The effect of organic and conventional cropping systems on CO_2 emission from agricultural soils: preliminary results

* Mancinelli R.[1], Campiglia E.[1], Di Tizio A.[2], Lagomarsino A.[2], Grego S.[2]

[1] Department of Crop Production, University of Tuscia, Via S.Camillo de Lellis s.n.c., 01100, Viterbo.

[2] Department of Agrobiology and Agrochemistry, University of Tuscia, Via S.Camillo de Lellis s.n.c., 01100, Viterbo.

* Corresponding Author: Tel.: +39 0761 357556; Fax: +39 0761 357558; e-mail address: mancinel@unitus.it

Abstract

The effects of different agricultural systems on soil organic carbon content and CO_2 emission are investigated in this work. In a long-term experiment a conventional system, characterized by traditional agricultural practices (as deep tillage and chemical input) was compared with an organic one, including minimum tillage, green manure and organic fertilizers. Both systems have a three-year crop rotation including pea – durum wheat – tomato; the organic system is implemented with the introduction of common vetch (*Vicia sativa* L.) and sorghum (*Sorghum vulgare bicolor*) as cover crops. In the year 2006 (5 years after the experimentation beginning) was determined the soil C content and was measured the CO_2 emissions from soil.

The first results showed a trend of CO_2 production higher in organic soils in comparison with conventional one. Among the two compared cropping systems the higher differences of CO_2 emission were observed in tomato soil respect to the durum wheat and pea soils, probably due to the vetch green manuring before the tomato transplanting. These results are in agreement with the total organic carbon content and water soluble carbon (WSC), which showed the highest values in organic soil. The first observations suggest a higher biological activity and CO_2 emission in organic soil than conventional one, likely due to a higher total carbon soil content.

Key words: Conventional management, Organic management, Soil CO_2 emission.

Introduction

Soil organic carbon plays an essential role in determining soil quality, which is a central aspect to evaluate the sustainability and productivity of the agricultural systems. Moreover, soil has an important role in contributing to the atmospheric concentrations of CO_2 and other greenhouse gases (Merino et al., 2004).

The reduction of CO_2 emissions and the increase of its storage is being considered at international level, especially within the context of the Kyoto protocol (Sánchez et al., 2002). The flux of this gas is influenced by soil properties and management practices (Merino et al., 2004), which are essential to develop and implement strategies to maintain or increase the soil organic carbon. Increasing soil C stock requires increasing C input and/or reducing soil respiration. The relationship among tillage, soil structure and soil organic carbon dynamics is integral to the C sequestration capacity of agricultural soils (Paustian et al., 2000) and consequently to the change of CO_2 emission. The amount of organic C which can be stored in soil is generally determined by the balance of C input from plant residues and the mineralization of soil organic matter. These sets of processes are under some degree of management control, along with limits imposed by climate and soil conditions (Paustian & Cole, 1998).

The conventional farming system management, including soil tillage (with physical disturbance of the upper soil layers), chemical inputs, irrigations and crop residue removal, affects the soil organic matter increasing the mineralization processes (Andrews et al., 2002; Clark et al., 1998; Nannipieri et al., 1993).

Soil management in sustainable agriculture is aimed at developing economically sound environmentally safe cropping system that substitute biological management for chemical inputs. It involves tillage and crop rotations with different inputs and qualities of residues (Paul et al., 1999).

The organic farmers tend to add more organic carbon to their soils *via* organic fertilizers with consequence to increase the soil organic matter, which, generally, result higher than in the conventional (Andrews et al., 2002; Marinari et al., 2006; van Diepeningen et al., 2006).

The field CO_2 flux is dependent on root and microorganism respiration, moisture and temperature controls of plant residue decomposition and mixing of both above and below ground substrates (Paul et al., 1999).

The aim of this work was to evaluate the effects of organic and conventional management on CO_2 emission from agricultural soils in a three-year crop rotation (pea – durum wheat – tomato).

