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**Estimating soil  
carbon stocks of  
Africa**

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# Soil carbon stocks in ecoregions of Africa

**M. Henry<sup>1,2,3</sup>, R. Valentini<sup>2</sup>, and M. Bernoux<sup>1</sup>**

<sup>1</sup>Institut de Recherche pour le Développement, IRD, UR SeqBio, SupAgro, Bat. 12, 2 place Viala, 34060 Montpellier Cedex 1, France

<sup>2</sup>Laboratorio di Ecologia Forestale, Di.S.A.F.Ri. – Facoltà di Agraria, Università degli Studi della Tuscia, Via Camillo de Lellis, snc – 01100, Viterbo, Italy

<sup>3</sup>AgroParisTech – ENGREF, GEEFT, 648 rue Jean-François Breton, BP 7355, 34086 Montpellier Cedex 4, France

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Correspondence to: M. Henry (henry@unitus.it)

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## Abstract

The African continent plays a growing role in the carbon (C) cycle. However, Africa is one of the weakest links in our understanding of the global carbon cycle particularly when considering the soil compartment. Most of the soil organic carbon (SOC) estimates concern the global size of the soil C reservoir without indication on its distribution, or if given, limited to the contribution of a large ecosystems or region.

The aim of the study is i) to assess the original soil C stocks (SOC) of Africa for the different countries and Ecoregions, and ii) to compare SOC estimates from different soil properties databases and digital maps. Four recent global digital soil maps and five soil properties databases were used to estimate the SOC for different soil layers in Africa. Those databases hold between 1799 and 4043 soil profiles which are considered to represent the soil units showed on a 0.5 by 0.5 degree soil maps of Africa.

SOC of Africa ranged 133 420–184 116 Tg for 0–100 cm soil layer. The most recent databases estimated 166 397 Tg C which corresponded to 9% of the global SOC stock and 68% of the terrestrial C pool of Africa. Average SOC ranges  $0.4\text{--}8.2\text{ kg m}^{-2}$  at national scale and  $1.53\text{--}6.61\text{ kg m}^{-2}$  for ecoregions. Using different soil database or spatial data leads to up to 30% of difference. These quantities indicate a great potential to develop sink activities through soil C sequestration activities.

## 1 Introduction

Carbon dioxide (CO<sub>2</sub>) is, by far, the largest contributor to the anthropogenically enhanced greenhouse effect (IPCC, 2007a). The importance of CO<sub>2</sub> to the climate has provided the impetus for research on the global C cycle with particular attention on C stocks in main terrestrial compartments, mainly soils and phytomass. The increasing interest of the contribution of terrestrial ecosystems to mitigate climate change has given rise to the possibility of emission credits for soil organic carbon (SOC) sequestration. Carbon sequestration in terrestrial ecosystems is being considered as a way

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to mitigate the greenhouse effect and, simultaneously, combat land degradation (Lal, 2004).

Soil organic matter is a key component of any terrestrial ecosystem, and any variation in its abundance and composition has important effects on many of the processes that occur within the system. The magnitude of organic matter and soil carbon stock result from an equilibrium between the inputs (mostly from biomass detritus) and outputs to the system (mostly decomposition and transport), which are driven by various parameters of natural or human origins (Schlesinger and Palmer Winkler, 2000; Amundson, 2001). The decrease of organic matter in topsoils can have dramatic negative effects on water holding capacity of the soil, on structure stability and compactness, nutrient storage and supply and on soil biological life such as mycorrhizas and nitrogen-fixing bacteria (Sombroek et al., 1993).

The carbon balance of terrestrial ecosystems can be changed markedly by the direct impact of human activities. Land use change is responsible for 20% of the global anthropogenic CO<sub>2</sub> emissions during the 1990s (IPCC, 2007b) and is the main primary net C release in Africa, much of it through burning of forests (Williams et al., 2007). The impact of land use change varies according to the land use types. The clearing of forests or woodlands and their conversion into farmland in the tropics reduces the soil-carbon content, mainly through reduced production of detritus, increased erosion rates and decomposition of soil organic matter by oxidation. Various reviews agree that the loss amounts to 20 to 50% of the original carbon in the topsoil, but deeper layers would be little affected, if at all (Sombroek et al., 1993; Murty et al., 2002; Guo and Gifford, 2002). Conversion of forests to pasture did not change soil carbon (Guo and Gifford, 2002) or may actually increase the soil organic matter content (Sombroek et al., 1993). Changes in soil carbon under shifting cultivation were half as large (Detwiler, 1986). Commercial logging and tree harvesting did not result in long-term decreases in soil organic matter (SOM) (Knoepp and Swank, 1997; Houghton et al., 2001; Yanai et al., 2003). Changes in the amount of soil organic matter following conversion of natural forests to other land uses depend on several factors such as the type of forest

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ecosystem undergoing change (Rhoades et al., 2000), the post conversion land management, the climate (Pastor and Post, 1986) and the soil type and texture (Schjonning et al., 1999).

In Sub-Saharan Africa, the increasing demand for food can encourage farmers to reduce the length of fallow periods, cultivate continuously, overgraze fields, or remove much of the above-ground biomass through fuel collection or for building materials. Such practices can result in the reduction of SOC, water holding capacity, nutrients, as well as enhance soil erosion (Lal, 2004). Nevertheless, appropriate land management could revert this trend and contribute to soil carbon sequestration. Increasing the SOM could help reverse these problems and may be crucial for future African agriculture and food production (Bationo et al., 2007; Sanchez, 2000). Some operations that increase organic matter inputs such as reforestation of agricultural lands, improved fallow, reduced tillage or fertilization can increase SOM levels. Several studies have shown that a synergetic effect exists between mineral fertilizers and organic amendments in Sub-Saharan Africa, that leads both to higher yields and SOC content (Palm et al., 2001; Vagen et al., 2004; Bationo et al., 2007).

However, soil protection or conservation decisions cannot be made without maps of land properties. If projects have to be implemented with the objective of enhancing the storage of carbon in the terrestrial biosphere, potentially for carbon trading related to the Kyoto protocol, it is important to have the capabilities of verifying and monitoring the changes of soil organic carbon (SOC) over time and space (Post et al., 2001). While, Annex I country of the Kyoto protocol are committed to report national estimates of changes in the amount of soil organic carbon (SOC) in cropland, we can expect that in the future, all the countries will have to report their emissions.

