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# EFFECT OF SOIL MANAGEMENT IN AGRICULTURAL LAND FOR THE DEVELOPMENT OF SOIL ORGANIC CARBON STOCKS

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***Abstract:*** *Soil organic carbon (SOC) is important component of the soil which is influencing many soil properties. SOC stock in the topsoil of agricultural soils is largely affected by soil management. SOC and soil management interactions can be simulated by process-based models such as e.g. RothC which has already been successfully applied in conditions of Slovakia. Here we present an approach to modelling of the SOC stock changes with RothC model in the study area (Ondavská vrchovina highland region) in 1970 – 2020 periods. We simulated SOC stock dynamics for topsoil (0 – 30 cm) of agricultural soils using 1 x 1 km spatial resolution grid of simulation units providing all necessary input data for the model. Analyzing the historical and recently observed land cover datasets we observed significant changes in agricultural land extent and cropland/grassland ratio between 1970 and 2004. Since appropriate information on historical land cover changes was not available we designed set of theoretical scenarios to represent cropland to grassland (or vice versa) conversions occurring in the study area in respective years 1971, 1980, 1990 or 2000. The SOC stock in the study area we simulated for different scenarios increased by 15 – 28% between 1970 and 2020. We also observed good agreement between organic carbon inputs variability and the changes in SOC stock for all theoretical land cover change scenarios. We think that accurate modelling of SOC stocks in the study area would require detailed information on where land cover changes occured both in the space and time. We have also found that another important parameter affecting the SOC stock simulation results is stone content in the topsoil.*

***Key words:*** *RothC model, cropland/grassland conversions, land cover change, Ondavská vrchovina highland*

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## INTRODUCTION

Soil organic matter (SOM) is one of the basic soil parameters. It participates in a variety of biological, chemical and physical processes that take place in the soil and affect the production and non-production soil functions. Soil organic carbon (SOC) is included within all minimum set of indicators for any comprehensive evaluation of soil quality based on soil functions (Andrews et al., 2004, Ogle and Paustian, 2005). Most of soil organic carbon is in a continuous dynamic state of accumulation and decomposition (Schrumpf et al., 2008). This state is greatly influenced by soil microbial activity, conditional especially by soil temperature, moisture, nutrient supply, soil texture and climatic factors.

Human activity largely affects the carbon cycle by means of soil management. Soil cultivation, especially the conversion of pasture to cropland leads to significant losses of carbon (Janzen, 2006). Also low supply of organic residues or increasing air temperature disturbs the balance towards mineralization processes in soils. From the other hand, good agricultural practices such as quality organic fertilizers application, optimal crop rotation, and revitalization of degraded soils or good water management generate suitable conditions for sequestration of soil carbon.

The key issue in the present is to determine the dynamic and relatively subtle changes in SOC stock in time. Modelling of SOC stock changes is one of the methods how to detect human effects on SOC dynamics and interactions. RothC model (Coleman and Jenskinson, 2014) well predicts changes in SOC for different soil management methods (Ludwig et al., 2007, Leifeld et al., 2009) and has been already used in Slovakia for modelling SOC stock in agricultural soils. RothC model has been successfully tested on selected key monitoring localities (Barančíková, 2007), agriculture farms (Barančíková and Halás, 2008), in regional conditions of the Eastern Slovak Lowland (Barančíková et al., 2010a) and on agricultural soils of Slovakia (Barančíková et al., 2010 b, Barančíková et al., 2011). Modelling of SOC stock changes in agricultural soils of Slovakia (Barančíková et al., 2012) showed significant differences in SOC stock evolution in various agroclimatic regions of Slovakia (Barančíková et al., 2013 b). For this reason we think that it is necessary to focus on more detailed SOC stock modelling at the regional level.

In this study we present approach to SOC stock modelling in agricultural soils of *Ondavská vrchovina* highland region in 1970 – 2020 periods. During this period study area was subject to many changes in the land cover and soil management (cropland/grassland conversion) which we cannot identify exactly in the time based on the data available. We think, however, that most changes in land cover in the study area occurred during the 1990-ies. To overcome this problem, we designed several theoretical land cover conversion scenarios and this way made SOC stock modelling possible. The aim of the paper is to show respective SOC stock changes trajectories in *Ondavská vrchovina* highland under the different theoretical scenarios.

