A CENTURY 5 Model Using for Estimation of Soil Organic Matter Behaviour at Predicted Climate Change

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Abstract: The trends of carbon sequestration behaviour have been estimated for the most fertile soil type of Slovakia based on the prognosticated regional climate change scenario. The processes were modelled and simulated by CENTURY 5 model to provide these inputs: predicted information about quantification of carbon and nitrogen fluxes, and primary net of organic matter production. Soil conditions were represented by the soil type calcareous Haplic Chernozem (Danubian lowland), and the climatic scenario was related to the meteorological station Hurbanovo modelled for the period of 2005–2090. The dynamics of soil carbon and nitrogen was assessed using a conventional cropping system, concretely for 5-years crop rotation winter wheat – maize – oats (feed) – alfalfa – alfalfa modified into two alternatives: with fertilisation and without irrigation (ALT1), and excluding fertilisation and irrigation (ALT2). The model CENTURY 5 provides the simulation of three soil organic matter pools: the active (labile) pool (C_L), the slow (sequestration) pool (C_S), and the passive (resistant) pool (C_P). The results of the model simulation for the conventional crop rotation predict that the supplies of active and slow SOM pools (C_L, C_S) do not show any statistically significant decreasing tendency in relation to the expected climate scenario. A moderately linear decreasing trend is expected with the passive SOM pool (C_P), however, this decreasing tendency is not recognised during total carbon running (C_{TOT}). I.e., in the future conventional crop-rotation farming no significant climate change impacts on total carbon sequestration will be presumed. In the case of ALT1, the model shows a gradual but very moderate decrease mainly with C_S pool, and in that of ALT2 a significant decreasing trend is recognised with all SOM pools, mainly with C_S pool. Amazing is the finding that in the case of non-irrigated but fertilised cropping system (in dry weather), the anticipated significant decrease in carbon sequestration was not observed, however, more drastic changes can be predicted in the non-fertilised and non-irrigated alternative. The average aboveground live carbon and belowground live carbon in both alternative cropping systems in relation to the conventional one have been compared. It was, estimated: in ATL1, that the primary net of organic matter decreased by almost 38% (aboveground live C) and by 43% (belowground live C), and in ALT2 by 43% (aboveground live C) and 45% (belowground live C), respectively. All these findings can be considered as the modelling outputs at the given input data, not as a firmly confirmed prognosis. Nevertheless, the achieved results of CENTURY 5 modelling assume that in the case of sufficient fertilisation and irrigation with well-managed cropping rotation practice under fertile soil conditions of Slovakia, no serious changes in carbon supplies in all SOM pools can be expected.

Keywords: carbon sequestration; CENTURY 5 model; climate change; modelling; regional climate scenario

The prediction of soil organic carbon and nitrogen fluxes can be considered as most interesting at the present time. The behaviour of carbon sequestration in the predicted climatic change can be a very important indicator of the future farmland development and can serve as the crucial tool for the decision makers and planners to insure proper mitigation measures. The prognosis linked to carbon sequestration reflects the trends in the nutrient regime, production, and ecological capacity of soils. The modelling and simulation of these processes are one of the most preferred tools to anticipate possible impacts of the climate change on the soils and farmland. Model CENTURY 5 of the authors Parton *et al.* (1987), Parton *et al.* (1992), and Metherell *et al.* (1993) is the last version of agro-eco-systems adaptation and is continuously modified into version 5.0. The ambition of this model is to provide systematic analysis of global changes (as climate change) connected with alternatives in landscape use in the long-term range. CENTURY model simulates long-term dynamics of carbon (C), nitrogen (N), phosphorus (P) and sulphur (S) for various soil-plant systems, i.e. it is able to simulate the dynamics of grassland, farmland, forest systems, and savannas. These systems are interconnected by the submodel of soil organic matter (SOM) in what are integrated effects of the climate parameters, soil properties, as well as the impacts of various farmland practices in the soil – plant system.

The model comprehends and registers the applications in many countries, e.g. Sanford *et al.* (1991), Gijsman *et al.* (1996). Specific attention paid to the soil organic matter estimation or carbon behaviour (as submodel) can be found e.g. by Parton *et al.* (1987), Cole *et al.* (1989), Carter *et al.* (1993), Parton *et al.* (1994), Patwardhan *et al.* (1995), and others. A comparison between the CENRURY and RothC models was also made (Falloon & Smith 2002). CENTURY 5 submodel modelling soil organic matter (SOM) is its first application in Slovakia. The model is formatted in linguistic communication C++ for Windows users and available on website. Regional climate change scenario (needed for the climate change prediction) was modelled especially for Danubian lowland climate conditions (Lapin & Melo 2004; Lapin 2004).

