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Coupling high spatial resolution data, GIS approaches and modelling for reliable estimates of SOC stocks and their historical changes in agricultural lands

M.I. Khalil[1,*], *P. O'Brien*[2], *B. Osborne*[1]

[1] UCD SBES and UCD Earth Institute, University College Dublin, Belfield, Dublin 4, Ireland. E-mail: Ibrahim.khalil@ucd.ie
[2] Environmental Protection Agency, Richview, Clongkeagh, Dublin 14, Ireland

Abstract

The reduction of greenhouse gases, and the quantification of the offsetting potential of SOC are a global necessity. Data generated previously (Khalil et al., 2013) through overlaying land uses and soil databases using GIS approaches were reprocessed to develop non-linear depth-distribution models and pedotransfer functions, with R^2 ranged from 0.53 to 1.00, for estimation of SOC concentration and bulk density. An historical land use database (2000-2015) was also used to categorize grassland (G), rough grazing (R), tillage (T) and their rotations (GR, GT, RT), and the corresponding SOC concentrations, and densities/stocks on mineral, organo-mineral and organic soils. SOC densities were the highest in organic soils of the R category (121, 362 and 1207 t ha^{-1}) and the lowest for T (30, 79 and 142 t ha^{-1}) at 0-10, 0-30 and 0-100 cm layers, respectively. The corresponding national total stock was 270, 789 and 1894 Tg at the corresponding soil layers where grassland (G+R+GR) shared 87%, GT 10%, and the T and RT rotations 1% each. Results of historical changes in SOC stocks will be reported. The findings imply that the approaches used could reliably estimate SOC for LULUC accounting, offsetting and achieving its increase to 4 per mille per year.

Keywords: *Depth distribution models, Pedotransfer functions, GIS approaches, SOC densities and stocks, Soil types, Agricultural land uses, Land use changes.*

Introduction

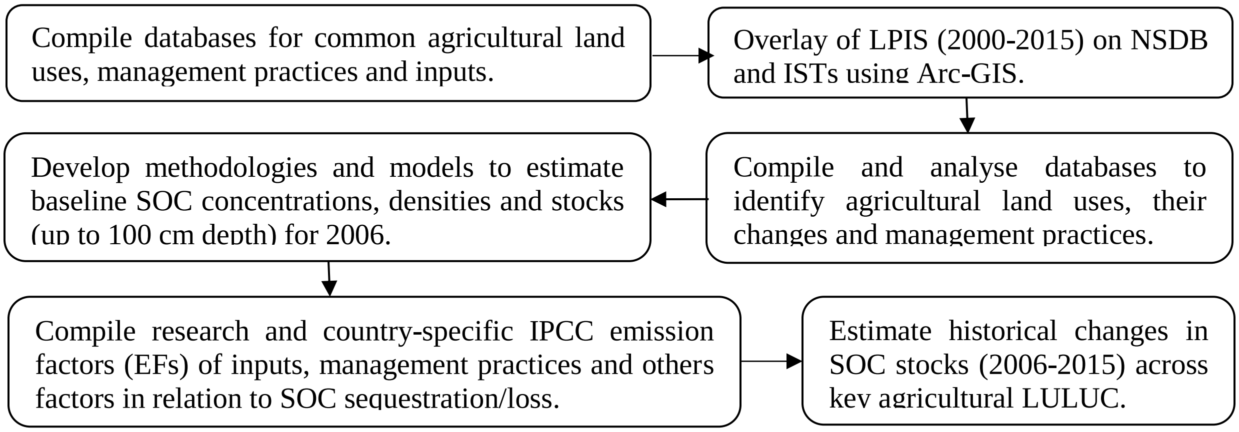
Recent international negotiations underscore the importance for significantly reducing anthropogenic greenhouse gas (GHG) emissions to keep global temperature below 2°C relative to pre-industrial times. The Paris Agreement emphasises enhanced mitigation measures, reducing GHG assessment uncertainties, better quantified sinks, and the tailored use of different offsetting mechanisms (UN, 2015). However, technological and economical limitations, and large uncertainties in achieving these goals exist. In addition to improved agricultural management practices, the SOC pool has the potential to act as a major source or sink of GHGs due to its large extent and active interaction with the atmosphere. Due to the lack of detailed, spatially explicit activity data, the Annex-I countries use the IPCC Good Practice Guidance Tier 1 methodology (IPCC, 2013) for inventory reporting. For quantification of baseline SOC stocks, robust country-specific activity data (Tier 2 approach) are essential in order to reflect the diversity of practices that influence soil carbon within a country or region, and identify potential land uses and soil types to increase SOC to reach the 4 per mille initiative (Minasny et al., 2017).

