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Modeling soil organic carbon dynamics in an Austrian long-term tillage field experiment

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ABSTRACT

An assessment of soil management impacts on carbon dynamics requires easily applicable tools. The carbon balance model CCB was applied to quantify the impact of different tillage systems on soil organic matter (SOM) dynamics. The model was able to describe the observed dynamics of SOM for conventional tillage (CT), but the correct simulation of ploughless soil management in the minimum tillage (MT) treatment required an adaptation of the calculation of the specific turnover conditions that are quantified as Biologic Active Time (BAT). We hypothesized a texture dependent reduction of the turnover activity with depth and calculated a site specific correction factor for the BAT of minimum-tilled soils where the topsoil is not mixed by ploughing. Without additional calibration we evaluated this approach using the data set of the field experiment in Fuchsenbigl (Austria) that was started in 1989 on a fine-sandy loamy Haplic Chernozem (FAO, 2006). The model predicted a reduced turnover activity with a BAT of 13 d yr^{-1} for the MT treatment versus 23 d yr^{-1} for the CT treatment having significant correlations between the modeled pool size of active SOM and the microbiological properties substrate induced respiration and potential nitrogen mineralization.

1. Introduction

Reduced or minimum tillage systems without ploughing are becoming increasingly popular in agriculture. Besides carbon input and site conditions, soil tillage is known to have an impact on SOM dynamics, which is illustrated by several results presented in a review by Ogle et al. (2005). In general, the impact of minimum tillage on SOM can be related not only to the reduced mechanical disturbance and cultivation depth, but also to the different deposition of fresh organic matter (FOM) due to changed crop rotations and different yields. The investigation of tillage effects on SOM dynamics requires long observation times. Therefore, modelling is used to transfer the knowledge from experimental sites to practical application. SOM modeling can be advanced in two directions. The first is an increasingly more comprehensive description of processes in the soil, based on a more or less complete description of soil properties in the profile or a simplified description of the main impacts using only the most important input variables, such as crop yield, soil texture and climate. The second strategy is more suitable for practical applications. Therefore, from the CANDY model (Franko et al., 1995) the carbon balance algorithm was extracted, simplified, and represents a separate model with the acronym CCB (CANDY carbon balance). CCB is explained in detail by Franko et al. (2011). It simulates the dynamics of organic carbon (C_{org}) and nitrogen (N_t) in annual time steps considering three SOM pools with different decomposability. The CCB model has been proven valid over a wide range of site conditions and cropping systems. The model approach is based on the combination of different types of fresh organic matter to the flux of SOM reproducing carbon (C_{rep}) and also on the integration of the complexity of site conditions given by soil texture, air temperature and rainfall to Biologic Active Time (BAT) as described in Franko et al. (2011). According to the BAT concept (Franko and Oelschlägel, 1995) the real time is split into an active and a passive part in order to address the effect of site conditions on turnover rates. CCB considers management activities such as cropping, organic amendments and irrigation but, to date, had not included different soil tillage options.

Models that consider different tillage systems are usually based on calibration. Alvaro-Fuentes et al. (2012) showed that models (CENTURY and RothC) can be adapted to deal satisfactorily with the problem of tillage/no tillage impact on SOM dynamics. For the CENTURY approach, Ogle et al. (2012) reported a modeling strategy based on the description of Parton et al. (1987). The tillage impact

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is modeled using a rate modifier and a differentiation of the microbial yield efficiency for crop residues on the surface and buried in the soil. This involves a calibration procedure using generalized information from a meta-analysis of a large number of long-term experiments (Ogle et al., 2005). Although a site specific calibration may produce the best results, in this paper we sought a more general approach that may be usable for a variety of site conditions.

Addiscott and Dexter (1994) stated that soil tillage improves mineralization of soil organic matter. The mixing effect of the tillage operations leads to a movement of soil layers with poor turnover conditions to places with better conditions. We based our approach on the hypothesis that the bottom layers of the topsoil have worse aeration conditions than the top layers, and that the repeated mixing of soil layers by ploughing over a long time compensates the reduction of microbial activity with soil depth.

The solution described in this paper was directed at adapting of the BAT calculation, because it integrates the site specific impact from climate and soil texture on turnover activity. The annual BAT sum represents the time required under optimal conditions in laboratory for a given turnover result that is equivalent to one year under field conditions. For a given C_{rep} flux a lower BAT leads to less carbon mineralization during one year resulting in an increased SOM storage.

