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Carbon pool in soil under organic and conventional farming systems

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Abstract: Changes in the agricultural management and climatic changes within the past 25 years have had a serious impact on soil organic matter content and contribute to different carbon storage in the soil. Prediction of soil carbon pool, validation, and quantification of different models is important for sustainable agriculture in the future and for this purpose a long-term monitoring data set is required. RothC-26.3 model was applied for carbon stock simulation within two different climatic scenarios (hot-dry with rapid temperature increasing and warm-dry with less rapid temperature increasing). Ten years experimental data set have been received from conventional and organic farming of experimental plots of Mendel University School Enterprise (locality Vatín, Czech-Moravian Highland). Average annual temperature in this area is 6.9°C, average annual precipitation 621 mm, and altitude 530 m above sea level. Soil was classified as Eutric Cambisol, sandy loam textured, with middle organic carbon content. Its cumulative potential was assessed as high. Results showed linear correlation between carbon stock and climatic scenario, and mostly temperature and type of soil management has influenced carbon stock. In spite of lower organic carbon inputs under organic farming this was less depending on climatic changes. Conventional farming showed higher carbon stock during decades 2000–2100 because of higher carbon input. Besides conventional farming was more affected by temperature.

Keywords: crop management and climatic scenarios; RothC-26.3 model; soil organic carbon

Current status and changes in soil organic carbon stock as response to agronomic and climatic conditions become extremely important today. There is an effective strategy to mitigate global climate change by increasing carbon stock in soil (Smith *et al.* 2010; Machmuller *et al.* 2015). The level and balance of soil organic carbon is also the main criterion of agricultural sustainability. The last depends

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on soil ability to maintain productive and other non-productive functions (biodiversity provision, hygienic, environmental etc.). In this way soil organic carbon is regarded as a key factor influencing both of them. Whether soils are a sink or source of carbon depends on the current organic carbon stock, agricultural practices over time, soil properties (e.g. clay content, soil depth, content and quality of plant and organic input, fertilizing etc.), and climatic conditions (Baldock & Skjemstad 1999; Song *et al.* 2014). As quoted De Liu *et al.* (2016) the amount of soil organic carbon that is attained under agriculture largely depends upon the carbon input and its decomposition rate under various agronomical practices. Today the agricultural measures encouraged soil conversion to the organic farming and minimum tillage technology, with aim to increase carbon stock in soil (Smith *et al.* 2007; Kaczynski *et al.* 2013). On the other hand, conventional and intensive farming, simplification of crop rotation cause the decreasing of carbon stock. Sustainable soil management systems require the proper choice of crop rotation system, agricultural technics, carbon stock, as well as a supply of nutrients to reach the higher productivity (King *et al.* 2005; Lamar *et al.* 2006). Lorenz and Lal (2005) stress that conventional analytical methods for measuring of total organic carbon (TOC) are expensive, time-consuming, and not always comparable. Viscarra Rossel *et al.* (2016) demonstrate using of spectroscopic and gamma attenuation sensors for TOC stocks estimating. For their validation and quantification long-term monitoring data set is required. Widely used models for carbon stock prediction are RothC 26.3, CENTURY, CANDY, and DAISY. They were validated in Europe for the period of 1990–2080 (Falloon *et al.* 1998, 2000; Pohanková *et al.* 2015). RothC model was originally developed and parametrized to model turnover of organic carbon in arable soil from Rothamsted long-term field experiments. Later it was extended to model turnover in grassland and woodland and operates in different soils and under different climates (Coleman *et al.* 1997; Smith *et al.* 1997, 2005, 2007; Keryn & Polglas 2004). It has also been set from an empirically-derived relationship between inert and total soil organic carbon content (SOC) (Falloon *et al.* 1998, 2000; Falloon & Smith 2002). Inert organic carbon was according to Jenkinson *et al.* (1987, 1999) defined as a fraction of soil organic matter that is biologically inert and has an equivalent radiocarbon age of more than 50 000 years. Besides inert organic carbon, total organic carbon includes relatively stable and labile carbon forms. Stable carbon forms are represented by carbon of humic acids, fulvic acids and humins (Stevenson 1994; Kučerík *et al.* 2007; Song *et al.* 2014). Humic substances can remain stored in the geosphere for thousands of years. Labile carbon forms are important from point of view soil biological activity. All of the organic carbon forms in soils are still not well studied and understanding of carbon sequestration is very important for evaluation of the global carbon cycle.