## MATERIALS AND METHODS

### Study area

*Ondavská vrchovina* highland is located in the northeast part of Slovakia (Fig. 1). It is situated in the administrative regions (NUTS4) Prešov, Bardejov, Svidník, Stropkov, Medzilaborce, Vranov nad Topľou, and Humenné. Study area is located within *Ondavská vrchovina* highland (most of the area), Busov, Ľubovňa Highlands, Čergov, Laborec Highlands, Beskidian Piedmont geomorphological regions. Area extent of the study area is 3129 km$^2$.

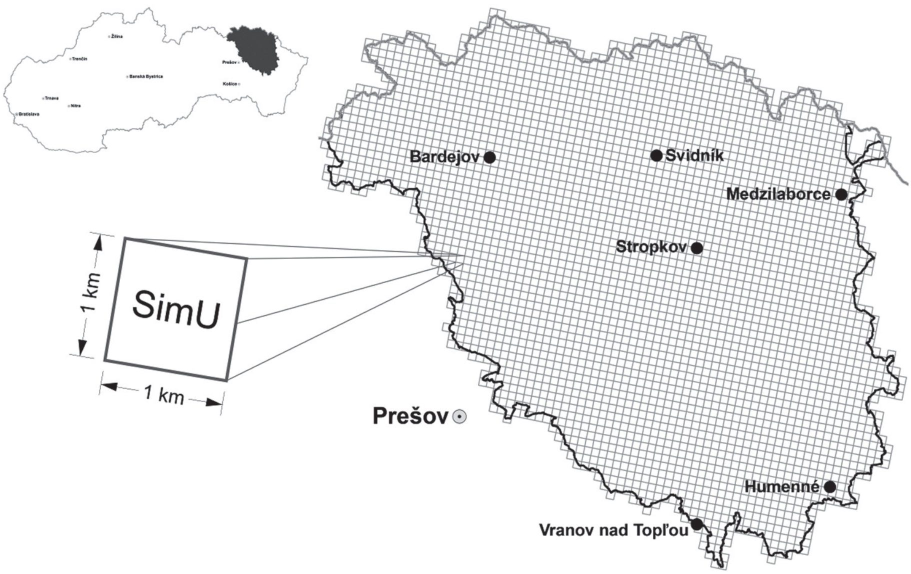


***Fig. 1*** *Location of Ondavská vrchovina highland region*

### RothC model

RothC 26.3 model (Coleman and Jenskinson, 2014) was used for SOC stock changes modelling in *Ondavská vrchovina* highland region. Rothc 26.3 is a model of the turnover of organic carbon in non-waterlogged soils that allows for the effects of soil type, temperature, moisture content and plant cover on the turnover process. It uses a monthly time step to calculate total organic carbon (t.ha$^{-1}$), microbial biomass carbon (t.ha$^{-1}$) and $\Delta^{14}C$ (from which the radiocarbon age of the soil can be calculated) on a years to centuries timescale. Modelling of the SOC stock with RothC 26.3 model requires three types of data:

a) Climatic data – monthly rainfall [mm], monthly evapotranspiration [mm], average monthly mean air temperature [°C];

b) Soil data – clay content [%], inert organic matter (IOM), initial soil organic carbon (SOC) stock [t $C.ha^{-1}$], depth of the soil layer considered [cm];
c) Land use and land management data – soil cover, monthly input of plant residues [t $C.ha^{-1}$], monthly input of farmyard manure (FYM) [t $C.ha^{-1}$].

**Input data for RothC 26.3 model**

The agricultural land of *Ondavská vrchovina* highland was divided into regular square simulation units (SimU) with the size 1 x 1 km. The regular network of SimU was created and indexed in accordance with the basic spatial framework for environmental information in the EU (ANNONI, 2005). *Ondavská vrchovina* highland region is covered by 3341 SimUs (Fig. 1).

Climate data were obtained from three meteorological stations. These stations have sufficient time series of data and are located either directly in the region (Stropkov – Tisinec and Medzilaborce) or at its periphery (Kamenica nad Cirochou). All SimUs of *Ondavská vrchovina* highland region were assigned to one of the meteorological stations. For Stropkov – Tisinec station climate data projection covering 2014-2020 period has been done using CCCM climate scenario (Lapin and Melo, 2004, Lapin et al, 2006). Climate data projection for this meteorological station was then used for all SimUs.

