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Tillage and cropping effects on soil organic carbon in Mediterranean semiarid agroecosystems: testing the Century model

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ABSTRACT

Carbon sequestration in agricultural soils can contribute to offseting CO_2 anthropogenic emissions and also to enhance soil fertility, soil water retention and crop production. In this experiment, our main objective was to validate the Century model for Mediterranean semiarid agroecosystems and to investigate management effects on soil organic carbon (SOC) dynamics in these areas. Data from a long-term experiment in NE Spain comparing three tillage systems (no-tillage, NT; reduced tillage, RT; conventional tillage, CT) and two cropping systems (barley-fallow rotation, BF and continuous barley system, CB) was used to simulate SOC with the Century model in the 0-30 cm soil depth. The model was able to accurately simulate SOC and above-ground C inputs under different tillage systems although it over-estimated C inputs in some growing seasons (e.g. 2000). Simulated and measured C inputs showed a significant relationship ($P<0.001$; $R^2=0.83$) and both tended to decrease as tillage intensity decreases but differences were not statistically significant. However, SOC content was greater under NT than under CT and RT. Also, intensification of cropping systems (i.e. eliminating bare fallow) led to greater SOC in all tillage treatments. Consequently, SOC sequestration rates were greatest in NT followed by RT and CT in the CB system with 0.46, 0.24 and 0.18 Mg C $ha^{-1}yr^{-1}$, respectively. In the BF rotation lower SOC sequestration rates were found with values ranged from 0.15 to -0.004 Mg C $ha^{-1}yr^{-1}$ in NT and CT, respectively. Both simulation and measured values showed that reduction in tillage intensity and an intensification of the cropping system are promising strategies to increase SOC sequestration under semiarid Mediterranean conditions. The Century model is a useful tool to simulate tillage

and cropping system effects on SOC dynamics in semiarid Mediterranean agroecosystems.

Key words: semiarid Spain, dryland agroecosystems; simulation modeling; soil organic carbon; tillage

1. INTRODUCTION

Reduced tillage and cropping intensification have been recognized as two promising strategies for offsetting anthropogenic CO_2 emissions through soil organic carbon (SOC) sequestration (Paustian et al., 1997; Lal, 2004). Freibauer et al. (2004) reported a C sequestration potential of up to 16-19 Tg C yr^{-1} for agricultural soils of the EU-15 countries during the first commitment period of the Kyoto Protocol (2008-2012). This sequestration potential would be equivalent to 2% of European anthropogenic emissions. Furthermore, C sequestration in agricultural soils also contributes to enhance soil fertility, soil water retention and crop production (Schlesinger, 1999). However, the impact of these management practices on SOC sequestration can be different depending on the area studied.

In Mediterranean semiarid Spain, several experiments in the last decade have investigated the impacts of soil management on SOC levels (e.g. Martín-Rueda et al., 2007; Moreno et al., 2006; Ordóñez-Fernández et al., 2007; Virto et al., 2007; Álvaro-Fuentes et al., 2008). These experiments collected SOC data at specific intervals from the beginning of the experiment. These experiments provide information on the effects of alternative management practices on SOC content at a few locations and over a limited time periods. However, we still lack a more general understanding of the temporal dynamics of SOC under different management practices in Mediterranean Spain.

Simulation models are a useful tool to analyze the mechanisms controlling soil organic matter (SOM) dynamics in soil (Paustian et al., 1992). Consequently, a better understanding of the relationships and interactions between management practices and their effects on soil organic matter can be achieved with the use of these models. In European agroecosystems, simulation models have been used to determine SOM dynamics under different management practices on both regional (Fallon et al. 2002) and field scale (Paustian, 1992; Coleman et al., 1997; Kelly et al., 1997; Fallon and Smith, 2002; Foereid and Høgh-Jense, 2004; Lugato et al., 2007). The Century model (Parton et al., 1987) is one of the most commonly used SOM models worldwide; and the model has already been validated for some European agroecosystems. For example, Paustian et al. (1992) modeled the effects of organic matter and fertilizer additions on soil organic matter (SOM) dynamics from a Swedish long-term experiment. Kelly et al. (1997) used Century to simulate some agricultural long-term experiments from central Europe. Foereid and Høgh-Jense (2004) used Century to simulate SOM dynamics under organic agriculture in northern Europe. Recently, Lugato et al. (2007) simulated SOC dynamics in two long-term experiments in north-eastern Italy comparing different nutrient management and soil types. However, little information exists about modeling SOC in European semiarid Mediterranean agroecosystems. Jenkinson et al. (1999) simulated SOC dynamics from two-course rotations from the long-term trials at ICARDA (Syria) using the RothC model. Consequently, validating the Century model for European semiarid Mediterranean conditions might help us to better understand the processes and mechanisms that control SOM dynamics in these agroecosystems. In this study, we evaluated the Century model to simulate long-term management effects on SOC for a Mediterranean semiarid agroecosystem in NE Spain.

