Rend. Fis. Acc. Lincei (2017) 28:481–495
DOI 10.1007/s12210-017-0621-3

Effect of the different types of land-use on the distribution of soil organic carbon in north Nile Delta, Egypt

Ebrahem M. Eid[1,2] · **Farahat S. Moghanm**[3] · **Kamal H. Shaltout**[4]

Received: 11 May 2016 / Accepted: 28 April 2017 / Published online: 5 May 2017

Abstract In Egypt, the need for accurate information on soil organic carbon (SOC) content has increased due to the importance of SOC stocks for sustainable use of natural resources and to meet the requirements of the Kyoto Protocol. Thus, the objectives of the present study are: (1) to quantify the vertical distribution of the soil bulk density (SBD) and SOC content in the soil of north Nile Delta, Egypt under different types of land-use; (2) to provide estimates of the carbon sequestration rate (CSR) of those soils under different types of land-use; and (3) to establish a baseline data on SOC stocks for future studies on SOC dynamics. Ten sampling stations were selected to represent the north Nile Delta during May 2014. In each of the sampling station, 4 sampling sites were selected to represent the virgin lands, 4 to represent fish farms and 12 to represent crop lands (four cultivation histories: 5, 15, 30 and 50 years × three crop types: clover, *Trifolium alexandrinum* L., sugar beet, *Beta vulgaris* L., and rice, *Oryza sativa* L.). Effect of crop type was significant in relation to SBD, SOC content, and SOC stock. In general, SOC stock increases as the number of years of cultivation increases. The SOC stock under crop land and fish farm were 1.6 and 1.5 times as that of virgin land. Rice was the crop with lowest SBD and highest SOC stock. The average CSR of crop land was 352, 134, 88 and 62 g C m^{-2} $year^{-1}$ for 5, 15, 30 and 50 years of cultivation, respectively. The highest CSR (545 g C m^{-2} $year^{-1}$) was observed in crop land cultivated for 5 years by rice, while the lowest (21 g C m^{-2} $year^{-1}$) was observed in crop land cultivated for 50 years by sugar beet. On the other hand, the average CSR of fish farm was 143 g C m^{-2} $year^{-1}$. In conclusion, the conversion of virgin land into crop land or fish farm contributed to SOC sequestration.

Keywords Carbon vertical distribution · Carbon sequestration · Global warming · Kyoto Protocol · Land-use · Soils

1 Introduction

The Earth's surface temperatures became increasingly high during the last century due to human activities mainly fossil fuels burning, which were disturbing the planet and causing global warming (Hay 2014). Therefore, there is a growing public and scientific concern about the carbon sequestration potential of various terrestrial ecosystems with the increase of atmospheric CO_2 concentration (Eid and Shaltout 2013). As a result, the Kyoto Protocol was signed to mitigate greenhouse gas concentrations in the atmosphere through improving the terrestrial carbon sinks (Yimer et al. 2006). Carbon sequestration refers simply to CO_2 removal from the atmosphere and storage in an organic form in the soil or plants (Feller and Bernoux 2008). The carbon sequestration in soil has been widely considered to be a promising measure for mitigating the

✉ Ebrahem M. Eid
ebrahem.eid@sci.kfs.edu.eg; ebrahem.eid@gmail.com; eeid@kku.edu.sa

1 Present Address: Biology Department, College of Science, King Khalid University, P.O. Box 9004, Abha 61321, Saudi Arabia

2 Botany Department, Faculty of Science, Kafr El-Sheikh University, Kafr El-Sheikh 33516, Egypt

3 Soil and Water Sciences Department, Faculty of Agriculture, Kafr El-Sheikh University, Kafr El-Sheikh 33516, Egypt

4 Botany Department, Faculty of Science, Tanta University, Tanta 31527, Egypt

increasing atmospheric CO_2 concentration (Smith 2008). Pacala and Socolow (2004) outlined 15 options for stabilizing the atmospheric concentration of CO_2 by 2050 at approximately 550 ppm; three of these 15 options were based on carbon sequestration in terrestrial ecosystems.