Pedotransfer functions (PTFs) and regression modelling have been used to obtain a more complete and detailed spatial distribution of SOC content, with or without GIS techniques (e.g., Meersmans et al., 2009; Khalil et al., 2013). To reconcile the above discrepancies, a more detailed spatial assessment of baseline SOC stocks covering disaggregated agricultural land uses, soil types and management scenarios at land parcel levels is required. This will contribute to national assessment methodologies, provide an improved understanding of the consequences of historical changes in SOC stocks across land uses and identify potential GHG mitigation and offsetting approaches. This will build capacity in the understanding and application of model interfaces. The end target is to provide a tool for the quantitative assessment of the consequences of different scenarios on carbon stocks and the GHG balance.

Methodology

Based on UNFCCC reporting requirements, methodologies and models for estimates of SOC stock changes in agricultural land use and land use change (LULUC) were developed. SOC concentrations and bulk density across major land covers and general soil groups (GSGs) were estimated through the development of depth-distribution models and PTFs (Khalil et al., 2013). Due to lack of information on the impacts of LULUC on SOC stock changes for longer periods, the model-derived data was reprocessed to develop depth distribution models and PTFs covering various soil types as per Indicative Soil Types (ISTs), representing major soil characterises (e.g., acidity, mineral/organic, and drainage classes) and the corresponding key land uses and their rotations, National Soil Database ((NSDB) containing SOC data (10 cm depth), and Land Parcel Identification System (LPIS) consisting of land use data from 2000-2015. The derived land uses were grassland (G), rough grazing (R) and arable/tillage (T), and their rotations (GR, GT, RT), and soils categorized as mineral (M = SOC<10%), organo-mineral (OM = SOC 10-20% and >20% at <30cm depth: degraded and non-degraded) and organic (SOC >20% and 10-20% at >30cm depth: degraded and non-degraded) soils.

The database provided 311 of 1310 sampling/grid points included in NSDB. They were synthesized and compiled for the assessment of SOC concentration and densities up to 100 cm depth using the depth distribution models and PTFs. We considered 2006 as the base year for the analysis, as soils were sampled around this year for the determination of SOC concentration as part of the NSDB. SOC stocks were computed through distribution of the total agricultural farmed area reported by the Central Statistics Office (www.cos.ie) to the proportion of land uses on three soil categories derived from 311 sampling points. Synthesis/collation of the fractional contribution of key soil variables, inputs, management and climate, as well as estimation of SOC stocks and their historical changes in agricultural soils was carried out. The following steps were taken:



The coefficient of determination (R^2) and coefficient of variations (CV) were used to compare the extent of any relationships and the degree of uncertainty for variables. The indices used were mean square errors (MSE), and the root mean square error (RMSE). Statistical analyses were performed in Microsoft Excel (v. 2013,) and JMP v.13 (SAS Inc., USA). For overlaying maps and geo-processing of data, ArcGIS version 10 (ESRI, Ireland) was used.

Results

Depth distribution models and PTFs

The non-linear (exponential for mineral and organio-mineral; natural logarithmic for organic soils) depth distribution models redeveloped using data of Khalil et al. (2013) with soil depth ratio functions fitted well for all soil types (mineral, organo-mineral and organic) and the corresponding IST categories (e.g., acidity and drainage classes) and agricultural land uses (G, R and T) with the R^2 and CV ranging from 0.53-1.00 and 09-63%, respectively (data not shown). The k values (scale constant, cm-1) differed between mineral and organo-mineral soils (-0.26 to -0.42) within or between land uses. For organic soils the values differed largely, with non-degraded ranged from -0.066 to -0.164, and the degraded ranged from 0.269 to 1.351.

The soil type-specific and land use-specific empirical equations of Khalil et al. (2013) were reprocessed to estimate bulk density (ρd) from PTF (SOC) (data not shown). The k values, which varied between the soil types and land uses, ranged from -0.031 to -0.260, and the R^2 varied from 0.67 to 0.99. Statistical evaluation of the models for the predictions of ρd from SOC was also performed. Irrespective of soil type and land use, the MSE was ≤ 0.028 and RMSE was ≤ 0.166.

Key land use categories

The preliminary compilation of the LPIS (2000-2015) and other databases results in 13 key agricultural land use classes and their rotations on three soil categories i.e. mineral, organo-mineral and organic soils (data not shown). Analyses indicate that grassland occupied the major share (59%) of Irish land uses and was dominant on mineral, followed by organo-mineral soils. Grassland-tillage rotation on mineral soil (14%) and rough grazing on organo-mineral and organic soils (12%) was significantly less. Tillage on mineral soils only represented ~3%.