2. MATERIALS AND METHODS

2.1. Site, tillage and cropping systems

A long-term experiment started in 1989 at the dryland research farm of the Estación Experimental de Aula Dei (Consejo Superior de Investigaciones Científicas) in the Zaragoza province NE Spain (41º44’30´´N, 0º46’18´´W, 270 m). The climate is semiarid, with an average annual precipitation of 340 mm and an average annual air temperature of 14.7 ºC. The soil is a fine-loamy, mixed, thermic Xerollic Calciorthid (Soil Survey Staff, 1975) with the following main properties for the 0-20 cm soil layer: pH (H_2O, 1:2.5): 8.3; electrical conductivity(1:5): 0.25 dS m^{-1}; $CaCO_3$: 432 g kg^{-1}; sand (2000-50 µm), silt (50-2 µm), and clay (<2 µm) content: 293, 484 and 223 g kg^{-1}, respectively. The experiment consisted of a long-term tillage and cropping systems comparison experiment with three tillage treatments: conventional tillage (CT), reduced tillage (RT) and no-tillage (NT). Each tillage treatment was represented under a continuous barley (*Hordeum vulgare*, L.) (CB) system and a barley -fallow (BF) rotation. The cereal-fallow rotation with barley was used since it is the most widespread cropping system used by farmers in these Mediterranean semiarid areas. In the CB system, the CT treatment consisted of mouldboard ploughing to a depth of 30 cm every fall as primary tillage. The mouldboard plough consisted of three bottoms of 0.50 m width. The RT treatment was chisel ploughed every fall to a depth of 25 cm. The chisel plough consisted of 5 rigid shanks spaced 20 cm apart and a shank width of 5 cm. In the CT and RT plots, primary tillage was followed by a pass of a sweep cultivator to a depth of 10-15 cm as secondary tillage. In the BF rotation, primary tillage was implemented in early spring every two seasons during the fallow phase of the rotation and secondary tillage in late spring with a cultivator pass to a depth of 15-20 cm. In the NT treatment no tillage operations were done and for sowing a direct drill planter was used. In this treatment, the soil was kept free of weeds by a herbicide (glyphosate). Inorganic nitrogen was applied in all the treatments since 1998. The N fertilization rates have been changed every season and ranged from 26 to 60 kg N ha^{-1} was applied. From the records found, it is known that prior to the establishment of the long-term experiments fields had been under CT and BF rotation for several decades. The experiment design was a randomized complete block design with three replicates. Treatment plot size was 33.5 m x 10 m.

2.2. Above-ground C inputs and SOC measurements

Above-ground crop residue inputs were measured prior to mechanical harvest from 1999 to 2003. Four 0.5 m long rows were hand-harvested per plot and the grain was removed from the plant and the straw was oven-dried for 48 h at 65 ºC and weighed. The C concentration in the straw was measured during the 2003 sampling. We assumed a C concentration of 0.45 for the overall experiment.

In 1989, prior to the establishment of the experiment, SOC and bulk density from the 0-20 cm depth were measured. SOC was measured again during 1994, 1998, 2001, 2003 and 2005 in the CB systems and the same years except for 1994 in the BF system. Since the experimental plots were originally set up for soil water and wind erosion studies (López et al., 1996), from 1989 to 2003 soil samples were only taken from the 0-20 cm soil depth. However, in 2005 soil sampling was performed in the 0-30 cm soil depth. The Century model has been parameterized to simulate SOC dynamics in the 0-20 cm depth. However, we modified the model to simulate SOC dynamics in the 0-30 cm soil depth according to the procedure proposed by Metherell et al. (1993). Therefore, in order to report measured SOC values in the 0-30 cm depth from 1989 to 2003, the SOC in the 20-30 cm depth was estimated from the proportion of SOC in this soil depth measured in 2005. The SOC was measured by the wet oxidation method of Walkley and Black (Nelson and Sommers, 1982). Soil bulk density was measured in each treatment by the core method (Grossman and Reinsch, 2002) from samples collected during 2003 and 2005. Since soil bulk density was not measured in 1994, 1998 and 2001 an approximation was made by assuming a linear variation of soil bulk density from the beginning (1989 single value) to the end of the experiment (2005 values for each treatment).

2.3. Model description, parameterization and initialization

The Century model is a general ecosystem model designed to simulate C, N, S and P dynamics in a monthly time step. The model is described in detail by Parton et al. (1987, 1994). Briefly, the SOM submodel is composed by different pools with different turnover rates. Four of these SOM pools represent surface and soil litter (metabolic and structural) and the other three represent SOM (active, slow and passive). Decomposition rates are functions of first-order rate constants modified by climate (soil temperature and moisture), tillage intensity, soil texture and litter quality (C/N ratio and lignin content). In the plant growth submodel, the maximum plant growth is calculated as a function of the precipitation and reduced if there is insufficient mineral N supply (Parton et al., 1987).

In order to establish the initial distributions of the different SOC pools at the beginning of the experiment two simulation periods were run before the start of the experiment following a similar procedure to Paustian et al. (2002). The importance of simulating previous conditions is to initialize the two most stabilized SOM pools: the passive and the slow pools. To initialize the proportion of SOC in the most recalcitrant pool (passive pool) an equilibrium period was simulated for 5000 years with a tree-grass system according with the data reported by Gonzalez-Samperiz et al. (2008). For this equilibrium simulation, a 30 year fire frequency was assumed. The initialization of the slow SOM pool was accomplished by simulating a base period consisting of the 100 years previous to the establishment of the experiment. This base simulation consisted of a barley- fallow rotation with conventional tillage, as mentioned in the historical records of the experimental site.

Measured site-specific parameters like soil texture, bulk density, initial soil C and soil depth were used to run the model. Non-site parameters that control C flow and decomposition among different SOM pools were left unchanged. Also, crop rotations, tillage, fertilization, straw management and crop type were set up in the model according to the conditions of the experiment. Further, parameter constants controlling crop growth (e.g. harvest index (HIMAX), the effect of water deficit on harvest index (HIWSF and HIMONN), the fraction of N which goes to the grain (EFGRN) or potential aboveground production (PRDX)) were calibrated to better represent crop growth according with the values measured during the experimental period.

3. RESULTS

3.1. C inputs

Measured above-ground C inputs averaged over 1999 to 2005 are shown in Table 1. In both cropping systems, measured above-ground C inputs decreased as tillage intensity decreased. Among cropping systems, the average above-ground C inputs for all the three tillage systems were 117.3 and 42.9 gC m^{-2} in the CB and BF system, respectively (Table 1).

From the beginning of the experiment to 1998, simulated above-ground C inputs kept steady with values lower than 100 g C m^{-2} for all the three tillage treatments,. However, since 1999, simulated above-ground C inputs increased to three times greater C inputs over the course of the experiment (Fig. 1). In the three tillage treatments, there was good correspondence between measured and modeled values. Measured above-ground C inputs increased with time with the greatest value in 2003 of more than 150 g C m^{-2} which was similar to the simulated values (Fig. 1).