Soil is a major carbon sink or source on terrestrial ecosystems (Cicuzza et al. 2015). The content and spatial distribution of soil organic carbon (SOC) is of great significance when studying the global carbon cycle and the greenhouse effect (Lal 2004), and provides a scientific basis for the assessment of the magnitude of carbon stored in each area (Wang et al. 2013). The SOC depends on climate, topography, hydrology, land-use, soil type, the balance between additions and losses of carbon, and other properties (Fang et al. 2012). Jobbagy and Jackson (2000) found that vegetation type and/or land-use are important factors in determining SOC depth distribution, especially close to the surface, and highlighting the importance of vegetation change for carbon sequestration strategies. Moreover, identifying changes in SOC distribution with depth by time would help in understanding the effect of climate and land-use changes on SOC stocks (Meersmans et al. 2009).

The management of crop land is among those activities that a country signatory of the Kyoto Protocol may elect for meeting its emission reduction target. SOC stock and dynamics in the soils of crop land are important for quantifying the carbon emissions and removals involved in land-use change processes (Chiti et al. 2012). In Egypt, the need for accurate information on SOC content has increased due to the importance of SOC stocks for sustainable use of natural resources. Moreover, information on SOC stocks is necessary for assessing the potential role of soils as CO_2 sinks. Studying the SOC in relation to different land-uses and different vegetation types for ecological rehabilitation is crucial for improving SOC sequestration and soil quality (Fang et al. 2012). To evaluate the carbon sequestration potential of various terrestrial ecosystems, baseline data on SOC stocks are critical for understanding current conditions and the content of SOC that could be sequestrated both in natural and agricultural systems. According to the authors' knowledge, so far, no country assessment of SOC stocks under different land-use practices has been carried out in Egypt. Thus, the objectives of the present study are: (1) to quantify the vertical distribution of the soil bulk density (SBD) and SOC content in the soil of north Nile Delta, Egypt under different types of land-use; (2) to provide estimates of the carbon sequestration rate (CSR) of those soils under different types of land-use; and (3) to establish a baseline data on SOC stocks for future studies on SOC dynamics. The definition of an SOC stock baseline is essential for future evaluations of the status of this stock. Furthermore, the identification of a baseline for the SOC stock in crop land and fish farm ecosystems could contribute to the assessment of the possible effects of conversion of virgin land to agricultural or fish farm uses on the SOC stocks in Nile Delta.

2 Methods

2.1 Study area

The study area (Lat. 30°34′–31°19′N, Long. 31°08′–31°38′E) lies in the north Nile Delta bounded by the two branches of the Nile: Rosetta to the west and Damietta to the east. The Nile Delta, an area of about 2200 × 10^3 ha, is a place of one of the most ancient agricultural systems in the world (Aly et al. 2013). It accounts for two-thirds of Egypt's agricultural land (Abu Al-Izz 1971), and at the same time houses almost half of the population in a country with a high population growth rate (Alfiky et al. 2012). Agricultural lands represent 61% of the Nile Delta, virgin lands represent 13%, while fish farms represent 7% (Elhag et al. 2013). As reported in Alfiky et al. (2012), 25,200 ha of fertile agricultural lands are lost each year in Egypt and most of those lands are located in the Nile Delta. Moreover, virgin lands at the north of Nile Delta are subject to coastal erosion due to sea rise (El Nahry et al. 2008). In Egypt, most cultivated lands are irrigated through a network of canals integrated by a similar network of drainage canals (Shaltout et al. 2010). The total length of both networks exceeds 47,000 km, of which 31,000 km are irrigation canals (Khattab and El-Gharably 1984). There are three cropping seasons in Egypt: winter (November to May), summer (April/May to October) and nil (July/August to October). In Egypt, rice occupies about 588,000 ha (22% of field crops), sugar beet 16,380 ha (14% of sugar crops) and clover 974,400 ha (76% of fodder crops) (El-Nahrawy 2011). The fertilizer application was 476/238/0 kg ha^{-1} N/P/K for rice, 476/0/0 kg ha^{-1} N/P/K for clover and 476/476/119 kg ha^{-1} N/P/K for sugar beet (El Shimi 2005). Compost manure is used at 12 tons ha^{-1} on agricultural lands and added during soil preparation, prior to the cultivation of summer crops (cotton, maize, rice, sugar cane, citrus, grapes) as a first crop of agriculture rotation. However, the residual effect of organic matter will continue for the second crop in the winter season (wheat, fava bean, fodder, clover) (El Shimi 2005). Ploughing to 40 cm depth was done every year before planting.