The aim of this study is to predict carbon sequestration under two different climatic scenario and crop management systems. Furthermore validation of RothC model for Cambisols, the most spread soil in the Czech Republic, is presented. Among the evaluated criteria are both quantitative and qualitative criteria of soil organic carbon.

MATERIAL AND METHODS

Field experiments have been continuously conducted at locality Vatín (Czech-Moravian Highland). This area belongs to the potatoes growing area with average annual temperature 6.9°C, average annual precipitation 621 mm, and altitude 530 m a.s.l. Original *Sanguisorba-Festucetum comutatae* grassland (native) was ploughed and two crop sequences were chosen – organic and intensive crop sequences. Organic crop sequence (OCS) was represented by 33.4% of cereals, 16.6% of root crops, 16.6% of technical crops, and 33.4% of fodder. Nutrients were applied according to ratios (N-P-K, kg/ha/year), and involved 90-30-80 to winter wheat and 40-30-60 to spring barley; however 60% of inputs were in the organic form utilizing farmyard manure. Intensive crop sequence (ICS) was characteristic by more intensive agriculture and an optimal level of chemical inputs (mineral fertilizers, pesticides), but without organic farmyard manure. It was represented by 50% of cereals, 16.6% of root crops, and 33.4% of technical crops. Nutrients were applied at ratios (N-P-K, kg/ha/year): 130-40-80 (winter wheat) and 60-35-80 (spring barley). A split plot method was used. Soil was sampled in the upper 0–20 cm Ap horizon twice a year (spring and autumn) during the period 1999–2016. The coordinates of soil profile were measured by Garmin Dakota 10 (Garmin International, Inc., USA) and are as follows: 49°31.091'N, 15°58.196'EO. Soil was classified according to the IUSS Working Group WRB (2015) as Eutric Cambisol. Horizon designation was done

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by Jahn *et al.* (2006). Basic soil characteristics were determined by commonly used standard methods (Zbíral *et al.* 2010). Soil reaction was determined by potentiometric method in distilled water and in 1M KCl solution (1 : 2.5). Particle size analysis was determined by the pipette method. Total organic carbon content was determined by oxidimetric titration method (Nelson & Sommers 1996). Fractional composition of humic substances was measured according to Kononova and Beltchikova method (1963, in: Pospíšilová *et al.* 2016). RothC-26.3 mode was set from an empirically-derived relationship between inert organic matter and total stock of organic carbon (Falloon & Smith 2002; Coleman & Jenkinson 2005). Four active organic carbon forms in soil (decomposable plant material = DPM, resistant plant material = RPM, microbial biomass = BIO, humified organic matter = HUM), and inert organic carbon (IOC) were recognized. The incoming plant carbon is split between DPM and RPM, depending on their ratio. The decomposition rate is modified as a function of temperature, moisture and soil cover. The main model's input data are as follows:

Climatic data – monthly rainfall (mm), monthly evapotranspiration (mm), monthly air temperature (°C),

Soil data – clay content (%), inert organic carbon content (%), initial organic carbon stock (t/ha), soil depth (cm),

Land use and management data – soil cover, monthly input of plant residues (t/ha), monthly input of organic manure (t/ha), residue quality factor (DPM/RPM ratio).

Climatic data were received from Meteorological station at Vatín. Monthly data were calculated as well as evapotranspiration using Pennmann quotation (Barančíková 2005; Barančíková *et al.* 2014). Simulation of soil organic carbon stock was calculated for two climatic scenarios: M2 – rapid rate of temperature increasing, M3 – less rapid increasing of temperature. Source of climatic scenarios (2000 to 2100) are up- to-data from two global circulation models HadGEM2 and MRI-CGCM3 selected from CMIP5 ensemble (Taylor *et al.* 2012) These projections were prepared using M&Rfi weather generator (used e.g. within Rötter *et al.* 2011) in connection with the Representative Concentration Pathway (RCP) 8.5 greenhouse gas concentration trajectory. Soil data were collected twice a year (spring and autumn) during the period 1999–2015 and calculated according to Falloon *et al.* (2000) and Falloon & Smith (2002) as follows:

$$\text{Initial SOC stock} = \text{SOC} \times \text{BD} \times \text{SD}$$

where:
SOC – soil organic carbon content (%)
BD – bulk density (g/cm^3)
SD – soil depth (cm)

The initial SOC content was used for running RothC model to equilibrium (10 000 years) under constant environmental conditions. Than the carbon inputs were fitted to match the initial SOC stock, DMP, RMP, BIO, and HUM with different decomposition rate. Organic carbon inputs of plant residues or farmyard manure were calculated according to Bielek and Jurčová (2010). Data of carbon and radiocarbon ages were received in equilibrium mode (initial soil state, initial radiocarbon age), and were applied to run model in short term mode (1999–2015), and for prediction in long term mode (2015–2100). Total differences between simulated and measured data were calculated according to Loague and Green (1991) as a root mean square error (RMSE).

