Geoderma 286 (2017) 104–115

Contents lists available at ScienceDirect

Geoderma

journal homepage: www.elsevier.com/locate/geoderma

Modelling soil carbon trends for agriculture development scenarios at regional level

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ARTICLE INFO

Article history:
Received 20 January 2016
Received in revised form 18 October 2016
Accepted 21 October 2016
Available online xxxx

Keywords:
Agriculture
Mixed farming
Modelling
Soil organic carbon
Specialized crop production

ABSTRACT

There is an increasing demand for evaluating the impact of specialization in agriculture on soil carbon balance. The main aims of the study were (1) to model the impact of long-term changes in agriculture on soil organic carbon (SOC) stocks at regional level using the Rothamsted C model (RothC), (2) validate these results by conventional SOC analysis, and (3) to compare impacts of "as was" and "mixed farming system" scenarios on SOC trends. The study area covered 1800 km^2 of Dolnoslaskie province, Poland. The significant changes have occurred in this area since 60's. The production system has changed from the mixed crop-animal farming to highly specialized crop production.

We evaluated two scenarios. The starting point for both scenarios was the situation in 1960 (co-existing low intensity crop and animal production). The scenario S-1 reflected recorded changes in agriculture, namely slow transition into specialized and more intensive production with progressive simplification of crop rotation and decline in livestock density. Scenario S-2 constituted hypothetical continuation of the starting situation (i.e. low intensity crop and animal production).

In the period 1960–2014 SOC accumulation was observed in "as was" scenario (S-1) in almost all locations of the area characterized by low initial SOC content. The model outputs were then validated using SOC measurements in samples collected in two periods: 1960–1970 and 2010–2014. The modelled SOC stock explained 56% of variability of the measured SOC stock. Comparison of S-1 and S-2 scenarios revealed that re-introduction of mixed farming with current intensity of agricultural production has capacity for further increasing SOC stocks in the region.

Contents

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http://dx.doi.org/10.1016/j.geoderma.2016.10.026

1. Introduction

Global demand for plant and animal food products driven by growing populations and changing dietary preference causes intensification of agricultural production. On the other hand competitiveness between individual farms and national/regional agriculture stimulates specialization in agricultural production (Neumann et al., 2009; Peyraud et al., 2014). As a result, animal production is concentrated in certain regions whereas other regions are specialized in crops and suffer lack of manure. Such specialization of farms is observed worldwide, generating discussion on its ecological effects and potential reintegration of crop and livestock systems (Hendrickson et al., 2008; Lemaire et al., 2014). Any agricultural system must consider conservation of natural resources (soil, water) and ecosystem functions of rural areas.

There is increasing demand for evaluation of all positive and negative effects of various agricultural production systems. One of key criteria for assessing environmental impacts of the systems is the trend of SOC changes. SOC plays a vital role for soil functioning and sequestration of carbon by terrestrial ecosystems (Paustian et al., 1997; Lal, 2004; Ciais et al., 2010). SOC decline was listed as a major threat for European soils by the Soil Thematic Strategy for soil protection (COM, 2006).

Integration of crop and livestock is one candidate way to cope with this issue. CANTOGETHER project (www.fp7cantogether.eu), funded by FP7 of EC, contributed to the discussion on re-implementation of mixed farming systems (MFS), at farm, district or landscape level. It can be assumed that return to MFS at farm level is less realistic under current economic conditions. However, at regional level MFS might propose more opportunities, e.g. in a form of land sharing or manure and feed exchange (Regan et al., 2016).

The main aims of the study were (1) to evaluate the impact of long-term changes in agriculture on SOC stocks at the regional level using the RothC model, (2) to validate the model outputs by conventional SOC analysis, (3) to compare impacts of “as was” and MFS scenarios on SOC trends, and (4) check feasibility of linking agricultural census data with point soil information for modelling C stock trends.