In the BF system, modeled differences prior and posterior to 1998 were lower compared with the CB system (Fig. 2). Above-ground C inputs kept steady during the overall experiment with values ranging between 125 and 175 g C m^{-2} (Fig. 2). However, there was a slight increase in the measured above-ground C inputs in the 2002 season which was well simulated by the model in the three tillage treatments (Fig. 2).

A significant linear relationship (*P*<0.001) was found between the simulated and the measured above-ground C inputs with a R^2 of 0.83 (Fig. 3).

3.2. Temporal SOC dynamics

At the onset of the experiment, measured and simulated SOC content in the first 30 cm soil depth was 3210 and 3282 g C m^{-2}, respectively (Figs. 4 and 5). The simulated initial SOC pool size distribution was: 3021 g C m^{-2} for the passive pool and 219 gC m^{-2} for the slow pool (data not shown). In the CB system, across all the three tillage treatments, simulated and measured SOC content kept constant until 1999 and with little increase from the initial SOC content. But since 1999, simulated and measured SOC content increased over time in all three tillage treatments (Fig. 4). However, this increase was greatest in the NT, followed by and RT and CT (Fig. 4). The greatest SOC contents were measured at the end of the experiment with 3950, 3590 and 3490 g C m^{-2} in NT, RT and CT, respectively (Fig. 6). The model performed well simulating SOC changes over time in the CB system (Fig. 4), particularly in the NT treatment where the SOC content increase was greatest. Over the duration of the experiment, greater SOC content was measured in CT compared to both RT and NT until 2005 when NT treatment had greater SOC content than CT (Fig. 6). However, differences between simulated SOC in CT and both RT and NT were low over the course of the experiment (Fig. 6).

In the BF rotation, for all tillage treatments, both the measured and simulated SOC content kept constant over the duration of the experiment (Fig. 5). Contrary, the increase in SOC observed in the CB system after 1999, was not observed in the BF rotation. At the end of the experiment, measured SOC contents were 3450, 3220 and 3200 g C m^{-2} in

NT, RT and CT, respectively (Fig. 5). Simulated SOC content in RT and CT were slightly higher than the measured values, especially at the end of the experiment (Fig. 5). Differences between simulated and measured SOC values calculated as the root mean square error (RMSE) are shown in Table 2. In the CB and BF cropping systems, the average percentage errors were 3.6% and 5.2%, respectively.

3.3. SOC sequestration rates

After 16 years, for each cropping system, NT and CT accumulated the greatest and the lowest amount of SOC, respectively (Table 3). The greatest SOC sequestration rate was observed in the NT treatment of the CB system with simulated and measured values greater than 0.35 Mg C ha^{-1} yr^{-1} (Table 3). In general, lower SOC sequestration rates were found in the BF rotation as compared with the CB system. The CT treatment in the BF rotation had the lowest sequestration rate, with a negative sequestration rate (Table 3).

4. DISCUSSION

Water content is the most limiting factor to crop development and yield in Mediterranean semiarid agroecosystems (Austin et al., 1998; Moret et al., 2007). In our study, the dynamics of the above-ground C inputs can be split in two differentiated phases. The first phase would cover from the beginning of the experiment in 1990 until the 1999 season. It is characterized by a low and a constant residue production that resulted from the lack of N fertilization in any of the treatments. Slightly differences in C inputs among growing seasons during this first phase may have resulted from differences in rainfall. For example, about 50% more rainfall during the 1997 season led to greater C input simulated in this season as compared with the other seasons in this first phase. The second phase would cover from 1999 until the end of the experiment in 2005. This second phase was characterized by an increase in the C inputs along the growing seasons and all three tillage treatments for both cropping systems. This increase in C inputs responded to the applications of N fertilizer during this phase. The N application doses were lower at the beginning of the phase (e.g. 26 kg N ha^{-1}) and highest at the end (e.g. 60 kg N ha^{-1}). The effects of N fertilizer on crop growth and C inputs have been widely reported in Mediterranean semiarid conditions (Mossedaq and Smith, 1994; Cantero-Martínez et al., 2003). The model simulated the increases for C inputs in both systems after the application of N fertilizer fairly well. Simulated and measured above-ground C inputs had a good linear relationship ($P<0.001$, $R^2 = 0.83$). The only exception was the 2000 season in which simulated C inputs were higher than measured. This season, had the lowest recorded precipitation during the experiment with 244 mm from October to June. We hypothesized that with this exceptionally low amount of precipitation, the model was not be able to accurately simulate the diminished yields measured during this growing season.

As observed in the above-ground C inputs (for the NT and RT treatments of the CB system), we found a similar simulated and measured SOC content which did not change until 1999; and then a second phase from 1999 to 2005 with increases of SOC contents. However, both measured and simulated SOC content in the CT and RT treatments showed a lower increase in the SOC content at the end of the experiment compared with NT, although C inputs were similar among the all tillage treatments. It is well established that an increase in tillage intensity results in greater SOM decomposition rates due to tillage effects on aggregate breakage, soil aeration and burial of crop residues (Paustian et al., 1997; Lal, 2004; Álvaro-Fuentes et al., 2009). Consequently, the model was able to simulate the effects of tillage intensity on SOM decomposition under our conditions. However, in the BF rotation, the RT and CT treatments showed slightly lower measured than simulated values of SOC content. Two possible reasons could be attributed to the overestimation of the SOC by the model. Firstly, the model could be overestimating C inputs in these two treatments. Despite the fact that above-ground C inputs were only measured from 1999-2003, greater simulated C inputs were observed in the 2000. Also, differences in below-ground C inputs and their subsequent dynamics could explain the differences in SOC contents between measured and simulated values. Although below-ground C inputs were not measured in this experiment, it has been reported that below-ground C inputs have higher impact on SOC dynamics than above-ground C inputs (Balesdent and Balabane, 1996; Gale et al., 2000). Consequently, an overestimation of below-ground C inputs by the model could result in the difference between simulated and measured SOC content. Another reason to explain the differences between simulated and measured SOC could be an underestimation of the SOC decomposition. Opposite to the CB system, SOC in the BF rotation did not increase with the application of N fertilization after 1999. Although slight increases in the above-ground C inputs were observed after 1999 in the three tillage systems, simulated and measured SOC remained similar over the experiment.