Materials and methods

A long-term field study, established in 2001, is conducted at University of Tuscia experimental farm (Viterbo) on a volcanic soil. In the experimental site organic and conventional system management are compared in a randomized block design with three replications. In the conventional system the traditional agricultural practices are adopted (e.g. deep tillage, chemical fertilizers and pesticides, etc.) and in the organic one the organic practices are applied according to the 2092/91/EEC Regulation (minimum tillage, organic fertilizers, etc.). Both systems have a three-years crop rotation (pea (*pisum sativum* L.) – winter durum wheat (*Triticum durum* Desf.) – tomato (*Licopersicum esculentum* Mill.). In the organic management, the rotation is implemented with common vetch (*Vicia sativa* L.) and sorghum (*Sorgum vulgare bicolor*) cover crops manured before tomato transplanting and pea planting, respectively. All the crops are planted every year in the experimental field, which is constituted by 18 plots (2 rotations x 3 main crops x 3 replications). In December 2005 (before the winter crops planting), two soil samples were randomly taken at 0-20 cm depth from individual plot (total 36 soil samples) and were analyzed for chemical and physical characterization. Samples were immediately sieved (< 2 mm) and stored at 4 °C. Total organic carbon (TOC) was estimated following the method by Springer and Klee (1954); total nitrogen (TN) was determined by the Kjeldhal method and ammonium content was determined colorimetrically by Anderson and Ingram (1993); water soluble carbon (WSC) was determined by the method of Burford et al., (1975).

Soil CO_2 emission was measured in three randomized areas for each plot every 10 days from March to September 2006. The gas flux was measured using the non-steady-state through-flow chamber: EGM-4 instrument (PP Systems, Stotfold, UK), a portable infrared gas analyzer (IRGA), described in details by Pumpanen et al. (2004).

Statistical analysis were conducted by using the SAS statistical package (SAS Inst., 2002). Analysis of variance for physical and chemical properties was conducted using the one-way ANOVA procedure. For soil CO_2 emission an ANOVA procedure was used for each time measurement. The means were compared using the t-student test.

Results and discussions

Soil physical and chemical properties and relative analysis of variance are reported in table 1. Total organic carbon (TOC) resulted significantly affected by management and showed the higher values in the organic soil than in the conventional (1.42 % and 1.04 % in organic and conventional soil, respectively). These outcomes confirm that organic agriculture techniques may increase soil organic matter content, according to other Authors (Andrew et al., 2002). Also the water soluble carbon (WSC) in the organic soil showed significant higher values than conventional one (63.54 and 48.51 μg C g^{-1} in organic and conventional, respectively). Only an extremely small fraction of the total organic matter is water-soluble but this fraction plays an important role in many ecosystem processes, as production of greenhouse gases (Gregorich et al., 2003). Plant residue and humus are the most significant sources of WSC (Kalbitz et al., 2000) and it consists of simple sugars, organic acids and proteins. Soluble organic matter is an important substrate for microorganisms (Marschner and Bredow, 2002) and can be readily metabolized during the initial stages of decomposition. Wang et al. (2003) reported that the WSC is positively correlated with the CO_2 production, therefore a higher amount of this active C pool corresponds a higher CO_2 production. According to these studies, in this work a trend of CO_2 field emission higher in the organic soils than the conventional one was generally observed (Figs. 1, 2, 3).

In durum wheat the first observations showed a general trend of CO_2 emission lower than the other main crops. This crop showed the highest CO_2 emission differences among organic and conventional in the beginning of the grain-filling period (0.55 and 0.33 g m^2 h^{-1} in organic and conventional respectively) and in the physiological maturity period (0.13 and 0.23 g m^2 h^{-1} in organic and conventional respectively) (Fig. 1).

In the pea crop the highest value was observed in organic soil at the end of summer time (0.75 g m^2 h^{-1}) and the lowest in conventional soil in springtime (0.10 g m^2 h^{-1}) (Fig. 2).