Several attempts were developed to report the soil organic mass of the world. The global soil C storage estimates over the past 70 years range 400–9120 Pg C (Amundson, 2001). However, most recent studies give estimates ranging from 1115 to 2200 Pg C in the first meter and generally converge on a value of about 1500 Pg (Post et al., 1982; Batjes, 1996; Schlesinger and Palmer Winkler, 2000) while plant biomass

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is estimated to range between 560 and 835 Pg C (Whittaker and Likens, 1975; Bouwman, 1990). Furthermore, the world's mineral soils represent a large reservoir of C of about two third of the global terrestrial C stocks. Soils contain nearly as much carbon as the vegetation under rainforest, but considerably exceed the biomass in other ecosystems, by a factor 2 to 10 (Sombroek et al., 1993). According to Sombroek (1993), this large variation of SOC estimates between authors is explained by the difference in base maps selected (FAO/Unesco Soil Map of the World, Holdridge Life Zones, Vegetation Maps) and the various assumptions made about soil attributes directly related to the total content of organic-matter per soil type such as organic matter content and distribution in the soil profile, bulk density of soil layer, and average soil depths. Nonetheless, the size and dynamics of the soil carbon pool of the world, it is still poorly known (IPCC, 2007b). Uncertainties concerning (1) estimates of C in ecosystems, (2) per hectare changes in C stocks in response to different types of land-use change and (3) legacy effects, are important particularly in Africa (Houghton and Goodale, 2004). There are great needs to improve the understanding comprehension of the C cycle in Africa.

Most of the time, the reported values consist of estimates of the global size of the soil C reservoir without indication on its distribution, or if given, limited to the contribution of a large ecosystems or region. Models of the global C cycle require accurate estimations of the masses in the different reservoirs. Regarding the soil compartment, global C pools are difficult to estimate because of still limited knowledge about specific properties of soil types (Sombroek et al., 1993; Batjes, 1996), the high spatial variability of soil C even within one soil map unit (Cerri et al., 2000), and the different effects of the factors controlling the soil organic C cycle (Pastor and Post, 1986; Parton et al., 1987). Thus, regional studies are being proved necessary in order to refine global estimations obtained by aggregation of regional estimates, mainly at country scale (Milne et al., 2007). Aggregate of more precise studies, at a country or regional scale, certainly would improve the global estimates. But only few and not homogeneous (different layers used to report results) data exists.

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In order to provide reliable predictions, successful global carbon cycle models must accurately represent fundamental controlling processes and conditions in robust model structures that can be validated by comprehensive data sets collected over a wide range of controlling environmental conditions. However, global observational data sets of SOC are currently incomplete and large-scale validating data sets are needed in global carbon cycle models (Bombelli et al, this issue). Models of global climate change need accurate and complete SOC inventories because the SOC pool represents the largest component of the global C pool and acts as a regulator of atmospheric CO<sub>2</sub> levels (Amundson, 2001).

The objectives of this study are 1) to assess the soil C stocks of Africa for the different countries and ecoregions, and 2) to compare SOC estimates from different digital map and soil properties database.

## 2 Materials and methods

### 2.1 Source of data

Different soil databases were collected from the World Soil Information (ISRIC) website (Table 1). Soil properties were compiled in a harmonized way, based on using uniform taxonomy based pedotransfer rules and were compiled into the World Inventory of Soil Emission (WISE) database (Batjes, 1996, 2002, 2005, 2006) and the Harmonized World Soil Database (FAO/IIASA/ISRIC/ISSCAS/JRC, 2008). The databases reported soil properties for different soil layers, from 0–20 to 0–200 cm. Soil parameter estimates for all secondary SOTER database (SOTWIS) that were included into the Harmonized World Soil Database (HWSD) were derived from the WISE database v.02 (Batjes, 2002). The number of soil profiles for Africa that were found in the WISE (Batjes, 1996, 2002, 2005, 2006) and HWSD databases (FAO/IIASA/ISRIC/ISSCAS/JRC, 2008) were 1799, 3998, 3998, 4043 and 3998, respectively.

Four spatial components were used to represent soil spatial distribution (Table 1).

The Digital Soil Map of the World (DSMW – FAO, 1995), the ISRIC-WISE and ETOPOS-DSMW spatial data are 0.5 by 0.5 degree grid version of the edited and corrected 1:5M Soil Map of the World. The spatial data used for Harmonized World Soil Database is a mosaic of the Digital Soil Map of the World and the SOTER regional studies (Northeastern Africa, and Southern Africa). The numbers of maps units within those four spatial data for Africa are 1598, 7964, 1588 and 6994 respectively. The FAO-UNESCO (1974) legend was used to aggregate available soil profile data and to link derived interpretations of soil properties with the soil units on the grid maps.

## 2.2 Calculation of carbon stock

The estimates correspond to the SOC present in the layer after correction using the volume percentage of fragments coarser than 2 mm. SOC was estimated using the following formula:

$$C = V \times (1 - Gr) \times Bd \times Cc \quad (1)$$

where  $C$  is carbon density ( $\text{kg m}^{-2}$ ),  $V$  is the volume of soil per square meter ( $\text{m}^3$ ),  $Gr$  is the volume of gravel ( $\text{m}^3$ ),  $Bd$  is the bulk density ( $\text{kg dm}^{-3}$ ) and  $Cc$  is the carbon content ( $\text{g C kg}^{-1}$ ).

Organic carbon content is universally determined by oxidation of  $\text{CO}_2$ , and is directly measured as  $\text{CO}_2$  or by weight loss of the sample or by back-titration of the excess of the added oxidant. Bulk density is critical for converting organic carbon percentage by weight to content by volume, but it varies with the structural condition of the soil, in particular the mineralogy, water content and packing. In general, bulk density is determined by the core sampling method which is comparable with values obtained by the clod method. The mean bulk density was computed for each profile and when there was no bulk density for a particular soil profile the mean bulk density of the corresponding soil unit was used in the derived database. Gravel is not considered to contain organic carbon (Anderson and Ingram, 1993) and its volume is subtracted from the total volume.

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## 2.3 Computation of soil carbon stocks

The soil properties are given per soil classes. The spatial data are identified as map units. Within one map unit different soil classes could be found. In order to report the soil properties of one map unit, the SOC estimate was calculated according to the relative proportion of all soil classes per soil layer. The soil composition of map units is homogenized per soil profiles types. Furthermore, the calculation of C density ( $\text{kg m}^{-2}$ ) for each soil profile results from the soil properties per soil classes and the composition of soil classes per layer. For an individual soil profile with  $k$  layers, the organic carbon by volume is:

$$C_d = \sum_{i=1}^k V_i \times (1 - Gr_i) \times Bd_i \times Cc_i \quad (2)$$

where  $C_d$  is the total amount of organic carbon ( $\text{kg m}^{-2}$ ) over depth,  $Bd_i$  is the bulk density ( $\text{kg dm}^{-3}$ ) of layer  $i$ ,  $Cc_i$  is the carbon content ( $\text{g C kg}^{-1}$ ) of the layer  $i$  and  $Gr_i$  is the volume of gravel ( $\text{m}^3$ ) of the layer  $i$ .