MATERIAL AND METHODS

The submodel of soil organic matter (SOM) simulates the fluxes of C, N, P, and S via plant residues and various organic and inorganic forms (pools) in soil. The scenario of CENTURY 5 simulates three soil organic carbon pools considered as carbon sequestration indicators. They are: (i) active SOM pool (C_L), (ii) slow SOM pool (C_S) and (iii) passive SOM pool (C_P) with various potential rates of decomposition. The active (labile) SOM pool (C_L) includes labile products of microbial decomposition which persist for several months. The supplies of low (weakly active) SOM pools C_S include resistant material derived from lignin base and stabilised products of microbial decomposition present (this pool is denoted as sequestration carbon lasting for several decades). The supplies of passive SOM pool C_P contain organic substances very resistant to microbial decomposition with firm organic-mineral bonds; the existence of which persists for several thousand years.

The input data for the CENTURY model can be distinguished into three groups: (i) meteorological (climatic) inputs, (ii) soil inputs, and (iii) inputs from the farmland practice.

The regional climatic change scenario, representing dry and warm climate conditions of Danubian lowland (hydro-meteorological station Hurbanovo), was used as climatic parameters (Lapin *et al.* 2003; Lapin & Melo 2004; Lapin 2004). It includes individual scenarios of air temperature, the sum of precipitations, air humidity, and global radiation in monthly time series in the period of 2001–2090. This scenario is the output of two GCMs (General Circulation Model) scenarios: CCCM2000 (Canadian Centre for Climate Modelling), and GISS 1998 (Goddard Institute for Space Studies at NASA). As the standard period for the reference climatic parameters modelling was chosen the time series 1901–1990 using IS92a emission scenario up to the year 2100. According to Lapin (2004), the climate change scenario cannot be perceived as "prognosis", but only as the time series modelling of climatic parameters founded on healthy scientific principles.

The soil situation has been represented by the soil profile 400130 (Pribeta village near Komárno) chosen from the "Partial soil monitoring database" (Kobza *et al.* 2002) as a representative of the typical soil in Danubian lowland conditions with a dry and warm climate. The soil is very fertile and well conditioned, classified as loamy calcareous Haplic Chernozem (IUSS-ISRIC-FAO 2006) and developed from terraced sandy loess with well-formed and structured mollic horizon and a favourable air-water regime. Soil properties were estimated in regard to the model postulates and the units were indicated in compliance with Metherell *et al.* (1993). The soil profile was subdivided into 10 subhorizons

Table 1. Conventional cropping system (wheat – maize – oat – alfalfa – alfalfa)

Year	Month	Farmland practice	Description
R1	M1	crop (oat)	oat
R1	M3	fertilisation (N5)	5 g N/m^2
R1	M3	cultivation (herbicide)	
R1	M3	cultivation (cultivator)	
R1	M3	seeding	
R1	M3	germination	
R1	M5	fertilisation	5 g N/m^2
R1	M6	haymaking (hay)	residues 25%
R1	M6	end of cropping (oat)	
R1	M7	cultivation (tillage)	
R1	M7	cultivation (cultivator)	
R1	M7	crop (alf)	alfalfa
R1	M7	seeding	
R2	M5	haymaking (hay)	residues 25%
R2	M6	irrigation	5 cm
R2	M8	haymaking (hay)	residues 25%
R2	M8	irrigation	5 cm
R2	M9	haymaking (hay)	residues 25%
R3	M5	haymaking (hay)	residues 25%
R3	M6	irrigation	5 cm
R3	M8	haymaking (hay)	residues 25%
R3	M8	end of cropping (alf)	
R3	M9	fertilisation (PS1)	125 kg superphosphate/ha
R3	M9	cultivation (tillage)	
R3	M9	crop (W2)	winter wheat
R3	M9	cultivation (cultivator)	
R3	M10	cultivation (herbicide)	
R3	M10	seeding	
R3	M11	germination	
R4	M3	fertilisation (N3)	3 g N/m^2
R4	M4	fertilisation (N3)	3 g N/m^2
R4	M5	fertilisation (N3)	3 g N/m^2
R4	M7	harvest (G75)	residues 25% of straw
R4	M7	end of cropping (W2)	
R4	M8	cultivation (cultivator)	
R4	M9	fertilisation (manure)	40 t/ha
R4	M9	fertilisation (PS1)	125 kg superphosphate/ha
R4	M9	cultivation (tillage)	
R5	M1	crop (C3)	grain maize
R5	M4	fertilisation (N10)	10 g N/m^2
R5	M4	cultivation (cultivator)	
R5	M4	cultivation (herbicide)	
R5	M4	seeding	
R5	M5	germination	
R5	M5	cultivation (row)	drill cultivator
R5	M6	irrigation	5 cm
R5	M6	cultivation (row)	drill cultivator
R5	M6	fertilisation (N10)	10 g N/m^2
R5	M7	irrigation	5 cm
R5	M10	harvest (G75)	residues 25% of bark
R5	M10	end of cropping (C3)	
R5	M11	fertilisation (PS1)	125 kg superphosphate/ha
R5	M11	cultivation (tillage)	

(thickness 10 cm) in which hydro-physical properties were generated for each interval using model ROSETTA (Schaap 2000).