Several studies have emphasized the need to estimate the uncertainty of the model to evaluate model performance (Smith et al., 1997; Ogle et al., 2007). In our study, uncertainty values expressed as percentage errors (RMSE) were below 6%. Even with site-specific model calibration, Fallon and Smith (2003) modeled SOC in several long-term experiments in Europe with calculated RMSE ranging from 1.8% to 16.4%. As pointed out by these authors, the RMSE errors does not equate directly to the model error since measurements can have errors. Nevertheless, it can be used as a useful estimator of the certainty of the model predictions when tested against measured data.

As explained previously, the Century model was adapted to simulate the 0-30 cm soil depth in order to match the plough layer in our experiment. In the same experimental plots, it was observed that only considering the upper soil layers, SOC content differences among tillage treatments were higher due to the accumulation of SOC in the lower soil layers of CT. Specifically, in the 20-30 cm depth, CT accumulated up to 35% of the SOC measured in the 0-30 cm depth (Álvaro-Fuentes et al., 2008). Recently, Angers and Eriksen-Hamel (2008) compiled results from long-term tillage experiments covering a wide range of soil and climatic conditions and showed that residue-derived C accumulates at the bottom of the plow layer resulting in a greater mean SOC content. In our study, the greatest SOC sequestration rates were observed in NT under CB. Several studies in different parts of the world reported that an absence of tillage and cropping intensification are two of the most promising ways for increasing SOC sequestration (Sá et al., 2001; Smith et al., 2005; Johnson et al., 2005). In our study, under CB, SOC sequestration rates in NT from measured and simulated values were 0.46 and 0.37 Mg ha^{-1} yr^{-1}, respectively. These values are similar to the SOC sequestration potential of 0.4 Mg ha^{-1} yr^{-1} established by Freibauer et al. (2004) with the adoption of NT in European soils. At the same time, Smith et al. (2005) assumed SOC sequestration potential in RT would be the half of the NT potential. In our study, measured and simulated SOC sequestration rates for RT were similar to this assumption. In the case of the BF rotation, the three tillage treatments showed lower SOC sequestration rates compared with the CB system. Kong et al. (2005) in a wheat-barley system under Mediterranean climate found a SOC sequestration rate of -0.05 Mg ha^{-1} yr^{-1}. Although the authors did not specify the type of tillage implemented in the study, the negative SOC sequestration rate was similar to the observed rate in the CT treatment of our BF rotation with a -0.004 Mg C ha^{-1} yr^{-1}. In our study, the adoption of NT and cropping intensification can offset up to 1.7 Mg CO_2 ha^{-1} yr^{-1}. A potential agricultural land in semiarid Spain of 10 Mha (MARM, 2008) could result in a CO_2 offset of 17 Tg CO_2 yr^{-1}. This is a coarse estimation that it does not consider differences in soil, climate and management among geographical Spanish areas. However, it can be considered an approximation to the potential of both tillage reduction and cropping intensification to offset CO_2 emissions in semiarid Spain. This value is far from the 360 Tg CO_2 total emissions in Spain measured in 2006 (http://unfccc.int/national_reports/items/1408.php). Nevertheless, as pointed out by Smith (2004), soil C sequestration by management change can be achieved fast and without large technological requirements.

5. CONCLUSIONS

This study demonstrated the viability of Century model to simulate agricultural management effects on SOC dynamics under Mediterranean semiarid conditions. The model accurately simulated soil C inputs and SOC stocks under different tillage systems in a continuous barley system and a barley fallow rotation. Both simulation and measured values showed that both cropping intensification and a reduction in tillage intensity are effective strategies to increase SOC sequestration under semiarid Mediterranean conditions. At the same time, measured and simulated SOC sequestration rates were in accordance with the general sequestration rates given in the literature for larger geographical areas like Europe. Cropping intensification and tillage reduction are potential strategies to increase SOC in semiarid Mediterranean and could subsequently to offset anthropogenic CO_2 emissions.

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Fig. 1. Evolution of simulated and measured above-ground C inputs in a continuous barley system under different tillage treatments (CT, conventional tillage; RT, reduced tillage; NT, no-tillage). Error bars represent standard errors.

Fig. 2. Evolution of simulated and measured above-ground C inputs in a barley-fallow rotation under different tillage treatments (CT, conventional tillage; RT, reduced tillage; NT, no-tillage). Error bars represent standard errors.

Fig. 3. Relationship between measured above-ground C inputs values measured and those predicted by the Century model.

Fig. 4. Evolution of simulated and measured SOC content in a continuous barley system under different tillage treatments (CT, conventional tillage; RT, reduced tillage; NT, no-tillage). Error bars represent standard errors.

Fig. 5. Evolution of simulated and measured SOC content in a barley-fallow rotation under different tillage treatments (CT, conventional tillage; RT, reduced tillage; NT, no-tillage). Error bars represent standard errors.

Fig. 6. Differences in SOC between no-tillage (NT) and conventional tillage (CT) and between reduced tillage (RT) and CT under two cropping systems (CB, continuous barley system and BF, barley-fallow rotation). Error bars represent standard errors.

TABLES

Table 1. Average measured above-ground C inputs (from 1999 to 2003) as affected by tillage (CT, conventional tillage; RT, reduced tillage; NT, no-tillage) in both cropping systems (CB, continuous barley and BF, barley-fallow rotation).

Cropping system	Tillage	Above-ground C inputs (g C m^{-2})
CB	CT	130.2±60.6[a]
	RT	114.2±50.6
	NT	108.5±46.0
BF	CT	48.8±75.7
	RT	47.2±72.1
	NT	32.8±50.8

[a] Mean values ± standard deviation.

Table 2. Performance of the model in simulating SOC content as affected by tillage (CT, conventional tillage; RT, reduced tillage; NT, no-tillage) in both cropping systems (CB, continuous barley and BF, barley-fallow rotation).