The C stock representative for each soil mapping unit was determined by:

$$M_{ud} = A \times C_{id} \quad (3)$$

where  $M_{ud}$  is the total mass of organic carbon (kg of C) held in the upper  $d$  cm of the soil,  $n$  is the total number of map unit,  $A$  is the area of the map unit ( $\text{m}^2$ ),  $C_{id}$  is the carbon density of the soil profile ( $\text{kg m}^{-2}$ ). It is assumed that each soil profile is homogenous in each map unit.

Soil carbon mass for one biome, one country or the continent is determined by aggregating the soil carbon stock of the corresponding map units:

$$M_d = \sum_{j=1}^n M_{udj} \quad (4)$$

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where  $M_d$  is the total mass of carbon (ton of C) held in the upper  $d$  cm of the soil and  $j$  is the number of map units within one biome, country or the continent.

## 2.4 The soil carbon map of Africa

5 Five different soil carbon maps for Africa were obtained using the different data sources (Table 1). It represents the evolution of the available data for the years 1996, 2002, 2005, 2006 and 2008. While the first map was obtained using the soil properties reported by Batjes (1996) and the digital soil map of the world (FAO, 1995), the most recent and precise map is considered to be the Harmonized World Soil Database (FAO/IIASA/ISRIC/ISSCAS/JRC, 2008). The digital soil map units were linked to the  
10 soil properties in order to represent the spatial distribution of the C stocks.

Each map unit is linked into a geographic information system to its respective soil profile type and soil properties using ArcGis 9.2.

## 2.5 Calculation of the carbon stocks per biomes and per country

15 Various biome classification could be found for Africa (Holdridge, 1947; White, 1981; FAO, 1999; WWF, 2000; Olson et al., 2001). The Terrestrial Ecoregions of the World (WWF, 2000) was considered as one of the most updated vegetation classification which reflecting the various vegetation types, not only the forest biomes, in a simplified form. The Global Administrative Layer updated for the year 2008 (FAO, 2008) was used to delineate the country boundaries. After digitally intersecting the Soil C map with countries boundaries and, the Terrestrial Ecoregions of the World, it was possible  
20 to derive for each country and each ecoregions the C stocks for the different soil depths.

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### 3 Results and discussion

#### 3.1 Map of soil C stocks of Africa

The Fig. 1 represents the unequal distribution (in  $\text{kg C m}^{-2}$ ) of SOC in Africa based on the data from the HWSD. According to the HWSD soil map, soil carbon stocks for the layers 0–30 cm and 0–100 cm were, respectively, 85 986 and 166 397 Tg C for Africa. Average SOC was  $2.37 \text{ kg m}^{-2}$  and  $4.60 \text{ kg m}^{-2}$  for 0–30 and 0–100 cm soil layers, respectively.

However, SOC varied between countries. Results for each country are reported in Table 2. The maximum SOC density was found in Congo ( $8.20 \text{ kg m}^{-2}$ ) while the minimum SOC density was found in Western Sahara ( $0.40 \text{ kg m}^{-2}$ ). Most of the C stock in Africa (0–100 cm) was located in Middle Africa (33%) while only 6% was located in southern Africa. While the SOC density was  $3.93 \text{ kg m}^{-2}$  in Middle Africa, it was  $2.23 \text{ kg m}^{-2}$  in Southern Africa. Most of the map units contained soil in both regions (96 and 97.4%, respectively). Furthermore, the difference could be mainly explained by different soil types. When considering soil types, it appeared that SOC varied between them. While Dystric Histosols (by definition soil rich in organic matter, WRB 2006) contained  $116 \text{ kg C m}^{-2}$ , Yermosols (also classified under the term Gypsisols – WRB, 2006, which correspond to desert soils found in the driest parts of the arid climate zone), contained only  $1.39 \text{ kg C m}^{-2}$ . In addition, SOC varies with depth. On one hand, the totality of SOC in the soil profile was contained in 0–30 cm soil layer in Rankers soils. On the other hand, only 26.6% was contained in 0–30 cm soil layer in Histosol soils. In average, 52% of the SOC contained in the whole profile was located in 0–30 cm soil layer.

While the horizon 0–30 cm is considered to be the most important SOC pool, it is also the most susceptible to be affected by land management (Bernoux et al., 2006).

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## 3.2 African SOC and the global cycle

Global carbon stocks were also calculated with the DSMW and the HWSO database (Fig. 2). Using the DSMW, these stocks were respectively 803 Pg, 1101 Pg, 1589 Pg and 2521 Pg of C for the layer 0–30 cm, 0–50 cm, 0–100 cm and 0–200 cm. Using the HWSO, the SOC of the world represented 814 Pg and 1850 Pg for 0–30 and 0–100 cm, respectively. Africa represented 8.6 and 9% of the SOC in the 0–100 cm soil layer according to the DSMW and the HWSO database respectively. Those results are lower than the 13% reported by Williams et al., (2007). On the other hand, Williams et al. (2007) reported that live plant carbon contained  $610 \pm 47$  and  $80 \pm 28$  at global scale and in Africa respectively. It means that 75 and 68% of the C stocks are contained in the 0–100 cm soil layer in the world and in Africa, respectively.

## 3.3 Soil C stocks in ecoregions of Africa

The corresponding stocks and areas for each biome are reported in Table 3. Tropical & Subtropical Grasslands, Savannas & Shrublands represented the most important SOC stock (79 325 Tg C for 0–100 cm soil layer) and Temperate Conifer Forests biome represented the lowest (183 Tg for 0–100 cm soil layer). There were marked differences in mean SOC content among biomes. While Tropical & Subtropical Moist Broadleaf Forests had the highest mean C stock ( $5.7 \text{ kg C m}^{-2}$ ), Deserts & Xeric Shrublands had the lowest C stocks ( $1.53 \text{ kg C m}^{-2}$ ). Higher net primary production in tropical regions is responsible for higher inputs of organic matter into the soil compartment. Moreover, tropical soils are deep and could contain important amount of SOC. On the other hand, in dry and arid regions, biomass production is limited by climatic constraints and leads to lower organic matter inputs. Soils are thin and the presence of rocks and deserts is higher.