The results of tomato soil showed the significant higher values of CO_2 emission in organic system than conventional one during the spring time (1.34 and 0.73 g m^2 h^{-1}, in organic and conventional respectively), after vetch green manuring (May 2006) (Fig. 3). During the CO_2 data recording period the management events for the three crops consisted only in the harvesting for both organic and conventional durum wheat and pea, while in tomato organic soil occurred the common vetch green manuring, with consequent biomass bringing in soil, transplanting, mechanical weeding and harvesting in both management. According with Vinther et al (2004) any significant variation occurred after the crop harvesting in CO_2 emission for durum wheat and pea, while tomato showed a significant decrease after the harvesting. Moreover tomato is the only one crop of this study that had the constant drip irrigation during the crop growing and it is known that soil moisture is among the most important factors controlling the soil respiration and consequently the CO_2 efflux (Lloyd and Taylor, 1994; Fang and Moncrieff, 2001; Shi et al., 2006). These different agricultural practices can explain the higher values of CO_2 and the general higher trend for both systems in tomato soil in comparison with durum wheat and pea soil.

Generally, during the whole period of data recording the highest CO_2 emission values were observed in May and August for both organic and conventional management in all three crops. The weather trend shows considerable precipitations in March and April, and an increase of a temperature in May (Fig. 4), with consequence of more temperature and moisture in the soil. Moreover, during the crops growth, the rhizosphere respiration is enhanced by photosynthetic activity due the allocation of assimilates into the roots and soil (kuzyakov and Cheng, 2001). Buyanovsky et al (1986) observed the highest root biomass in wheat to occur at about the time of flowering. In fact Sánchez et al (2002) observed in a cereal land, under conventional and reduced tillage, a picking of CO_2 emission in May in both systems, corresponding with the period of maximum vegetation index. In our study, the weather trend shows in August both high precipitation and temperature, after two months characterized by high temperature and low precipitation. These events can explain the peak of soil respiration in all three crops and in particular the tomato trend, which showed a highest CO_2 emission after the harvesting, (Fig. 3).

Conclusions

The first results of this study showed that the agricultural soil management has a significant effect on organic carbon content and CO_2 emission from the agricultural soils. The organic management has increased the organic soil carbon content, although in some crops the CO_2 soil emissions are higher than the conventional one, according to the higher amount of water soluble carbon (the active carbon pool) observed in organic soil compared to the conventional soil. More research is needed in order to better understand the soil quality in the two different managements.

References

Anderson J.M., Ingram J.S.I., 1993. Colorimetric determination of ammonium. In: Anderson J.M. & Ingram J.S.I. (eds): Tropical Soil Biology and Fertility, a handbook of methods. Second Edition.,. CAB International, Wallingford, U.K, pp.73-74.

Andrews S.S., Mitchell J.P., Mancinelli R., Karlen D.L., Hartz T.K., Horwath W.R., Stuart Pettygrove G., Scow K.M. e Munk D.S., 2002. On-Farm Assessment of Soil Quality in California's Central Valley. Journal of Agronomy 94:12-22.

Buyanovsky G.A., Wagner G.H. and Gantzer C.J. 1986. Soil respiration in a winter wheat ecosystem. Soil Science Society of America Journal 50: 338-344.

Burford J.R., Bremner J.M. 1975. Relationship between the denitrification capacities of soils and total, water-soluble and readily decomposable soil organic matter. Soil Biology and Biochemistry 7:389-394.

Clark S., Horwath W.R., Shennan C., and Scow K.M.. 1998. Changes is soil chemical propertied resulting from organic and low-input farming practices. Agron. J. 90:662-671.

Fang C., Moncrieff J.B. 2001. The dependence of soil CO2 efflux on temperature. Soil Biology and Biochemistry 33: 155-165.

Gregorich E.G., Beare M.H., Stoklas U., St-Georges P. 2003. Biodegradability of soluble organic matter in maize-cropped soils. Geoderma 113:237-252.

Kalbitz K., Solinger S., Park J.H., Michalzik B., Matzner E. 2000. Controls on the dynamics of dissolved organic matter in soil: a review. Soil Science 165:277-304.

Kuzyakov Y. and Cheng W. 2001. Photosynthesis controls of rhizosphere respiration and organic matter decomposition. Soil Biology and biochemistry 33: 1915-1925.

Lloyd J., Taylor J.A. 1994. On the temperature dependence of soil respiration. Functional Ecology 8: 315-323.

Marinari S., Mancinelli R., Campiglia E., Grego S., 2006. Chemical and biological indicators of soil quality in organic and conventional farming systems in Central Italy. Ecological Indicators 6: 701 – 711.