Dynamics of soil organic carbon and nitrogen has been evaluated in regard to the presumed farming system, more precisely for 5-years crop rotation: winter wheat – maize – oat (fodder) – alfalfa – alfalfa. The detailed schedule of agriculture practices as conventional crop rotation (KONV) is presented in Table 1. This cropping system was suggested in respect to the possibilities of the CENTURY 5 (list of crops) aiming at presenting real farming conditions.

The conventional cropping system was modified into two alternatives: alternative 1 (ALT1): with nitrogen and phosphorus fertilisation excluding irrigation, and alternative 2 (ALT2): excluding fertilisation and irrigation. The comparison of both cropping alternatives allows an assessment of the expected changes in carbon sequestration in relation to supplementary inputs requirement into soil (fertilisation, irrigation). Their weighting in the simulation can also be deduced. For the estimation of the initial values of organic carbon and nitrogen in soil and plant residues, we used the data published in Barančíková (1998), Jurčová (2001), and Kobza *et al.* (2002).

RESULTS AND DISCUSSION

Initiation of input data and preliminary simulation

The running of the climatic parameters in the preliminary stage of simulation was stochastically generated from the data gained from the period 1961–1990 (Table 2) using the generator which is a component part of the model.

The input data (in some cases these were only estimates) were optimised for the conventional

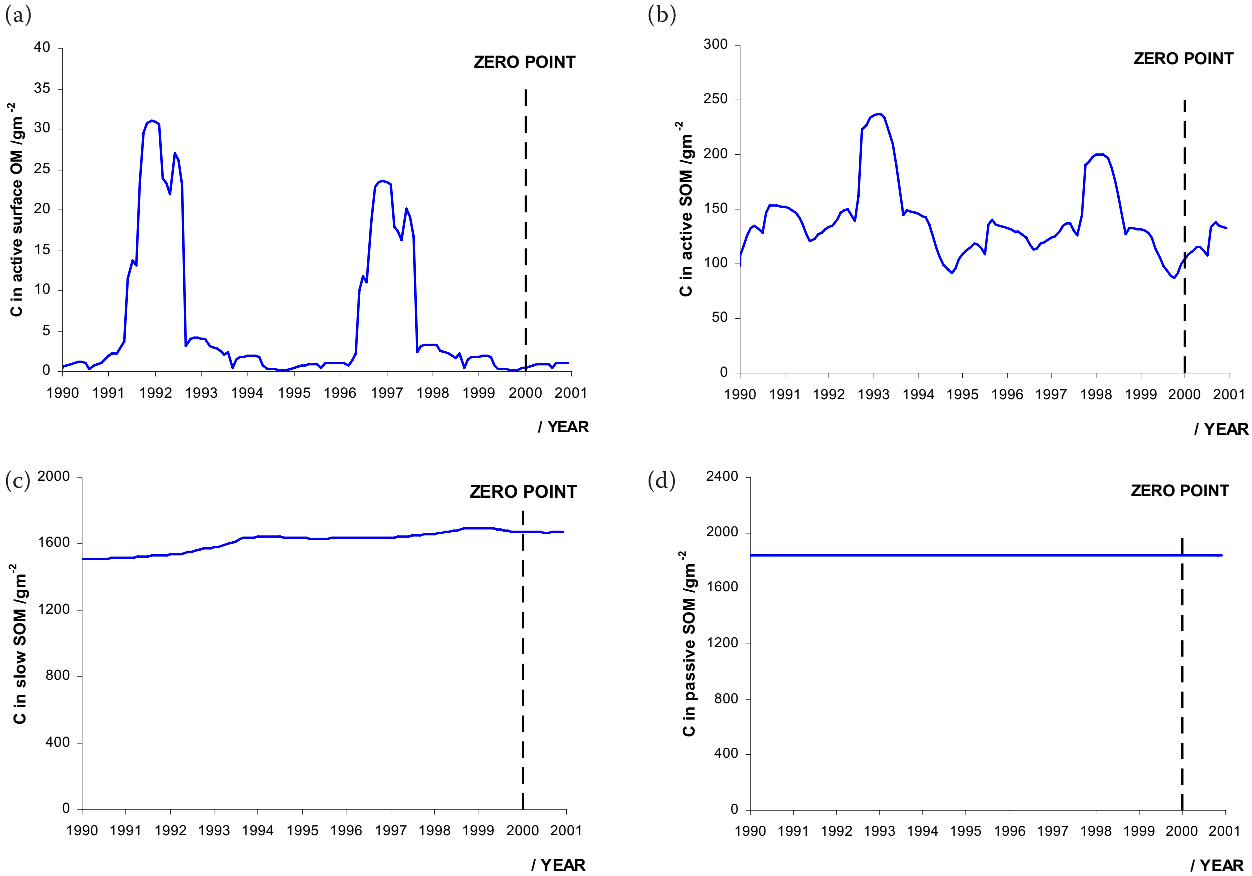

Figure 1. Optimalisation of initial values of organic matter fractionation by means of preliminary simulation for period 1990–2000 (conventional cropping system)