Land use change is responsible to higher emission rates in tropical regions than dry and arid regions (Ogle et al., 2005). The IPCC (2007a) reported relative stock change factors for different management activities on cropland. Those are ranging

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0.48–0.80 for long term cultivated cropland for tropical region and dry temperate climate respectively. Amudson (2001) reported that cultivation reduces the original soil C content by 30% but it was not mentioned under which ecological region. Impact of land use change depends on biomass productivity, mainly on ecosystem types, structure and composition, the soil substrate and the climate (Keeling and Phillips, 2007) and management, mainly fertility management and tillage (Shepherd and Soule, 1998; Reicosky et al., 1999). Moreover, estimating the impact of land use change should consider the ecology and the soil types, the management and the farming practices for each ecological regions.

### 3.4 Variation of soil C stocks of Africa estimates

Table 4 reports the SOC estimates using four spatial data and five soil databases. It represents the evolution of the SOC estimates based on the most precise data for 1996, 2002, 2005, 2006 and 2008. The SOC estimates for 0–100 cm soil layer of Africa, based on the soil databases and spatial data reported in Table 4, ranged 133 420–184 116 Tg C. While the oldest SOC estimate for Africa was reported to be 179 288 Tg, the most recent SOC estimate was 166 022 Tg. Moreover, the range of SOC estimates for Africa is higher than the 170–240 Pg C range proposed by Williams (2007).

The difference between SOC estimates at continental or global scale could be attributed to various factors (Sombroek et al., 1993). It is important to highlight that SOC estimates can be very imprecise mostly for the small islands i.e. Cape Verde or Canarias. However, the coastal boundaries that were used to correct the spatial data were the same. Furthermore, the difference of SOC estimates is attributed to the spatial scale of the spatial data and the soil properties of the soil database.

The data contained in the soil databases have changed over time. The main differences observed when estimating SOC stocks are (1) the number of soil profiles, (2) the data of organic content, bulk density and gravel, (3) the soil layer that are considered. Increasing the number of soil profiles and the spatial resolution of the soil maps should increase the SOC estimates. Since 1995 the number of soil profiles increased from

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4353 to 9607 (Table 1). The soil properties changed between databases and led to different SOC density estimates for an identical soil type. For example, Lithosols contained 2.7, 0, 4.1, 3.6 and 4.5 kg C m<sup>-2</sup> in the databases 1996, 2002, 2005, 2006 and 2008, respectively. While the database of 2005 considered Lithosols as rocks and were included into the miscellaneous, Lithosols were considered only for the 0–10 cm layer in the database of 2006 and 2008. Acrisols contained 6.50, 4.83, 6.83, 6.80 and 6.05 kg C m<sup>-2</sup> in the databases 1996, 2002, 2005, 2006 and 2008, respectively. Small difference in the soil properties can induce important errors when considering the continental scale. The soil properties estimates have to be accurate and consider the spatial variability of SOC. When changing scale, few soil profiles are available for Africa and are not randomly distributed. It is moreover difficult to increase the precision of the soil properties estimates without increasing the precision of the spatial data and vice versa. Both spatial and soil properties improvements have to be achieved to increase the precision of the SOC estimates at continental scale.

The soil layers are also different between the databases. While the SOC estimates of Batjes (1996) reported SOC for four soil layers, and Batjes (2006) reported SOC for five soil layers, the most recent SOC estimates (FAO/IIASA/ISRIC/ISSCAS/JRC, 2008) reported SOC only for 0–30 and 0–100 cm soil layer. This could be mainly explained by the increasing interest in climate change and the will to obtain SOC inventory for the 0–30 and 0–100 cm soil layers as reported by the IPCC methodology (IPCC, 2007a).

### 3.5 Error of SOC estimates

In order to assess the error due to the soil properties estimates, five maps were built using the same digital map (FAO, 1995) and different soil databases (Table 5). The SOC estimates ranged 211 956–117 356 Tg C. It appeared that the highest SOC estimate was obtained using the most recent HWSO database. When comparing the SOC estimates to the mean SOC estimates it appeared that the SOC estimates ranged +32% and –27%.

When estimating the error due to spatial data it was not possible to compare SOC

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from the different maps using the same database because the spatial data uses different legends. The error due to spatial data was estimated making a comparison with the SOC estimates from Tables 4 and 5. The SOC estimates using the same soil properties and different soil maps varied a lot (Tables 4 and 5): i.e. the SOC estimates using the soil properties from HWSD and the spatial map from DSMW and the HWSD were 166 450 and 211 956 Tg. It appeared that the percentage of error due to spatial data ranged -30% to +27%. It means that the spatial data could over or underestimate the SOC estimates at continental scale of about 30%.

When developing or monitoring land use change project, SOC data should be available for regional, national or local scale. According to our results we can assume that the estimate of SOC, based on the soil map of the world from FAO and IIASA and the soil properties from the WISE and the HWSD, could vary of up to 60% when considering the spatial and soil properties data. When considering national scale studies, SOC estimates vary also (Table 6). For instance, SOC assessment of Congo was estimated 3300 Tg of C by Schwartz and Namri (2002) while 9300 Tg of C were estimated in this study for 0–100 cm soil layers, respectively. But Schwartz and Namri (2002) based their calculation on only ca. 90% of the country area due to lacking information for specific landscape units, mainly in Northern areas, and concerning mostly hydromorphic soils and in a less extent peats; both soil types usually with high level of OC. Moreover Schwartz and Namri (2002) recognized that small areas of Podzols with humic horizon containing considerable quantities of OC (up to  $120 \text{ kg m}^{-2}$ ) could not be taken into account in their established procedure of calculation. SOC estimates of Benin ranged 251–260 and 526–543 Tg C in Volkoff et al. (1999) while the estimates of this study were 374 and 687 Tg C for 0–30 and 0–100 cm soil layers, respectively. In addition, average SOC density was estimated to be  $3.5 \text{ kg C m}^{-2}$  in this study while  $4.5 \text{ kg C m}^{-2}$  in Volkoff et al. (1999). SOC estimates of Kenya ranged 1896–2006, and 3452–3797 Tg C in Batjes (2004) while 1832 and 3989 Tg were estimated in this study for 0–30, 0–100 cm soil layers. The estimates obtained from the HWSD overestimated SOC of at least 2.8 and 15.4% for 0–30 and 0–100 cm layer in central Africa, 28.5%

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for 0–100 cm layer for Benin and 181% for Congo. The difference between estimates could be explained by (1) imprecision in the boundaries of the territory that lead to an overestimation of the area of about 12.4%, (2) lacking information for specific soil type, and (3) imprecision of SOC content which increased with soil depth. We observed that SOC estimates for Kenya (Batjes, 1996) were quite similar (% of error less than 5%) which could be explained by the same origin for soil characteristics.

