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Land cover and land use change driven change of regional soil organic carbon storage in croplands and grasslands of North-East Slovakia

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Abstract

Soil organic carbon (SOC) is mostly accumulated in topsoil and therefore sensitive to change in land cover and land use. This impact can be amplified when SOC storage is quantified across the regions instead of single sites. Effective way how to estimate regional SOC storage is coupling SOC turnover models with spatial data. The RothC model was used in this study together with national-coverage legacy soil data on soil dating back to 1970, land cover, and land use data with the goal to reconstruct current SOC storage in the *Ondavská Vrchovina* region. Estimated initial SOC stock in cropland and grassland was 4.21 Mt in 1970. It increased of 22.6 % between 1970 and 2013 to current value of 5.16 Mt. It was found that the SOC storage development trajectory was affected by both land cover change and the quantity of organic carbon coming to soil; the latter buffering negative impact of grassland to cropland conversions but the same time limiting possible positive impact of cropland to grassland conversions. The approach presented in this study allows for direct up-scaling for national-scale SOC storage estimates.

Keywords: RothC, gridded SOC model, legacy soil data, National soil inventory data

Introduction, scope and main objectives

Soil organic carbon (SOC) is mostly accumulated in top soil layers and therefore sensitive to land cover change and change in management practices. Conversion of grassland to cropland can lead to significant SOC loses in semi-natural ecosystems, whereas in intensively managed agro-ecosystems it is biomass removal, low input of plant residua, insufficient supply of organic fertilizers, and tillage practices leading to possible SOC loss. This could be amplified if impacts of land cover and land use change on SOC storage are summarised across the regions rather than individual sites. Possible way how to detect changes in SOC over larger regions is process-based modelling. The RothC model (Colleman & Jenkinson 2014) requires only limited number of easy-to-obtain inputs which makes it very applicable for regional studies covering the range from local to global scales. It also was proven well respond to soil management making it good tool for analysing impacts of land use on SOC stock. National agricultural soils inventory in Slovakia was finished in 1970 and produced polygon soil maps and measured soil profile data (Němeček et al. 1967). An attempt was done to estimate current SOC stock in agricultural soils from initial SOC stocks around 1970 with RothC model and historical records on weather and crop management (Barančíková et al. 2010, 2012). Given the spatial resolution of gridded data used to run the model (10k) and ignoring land cover change during the simulation period the outputs gave only very general and rough estimate. Here we focus on the cropland and grassland SOC stock change in the 3129.00 km^2 big highland region in eastern Slovakia (*Ondavská Vrchovina* mts.) between years 1970 and 2013. This region was subject of many land cover and land use changes with cropland to grassland (and vice-versa) conversions and varying intensity of crop management, both responding to socio-economic and political developments in Slovakia. Building upon our earlier work in this region (Koco et al. 2016) in which we introduced a set of theoretical soil management scenarios to mimic real land use change, we make a step forward with combining initial SOC stocks around 1970, historical record on land cover change, and theoretical land use scenarios to come up with estimates of current SOC stock in 1k spatial resolution. We also analyse the impacts of land cover and land use on regional SOC stock.

Methodology

The Rothc-26.3 model (Coleman & Jenskinson 2014) is a model of the turnover of organic carbon in non-waterlogged soils accounting for type of soil, weather, plant cover and input of organic carbon to the soil.

