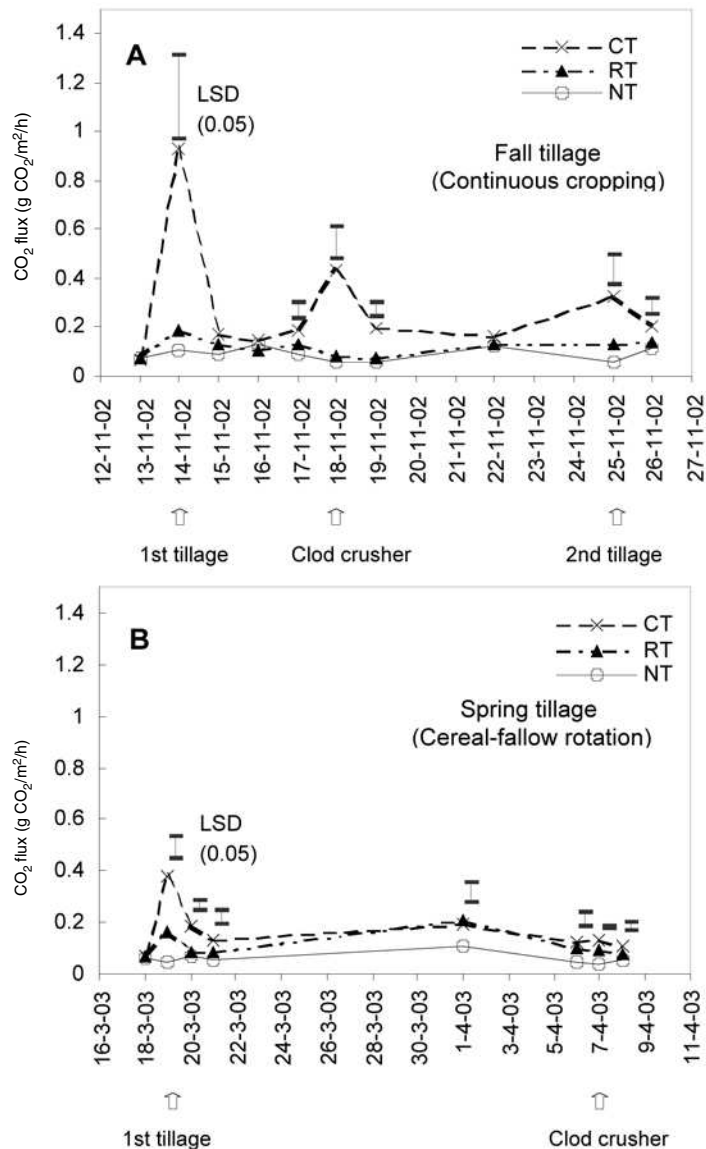


Fig. 1. Soil surface CO₂ fluxes during fall tillage (A) and spring tillage (B) periods under three tillage treatments (CT, conventional tillage; RT, reduced tillage; NT, no-tillage). Bars indicate LSD ($P < 0.05$) for comparisons between tillage treatments at the same date, where significant differences were found.

With regard to cropping systems, CO₂ flux values were, in general, higher under CC (fall tillage) than under CF (spring tillage). As mentioned before, CO₂ emissions immediately after primary tillage for the CT treatment in CC plots were 2.5 times higher than those measured in CF plots. According to Reicosky (1997), differences between fall and spring fluxes could reflect differences in soil CO₂ concentration due to a more limited microbial activity in spring before tillage. In our study, climatic conditions before fall tillage were favourable to microbial activity due to a high soil moisture (13.5-21.3 m³/m³) and moderate temperatures (9.9-11.0 °C). On the contrary, spring tillage was done in early spring when low and fluctuating temperatures probably affected microbial activity. This possible greater microbial activity in CC plots could be related to more frequent C inputs from crop residues in this system, as the higher soil organic C content measured in CC plots reflects (Table 1).

The increment in the CO₂ emissions immediately after the pass of clod-crushing implements in the CT plots, was significantly higher under CC than under CF (0.16 vs 0.012 g CO₂/m²/h) (Fig. 1). In addition to the factors previously indicated, this difference could be explained by a higher soil roughness observed at the time of passing the implement in the fall period. This would be in agreement with Reicosky and Lindstrom (1993), who observed that the higher the soil roughness at the time of tillage, the higher the magnitude of the CO₂ emissions.

Table 1. Average organic C content (g/kg) in the soil surface (0-5 cm) for a winter barley crop under continuous cropping (CC) and crop-fallow rotation (CF) and three tillage treatments

Cropping system	Tillage treatment		
	Conventional tillage	Reduced tillage	No-tillage
CC (fall tillage)	9.1	9.0	11.8
CF (spring tillage)	8.0	8.7	10.4

Conclusions

First results indicate that, in our conditions, conservation tillage practices decrease CO₂ emissions from soil after tillage in comparison with conventional tillage. Cropping system seems to be another factor affecting short-term CO₂ emissions, with higher fluxes during the period of fall tillage (continuous cropping) than during the period of spring tillage (cereal-fallow rotation).

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