(a) active pool C in surface organic matter; (b) active pool C in soil organic matter; (c) slow pool C in soil organic matter; (d) passive pool C in soil organic matter

Table 2. Statistical indicators of the average sum of precipitations (in cm) in months at the hydrometeorological station Hurbanovo (1961–1990)

	Mean	–95%	95%	Min	Max	Range	Var.	Standard Deviation	Skewness	Kurtosis
JAN	3.32	2.65	3.99	0	6.3	6.3	3.23	1.797	–0.256	–1.00
FEB	3.33	2.48	4.17	0.1	8.7	8.6	5.15	2.270	0.719	–0.22
MAR	2.72	2.23	3.21	0.5	6.4	5.9	1.73	1.316	0.343	0.75
APR	3.87	3.10	4.64	1.1	7.8	6.7	4.26	2.064	0.471	–1.13
MAY	5.64	4.31	6.97	0.3	14.3	14	12.65	3.556	0.803	0.07
JUN	5.80	4.89	6.71	1.5	10.4	8.9	5.99	2.447	0.192	–1.05
JUL	5.18	3.93	6.42	0.9	16.6	15.7	11.17	3.342	1.610	3.73
AUG	5.77	4.45	7.09	0.6	14.6	14	12.47	3.531	0.754	0.55
SEP	3.92	2.87	4.96	0.1	9.9	9.8	7.83	2.799	0.600	–0.72
OCT	3.26	2.16	4.36	0.1	13	12.9	8.64	2.940	1.870	3.91
NOV	5.36	403	6.70	1.6	15.7	14.1	12.80	3.578	1.282	1.20
DEC	3.96	3.23	4.69	0.6	8.7	8.1	3.84	1.960	0.027	–0.36

farming practice by 10-year preparatory simulation (1990–2000). The outputs were fed as the harmonised input into the model CENTURY 5 dating from 2001 in compliance with the start of the crop rotation. The set of the optimised input soil parameters is presented in Table 3. The preliminary simulation is presented in Figure 1.

At the primary initiation in the preliminary simulation, an abrupt change occurred in modelling SOM pools sequestration, which could be observed until the year 2005. This is evidence for the autonomous initiation of the model. This phenomenon can be caused by relatively great differences in the climatic parameters between the climate data series in 1961–1990 and those in 2001–2090, both at Hurbanovo. Therefore, the balance of the individual pools SOM were analysed from the year 2005.

Trend analysis of SOM pools for the period of 2005–2090

Statistical evaluation of the linear trend in the individual SOM pools contents is shown in Table 4. The evaluation was made for the conventional and two alternative farmland-practice simulations for the period of 2005–2090. As statistically significant are recognised the results at the significance level 0.01.

The simulation results of CENTURY 5 for the individual SOM pools are illustrated for conventional farmland practice (KONV) in Figure 2, for alternative 1 (ALT1) in Figure 3, and for alternative 2 (ALT2) in Figure 4.

Figures analysis made for conventional farmland practice (Figure 2) indicates that the supplies of the active and slow SOM pools (C_L, C_S) show no statistically significant trend in regard to the climate scenario. A moderately decreasing trend is indicative of the passive SOM pool (C_P), however, with total organic carbon (C_{TOT}) this trend is not recognised. This means that in the conventional farmland practice no significant impact of the climate change can be expected.

In the case of the simulated fertilised and non-irrigated cropping system (ALT1), the model shows a gradual but very moderate decrease in the total organic carbon supply during the simulation period (Figure 3). This tendency can be caused, first of all, by a decrease in the slow SOM pool (C_S). Although this trend is slight, regarding the long-term aspect beyond the year 2090, a more serious decrease of total carbon sequestration can be predicted.