All data necessary to run the RothC model were organized within the 1k spatial resolution grid yielding simulation units (SimU) with unique combination of weather, soil, land cover, and land use and their corresponding areas. Monthly annual means for years 1970 – 2013 on temperature, sum of rainfall, and sum of potential evapotranspiration (estimated by Penmann-Moneith method) were allocated to each SimU from three WMO weather stations (WMO 11993, WMO 11976, and WMO 1977). Cropland and grassland areas were taken from national Land Parcel Identification System (LPIS) for 2003 and 2013, or were interpreted from Landsat 5, Landsat 4, and Landsat 7 imagery for years 1994 and 1986. Cropland and grassland areas for starting year 1970 were interpreted from 1:10k scale historical topography maps. The LPIS 2013 borders were kept constant throughout whole modelling time period. Seven unique combinations of soil type and land cover class were identified based on topsoil SOC content from 1308 measured soil profiles and subsequently used to allocate land cover specific topsoil (0 – 30 cm) SOC densities [$t.ha^{-1}$] and clay content to all SimU via polygon data on soil type and land cover class in 1970. The SimU and year specific yearly quantities of organic carbon coming to soil from plant residua and farmyard manure were estimated from variety of input data including regional (NUTS2, NUTS4) statistical data on crop yields, farmyard manure production, and number of animals and LPIS dataset (Table 1). Theoretical scenarios of cropland to grassland and grassland to cropland conversions in respective years 1971, 1980, 1990, and 2000 and organic carbon input quantities associated (Table 1) were taken to mimic real changes of land use during the simulation period (Koco et al. 2016). The RothC model simulations were done for combination of all SimU and scenarios between years 1970 and 2013. Simulated SOC densities [$t.ha^{-1}$] were then used for calculating SimU and land cover specific SOC storage [Mt] in five distinct time intervals based on observed land cover change (1970, 1986, 1994, 2003, and 2013).

	cropland [tC/ha/y]			grassland [tC/ha/y]		
decade	C_PR	C_FYM	C_PR+ C_FYM	C_PR	C_FYM	C_PR+ C_FYM
1970 - 1980	1,74	0,54	2,28	2,88	1,07	3,95
1981 - 1990	1,64	0,54	2,18	2,88	1,17	4,05
1991 - 2000	1,75	0,53	2,28	2,09	0,66	2,75
2001 - 2013	2,62	0,57	3,19	1,77	1,07	2,84

Table 1: Land cover specific organic carbon input into the soil [$t.ha^{-1}$] from crop residua and farmyard manure in the period 1970 – 2013 as averaged across all SimU (Explanations: CPR – organic carbon from crop residua, C_FYM – organic carbon from farmyard manure)

Results

Total agricultural area in *Ondavská Vrchovina* region between 1970 and 2013 was 1072.5 km^2 with cropland area being 655.8 km^2 and grassland area 416.7 km^2 at the beginning of the simulation period (1970). Due to the land cover conversions it changed to current values in 2013 of 486.4 km^2 and 586.1 km^2 in cropland and grassland respectively. Cropland area initially extended in 1986 to its recorded maximum (709.7 km^2) and then subsided in 1994 and 2003 close to current values, corresponding to maximum extent of grassland 602.5 km^2 recorded in 2003. In the last decade slight increase of cropland area was observed again (Fig. 1). Initial estimated SOC storage in the *Ondavská Vrchovina* region was 4.21 Mt with cropland contributing 2.57 Mt and grassland contributing 1.64 Mt; the quantities mostly reflecting the ratio of cropland and grassland areas (Fig. 1). The SOC storage development over the simulation period had increasing trend before 1994, then kept balanced with only slight decrease in 2003. Current SOC storage estimated for 2013 was 5.16 Mt, with cropland contributing 2.34 Mt and grassland contributing 2.86 Mt (Fig. 1). Net SOC gain of the region between the years 1970 and 2013 was 0.95 Mt which represent 22.6 % of initial SOC storage in 1970. The SOC storage trajectories of cropland and grassland followed in general observed change in cropland and grassland areas; with 8.9 % decrease and 74.4 % increase of initial SOC storage in cropland and grassland, respectively. Current SOC storage estimated for 2013 in case of the scenario without any land cover change was 5.18 Mt, with cropland contributing 3.12 Mt and grassland contributing 2.06 Mt (Fig. 1).