Data from the national soil profile database (AISOP, Linkeš et al., 1988), digital soil map of Complex Soil Survey and spatial models of sand and clay distribution in the topsoils of agricultural soils of Slovakia (Balkovič et al., 2010) were used for calculating initial SOC concentration [%] and clay content [%] in the 0 – 30 cm topsoil layer for year 1970. Regional pedotransfer function (Makovníková and Širáň, 2011) was used to calculate the bulk density of the soil. Subsequently, the initial SOC stock was calculated:

$$SOC_{ij} = BD_{ij} \times COX_{ij} \times h \qquad (1)$$

where *i* is SimU identification, *j* is land cover type (cropland, grassland), *SOC* is initial SOC stock in the layer 0 – 30 cm [$t.ha^{-1}$], *BD* is soil bulk density [$g.cm^{-3}$], *COX* is SOC concentration [%] and *h* is depth of soil layer [cm].

Stone content in the soil has a significant impact on the SOC stock in the soil. We suppose the stones being an inert material considering SOC accumulation. Therefore we proportionally also calculated reduced values of initial SOC stock ($t.ha^{-1}$) for each SimU according to the equation:

$$SOCr_{ij} = SOC_{ij} * (1 - \frac{SC_{ij}}{100}) \qquad (2)$$

where *SOCr* is reduced SOC stock in the depth 0 – 30 cm, *SOC* is not reduced SOC stock in the depth 0 – 30 cm and *SC* is stone content (%) in the depth 0 – 30 cm.

We interpreted basic input data on inputs of organic carbon into the soil (crop residua and manure application) separately for 1970 - 1999 and 2000 – 2020 periods and this way reflected the changes in management which occurred in the study area.

LPIS database with land cover data and Veterinary GIS with geo-referenced data on animal production served the basic source of management data. District statisticson crop yields and production areas for 1970 - 1981 and the same statistical data for 1997 - 2009 period (NUTS4 regions) provided basic information on crop areas, crop yields, farmyard manure application rates and number of animals per area unit. For 1970 – 1999 years, values were adopted from existing national-wide 10 x 10 km spatial resolution model (Tarasovičová et al., 2009, Tarasovičová et al., 2011). Inputs for cropland in 2000 – 2020 periods were estimated from spatial model of crop distribution (Tarasovičová et al., 2009), spatial model of land cover, spatial model of intensification inputs (Tarasovičová et al., 2011) and spatial model of crop biomass distribution for 1997 – 2009 period. Inputs for grasslands in 2000 – 2020 periods were estimated from district level (NUTS4) agricultural statistics on grassland harvested areas and spatial model of intensification inputs (Tarasovičová et al., 2011). The values of monthly input of plant residues [t $C.ha^{-1}$] and monthly input of farmyard manure (FYM) [t $C.ha^{-1}$] required by RothC model were calculated from the data using published carbon conversion coefficients (Bielek and Jurčová, 2010).

## Land cover data

National agricultural soils inventory maps in 1:10.000 scale were used together with 1:10.000 scale military topography maps to identify land cover types (cropland, grassland) distribution in the study area for the year 1970 (Fig. 2a). Other available database with information about land cover after 1970 is the first version Land Parcel Identification System (LPIS) from 2004 (Fig. 2 b). LPIS identifies and quantifies agricultural land by land cover type. LPIS data was digitized on the background of digital orthophotomaps. Standard GIS methods were used to analyse and quantify the land cover changes in agricultural land of the study area between the 1970 and 2004 years.