Reliability of the information presented here is variable. While some parts of the world are highly reliable (Southern Africa, Latin America and the Caribbean, Central and Eastern Europe), other part of the world are considered less reliable (North America, Australia, West Africa and South Asia). Most of the improvement of the comprehension of the soil compartment at global scale could be attributed to the development of the SOTER database that already covers Africa: Northern Africa, Southern Africa, Kenya and Central Africa. However, in order to improve the estimates of the soil biophysical properties and the impact of anthropic activities, the data on spatial resolution of the soil map units and the land use units, the proportion of soil types within on soil map units, the soil properties and the stock change factors for different management activities have to be improved.

#### 4 Conclusions

There are uncertainties in any estimate of soil carbon stocks at national and continental scale. The SOC estimates using the Harmonized World Soil Database clearly overestimated the SOC for the different layers when comparing with other national studies. When comparing different soil databases and soil maps it appeared that SOC estimates ranged 133 420–184 116 Tg for 0–10 cm soil layer of Africa. On the other hand, a variation of about  $\pm 30\%$  was reported when comparing the soil properties or the spatial data of the different databases. With an estimate of 166 397 Tg for the 0–100 cm, soil appeared to contain 68% of the terrestrial C pool of Africa. Most of the CO<sub>2</sub> emissions in Africa is due to land use change that affect both aboveground and belowground compartments. It is difficult to estimate the amount of C that could be

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released from the soil as no data exist on SOC before conversion to agriculture and the impact of anthropic activities on the different soil types is not known. Adoption of recommended management practices can result in important C sequestration particularly in degraded/marginal soils. Soil degradation and food security are among major challenges in sub-Saharan Africa. Commoditisation of SOC through trading C credits under the Kyoto's CDM could improve livelihoods and provide incentives for exchanging soil quality and restoring degraded soils and ecosystems.

## References

Amundson, R.: The carbon budget in soils, *Annu. Rev. Earth Pl. Sc.*, 29, 535–562, 2001.

Anderson, J. M. and Ingram, J. S. I.: *Tropical Soil Biology and Fertility: A Handbook of Methods*, TSBF, Wallingford, UK, 1993.

Arđö, J. and Olsson, L.: Assessment of soil organic carbon in semi-arid Sudan using GIS and the CENTURY model, *J. Arid Environ.*, 54, 633–651, 2003.

Bationo, A., Kihara, J., Vanlauwe, B., Waswa, B., and Kimetu, J.: Soil organic carbon dynamics, functions and management in West African agro-ecosystems, *Agr. Syst.*, 94, 13–25, 2007.

Batjes, N. H.: Total carbon and nitrogen in the soils of the world, *Eur. J. Soil Sci.*, 47, 151–163, 1996.

Batjes, N. H.: Soil parameters estimates for the soil types of the world for use in global and regional modelling (Version 2.1, July 2002), ISCRI report 2002/02c, International food policy research institute (IFPRI), International soil reference and information centre (ISRIC), Wageningen, 52, 2002.

Batjes, N. H.: Soil carbon stocks and projected changes according to land use and management: A case study for Kenya, *Soil Use Manage.*, 20, 350–356, 2004.

Batjes, N. H.: ISRIC-WISE global data set of derived soil properties on a 0.5 by 0.5 degree grid (Version 3.0), Report 2005/08, ISRIC-World Soil Information, Wageningen, 24, 2005.

Batjes, N. H.: ISRIC-WISE derived soil properties on a 5 by 5 arc-minutes global grides, Report 2006/02 (available through: <http://www.isric.org>), ISRIC-World Soil Information, Wageningen, 2006.

Batjes, N. H.: Mapping soil carbon stocks of Central Africa using SOTER, *Geoderma*, 146, 58–68, 2008.

Bernoux, M., Cerri, C. C., Cerri, C. E. P. Siqueira Neto, M., Metay, A., Perrin, A. S., Scopel,

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- E., Razafimbelo, T., Blavet, D., Piccolo, M. C., Pavei, M., and Milne, E.: Cropping systems, carbon sequestration and erosion in Brazil, a review, *Agron. Sustain. Dev.*, 26, 1, 1–8, 2006.
- Bouwman, A. F.: Global distribution of the major soils and land cover types, in: *Soils and the greenhouse effect: Proceedings of the international conference on soils and the greenhouse effect*, edited by: Bouwman, A. F., John Wiley and Sons, New York, 31–59, 1990.
- 5 Cerri, C., Bernoux, M. C., Arrouays, D., Feigl, B., and Piccolo, M.: Carbon stocks in soils of the Brazilian Amazon. *Advances in Soil Science. Global climate change and tropical ecosystems*, in: *Carbon stocks in soils of the Brazilian amazon*, edited by: Lal, R., Kimble, J. M., and Stewart, B. A., CRC Press, Boca Raton, USA, 33–50, 2000
- 10 Detwiler, R. P.: Land use change and the global carbon cycle: The role of tropical soils, *Biogeochemistry*, 2, 67–93, 1986.
- FAO/IIASA/ISRIC/ISSCAS/JRC: *Harmonized World Soil Database (version 1.0)*, FAO, IIASA, Rome, Italy and Laxenburg, Austria, 42, 2008.
- FAO: *A concept and strategy for ecological zoning for the global forest resources assessment 2000*, Food and Agriculture Organization of the United Nations, Rome, 1999.
- 15 FAO: *Digital Soil Map of the World DSMW – version 3.5 CD*, 1995.
- FAO: *The Global Administrative Unit Layers (GAUL)*, Food and Agriculture Organization, Rome, 2008.
- 20 Guo, L. and Gifford, R. M.: Soil carbon stocks and land use change: a meta-analysis, *Glob. Change Biol.*, 8, 345–360, 2002.
- Holdridge, L. R.: Determination of world plant formations from simple climatic data, *Science*, 105, 367–368, 1947.
- Houghton, J., Ding, Y., Griggs, D., Noguer, M., van der Linden, P., Dai, X., Maskell, K., and Johnson, C.: *The Scientific Basis, Climate Change*, Cambridge University, Cambridge, New York, 881 pp., 2001.
- 25 Houghton, R. and Goodale, C.: Effects of land-use change on the carbon balance of terrestrial ecosystems, in: *Ecosystems and Land Use Change*, 85–98, 2004.
- IPCC: *2006 IPCC Guidelines for National Greenhouse Gas Inventories*, edited by: Eggleston, S., Buendia, L., Miwa, K., Ngara, T., and Tanabe, K., 2007a.
- 30 IPCC: *Climate Change 2007: Synthesis Report*, Intergovernmental Panel on Climate Change, 52 pp., 2007b.
- Keeling, H. C. and Phillips, O. L.: The global relationship between forest productivity and biomass, *Global Ecol. Biogeogr.*, 16, 618–631, 2007.