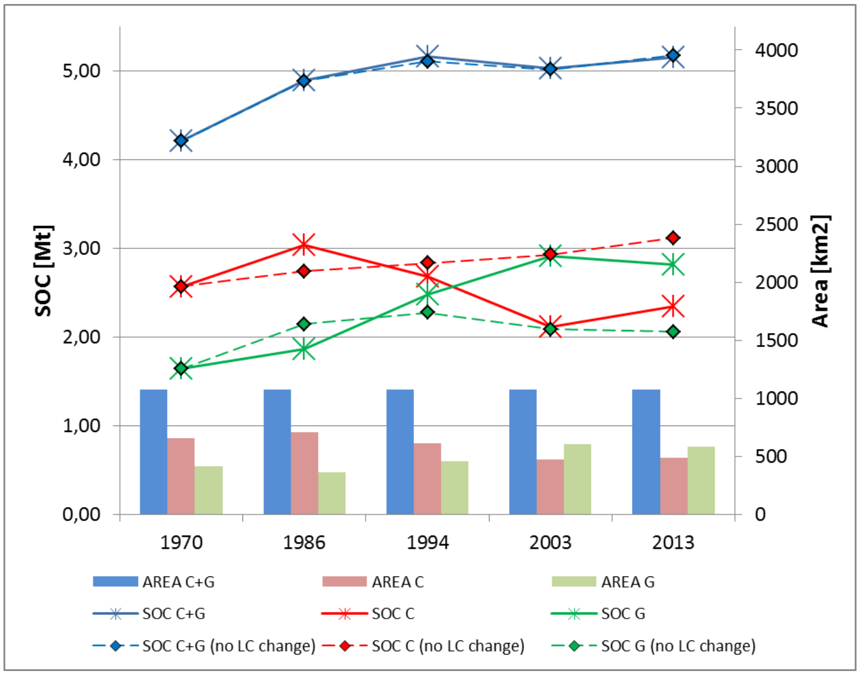

Fig. 1: The SOC storage and corresponding cropland and grassland areas as estimated for the *Ondavská Vrchovina* region for the years with observed land cover change (Explanations: C – cropland, G - grassland)

Discussion

Increasing trend of SOC storage over the last 54 years which was simulated with RothC model in the *Ondavská Vrchovina* region was also reported by Barančíková et al. (2010) in their study about SOC stock development in Slovakia after 1970 using both the RothC modelling and independent set of measured soil profile data covering period of 1970 – 2007. Increase of SOC stock in topsoil during last fifty years was also simulated by Kaczynski et al. (2017) with reconstructed land use and theoretical scenarios in southwest Poland. Similarly, slight SOC stock increase in last thirty years was also shown for different climate conditions in northeast of Spain by Alvaro-Fuentes et al. (2011). It is obvious, that the quantities of land cover conversions – 25.83 % decrease of cropland area and 40.65 % increase of grassland area in *Ondavská Vrchovina* region do not fully correspond to those of SOC storage (with 8.9 % decrease in cropland and 74.4 % increase in grassland). The amount of organic carbon coming to soil from the management (Table 1) played also an important role. Although it makes only slight difference in total SOC storage values (5.16 Mt compared to 5.18 Mt in 2013), there is an obvious shift in cropland and grassland SOC storage development trajectories with and without land cover change assumed (Fig. 1).The SOC storage trajectories in case of no land cover change responded clearly to organic carbon inputs to the soil, this leading to 21.4 % and 25.5 % increase of initial SOC storage over the modelling period in cropland and grassland, respectively. After

1994 the SOC storage in *Ondavská Vrchovina* region was affected by the land cover and the land use change acting in opposite directions. Although cropland was continuously subsiding in area, its organic carbon inputs kept growing at the end which well buffered potential SOC loss. On the contrary, the adverse effect of decreased amount of organic carbon inputs to grassland after 1994 caused SOC storage loss in existing grassland areas as well as it weakened otherwise very positive impact of cropland to grassland conversion.

Conclusions

The SOC storage in topsoil of cropland and grassland soils in *Ondavská Vrchovina* region was simulated over the period of 1970 – 2013 with RothC model and national-scale legacy soil data, weather data, and time record of land cover and land use change; all data organized within the 1k spatial resolution grid. Estimated initial SOC stock in croplands and grasslands was 4.21 Mt in 1970 which increased till 2013 of 22.6 % to current estimated value of 5.16 Mt. The SOC storage development between 1970 and 2013 was affected by both the land cover change and the quantity of organic carbon coming to soil under cropland or grassland management. Management intensity also buffered negative impact of grassland to cropland conversions, as well as it limited possible positive impact of cropland to grassland conversions; this mostly after 1994. The approach presented in this study can be up-scaled to national scale for estimating current levels of SOC storage in croplands and grasslands of Slovakia.

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