Cropping system	Tillage	RMSE (%)[a]
CB	CT	4.5
	RT	3.2
	NT	3.2
BF	CT	5.1
	RT	5.8
	NT	4.8

[a] Root mean square error

Table 3. Measured and simulated SOC sequestration rates and total SOC sequestration as affected by tillage (CT, conventional tillage; RT, reduced tillage; NT, no-tillage) in both cropping systems (CB, continuous barley and BF, barley-fallow rotation).

Cropping system	Tillage	Measured SOC sequestration rate (Mg C ha^{-1} $year^{-1}$)	Measured SOC sequestration in 16 years (Mg C ha^{-1})	Simulated SOC sequestration rate (Mg C ha^{-1} $year^{-1}$)	Simulated SOC sequestration in 16 years (Mg C ha^{-1})
CB	CT	0.18±0.07[a]	2.81±1.04	0.21	3.43
	RT	0.24±0.13	3.87±2.13	0.26	4.13
	NT	0.46±0.07	7.36±1.14	0.37	5.89
BF	CT	-0.004±0.06	-0.07±1.06	0.09	1.43
	RT	0.003±0.08	0.05±1.27	0.10	1.54
	NT	0.15±0.05	2.39±0.83	0.15	2.37

[a] Values ± standard error of the mean. SOC sequestration rates refer to the land use previous to the establishment of the experiment in 1989.

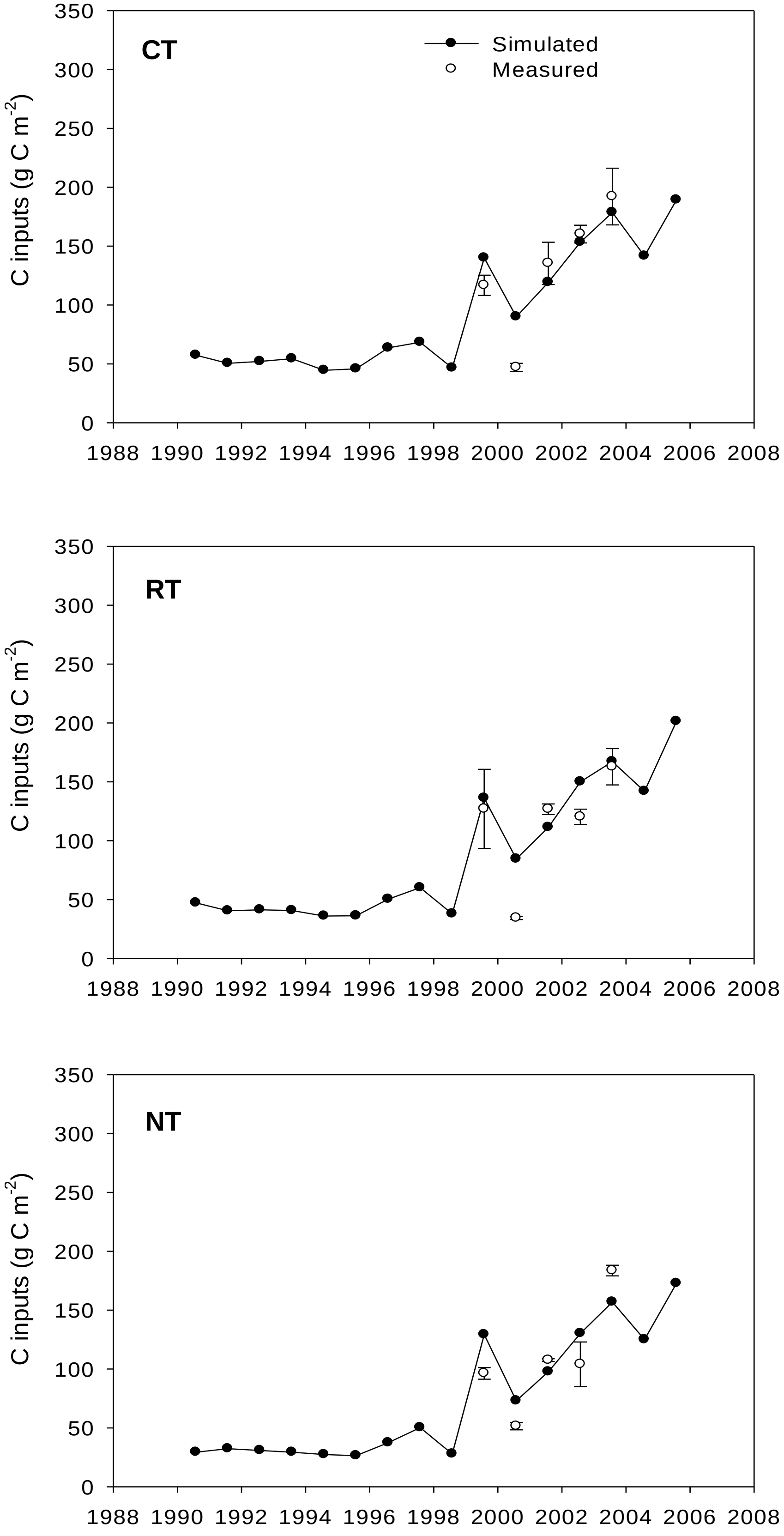
CT
RT
NT
Simulated
Measured
C inputs (g C m^{-2})
0
50
100
150
200
250
300
350
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008

Fig. 1.