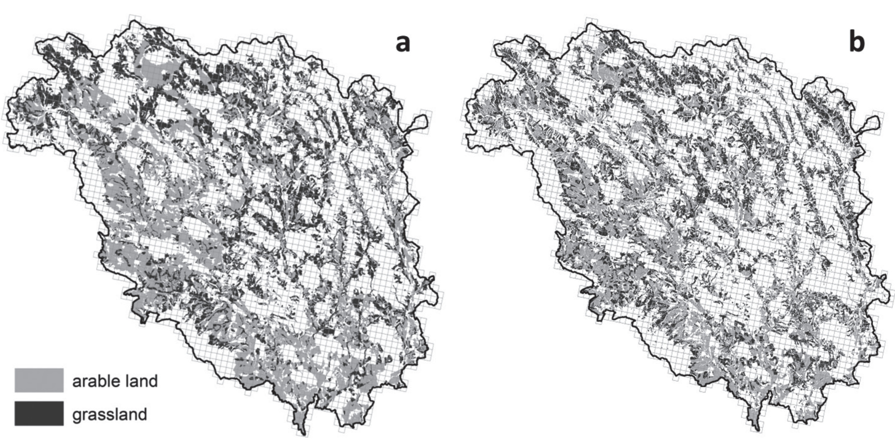


***Fig. 2*** *Agriculture land of Ondavská vrchovina highland in a) 1970 and b) 2004*

### SOC stock modelling scenarios

We set the land cover, initial SOC stock, and corresponding management of the year 1970 for all SimUs as the base-line for all cropland/grassland conversion scenarios. We set land cover change scenarios subsequently so that various combinations of cropland to grassland (or vice/versa) conversions occurred in respective years of 1971, 1980, 1990 and 2000. Two scenarios were set with no change in land cover during the simulated period (Fig. 3). Management options (organic carbon inputs into soil) were assigned to the scenarios accordingly.

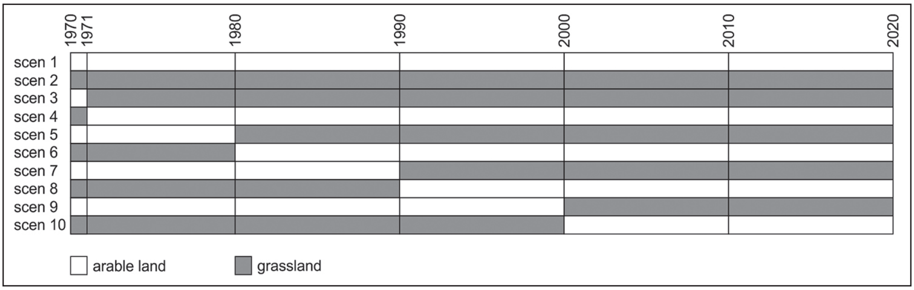


***Fig. 3*** *Land use changes in various scenarios*

## RESULTS AND DISCUSSION

### Land cover change

*Ondavská vrchovina* highland territory has heterogeneous spatial pattern of cropland and grassland (Fig. 2). We think that that this heterogeneity together with social changes between 1970 and 2004 were major drivers of the land cover change observed in the study area. As it is shown in table 1 there was significant loss of agricultural land (more than 23 % decrease) between the 1970 and 2004 years. We assume it was mainly due to abandonment of grassland and cropland areas with less favourable conditions for agricultural production.

***Tab. 1*** *Area (ha) of cropland and grassland in 1970 and 2004 years and its change*

| Year | Cropland | Grassland | SUM |
|---|---|---|---|
| 1970 | 84137.20 | 66690.29 | 150827.49 |
| 2004 | 47432.91 | 67891.24 | 115324.15 |
| **2004 - 1970** | -36704.29 | 1200.95 | -35503.34 |
| % increase (+) / decrease (-) | -43.62 | -11.51 | -23.54 |

Significant cropland to grassland conversions also occurred in the study area between 1970 and 2004. Even though abandonment of significant part of grassland occurred (more than 42 %, table 2), at the end grassland area decreased only by 11,5 %

(table 1) in 2004 compared to 1970 due to the cropland to grassland conversion. Cropland area dropped down of 43.5% in 2004 compared to the original cropland area in 1970 table 1).

***Tab. 2*** *Detailed view on cropland/grassland conversions between 1970 and 2004*

| **Change** | | **Area** | |
|---|---|---|---|
| **1970** | **2004** | **ha** | **%** |
| **Cropland** | **X** | 16068.26 | 19.10 |
| **Grassland** | **X** | 28222.45 | 42.32 |
| **X** | **Cropland** | 1582.99 | - |
| **X** | **Grassland** | 7204.86 | - |
| **Cropland** | **Cropland** | 37956.40 | 45.11 |
| **Cropland** | **Grassland** | 30112.55 | 35.79 |
| **Grassland** | **Grassland** | 27431.44 | 41.13 |
| **Grassland** | **Cropland** | 11036.41 | 16.55 |

Natural conditions of the *Ondavská vrchovina* highland region such as altitude or soil quality are more suitable for grasslands. However, during the modelled period also social and economic situation influenced trends in agriculture and e.g. less suitable areas were used as cropland or generally as agricultural land before and then converted (Bielek and Jurčová, 2010; Kobza, 2013, Bielek, 2014).