SOC density

Irrespective of land use and soil layers/profiles, there were significant variations of SOC densities among the three categories, showing the highest from organic soils (Fig. 1). For 0-10, 0-30 and 0-100 cm layers, the corresponding SOC densities were the highest (121, 362 and 1207 t ha^{-1}) for rough grazing on organic soils and the lowest from tillage (30, 79 and 142 t ha^{-1}). Considering the 0-10 cm layer, the weighted average of it was higher from GR, R and RT (85-92 t ha^{-1}) than the other land uses (30-56), with the lowest from tillage lands. Similar trends were observed for the 0-30 cm layer, and the corresponding values are 260-301 versus 79-150 t ha^{-1}. For the 0-100 cm layer, the weighted average of SOC density was significantly higher from GR (1003 t ha^{-1}) than from R (657) and RT (516), followed by the other land uses (213-305). Under RT on organo-mineral soils, it was significantly higher for RT (85 t ha^{-1}) than GT (46).

SOC stocks

Being the dominant land use, grassland had a higher SOC stock of 154, 449 and 1034 Tg at 0–10, 0–30 and 0–100 cm soil depths, respectively, than the other land uses (Fig. 2). This was followed by rough grazing and the GR rotation, and the lowest from tillage and the RT rotation (4, 11 and 19/21 Tg). The percent national total (the sum of grassland, rough grazing and GR) for grassland was estimated to be 87%, and the GT rotation shared 10% and the tillage and RT rotation 1% each of the total SOC stock (270, 789 and 1894 Tg for 0-10, 0-30 and 0-100 cm layers). Analysis of the results for historical changes in SOC stocks in disaggregated agricultural land uses are in progress and will be presented.

Discussion

Previous work developed both depth-distribution models and PTFs across key land covers considering GSGs (Khalil et al., 2013). Given strong functional relationships between land use classes, management practices and soil types that impact on soil carbon, ISTs denoting acidity, drainage and other soil characteristics are well-thought-out for the development of methods/models and the estimation of SOC content. Both LPIS and NSDB are unable to provide details of existed land use classes in Ireland but grassland, rough grazing, tillage and their rotations derived from the historical LPIS (2000-2015). This was found to be promising in providing further details of the impact of LUC and other variables with reduced uncertainly on a yearly basis, leading to offer reliable estimates of SOC densities/stocks across land uses and soil types.

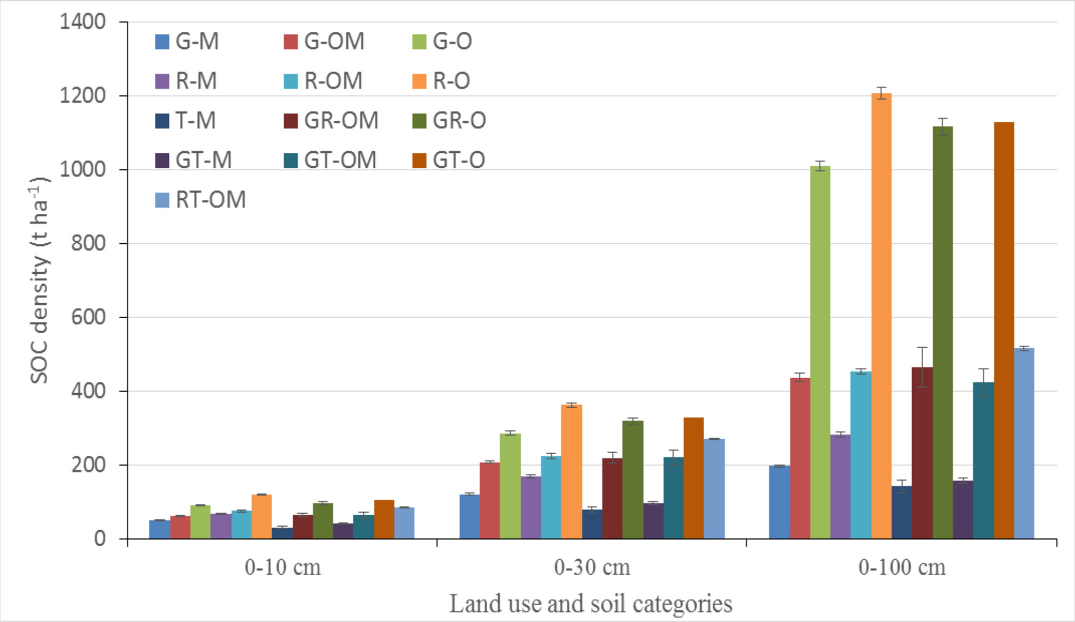


Fig. 1: Estimates of soil organic carbon (SOC) density (tonne per hectare) in the mineral (M), organo-mineral (OM) and organic (O) soils for three soil layers under major agricultural land uses (G= Grassland, R= Rough grazing and T= Tillage and their rotations i.e. GR, GT and RT).