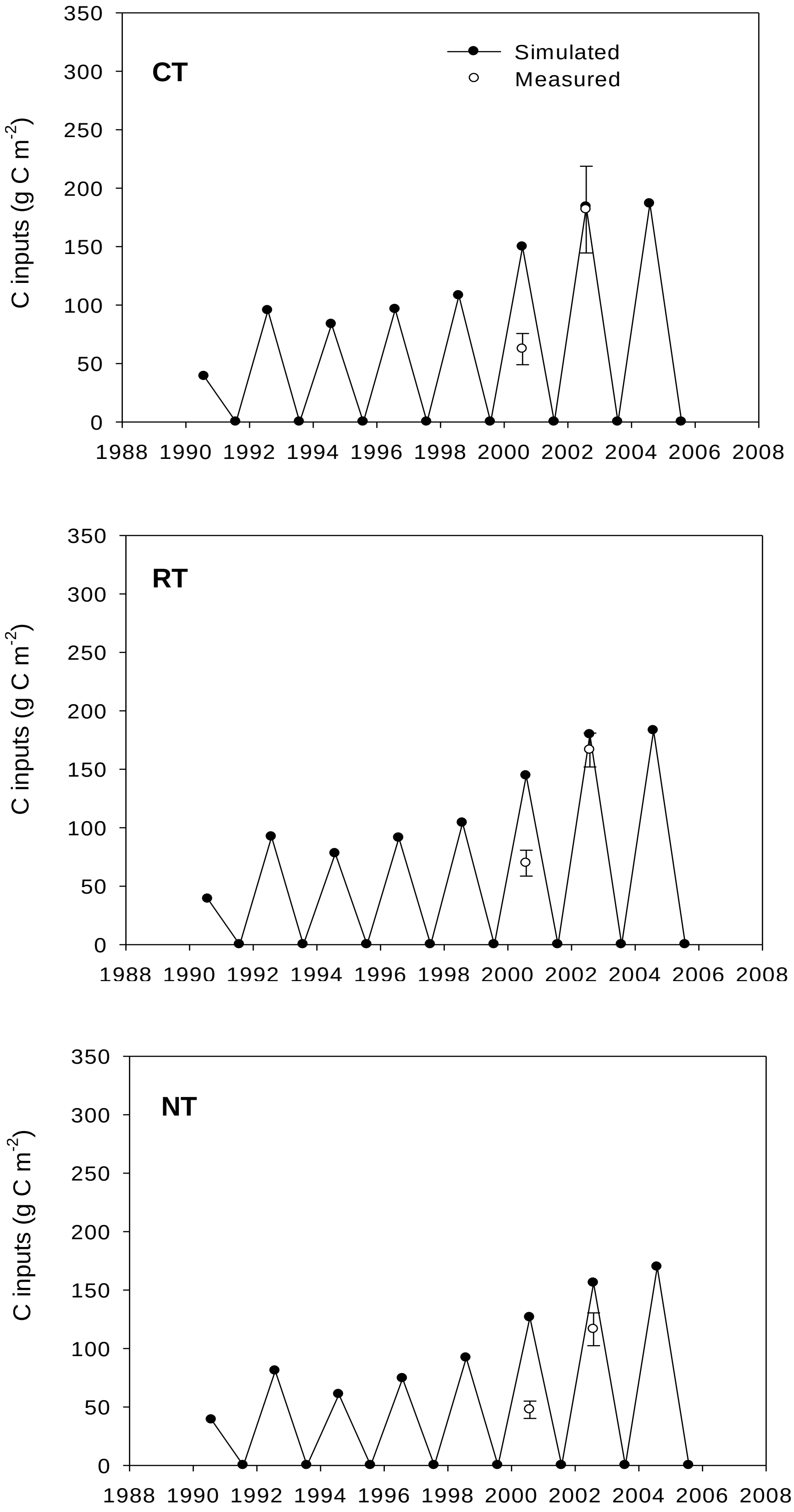
CT
RT
NT
Simulated
Measured
C inputs (g C m^{-2})
0
50
100
150
200
250
300
350
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008

Fig. 2.

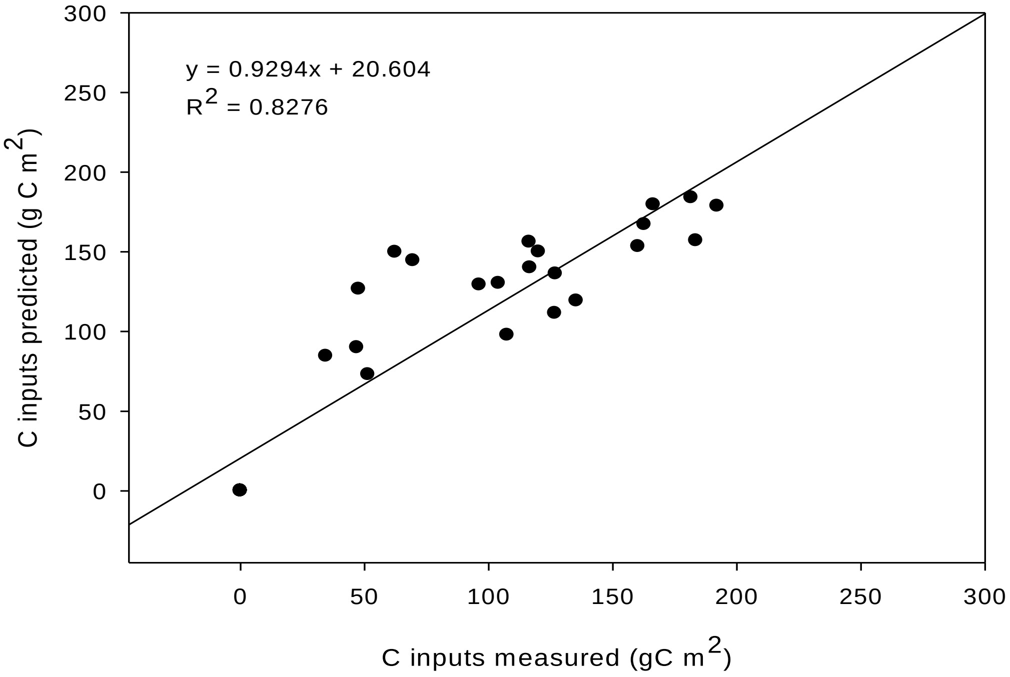
y = 0.9294x + 20.604
R^2 = 0.8276
C inputs predicted (g C m^2)
C inputs measured (gC m^2)
0
50
100
150
200
250
300
0
50
100
150
200
250
300

Fig. 3.

