Science of the Total Environment 557–558 (2016) 838–850

Contents lists available at ScienceDirect

Science of the Total Environment

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

Assessment of soil organic carbon stocks under future climate and land cover changes in Europe

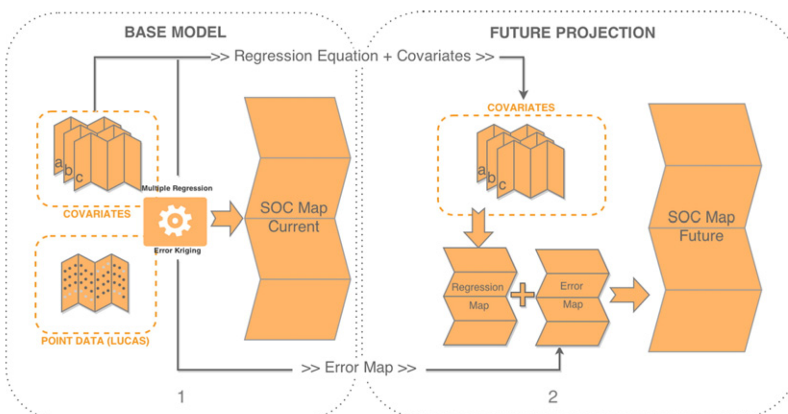
Yusuf Yigini *, Panos Panagos

European Commission Joint Research Centre, Land Resource Management Unit, Via Enrico Fermi 2749, 21027 Ispra, VA, Italy

HIGHLIGHTS

- We predicted present and future SOC stocks using climate and land cover change scenarios.
- The model produced two main outputs: present and future (2050) SOC stocks in Europe.
- The results suggest an overall increase in SOC stocks by 2050 for selected Global Climate Models.
- The extents of the increase in SOC stocks vary by different GCMs and their RCPs.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 5 January 2016
Received in revised form 10 March 2016
Accepted 11 March 2016
Available online xxxx

Keywords:
Soil organic carbon
Land cover change
Climate change
Regression-kriging
Climate scenarios
LUCAS Soil Survey

ABSTRACT

Soil organic carbon plays an important role in the carbon cycling of terrestrial ecosystems, variations in soil organic carbon stocks are very important for the ecosystem. In this study, a geostatistical model was used for predicting current and future soil organic carbon (SOC) stocks in Europe. The first phase of the study predicts current soil organic carbon content by using stepwise multiple linear regression and ordinary kriging and the second phase of the study projects the soil organic carbon to the near future (2050) by using a set of environmental predictors. We demonstrate here an approach to predict present and future soil organic carbon stocks by using climate, land cover, terrain and soil data and their projections. The covariates were selected for their role in the carbon cycle and their availability for the future model. The regression-kriging as a base model is predicting current SOC stocks in Europe by using a set of covariates and dense SOC measurements coming from LUCAS Soil Database. The base model delivers coefficients for each of the covariates to the future model. The overall model produced soil organic carbon maps which reflect the present and the future predictions (2050) based on climate and land cover projections. The data of the present climate conditions (long-term average (1950–2000)) and the future projections for 2050 were obtained from WorldClim data portal. The future climate projections are the recent climate projections mentioned in the Fifth Assessment IPCC report. These projections were extracted from the global climate models (GCMs) for four representative concentration pathways (RCPs). The results suggest an overall increase in SOC stocks by 2050 in Europe (EU26) under all climate and land cover scenarios, but the extent of the increase varies between the climate model and emissions scenarios.

* Corresponding author.
E-mail addresses: yusuf.yigini@jrc.ec.europa.eu (Y. Yigini), panos.panagos@jrc.ec.europa.eu (P. Panagos).

http://dx.doi.org/10.1016/j.scitotenv.2016.03.085

1. Introduction

Soil is the largest organic carbon pool of the terrestrial ecosystems on earth which interacts *strongly* with atmospheric composition, climate, and land cover change (Jobbagy and Jackson, 2000). Soil organic carbon dynamics are driven by changes in climate and land cover or land use. In natural ecosystems, the balance of SOC is determined by the gains through plant and other organic inputs and losses due to the turnover of organic matter (Smith et al., 2008). In the soil ecosystem, soil organic carbon influences soil physical and chemical processes, and serves as a source of plant nutrients. The storage of organic carbon in the soil depends on the balance between gains and losses of C. Biotic characteristics such as biomass production and microbial abundance, mean annual precipitation and temperature, soil characteristics including texture and lithology and anthropogenic activities, like land use and management, influence the processes of SOC storage or losses. A clear description of the distribution and changes of SOC and its factors of control will help predict the consequences of climate change (Albaladejo et al., 2013).

Soil carbon stocks are strongly controlled by the climate and land cover and these main drivers, especially the land use patterns are changing rapidly by human activities. The climate and land-use changes are significantly visible, and their impacts on terrestrial ecosystems are increasingly being studied. There are numerous studies focused on the future climate and land-use change. One of the modelling platforms projecting the land use changes into the near future is LUISA (Land-Use-based Integrated Sustainability Assessment Modelling Platform). The platform is the Joint Research Centre's land use model which downscales an aggregated amount of land use expected in the future (Maes et al., 2015). The LUISA is a modular modelling platform and land use change simulations take part in the allocation module. The platform's land cover projection data suggest an increase in forest cover and decrease in agricultural, pastures and wetland lands by 2050 in Europe. In much of continental Europe, the majority of forests are now growing faster than in the early 20th century (EEA, 2015).