RESULTS AND DISCUSSION

Studied Eutric Cambisol was loamy-sand textured, with acid soil reaction, low cation exchange capacity, and low soil colloidal complex saturation. Average measured values of SOC during field experiment 2006–2016 are showed in Figure 1. Humus content was satisfactory but its quality was low, with prevalence of fulvic acids ($C_{HA}/C_{FA} < 1$). Humification degree was less than 25%. Soil contains no carbonates. Comparison of soil properties under both studying cropping systems (organic and intensive) is showed in Table 1 and 2. Organic crop sequence was represented by 33.4% of cereals, 16.6% of root crops, 16.6% of

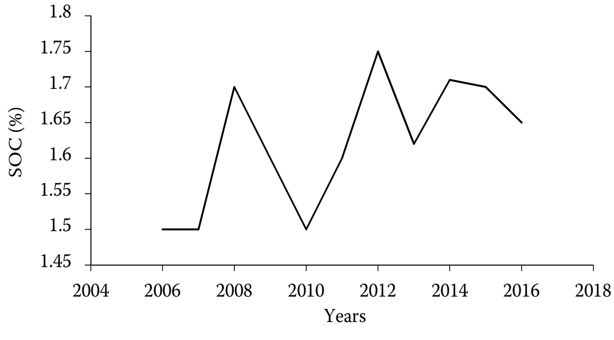

Figure 1. Measured average carbon content in 0–0.20 m during 2006–2016
SOC – soil organic carbon content

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Table 1. Basic physical and chemical properties of Eutric Cambisol

Eutric Cambisol	pH*		CEC	V	Clay content
	H_2O	KCl	(cmol/100g)	(%)	
OCS	5.5	4.5	14.2	63.4	22.2
ICS	5.3	4.3	15	63.3	22

*pH/H_2O – active soil reaction, pH/KCl – exchangeable soil reaction; CEC – cation exchange capacity; V – saturation of soil colloidal complex; OCS – organic crop sequence; ICS – intensive crop sequence

Table 2. Average content of total organic carbon and fractional composition of humic substances in Eutric Cambisol

Eutric Cambisol	TOC (%)	Σ HS	Σ HA	Σ FA	HA/FA	HD (%)
		(g/kg)				
OCS	2	4.5	2	2.5	0.8	22.5
ICS	1.8	4.5	2	2.5	0.8	25

TOC – total organic carbon; HS – humic substances; HA – humic acids; FA – fulvic acids; HD – humification degree; OCS – organic crop sequence; ICS – intensive crop sequence

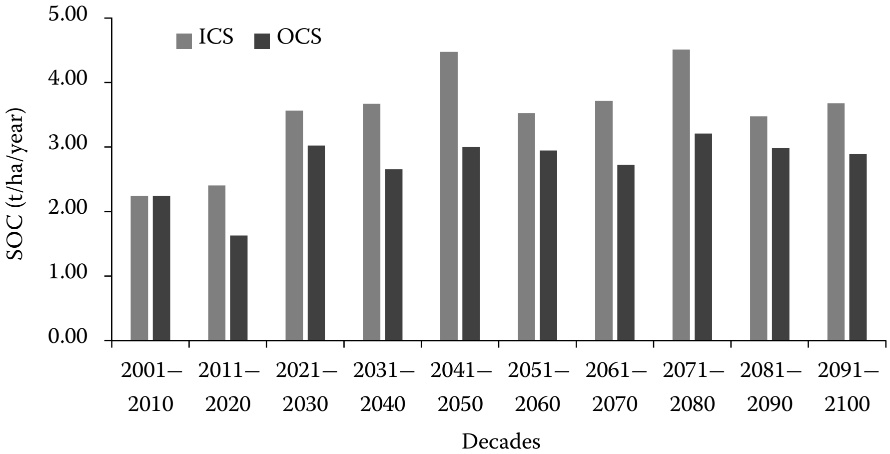

Figure 2. Projected average carbon input (t/ha/year) 0–0.20 m under different management scenario for decades
SOC – soil organic carbon content; OCS – organic crop sequence; ICS – intensive crop sequence