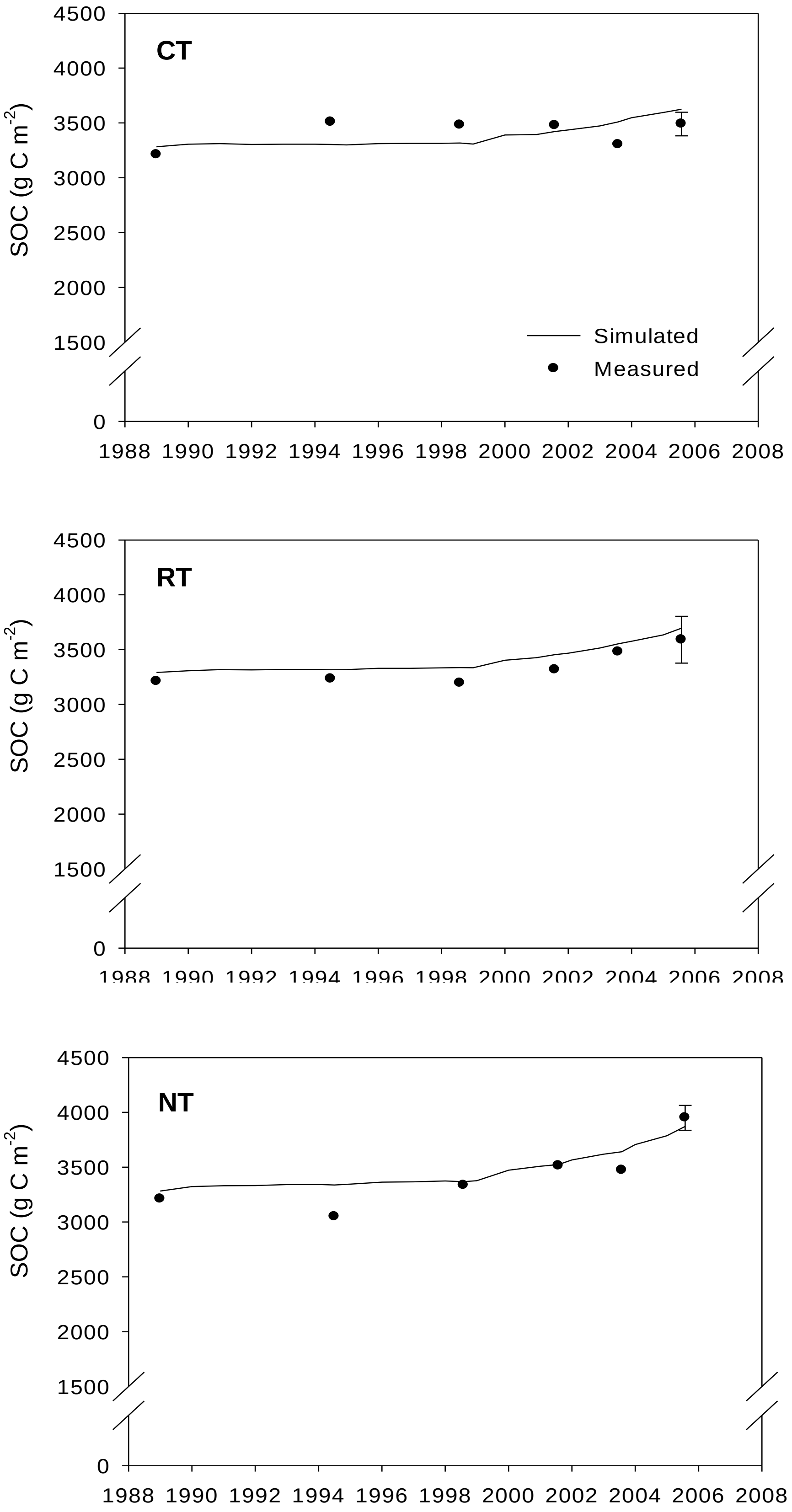
CT
RT
NT
SOC (g C m-2)
4500
4000
3500
3000
2500
2000
1500
0
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
Simulated
Measured

Fig. 4.

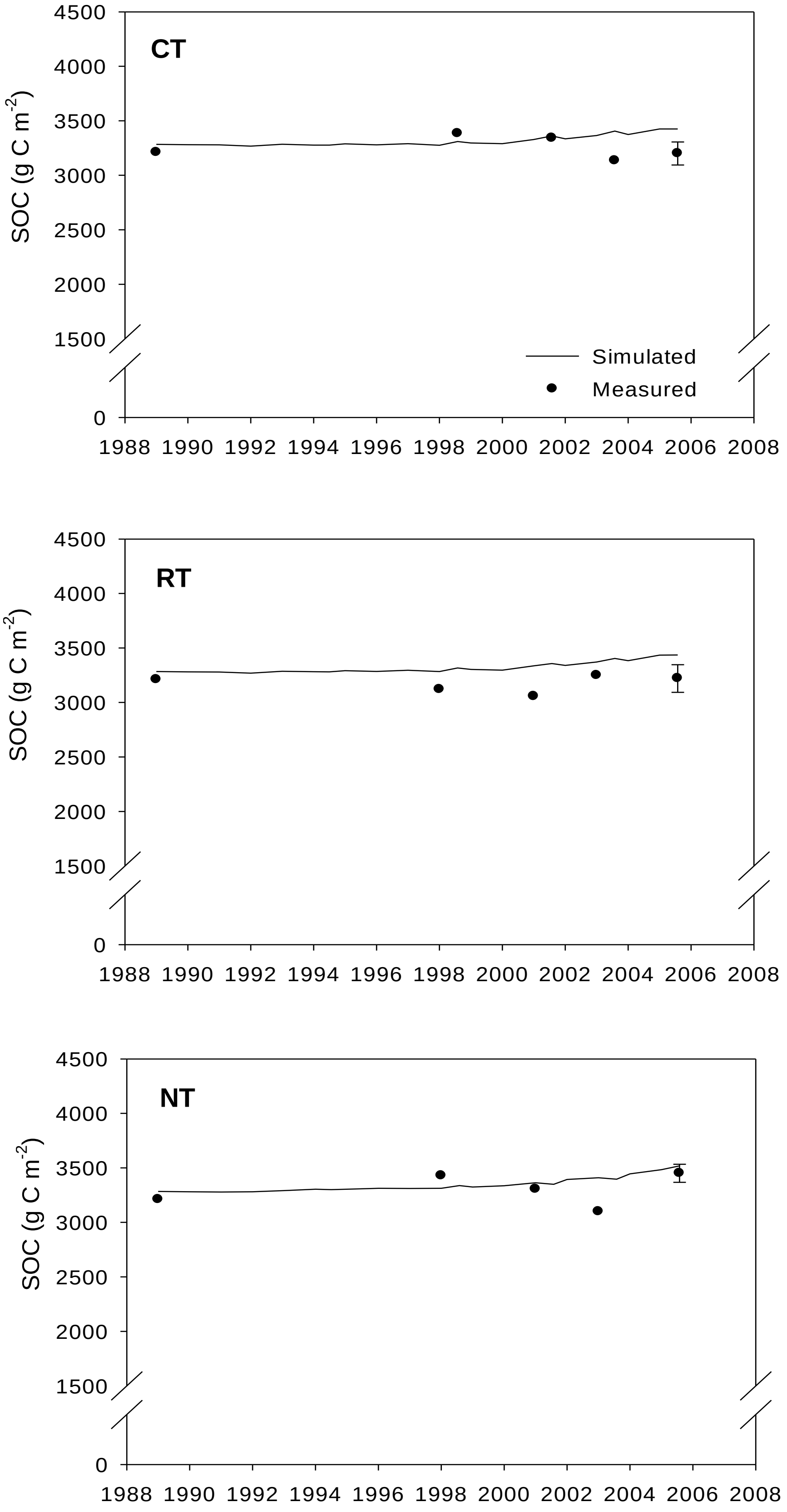
CT
RT
NT
SOC (g C m^{-2})
4500
4000
3500
3000
2500
2000
1500
0
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
Simulated
Measured