Marschner B., Bredow A. 2002. Temperature effects on release and ecologically relevant properties of dissolved organic carbon in sterilized and biologically active soil samples. Soil Biology and Biochemistry 34:459-466.

Merino A., Batallon Perez P., Macias F. 2004. Responses of soil organic matter and greenhouse gas fluxes to soil management and land use changes in a humid temperate region of southern Europe. *Soil* Biology and Biochemistry 36**:**917-925.

Nannipieri P. 1993. Ciclo della sostanza organica nel suolo : aspetti agronomici, chimici, ecologici e selvicolturali. Patron, Bologna 334 p.

Paul E.A., Harris D., Collins H.P., Schulthess U., Robertson G.P. 1999. Evolution of CO2 and soil carbon dynamics in biologically managed, row-crop agroecosystems. Applied Soil Ecology 11:53-65.

Paustian K., Six J., Elliott E.T., Hunt H.W. 2000. Management options for reducing CO_2 emissions from agricultural soils. Biogeochemistry 48**:**147-163.

Paustian K.H., and Cole C.V., 1998. CO_2 mitigation by agriculture – an overview. Climatic Change 40: 135-162.

Pumpanen J., Kolari P., Ilvesniemi H., Minkkinen K., Vesala T., Niinistö S., Lohila A., Larmola T., Morero M., Pihlatie M., Janssens I., Yuste J. C., Grünzweig J. M., Reth S., Subke J.A., Savage K., Kutsch W., Ostreng G., Ziegler W., Anthoni P., Lindroth A., Hari P. 2004. Comparison of different chamber techniques for measuring soil CO2 efflux. Agricultural and Forest Meteorology 123:159-176.

Sánchez M.L., Ozores M.I., Colle R., López M.J., De Torre B., García M.A., Pérez I. 2002. Soil CO2 fluxes in cereal land use of the Spanish plateau : influence of conventional and reduced tillage practices. Chemosphere 47:837-844.

SAS Institute. 2002. The SAS system for Microsoft Windows. Release 8.2. SAS Inst., Cary, NC.

Shi P.L., Zhang X.Z., Zhong Z.M., Ouyang H. 2006. Diurnal and seasonal variability of soil CO2 efflux in a cropland ecosystem on the Tibetan Plateau. Agricultural and Forest Meteorology 137: 220-233.

Springer U., Klee J. 1954. Prüfung der Leistungsfähigkeit von einigen wichtigeren Verfahren zur Bestimmung des Kohlenstoffs mittels Chromschwefelsäure sowie Vorschlag einer neuen Schnellmethode. Z. Pflanzenernährung Bodenk 64, 1.

van Diepeningen A. D., de Vos O. J., Korthals G. W., van Bruggen A. H. C., 2006. Effects of organic versus conventional management on chemical and biological parameters in agricultural soils. Applied Soil Ecology 31: 120 – 135.

Vinther F.P., Hansen E.M. and Olesen J.E. 2004. Effect of plant residues on crop performance, N

mineralisation and microbial activity including field CO_2 and N_2O fluxes in unfertilised crop rotations. Nutrient Cycling in Agroecosystems 70: 189-199.
Wang W.J., Dalal R.C., Moody P.W., Smith C.J. 2003. Relationship of soil respiration to microbial biomass, substrate availability and clay content. Soil Biology and Biochemistry 35:273-284.

Table 1. Physical and chemical properties of organic and conventional soils. Data reported in brackets are the standard error (n = 9). TOC = Total Organic Carbon; TN = Total Nitrogen; CEC = Cation Exchange Capacity; WSC = Water Soluble Carbon. * = significant P≤0.05; ns = not significant.