- Knoepp, J. D. and Swank, W. T.: Forest management effects on surface soil carbon and nitrogen, *Soil Sci. Soc. Am. J.*, 61 928–61 935, 1997.
- Lal, R.: Soil carbon sequestration to mitigate climate change, *Geoderma*, 123, 1–22, 2004.
- Milne, E., Al-Adamat, R., Batjes, N. H., Bernoux, M., Bhattacharyya, T., Cerri, C. C., Cerri, C. E. P., Coleman, K., Easter, M., Falloon, P., Feller, C., Gicheru, P., Kamoni, P., Killian, K., Pal, D. K., Paustian, K., Powlson, D., Rawajfih, Z., Sessay, M., Williams, S., and Wokabi, S.: National and sub national assessments of soil organic carbon stocks and changes: the GEFSOC modelling system, *Agr. Ecosyst. Environ.*, 122,1, 3–12, 2007.
- Murty, D., Krischbaum, M. F., McMurtrie, R. E., and McGilvray, H.: Does conversion of forest to agricultural land change soil carbon and nitrogen? A review of the literature, *Glob. Change Biol.*, 8, 105–123, 2002.
- Ogle, S. M., Breidt, F. J., and Paustian, K.: Agricultural management impacts on soil organic carbon storage under moist and dry climatic conditions of temperate and tropical regions, *Biogeochemistry*, 72, 87–121, 2005.
- Olson, D. M., Dinerstein, E., Wikramanayake, E. D., Burgess, N. D., Powell, V. N., Underwood, E. C., D'Amico, J. A., Itoua, I., Strand, H. E., Morrison, J. C., Loucks, C. J., Allnutt, T. F., Ricketts, T. H., Kura, Y., Lamoreux, J. F., Wettengel, W. W., Hedao, P., and Kassem, K. R.: Terrestrial ecoregions of the world: A new map of life on Earth, *Bioscience*, 51, 933–938, 2001.
- Palm, C. A., Giller, K. E., Mafongoya, P. L., and Swift, M. J.: Management of organic matter in the tropics: Translating theory into practice, *Nutr. Cycl. Agroecosys.*, 61, 63–75, 2001.
- Parton, W. J., Schimel, D. S., Cole, C. V., and Ojima, D. S.: Analysis of factors controlling soil organic matter levels in Great Plains grasslands, *Soil Sci. Soc. Am. J.*, 1173–1179, 1987.
- Pastor, J. and Post, W. M.: Influence of climate, soil moisture, and succession on forest carbon and nitrogen cycle, *Biogeochemistry*, 2, 3–27, 1986.
- Post, W. M., Emmanuel, W. R., Zinke, P. J., and Stangenberger, A. G.: Soil carbon pools and world life zones, *Nature*, 298, 156–159, 1982.
- Post, W. M., Izaurralde, L. K., Mann, L. K., and Bliss, N.: Monitoring and verifying changes of carbon in soil, *Climatic Change*, 51, 73–99, 2001.
- Reicosky, D. C., Reeves, D. W., Prior, S. A., Runion, G. B., Rogers, H. H., and Raper, R. L.: Effects of residue management a controlled traffic on carbon dioxide and water loss, *Soil Till. Res.*, 52, 153–165, 1999.
- Rhoades, C. C., Eckert, G. E., and Coleman, D. C.: Soil carbon differences among forest

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- agriculture and secondary vegetation in lower montane Ecuador, *Ecol. Appl.*, 10, 2000.
- Sanchez, P. A.: Linking climate change research with food security and poverty reduction in the tropics, *Agr. Ecosyst. Environ.* 82, 371–383, 2000.
- Schjonning, R., Thomsen, I. K., Moberg, J. P., de Jonge, H., Kristensen, K., and Christensen, B. T.: Turnover of organic matter in differently textured soils: I. Physical characteristics of structurally disturbed and intact soils, *Geoderma*, 89, 177–198, 1999.
- Schlesinger, P. and Palmer Winkler, J.: Soils and the global carbon cycle in: *The Carbon Cycle*, edited by: Wigley, T. M. L. and Schimel, D. S., Cambridge University Press, Cambridge, 93–101, 2000.
- Schwartz, D. and Namri, M.: Mapping the total organic carbon in soils of the Congo, *Global Planet. Change*, 681, 77–93, 2002.
- Shepherd, K. D. and Soule, M. J.: Soil fertility management in west Kenya: dynamic simulation of productivity, profitability and sustainability at different resource endowment levels, *Agr., Ecosyst. Environ.*, 71, 131–145, 1998.
- Sombroek, W., Nachtergaele, F. O., and Hebel, A.: Amounts, dynamics and sequestering of carbon in tropical and subtropical soils, *Ambio*, 22, 417–426, 1993.
- Vagen, T. G., Lal, R., and Singh, B. R.: Soil carbon sequestration in sub-saharan Africa: a review, *Land Degrad. Dev.*, 16, 54–71, 2004.
- Volkoff, B., Faure, P., Dubroeuq, D., and Viennot, M.: Estimation des stocks de carbone des sols du Bénin, *Etude et Gestion des Sols*, 6, 115–130, 1999.
- White, F.: *La végétation de l’Afrique. Mémoire accompagnant la carte de végétation de l’Afrique – Unesco/AETFAT/UNSO*, edited by: *Recherches sur les ressources naturelles*, Orstom-Unesco, Paris, 384 pp., 1981.
- Whittaker, R. H. and Likens, G. E.: *The biosphere and man*, *Ecol. Stud.*, 14, 305–328, 1975.
- Williams, C. A., Hanan, N. P., Neff, J. C., Scholes, R. J., Berry, J. A., Denning, A. S., and Baker, D. F.: Africa and the global carbon cycle, *Carbon Balance Manage.*, 2(3), 1–13, 2007.
- Woomer, P.L., Toure, A., and Sall, M.: Carbon stocks in Sahel transition zone, *J. Arid Environ.*, 59, 499–510, 2004.
- WWF: *Terrestrial ecoregions of the world*, Washington, D. C., 2000.
- Yanai, R. D., Currie, W. S., and Goodale, C. L.: Soil carbon dynamics after forest harvest: an ecosystem paradigm reconsidered, *Ecosystems*, 6, 197–212, 2003.

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**Table 1.** The organic soil database and digital data used to make soil carbon maps.