During the last few decades, land use changes have largely affected the global warming process through emissions of CO_2. However, C sequestration in terrestrial ecosystems could contribute to the decrease of atmospheric CO_2 rates. Muñoz-Rojas (2012) studied impacts of LU changes on SOC stocks at a regional scale in Andalusia (Southern Spain). Muñoz-Rojas estimated SOC sequestration rates for different soil types and land cover flows for a period of 51 years, providing baseline information for future studies on C emissions, soil organic C modelling and mitigation scenarios associated with the land use change processes. While the intensification of agriculture between 1956 and 2007 has resulted in a general decrease of SOC stocks in Andalusia, soils like Arenosols have been largely affected by these transformations, in particular with changes from arable land to permanent crops. Remarkable positive rates of change of SOC stocks were found in Fluvisols and Luvisols as a result of the conversion to arable land or heterogeneous agricultural areas.

Another study by Qiu et al. (2013) carried out a study to understand spatial and temporal variations of soil organic carbon (SOC) under rapid urbanization and support soil and environmental management in Zhejiang Province, China. It is concluded that the average SOC in 2006 was 18.5 $g \cdot kg^{-1}$, significantly higher than 17.3 $g \cdot kg^{-1}$ in 1979. Although on average, this difference is small, it was greater in specific areas. The SOC measured in 2006 under peri-urban areas was higher than the under natural conditions. Extrinsic anthropogenic activities caused most of the spatial and temporal variations of the SOC. The study shows that the changes of agricultural use types and the transitions from agricultural to industrial or urbanised uses were the main factors influencing SOC (Qiu et al., 2013).

Another study by Poeplau and Axel (2013) was carried out in 24 paired study sites in Europe comprising the major European LUC types, cropland to grassland, grassland to cropland, cropland to forest and grassland to forest. The researchers found that the SOC sequestration after grassland establishment on croplands equaled the SOC sequestration of cropland afforestation. Converting grassland to forest has no significant effect on the total SOC stock.

Climate conditions strongly influence both the trends and rates of accumulation and transformation of organic compounds in the soil. There is constant interaction between soil organic carbon and atmospheric CO_2. Moreover, CO_2 is currently the main driver of the long-term climate change. According to European Environment Agency's "Climate change, impacts and vulnerability in Europe 2012" report (EEA, 2012), the projected changes in the climate during the 21st century will change the contribution of soil to the CO_2 cycle in most areas of the EU. Adapted land-use and management practices could be implemented to counterbalance the climate-induced decline of carbon levels in soil (EEA, 2015). Smith et al. (2006) reported that the climate change was found to be an important driver of change in forest soil organic carbon over the 21st century, projected forest management and land-use change will have greater effects, leading to only small losses or increasing European forest SOC stocks. According to same study climate change may cause loss of soil organic carbon for most areas in Europe. This decline could be reversed if adaptation measures in the agricultural sector to enhance soil carbon were implemented. It should be noted that these modelled projected changes are very uncertain.

Environmental issues such as land degradation and global climate change, require assessing soils in the context of ecosystem change and environmental stressors impacting control on soil properties (Grunwald, 2010). However, it is hard to make accurate predictions in very dynamic and complex environments such as soils. The data on soils is very often outdated, limited in coverage, and fragmented in nature. Predicting and mapping the soil properties with limited data needs more sophisticated analysis. Digital soil mapping (DSM) is increasingly gaining worldwide acceptance as a means for fulfilling the demand for accurate soil information at different spatial resolutions and extent (Omuto and Vargas, 2014). Numerous environmental and socio-economic models require soil parameters as inputs to estimate and forecast changes in our future life conditions. However, the availability of soil data is limited on both national and European scales. European countries are great reservoirs of existing large and medium scale soil maps, many still in paper form. The major limitation of such kind of data is the lack of exact geographic positioning (Jones et al., 2005a). In these existing data sources, soil information is either missing at the appropriate scale, its meaning is not well explained for reliable interpretation, or the quality of the data is questionable (Dobos et al., 2006a, 2006b). Digital soil mapping has evolved as a discipline linking field, laboratory, and proximal soil observations with quantitative methods to infer on spatial patterns of soils across various spatial and temporal scales. Studies use various approaches to predict soil properties or classes including univariate and multivariate statistical, geostatistical and hybrid methods, and process-based models that relate soils to environmental covariates considering spatial and temporal dimensions (Grunwald, 2010).

Statistical models are the functions that predict soil classes or soil properties from soil covariates or available soil data (Lagacherie and McBratney, 2007). These are the functions that predict soil properties or soil classes. Most of these models have been calibrated with soil samplings and have been tested over small areas. The limitation of soil sampling dense enough to capture the spatial variability and limit the use of numerical models to for large areas (Hartemink et al., 2008).

Prediction of soil organic carbon stocks has become a key issue over recent years, because of the potential impacts of carbon on climate change. Spatial prediction of soil organic carbon stocks has received significant attention because of the large variation of SOC at all scales from national to field, and also due to the expense of obtaining accurate measurements of SOC. As a result, research into approaches to improve spatial prediction of SOC stock is on-going (Minasny et al., 2013).

The method that we used in this study is regression-kriging which is a spatial interpolation technique that combines a regression of the