On one side, it is amazing that in the passive SOM pool (C_P) in ALT1 assuming dry climate conditions, no decrease of soil carbon was recognised (Figure 3c). The model CENTURY 5 even presumes a slight increase of organic carbon supplies in the period of 2005–2090 by comparing the data of the conventional cropping system: on average, about 1.6% at C_L, 3.3% at C_S, 0.2% at C_P, and about 1.8%

Table 3. Input soil data (Haplic Chernozem – soil profile 400130) using for model CENTURY 5

Initial soil parameters :	BULK(1): 1.13	AWILT(10): 0.100	RCELIT(1.1): 41
	BULK(2): 1.13	AFIEL(1): 0.281	RCELIT(1.2): 188
IVAUTO: 0	BULK(3): 1.13	AFIEL(2): 0.281	RCELIT(2.1): 68
NELEM: 2	BULK(4): 1.25	AFIEL(3): 0.281	RCELIT(2.2): 243
SAND(1): 0.325	BULK(5): 1.25	AFIEL(4): 0.286	AGLCIS(1): 0
SAND(2): 0.325	BULK(6): 1.25	AFIEL(5): 0.286	AGLIVE(1): 0
SAND(3): 0.325	BULK(7): 1.25	AFIEL(6): 0.286	AGLIVE(2): 0
SAND(4): 0.313	BULK(8): 1.25	AFIEL(7): 0.286	BGLCIS(1): 0
SAND(5): 0.313	BULK(9): 1.35	AFIEL(8): 0.286	BGLIVE(1): 0
SAND(6): 0.313	BULK(10): 1.35	AFIEL(9): 0.320	BGLIVE(2): 0
SAND(7): 0.313	THICK(1): 10	AFIEL(10): 0.320	STDCIS(1): 0
SAND(8): 0.313	THICK(2): 10	PH: 7.9	STDEDE(1): 0
SAND(9): 0.283	THICK(3): 10	PSLSRB: 1.5	STDEDE(2): 0
SAND(10): 0.283	THICK(4): 10	SORPMX: 34	
SILT(1): 0.455	THICK(5): 10		Initial parameters of mineral N. P:
SILT(2): 0.455	THICK(6): 10	Initial parameters of organic matter:	
SILT(3): 0.455	THICK(7): 10		MINERL(1.1): 0.25
SILT(4): 0.454	THICK(8): 10	SOM1CI(1.1): 0.61	MINERL(1.2): 35.4
SILT(5): 0.454	THICK(9): 10	SOM1CI(2.1): 108.6	PARENT(2): 50
SILT(6): 0.454	THICK(10): 10	SOM2CI(1): 1860	SECNDY(2): 27.8
SILT(7): 0.454	NLAYER: 9	SOM3CI(1): 1836	
SILT(8): 0.454	NLAYPG: 8	RCES1(1.1): 16	Initial parameters of water content:
SILT(9): 0.488	DRAIN: 0.5	RCES1(1.2): 50	
SILT(10): 0.488	BASEF: 0.19	RCES1(2.1): 10	RWCF(1): 0.037
CLAY(1): 0.220	STORMF: 0	RCES1(2.2): 50	RWCF(2): 0.0001
CLAY(2): 0.220	AWILT(1): 0.110	RCES2(1): 13	RWCF(3): 0. 0001
CLAY(3): 0.220	AWILT(2): 0.110	RCES2(2): 100	RWCF(4): 0.243
CLAY(4): 0.233	AWILT(3): 0.110	RCES3(1): 7	RWCF(5): 0.280
CLAY(5): 0.233	AWILT(4): 0.105	RCES3(2): 50	RWCF(6): 0.280
CLAY(6): 0.233	AWILT(5): 0.105		RWCF(7): 0.290
CLAY(7): 0.233	AWILT(6): 0.105	Initial parameters of plant residues:	RWCF(8): 0.290
CLAY(8): 0.233	AWILT(7): 0.105		RWCF(9): 0.290
CLAY(9): 0.229	AWILT(8): 0.105	CLITTR(1.1): 5.5	RWCF(10): 0.400
CLAY(10): 0.229	AWILT(9): 0.100	CLITTR(2.1): 207	

at C_{TOT}, respectively. Nevertheless, this increase can be considered as a result of a very fast primary initiation of compounds inside the model in the simulated period of 2001–2005. The individual SOM pools were quickly stabilised to the balance with a low decomposition factor (which is the function of soil humidity and temperature). The CENTURY model assumes a decrease of the decomposition factor in both alternatives (ALT1, ALT2) approximately by about 30% as compared to the conventional one.