Map ID	Soil Database	Year	Total soil profiles	Soil profiles for Africa	Map	Scale	Total Map Units	Map units for Africa
1	Batjes	1996	4353	1799	DSMW	1:5M	6998	1598
2	Batjes	2002	9607	3998	DSMW	1:5M	6998	1598
3	Batjes	2005	9607	3998	ISRIC-WISE	1:5M	45 948	7964
4	Batjes	2006	10 100	4043	ETOPOS-DSMW	1:5M	4931	1588
5	FAO/IIASA/ISRIC/ISSCAS/JRC	2008	9607	3998	HSWD	1:1–1:5M	31 044	6994

**Table 2.** Inventory of soil carbon pools for the different countries of Africa.

Regions and countries or Territories	Spatial component information			Soil carbon stock for different layer		
	Number of map units Total	Area All map unit km <sup>2</sup>	% with soil	0–30 cm T <sub>g</sub> (or millions tonnes) of C	0–100 cm	0–30 cm Average
<b>Eastern Africa</b>						
British Indian Ocean Territory	22	12	0.0	0	0	0.00
Burundi	159	25 098	92.8	146	268	2.60
Comoros	50	1530	97.9	12	21	0.98
Djibouti	123	20 676	99.1	30	25	0.77
Eritrea	982	116 719	99.7	262	426	1.09
Ethiopia	2361	1 069 066	99.0	3511	6459	2.84
Europa Island	2	16	0.0	0	0	0.00
Kenya	3698	541 841	98.0	1833	3989	3.67
Madagascar	1311	578 170	99.7	2588	5172	2.42
Malawi	136	112 278	79.4	435	825	4.70
Mauritius	24	1534	93.4	10	18	1.64
Mayotte	27	336	95.6	1	2	1.04
Mozambique	1350	760 193	98.4	2558	4840	2.72
Réunion	33	2442	99.0	25	45	1.26
Rwanda	198	23 464	94.6	143	246	3.65
Seychelles	87	140	0.0	0	0	0.00
Somalia	1022	595 328	99.7	1047	1901	1.24
Uganda	810	224 933	84.8	694	1309	3.47
United Republic of Tanzania	1227	880 012	94.2	4227	7810	3.56
Zambia	228	715 202	98.5	4500	11 235	6.08
Zimbabwe	1017	381 257	99.2	859	1640	2.47
<i>Subtotal</i>	14 867	6 050 248	97.3	22 881	46 230	2.91
<b>Middle Africa</b>						
Angola	660	1 183 219	100.0	3601	6655	2.59
Cameroon	211	437 840	99.3	2410	5098	5.16
Central African Republic	114	583 371	99.8	2141	3859	4.42
Chad	242	1 237 900	84.5	3097	5434	2.59
Congo	122	318 214	99.6	3424	9300	8.20
Democratic Republic of the Congo	362	2 173 660	98.2	10 511	21 932	5.60
Equatorial Guinea	56	25 105	99.8	166	270	1.38
Gabon	148	246 380	99.3	1276	2738	3.62
Sao Tome and Principe	18	882	98.8	6	12	1.89
<i>Subtotal</i>	1933	6 206 571	96.1	26 632	55 298	3.93
<b>Northern Africa</b>						
Algeria	608	2 484 691	66.4	4021	6638	0.75
Egypt	2533	1 033 941	93.1	1393	2385	0.79
Hala ib triangle	136	18 177	99.8	31	50	0.79
Item triangle	23	2978	100.0	4	11	1.59
Libyan Arab Jamahiriya	666	1 713 136	75.4	2704	4986	0.61
Ma tan al-Sarra	12	1995	100.0	4	6	1.94
Morocco	569	451 916	99.8	1423	2594	0.67
Sudan	3576	2 404 150	99.7	5927	11 318	1.66
Tunisia	407	177 065	89.7	498	727	0.77
Western Sahara	214	278 353	85.3	601	966	0.40
<i>Subtotal</i>	8744	8 566 401	83.7	16 606	29 652	1.10
<b>Southern Africa</b>						
Botswana	310	575 324	98.9	753	1723	1.59
Lesotho	161	32 123	99.9	150	237	1.12
Namibia	655	820 695	92.5	1093	2009	1.49
South Africa	11 664	1 281 521	99.8	2874	5240	2.29
Swaziland	61	17 761	99.9	96	158	4.29
<i>Subtotal</i>	12 851	2 727 424	97.4	4966	9367	2.23
<b>Western Africa</b>						
Benin	42	109 714	100.0	374	687	3.50
Burkina Faso	174	262 057	100.0	801	1498	3.13
Côte d'Ivoire	131	303 559	99.2	1159	2265	5.23
Cape Verde	73	3479	98.9	22	34	0.88
Gambia	74	10 357	97.0	39	75	1.18
Ghana	139	225 377	94.9	759	1384	3.38
Guinea	174	233 055	100.0	1032	1832	7.63
Guinea-Bissau	337	32 275	99.6	134	247	1.84
Liberia	63	90 067	100.0	504	839	2.63
Mali	183	1 232 616	77.5	2634	4489	2.47
Mauritania	200	1 041 888	56.5	1560	2346	2.26
Niger	117	1 165 832	75.9	1937	3172	2.22
Nigeria	363	863 313	98.8	2873	5108	3.94
Saint Helena	7	260	0.0	0	0	0.00
Senegal	103	190 340	99.5	561	1019	2.26
Sierra Leone	206	68 259	99.8	325	536	3.22
Togo	51	53 930	99.9	184	317	3.32
<i>Subtotal</i>	2437	5 886 378	82.4	14 897	25 850	3.19
<i>Total</i>	40 832	29 437 022	90.1	85 981	166 397	2.37

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**Table 3.** Soil C stocks and mean C content for African ecoregions.

Biome	Area (1000 km <sup>2</sup> )	Carbon stock 0–30 cm (Tg)	Carbon stock 0–100 cm (Tg)	Mean C content 0–30 cm (kg m <sup>-2</sup> )
Deserts & Xeric Shrublands	10 084	15 450	25 469	1.53
Flooded Grasslands & Savannas	695	2896	7209	4.17
Mangroves	70	465	1054	6.61
Mediterranean Forests, Woodlands & Scrub	953	2700	4924	2.83
Montane Grasslands & Shrublands	864	2999	5412	3.47
Temperate Conifer Forests	27	105	183	3.92
Tropical & Subtropical Dry Broadleaf Forests	186	928	2033	5.00
Tropical & Subtropical Grasslands, Savannas & Shrublands	13 291	41 815	79 325	3.15
Tropical & Subtropical Moist Broadleaf Forests	3267	18 623	40 788	5.70
Total	29 437	85 981	166 397	2.92

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**Table 4.** Continental carbon stock estimates based on different digital maps and soil properties databases.