	Texture USDA	**pH** $_{H2O}$ 1::2.5	**pH** $_{KCl}$ 1::2.5	**CEC** Cmol$^+$ kg^{-1}	**TOC** %	**TN** %	**C:N** ratio	**WSC** μg C g^{-1}
Organic soil	Clay Loam	6.86	5.51	19.35	1.42	0.13	10.92	63.54
		(0.07)	(0.1)	(3.75)	(0.13)	(0.03)	(2.02)	(4.58)
Conventional soil	Clay Loam	6.88	5.54	22.14	1.04	0.14	7.43	48.51
		(0.15)	(0.11)	(1.63)	(0.13)	(0.03)	(2.21)	(5.30)
		ns	ns	ns	*	ns	ns	*

Figure 1. CO_2 emission from winter durum wheat soil. The bars are the standard error (n = 9)

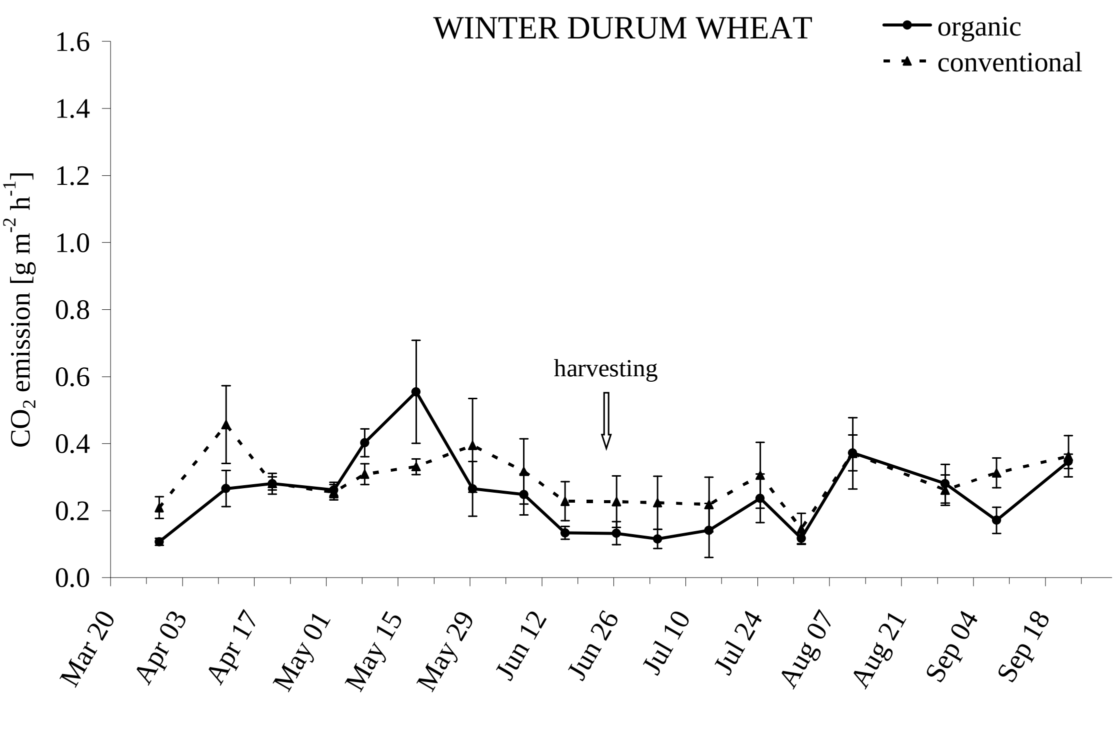

Figure 2. CO_2 emission from pea soil. The bars are the standard error (n = 9)