On the other side, we can take into account the hypothesis that the prolongation of the dry period and the shortening of the period with intensive microbial decomposition, the exclusion of irrigation and farming on calcareous soils can condition

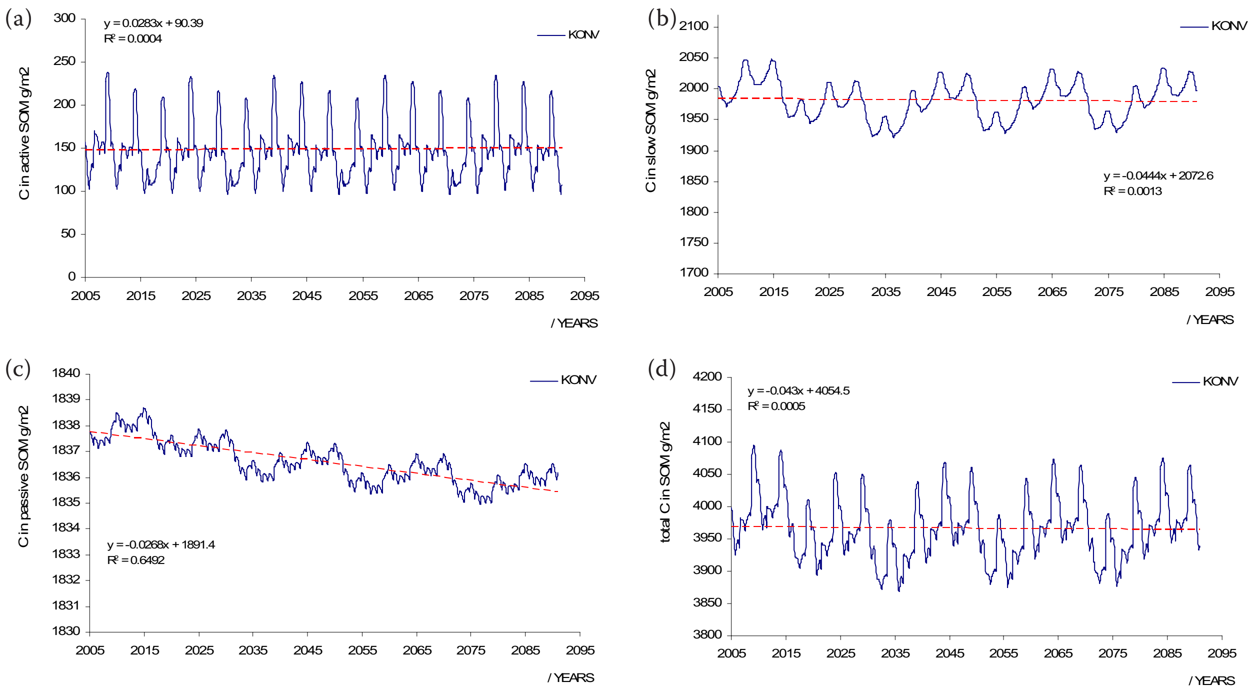

Figure 2. Simulation results of CENTURY 5 for individual SOM pools at conventional farmland practice (KONV)

(a) active carbon; (b) slow carbon; (c) passive carbon; (d) total carbon

stabilisation of organic matter of chernozemic type incl. humine acids. The question is to what extent are these ideas close to reality as well as the results of the inner model calibration. In any case, these changes are slight and the omission of irrigation cannot affect organic carbon supplies into soil.

The simulated exclusion of fertilisation (with nitrogen and phosphorus) and irrigation from the cropping system (ALT2) can provoke a significantly

Table 4. Statistical analysis of linear trend in individual SOM pools contents in time interval 2005–2090

Alternative		β	SE(β)	A	SE(A)	B	SE(B)	*p*-level
KONV	C_L	0.021	0.0311	0.0282	0.0417	90.39	85.521	0.4984
KONV	C_S	–0.036	0.0311	–0.0444	0.0382	2072.6	78.283	0.2451
KONV	C_P	–0.806***	0.0184	–0.0267	0.0006	1891.4	1.256	< 0.0001
KONV	C_{TOT}	–0.022	0.0311	–0.0429	0.0606	4054.4	124.18	0.4788
ALT1	C_L	–0.086***	0.0310	–0.0810	0.0291	316.63	59.78	0.0056
ALT1	C_S	–0.451***	0.0278	–0.4689	0.0289	3008	59.21	< 0.0001
ALT1	C_P	0.675***	0.0230	0.0134	0.0004	1812.3	0.936	< 0.0001
ALT1	C_{TOT}	–0.354***	0.0291	–0.5365	0.0441	5137	90.37	< 0.0001
ALT2	C_L	–0.018	0.0311	–0.0158	0.0277	175.4	56.86	0.5673
ALT2	C_S	–0.588***	0.0252	–0.7377	0.0316	3472.3	64.75	< 0.0001
ALT2	C_P	–0.989***	0.0045	–0.0792	0.0003	1997.3	0.740	< 0.0001
ALT2	C_{TOT}	–0.489***	0.0272	–0.8328	0.0463	5645	94.78	< 0.0001

β – correlation coefficient; SE – standard error; A, B – regression parameters Y = AX + B; *p*-level – statistical significance of regression result