Map ID	Soil data	Spatial Data	Year	SOC (Tg)
1	FAO/IIASA/ISRIC/ISSCAS/JRC	HSWD	2008	0–30 cm : 85 981, 0–100 cm : 166 397
2	Batjes	ETOPOS-DSMW	2006	0–20 cm: 57 032, 0–40 cm: 112 007, 0–60 cm: 144 994, 0–80 cm: 169 022 and 0–100 cm: 184 116
3	Batjes	ISRIC-WISE	2005	0–30 cm: 68 891 and 0–100 cm: 133 420
4	Batjes	DSMW	1995	0–30 cm: 86 948 and 0–100 cm 166 133
5	Batjes	DSMW	1995	0–30 cm: 94 537, 0–50 cm: 124 954, 0–100 cm: 179 288 and 0–200 cm: 284 400

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**Table 5.** Continental carbon stock estimates based on various soil properties databases (na: not available, the soil layer 0–30 cm is not reported into the database Batjes, 2006).

Source of soil data	0–30 cm	0–100 cm
Batjes (1996)	94 676	179 288
Batjes (2002)	86 948	166 133
Batjes (2005)	56 909	117 356
Batjes (2006)	na	128 032
FAO/IIASA (2008)	102 357	211 956

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**Table 6.** Comparison of SOC estimates at national scale.

Region or Country	Area (km <sup>2</sup> )	Spatial component	Published estimated (Tg)	Reference	Our estimate (Tg)	Soil area km <sup>2</sup>
Congo	302 616	Map of 31 elementary landscape units	0–10 cm: 800 0–100 cm: 3300 0–200 cm 3900	Schwartz and Namri (2002)	0–30 cm: 3423  0–100 cm: 9300	318 213
Benin	115 141	Soil map Scale: 1/200 000	0–20 cm: 251–260 0–50 cm: 408–424 0–100 cm: 526–543	Volkoff et al. (1999)	0–30 cm: 374  0–100 cm: 687	109 714
Kenya	582 646	KENSOTER Scale: 1/1 000 000	0–30 cm: 1896–2006 0–50 cm: 2654–2883 0–100 cm: 3452–3797	Batjes (2004)	0–30 cm: 1832  0–100 cm: 3989	541 841
Senegal	199 823	Ecological stratification Landsat images Scale: 1/100 000	0–40 cm: 452	Woomer et al. (2004)	0–30 cm: 561  0–100 cm: 1019	190 339
Sudan	262 144	Soil Map of the World (FAO)	0–20 cm: 146	Ardö and Olsson (2003)	0–30 cm: 5927  0–100 cm: 11 318	2 404 149
Central Africa (Burundi, DR Congo, Rwanda)	2 399 000	SOTER Scale: 1/2 000 000	0–30 cm: 10 400–10 600 0–50 cm: 14 000–14 300 0–100 cm: 19 300–19 600 0–150 cm: 21 500–21 800 0–200 cm: 22 900–23 300	Batjes, 2008	0–30 cm: 10 799  0–100 cm: 22 446	2 222 221

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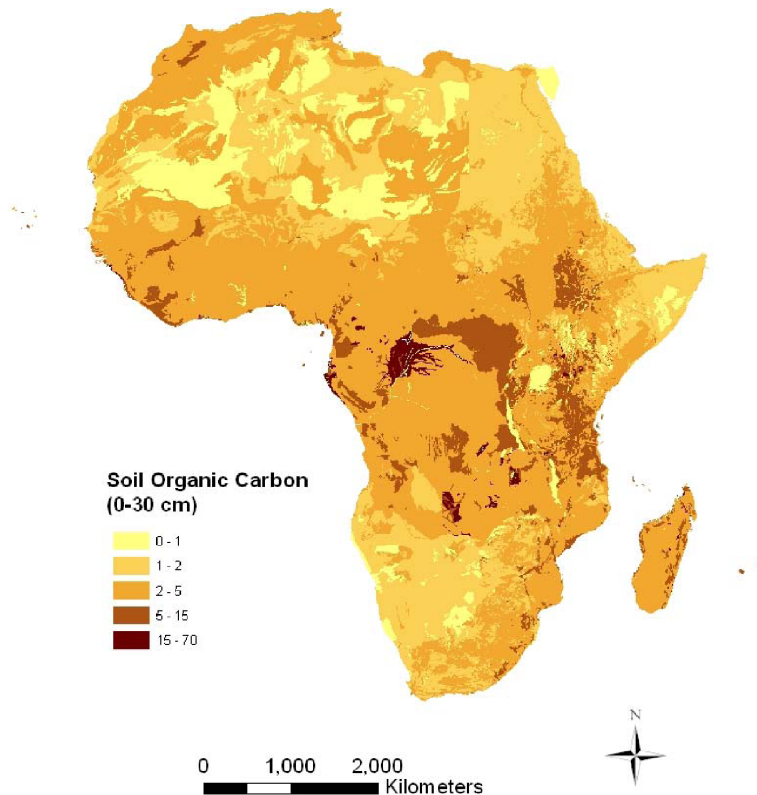
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**Fig. 1.** Soil carbon stock distribution in Africa for the 0–30 cm soil layer.

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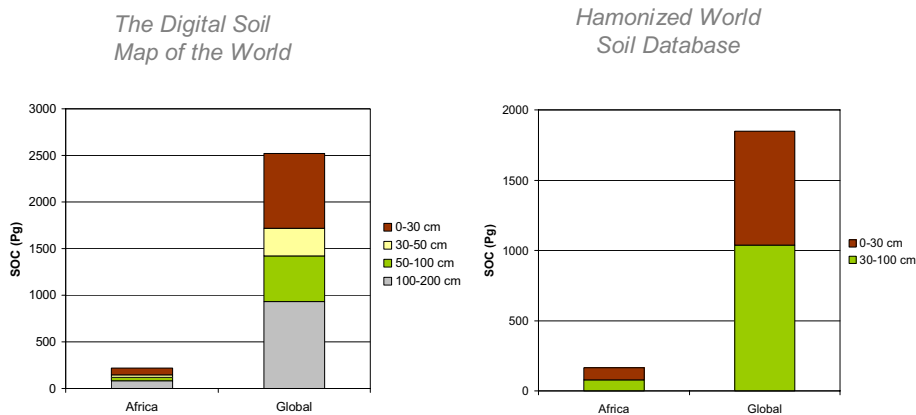


Fig. 2. Global and African soil carbon stocks estimates based on the digital soil Map of the World and the Harmonized World Soil Database.

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