technical crops, and 33.4% of fodder. Intensive crops sequence was represented by 50% of cereals, 16.6% of root crops, and 33.4% of technical crops. Results showed slightly higher quality of humus and soil colloidal complex saturation, and less acidity after ten years of organic farming. Both of them differ in the overall amount of postharvest remains and straw passing every year into the soil. Higher input of plant residues was under ICS management and therefore projected total organic carbon is higher – Figure 2. Typical average yield of grown plants during the selected period is listed in Figure 3. As quoted Tesařová *et al.* (2006) sum of stubble straw and root residues passing every year into the soil at this locality has reached 5.6–3.97 t/ha for winter wheat and spring barley. The postharvest residua of both crops involved 20–30% of the roots. No relationship was found between the total amount of postharvest residua and yields. Root remains of cereals were decomposed under field conditions substantially more slowly than the straw. The decomposition rate was higher under organic farming system. Validation of RothC-26.3 model was done using data from organic farming and calculated RMSE (mean quadratic standard deviation) was 14.90%. Literature data for long-term field experiments are between 2–30% (Smith *et al.* 1997, 2005, 2007; Falloon & Smith 2002; Barančíková *et al.* 2014). Measured data of soil organic carbon content under organic farming are in good accordance with simulated data.

As it was mentioned before for projection of soil organic carbon content during the period of 2000–2100 we used data from HadGEM2 and MRI-CGCM3

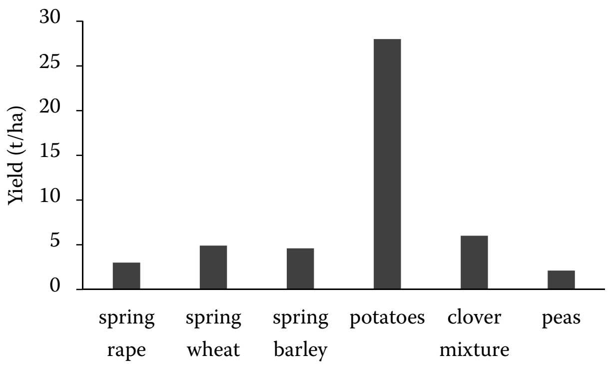

Figure 3. Typical average yield of grown plants at studied locality (intensive crop sequence; t/ha)

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Table 3. Temperature simulating over the decades for two climatic scenarios in connection with RPC 8.5

Decades	T (°C)	
	HadGEM2	MRI-CGCM3
2001–2010	7.54	7.54
2011–2020	8.30	8.08
2021–2030	8.43	7.93
2031–2040	8.87	8.18
2041–2050	9.86	8.95
2051–2060	10.20	9.05
2061–2070	11.06	9.66
2071–2080	11.90	10.26
2081–2090	12.38	10.48
2091–2100	13.34	11.21

HadGEM2 – hot-dry scenario; MRI-CGCM3 – warm-dry scenario

models – Table 3. Model's input data are listed in Table 4. Simulated prognosis of carbon stock in short term mode (1999–2015) and long term mode (2015–2100) indicated that at the beginning of the simulated period simulation soil organic carbon content was decreasing. Later (after 2020) higher SOC stock under intensive farming was obtained – Figure 4. Accumulation ability of Eutric Cambisol was evaluated as high and confirmed that type of land management is an important factor influencing soil organic carbon stock (Figures 4 and 5). It should be also stressed that besides crop management and climatic scenario plant input and microbial activity are very important factors as well. In Figure 4 it is showed simulated amount of SOC stock for decades under organic and intensive farming systems (OCS-M2 – organic crop sequence, hot-dry with rapid temperature changes, OCS-M3 – organic crop sequence, warm-dry with less rapid temperature changes, ICS-M2 – intensive crop sequence, hot-dry with rapid temperature changes, ICS-M3 – intensive crop system, warm-dry with less rapid temperature increasing). We can conclude that different farming systems on the same soil type lead to a completely different soil organic carbon stocks. In our case,

Table 4. Development of carbon input under different agronomic scenario over the decades (in t/ha/year)

Decades	ICS			OCS		
	carbon of PlantRes	carbon of FYM	sum	carbon of PlantRes	carbon of FYM	sum
2001–2010	1.34	0.91	2.25	1.34	0.91	2.25
2011–2020	1.95	0.45	2.4	1.63	0	1.63
2021–2030	2.43	1.13	3.57	1.94	1.08	3.02
2031–2040	2.42	1.25	3.67	2.01	0.65	2.66
2041–2050	2.89	1.59	4.48	1.84	1.16	3.00
2051–2060	2.39	1.13	3.52	1.85	1.08	2.95
2061–2070	2.47	1.25	3.72	2.07	0.65	2.72
2071–2080	2.92	1.59	4.51	2.07	1.14	3.21
2081–2090	2.34	1.13	3.48	1.90	1.08	2.98
2091–2100	2.43	1.25	3.68	2.24	0.65	2.89