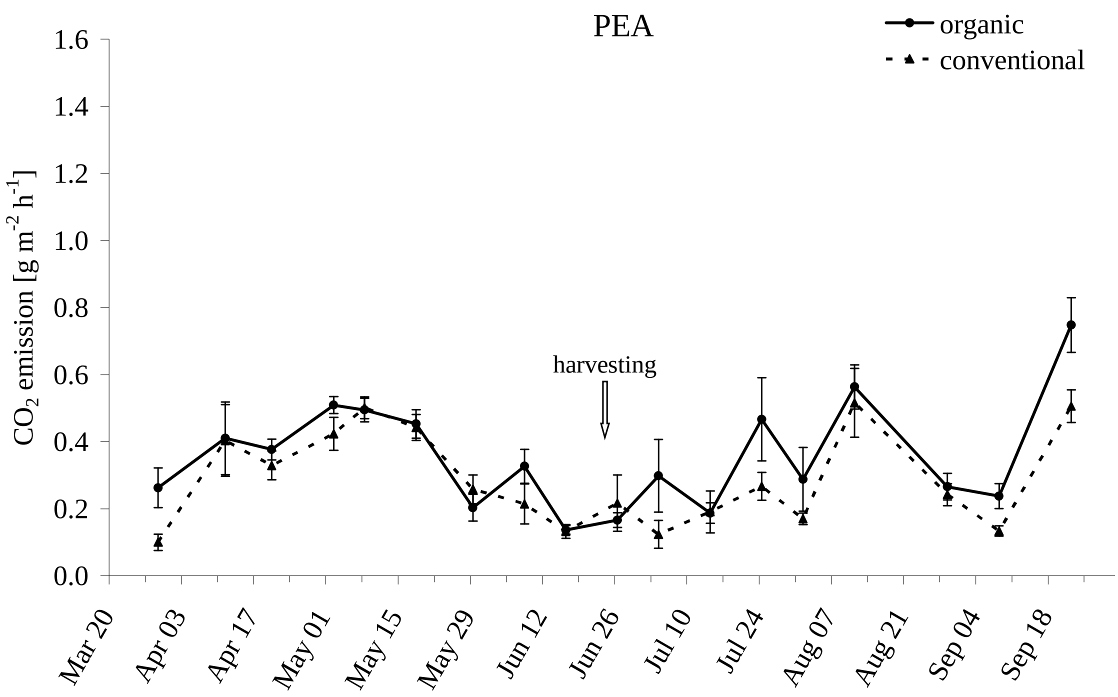

Figure 3. CO_2 emission from tomato soil. The bars are the standard error (n = 9).

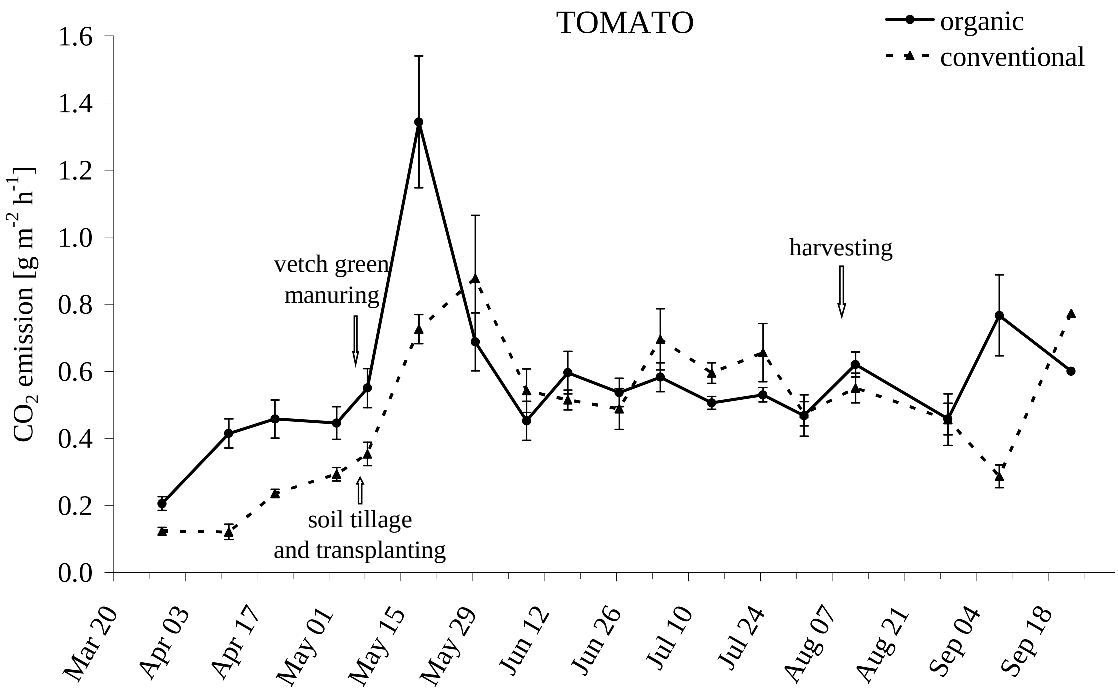

Figure 4. Total precipitation and average of air daily minimum and maximum temperature at ten-day intervals at the experimental site, from March to September 2006.