Fig. 5.

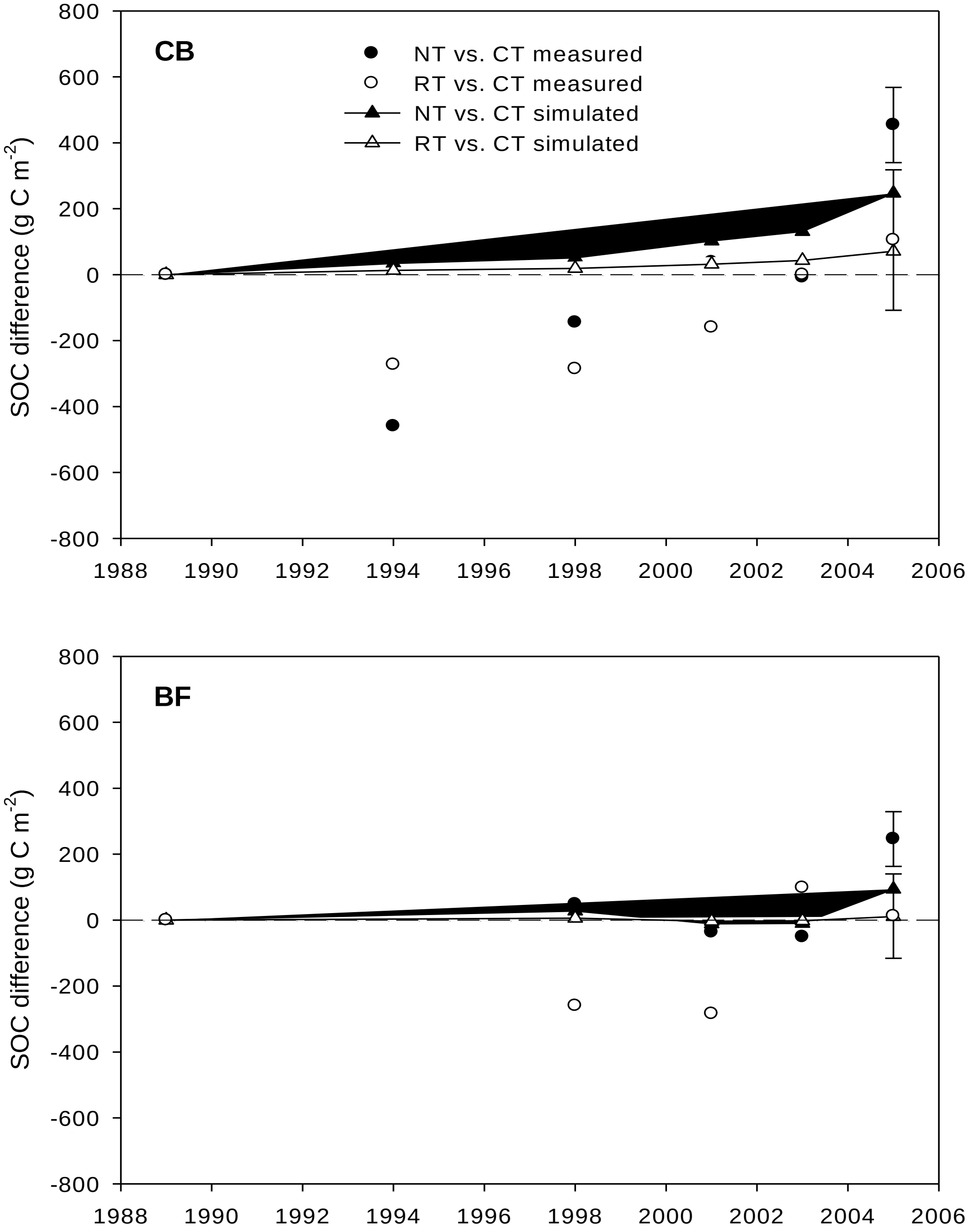
CB
NT vs. CT measured
RT vs. CT measured
NT vs. CT simulated
RT vs. CT simulated
SOC difference (g C m-2)
800
600
400
200
0
-200
-400
-600
-800
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
BF
SOC difference (g C m-2)

Fig. 6.