ICS – intensive crops sequence; OCS – organic crop sequence; PlantRes – plant residue; FYM – fytomass

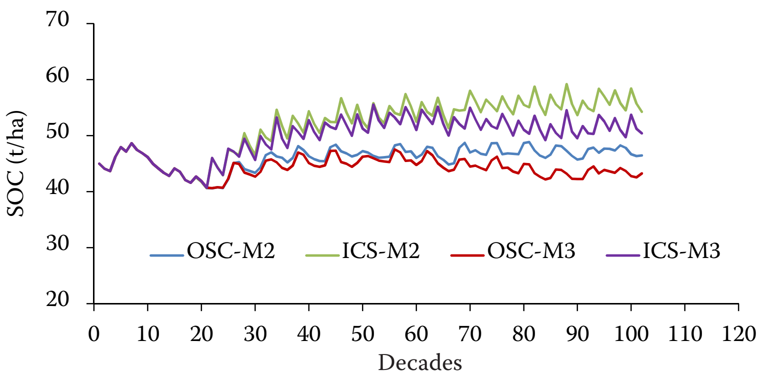

Figure 4. Projected development of soil organic carbon content (SOC) stock in 0–0.20 m for the period 1991–2100
OCS-M2 – organic crop sequence with hot-dry climatic scenario; OCS-M3 – organic crop sequence with war-dry climatic scenario; ICS-M2 – intensive crop sequence with hot dry climatic scenario; ICS-M3 – intensive crop system with warm-dry climatic scenario

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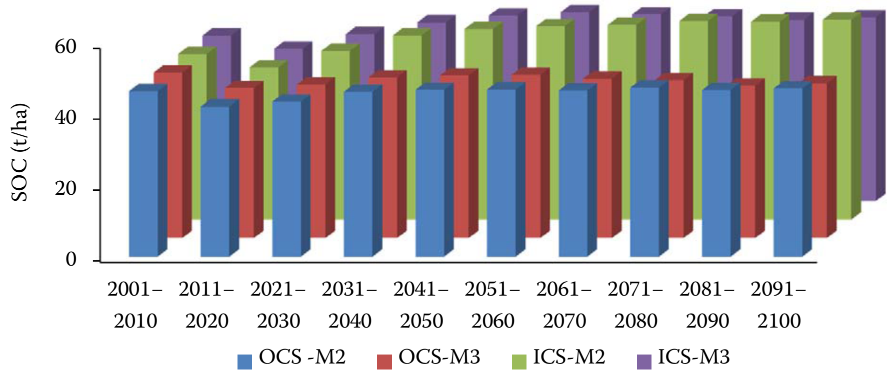

Figure 5. Average carbon stock (t/ha) in 0–0.20 m under different management and climatic scenario for decades
OCS-M2 – organic crop sequence and rapid temperature changes; OCS-M3 – organic crop sequence and less rapid temperature changes; ICS-M2 – intensive crop sequence and rapid temperature changes; ICS-M3 – intensive crop system and less rapid temperature increasing; SOC – soil organic carbon content

intensive farming because of higher plant residues input and lower mineralization rate was presented by higher soil organic carbon stock. Organic farming showed higher mineralization rate, and lower organic carbon stock during the projected period. Correlation coefficient between SOC stock and temperature (HadGEM2; hot-dry climatic scenario) was 0.65 in organic farming system. ICS at the same climatic scenario had correlation coefficient 0.76. Similar results were received for the MRI-CGCM3 (warm-dry) climatic scenario. Correlation coefficient R = 0.76 was reached for intensive farming and R = 0.71 for organic farming. Obtained results also confirmed that despite of lower carbon stock in soil under organic farming this management is less influence by climatic conditions to compare with intensive farming system.

CONCLUSION

Carbon sequestration in soil is an effective strategy to mitigate global climate change. High accumulation potential of carbon in Eutric Cambisol was determined. In spite of less carbon input organic farming was more stable to compare with intensive farming. Intensive farming system was much more effected by climatic condition and plant residues input. Application of RothC-26.3 is a useful tool for carbon stock projection in the long- and short-term mode.

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