**Topsoil SOC stock dynamics**

The average initial SOC stock in the study area is 45 $t.ha^{-1}$ in grasslands and 42 $t.ha^{-1}$ in cropland or 39 $t.ha^{-1}$ in grasslands and 39 $t.ha^{-1}$ in cropland if SOC stock when reduced by topsoil stone content (Fig. 4). For grassland scenario with no land cover change the SOC stock sharply increased in the first half of modelling period (Fig.4a) and then after 1990 it decreased and stayed balanced. In contrast, SOC stock for cropland with no land cover change initially stagnated and began to grow only after 2000. The SOC stock changes simulated for grassland and cropland during modelling period are mainly related to the inputs of organic carbon. Between 1970 and 1990 (Fig. 5) carbon inputs from plant residues and farmyard manure were higher in the grasslands. After 2000, these inputs began to decrease significantly while those to cropland began to rise (Fig. 5). Increased carbon inputs to cropland could be related to the change of crop rotations and implemented soil conservation measures. Observed drop-down of organic carbon inputs to grassland could also be related to the significant decrease of the animals. This trend is visible mostly in the 90-ies and as such it is a result of rapid social and economic changes in the Slovak agriculture production after 1990 (Kováč et al., 2010, Vilček and Kováč, 2011).

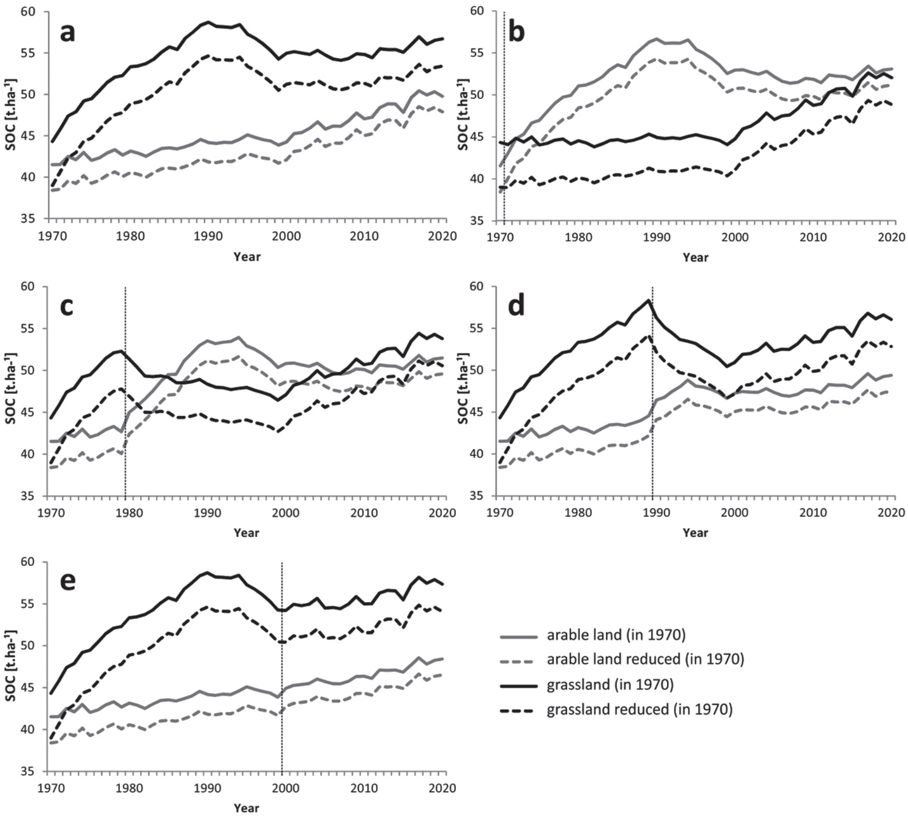


***Fig. 4*** *Development of SOC stock within different scenarios of land cover changes: a) without change, b) change in 1971, c) change in 1980, d) change in 1990, e) change in 2000.*

These effects of plant residues and farmyard manure inputs in the soil on the SOC sequestration we have observed are consistent with the findings of other authors (Schulp and Verbung,2009, van Wesemael et. al.,2010, and Wang et al.,2013). Results of no-conversion scenarios are supported also by the results we got for the cropland/grassland conversion scenarios. Comparison of simulated SOC stock development for different cropland/grassland conversion scenarios (Fig. 4 b, c, d, e) with the respective carbon inputs from plant residues and farmyard manure (Fig. 5) clearly shows this dependence. The same trajectory of the SOC stock development was also observed with stone content reduced initial SOC stock simulations. Development of SOC stock observed with the stones-reduced initial SOC stocks is the same as with the non-reduced initial SOC stock with only that difference that stone content reduced SOC stock values are shifted towards lower values. On average, this represents a decrease of 5% SOC stock for cropland and 8% SOC stock for grassland compared to non-reduced simulations.