***statistically significant results at the significance level 0.01

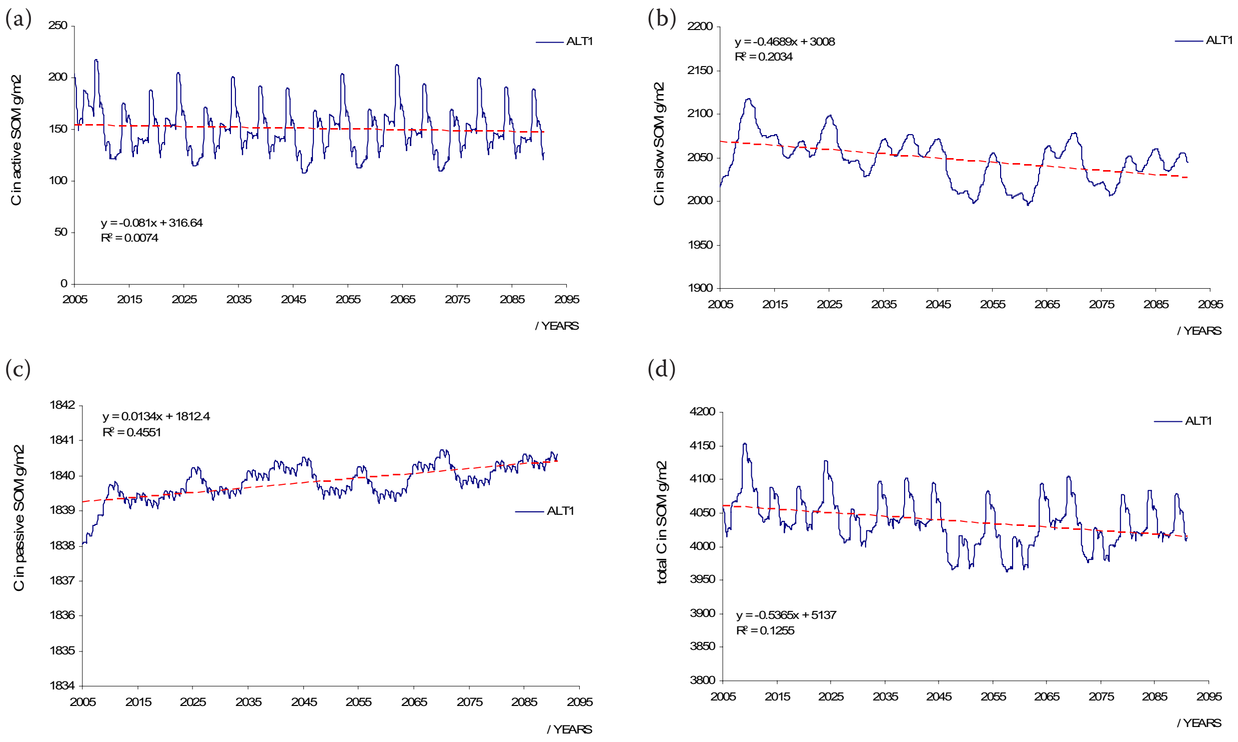

Figure 3. Simulation results of CENTURY 5 for individual SOM pools in fertilised and non-irrigated alternative of farmland practice (ALT1)

(a) active carbon; (b) slow carbon; (c) passive carbon; (d) total carbon

decreasing tendency in carbon sequestration in all SOM pools, mainly in the slow and passive ones.

Balance of aboveground C live and belowground C live for 2005–2090 period

In Figure 5, the balance is illustrated of aboveground C live and belowground C live in the period of 2005–2090. The average contents of carbon in aboveground and belowground live were compared in both alternatives of the cropping system to the conventional one. It is apparent that in the alternative ALT1 (fertilised and non-irrigated) the average carbon content in aboveground C live decreased by about 38%, and in belowground C live by about 43% as compared to the conventional cropping system. In the alternative ALT2 (non-fertilised and non-irrigated) serious changes were also found. The decrease of carbon inputs ranged at about 45% for the root residues, and about 43% for the aboveground biomass. According to the CENTURY 5 scenario, we can expect a rapid decline of biomass in both alternatives considered. Mainly the nutrient deficiency can cause a markedly decreasing trend in the organic carbon supplies, especially in the slow active and passive SOM pools.

CONCLUSION

The results of the CENTURY 5 modelling are partly in compliance with the results published by Parton *et al.* (1987), Cole *et al.* (1989), Metherell *et al.* (1993), and Parton *et al.* (1994), mainly as concerns the tendency, in the individual SOM pools behaviour in the temperate climate zone. The total comparison cannot be done because the climatic and pedological input data are different, also the farming practice is dissimilar, i.e. the soil-climatic parameters are defined for very specific milieu. It means that the overall procedure for the model simulation is very sensitive to the input data and any interpretations of the modelling results are relevant for a particular soil type and its use only.