In the CANDY model BAT is calculated in daily time steps for different soil layers taking into account soil moisture, soil temperature, and the reduced gas exchange in deeper soil layers (Franko et al., 1995). Assuming a turnover reduction with depth we developed an algorithm to quantify the tillage impact in terms of a changed turnover activity for the simplified BAT calculation in the CCB model. In order to evaluate this approach we applied it to a long-term (over 24 yr) data set from the soil tillage field experiment in Fuchsenbigl, Austria. We used the observed C_{org} dynamics together with selected soil microbiological parameters (substrate induced respiration and potential nitrogen mineralization) in the CT and MT treatments.

2. Materials and methods

2.1. Experimental site and treatments

In 1988 a field experiment was designed in Fuchsenbigl, Austria (48°12′N, 16°44′E, 147 m of altitude), to study the effects of different tillage systems on chemical, physical and microbial soil parameters, crop yields, and plant development. The trial was established with three tillage treatments: conventional tillage (CT), including moldboard ploughing to a depth of 25–30 cm and conventional seedbed preparation, minimum tillage (MT) using a rotary driller once a year with a cultivation depth of 5–8 cm, and reduced tillage treatment (RT) with a cultivator twice a year to a depth of 15–20 cm. All treatments were laid out in a randomized complete block design with three replications. The whole trial area is 6480 m^2. The plots are located side by side, each plot representing an area of 60 m × 12 m (=720 m^2) including a buffer of 1 m along each border. More information about the design is outlined in Spiegel et al. (2007). Selected information on cropping has been described by Spiegel et al. (2002). The most common crops were spring wheat (*Triticum durum*) and winter wheat (*Triticum aestivum*), spring barley (*Hordeum vulgare*), sugar beet (*Beta vulgaris*), and maize (*Zea mays*). All crop residues remained in the field.

The soil is classified as a fine-sandy loamy Haplic Chernozem (FAO, 2006) with 220 g kg^{-1} clay, 410 g kg^{-1} silt, and 370 g kg^{-1} sand. On average, soils at this experimental site had a pH of 7.6, 130 g kg^{-1} carbonate, 17.1 g kg^{-1} organic C and 1.6 g kg^{-1} total N in 0–30 cm (Kandeler et al., 1999, units adapted). The mean long-term annual temperature is 9.4 °C and the mean long-term annual precipitation is 529 mm. These site conditions represent a wide range of similar European sandy and loamy soils without groundwater influence (Körschens et al., 1998).

For the current study the MT and CT treatment were selected. The RT treatment with the reduced tillage depth was not included, because the CCB model – with its simplified structure – treats the topsoil as a whole and cannot handle different tillage depths. The used model inputs in terms of crops, irrigation, and crop yields from 1989 to 2012 for the CT and MT treatments are shown in Table 1.

Table 1
Cultivation data used as model input. Spring wheat: *Triticum durum*, winter wheat: *Triticum aestivum*, spring barley: *Hordeum vulgare*, sugar beet: *Beta vulgaris*, maize: *Zea mays*, pea: *Pisum sativum*

Year	Crop	Irrigation amount in mm	Crop yield in t ha^{-1}	
			Conventional tillage (CT)	Minimum tillage (MT)
1989	Winter wheat	0	5.60	5.57
1990	Pea	0	5.08	4.36
1991	Winter barley	0	8.39	8.08
1992	Sorghum	0	2.96	2.67
1993	Spring barley	0	2.04	2.63
1994	Sugar beet	95	51.70	53.04
1995	Spring barley	0	5.20	4.88
1996	Winter wheat	0	3.68	3.47
1997	Grain maize	0	9.04	9.51
1998	Spring wheat	0	3.02	3.17
1999	Spring barley	0	5.43	3.76
2000	Winter wheat	0	3.00	2.69
2001	Sugar beet	100	63.21	63.32
2002	Spring wheat	0	2.72	3.08
2003	Grain maize	90	7.03	6.95
2004	Winter wheat	0	5.13	5.23
2005	Spring wheat	30	2.50	2.44
2006	Grain maize	70	7.16	5.35
2007	Winter wheat	40	3.64	3.86
2008	Sugar beet	60	71.53	54.86
2009	Spring barley	60	2.96	2.64
2010	Grain maize	15	7.61	5.80
2011	Winter wheat	25	3.33	3.57
2012	Winter barley	0	2.96	2.32