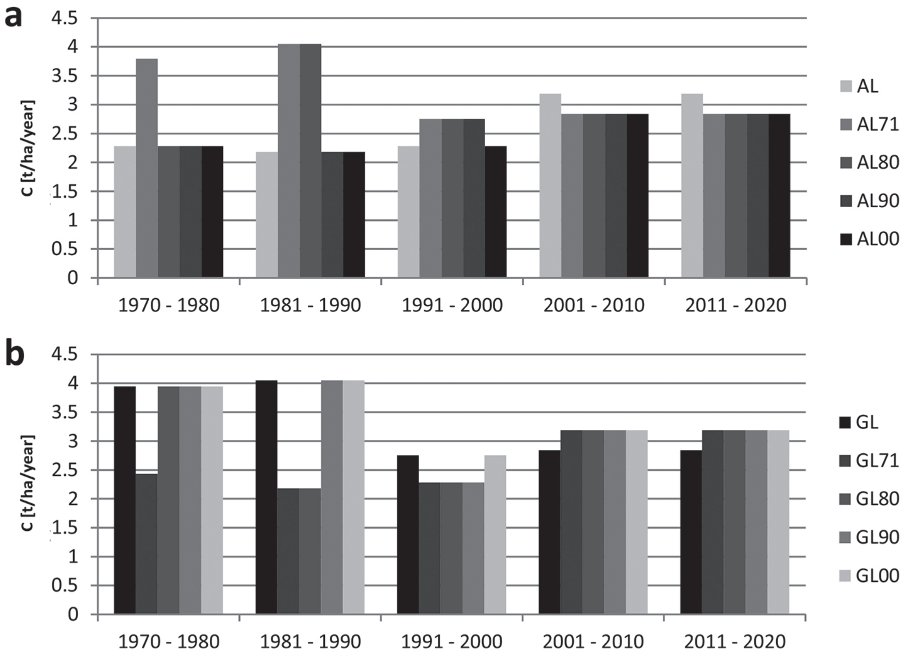


***Fig. 5** Average values of organic carbon inputs from plant residues and farmyard manure for:*

a) *cropland without change (AL), cropland to grassland conversion in 1971 (AL71), cropland to grassland conversion in 1980 (AL80), cropland to grassland conversion in 1990 (AL90), cropland to grassland conversion in 2000 (AL00) and*
b) *grassland without change (GL), grassland to cropland conversion in 1971 (GL71), grassland to cropland conversion in 1980 (GL80), grassland to cropland conversion in 1990 (GL90), grassland to cropland conversion in 2000 (GL00).*

## CONCLUSION

We analyzed the effect of the agricultural land management on development of soil organic carbon stocks with RothC model. We simulated the topsoil (0 – 30 cm) SOC stock dynamics in the agricultural soils of the *Ondavská vrchovina* highland region. We have set several theoretical scenarios of cropland/grassland conversion in the study area in order to capture changes in land cover which occurred in the study area between 1970 and 2004 years and which cannot be traced accordingly from the data available.

Changes in SOC stock development simulated for land cover conversion and non-conversion scenarios show significant effect of land management. Depending on the scenario the SOC stock in the study area increased by 15 to 28% during the simulated period of 1970 – 2020. We observed good agreement between variations in average values of organic carbon input from plant residues and farmyard manure and changes in SOC stock with all theoretical scenarios. We think, however, that accurate modelling of SOC stocks would require detailed identification of spatial-temporal changes in land cover for a given modelling period. We have also found that topsoil stone content is another important parameter which could significantly affect simulated SOC stock values. Even though we think that we have well described the SOC stock behaviour in the study area with theoretical scenarios we have set, we are sure that accurate SOC stock dynamics modelling in the study area would require precise reconstruction of cropland/grassland conversions both in space and time prior to RothC model application.

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