2. Materials and methods

2.1. Description of the study area

The study area covers 1800 km^2 of south-east part of Dolnoslaskie province, Poland. Due to a large diversity of natural conditions and organization of agriculture within the province, the case study does not cover the entire administrative area but its selected part (Fig. 1). Within the study area significant changes in agriculture have occurred for the last 50 years.

The area has favorable agro-climatic conditions for cropping, including demanding crops such as: wheat, barley, maize, rape, potato and sugar beet. Therefore these crops currently dominate in the cropping structure. Prevailing soil types are cambisols and luvisols and the textures are silt and silty loam. The soil organic carbon content is relatively low and oscillates around 1.2%. Soil water budget is precipitation dependent. The mean annual precipitation in the study area is 643 mm and mean annual temperature is 8.9 °C. The mean monthly temperatures are −0.8, 0.3, 3.8, 8.6, 13.5, 16.7, 18.2, 17.4, 13.7, 8.8, 4.2, 1.0 and mean monthly precipitation is 33, 30, 35, 47, 72, 78, 95, 79, 55, 45, 39, 36 from January to December, respectively. Agricultural land is almost all arable – the cropping area covers 93% of UAA (utilized agricultural areas) whereas permanent grasslands only 5.5%.

2.2. Data characterizing changes in agriculture

Indicators potentially explaining impact of agricultural management on SOC content and trends were extracted from National Agricultural Census of Poland (Central Statistical Office of Poland, 2015) for the following years: 1960, 1969, 1979, 1988, 1996, 2002 and 2010 with relatively high spatial resolution- data for LAU-2 (LAU-2 is Local Administrative Unit, level 2, according to EU Nomenclature of Territorial Units for Statistics (NUTS) regions. LAU-2 is equal to former NUTS-5 level). The database contains information on area of individual crops, yields, livestock density and mineral or organic fertilizer rates.

2.3. Application of Rothamsted C model and the input data

The RothC model was applied for modelling SOC changes in the study area as resulting from agronomy and pedo-climatic conditions. The RothC is one of the models currently used world-wide to study global C dynamics and to report national inventories of C stocks for the United Nations Framework Convention on Climate Change (Grace, 2005). Dynamics of the model has been extensively tested using long term SOC data from a wide range of soil types, land uses and environments and the model needs relatively few inputs (Skjemstad et al., 2004; Smith et al., 2005; Barancikowa, 2007). RothC enables analysis of the effects of soil type, temperature, moisture content and plant cover on the C turnover process. It was originally developed and parameterized to model the turnover of organic C in arable top soils of the Rothamsted long term field experiments, and later extended to model turnover in grassland and woodland, and also in different soil and different climates (Coleman and Jenkinson, 1999; Yokozawa et al., 2010).

The selection of the RothC-26.3 model for our purposes was based on its good performance in long-term experiments in neighbour countries using independent crop input data (Ludwig et al., 2007; Barancíkova et al., 2010a, 2010b). Furthermore, the input data required for running the RothC model correspond to what can be realistically collected at the LAU-2 level in Poland for the period 1960–2014.

The model was run for 94 locations with known initial (in 1960s) SOC content across the study area. Step approach was applied for modelling soil C using 10-year steps, corresponding to collection of official agricultural statistics. The soil C result of each modelling step constituted an input data to the subsequent step. Such approach enabled better illustration of relationship between trends in agronomic factors (and in consequence C-input from crop residues and manure) and changes in soil organic carbon stock.

The following information was used to obtain inputs to drive RothC in this study:

The **climatic** data needed to run the model (monthly rainfall, monthly potential evaporation, average monthly air temperature) were obtained from the Model of Agroclimate of Poland (MAP) in the grid format (Górski and Zaliwski, 2002). This model is based on the network of meteorological stations belonging to Institute of Meteorology and Water Management and mathematical algorithms (taking into account e.g. elevation). Potential evaporation was calculated from potential evapotranspiration (MAP giving by Pennman's equation) by dividing it by 0.75 as suggested by Coleman and Jenkinson (1999).