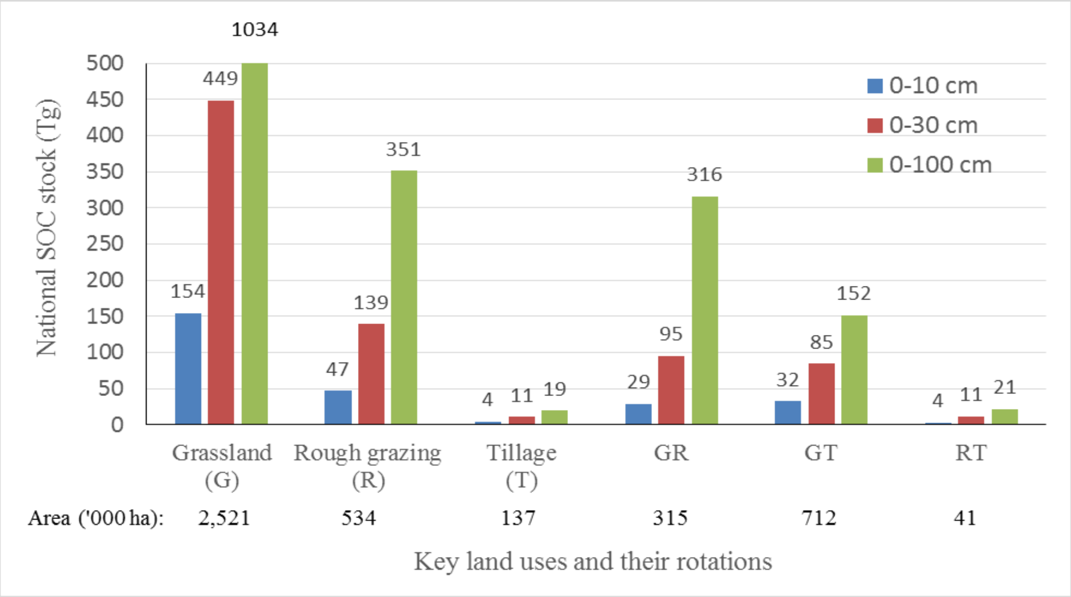


Fig. 2: Areas (hectare, ha) and soil organic carbon (SOC) stocks (Tg, Terragram) for key agricultural land uses and their rotations (G= Grassland, R= Rough grazing and T= Tillage and their rotations i.e. GR, GT and RT).

Despite some variations within the key soil types across land uses, the redeveloped models provide a good estimate of the SOC concentration and thereby its densities across the soil depths. The current estimates of SOC density considered disaggregated lands uses and soil types including widely applicable categories such as mineral, organo-mineral and organic soils. This study also observed significant variations in SOC densities among the ISTs although comparable to a previous study (Khalil et al., 2013). Importantly, the findings are distinguishable on an individual basis for the three soil categories and the overlapping of organic versus mineral soil types observed earlier have been removed. However, SOC densities were remarkably high in the RT rotation on organo-mineral soils in line with the previous study and that the errors associated with this needs to be corrected through field investigation. Overall, the SOC densities across land uses and soil types provide reasonable estimates.

The estimated national SOC stocks of the three soil layers are somewhat higher, taking into account the variations in the three soil categories, than the previous estimate (Khalil et al. 2013) and considerably higher than estimated by Eaton et al. (2008). In this study, the approaches considered the factors that influence variations in SOC content. Thus, the estimates of SOC stocks are consistent with historical changes, coupling with LPIS data and the EFs corresponding to inputs, soil types, management practices and weather conditions.

Conclusions

The reprocessed depth-distribution models and PTFs will be useful for the estimation of SOC concentration at national and regional levels. The higher spatial resolution databases (LPIS, ISTs and NSDB) and coupled empirical modelling and GIS approaches have the potential to provide robust estimates of SOC density/stocks in disaggregated agricultural land uses and soil types (Tier 2 development). The estimated baseline SOC stocks can be used for LULUC accounting and offsetting, including the supply of stratified input data for use in ecosystem models and their verification as well as to quantify and refine land use and soil-specific carbon sequestration required to achieve 4 per mille per year. The data can be used for mapping and developing a widely applicable tool to estimate historical changes in SOC stocks.

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