At last, we can point out that in the case of the conventional farmland practice and supplementary irrigation at chosen crop rotation, model

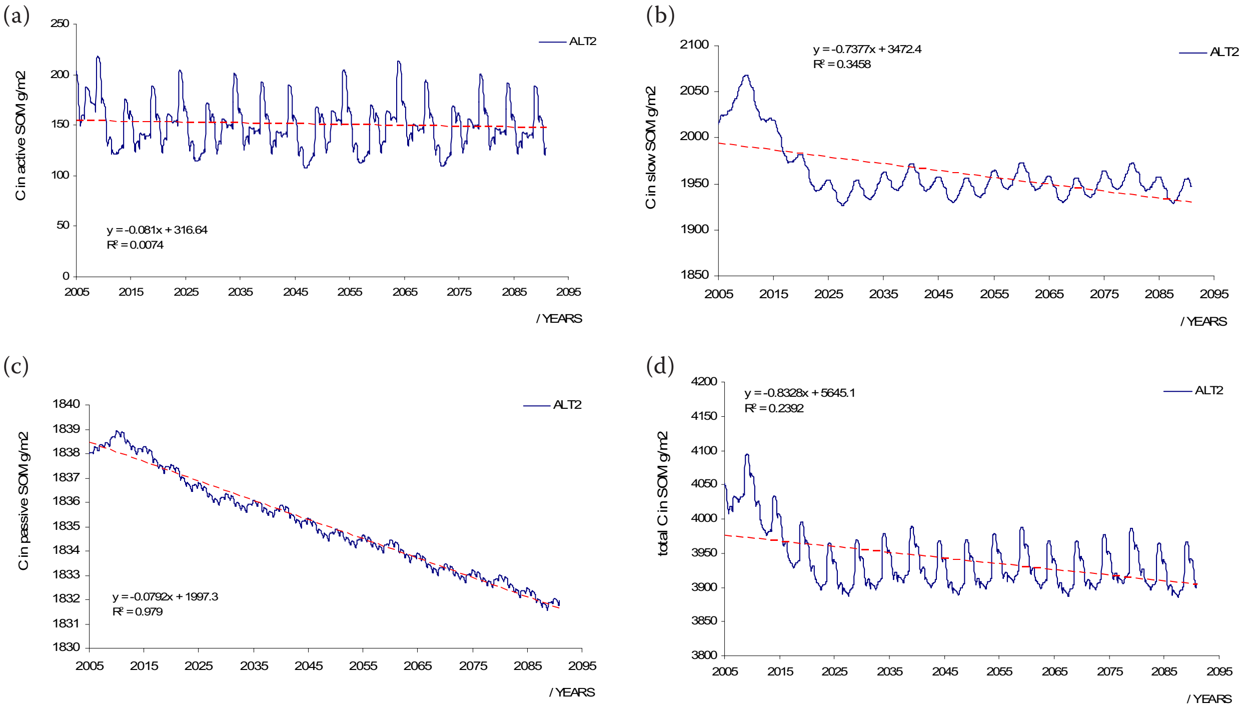

Figure 4. Simulation results of CENTURY 5 for individual SOM pools in non-fertilised and non-irrigated alternative of farmland practice (ALT2)

(a) active carbon; (b) slow carbon; (c) passive carbon; (d) total carbon

generated a very slightly decreasing tendency in organic carbon supplies in the period up to 2090. Excluding irrigation from the farmland practice results in a very moderately decreasing tendency accompanied by reduced mineralisation of organic matter in dry periods. Discussed is the question if this steppe soil formation will provoke chernozemic genesis of humus, as the model predicts. In the simulation of alternative 2 (excluding fertilisation and irrigation from the farmland practice), we can expect a drastic scenario in the organic carbon supplies decrease. Finally, we want to emphasise that the soil type modelled is characterised by very good quality with high land evaluation which can preserve natural soil properties for a long time.

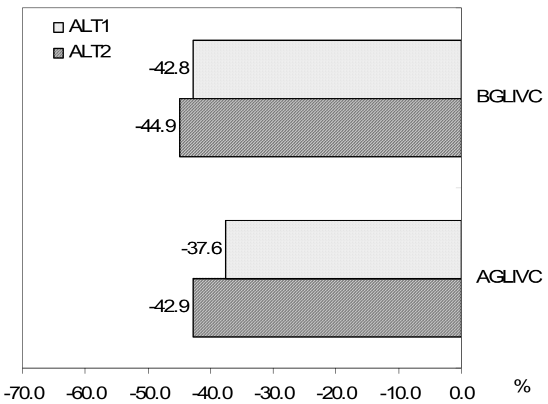

Figure 5. Balance of aboveground live C (AGLIVC) and belowground live C (BGLIVC) compared to conventional farmland practice

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http://www.nrel.colostate.edu/projects/century5

Received for publication November 22, 2006
Accepted December 1, 2006

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