According to the map of the world distribution of arid regions (UNESCO 1977), the northern part of Nile Delta lies in the arid region, while the southern part in the hyper-arid region. The climatic conditions are warm summers (20–30 °C) and mild winters (≥10 °C). The long-term annual mean air temperature decreases from 20.7 °C at the north to 19.9 °C at the middle of Nile Delta. The relative humidity decreases in the same direction from 69 to 65%. The average daily evaporation varies between 4.6 mm day^{-1} at the north and 6.8 mm day^{-1} at the middle. This is associated with an inverse gradient of annual precipitation where the annual rainfall varies between 175.2 mm $year^{-1}$ at the north and 56.9 mm $year^{-1}$ at the middle (EMA 1980).

2.2 Soil sampling

The main physiographic soil units in the study area are: alluvial plain (71.1%), lacustrine plain (19.3%), and marine plain (9.6%). Principal soils of the study area include Typic Torrifluvents, Vertic Torrifluvents, Typic Aquisalids and Typic Natrargids sub-great groups in alluvial plain; Typic Natrargids and Sodic Aquicambids in lacustrine plain; Typic Torripsamments sub-great group (see Elbasiouny et al. 2014). Ten sampling stations were selected to represent the north Nile Delta during May 2014. The sampling area was classified according to the dominant land-uses (crop land, permanent fish farm and virgin land). Virgin land is a wild and uninhabited area left in its natural condition with sparse vegetation such as *Arthrocnemum macrostachyum* (Moric.) K. Koch, *Cressa cretica* L., *Halocnemum strobilaceum* (Pall.) M. Bieb., *Juncus acutus* L., *Phragmites australis* (Cav.) Trin. ex Steud. and *Tamarix nilotica* (Ehrenb.) Bunge. Crop land was classified according to the cultivation history to 5, 15, 30 and 50 years old, and under each cultivation history to three crop types: clover (*Trifolium alexandrinum* L.), sugar beet (*Beta vulgaris* L.) and rice (*Oryza sativa* L.) fields. The age of the fish farms was 15 years and the average water depths ranged between 100 and 150 cm and soil sampling carried out along the shores where water depth less than 20 cm. In each of the sampling station, 4 sampling sites were selected to represent the virgin land, 4 to represent fish farm and 12 to represent crop land (four cultivation histories: 5, 15, 30 and 50 years × three crop types: clover, sugar beet and rice). Three soil cores were taken in each sampling site, spaced in a triangular pattern with 50 cm between each core, and were pooled together into one composite core per sampling site. One sample from each of the four soil layers (0–30, 30–60, 60–90 and 90–120 cm) at each of the 200 sampling sites, in total, 800 soil samples were collected to determine SBD, SOC content, and SOC stock.

Within the field of SOC sequestration research, attention has recently been drawn to sub-soils, since they store approximately 53% of the SOC in the 0–100 cm layer and 71% between 0 and 200 cm depth (Batjes 2014). In addition, sub-soils have attracted interest because SOC radiocarbon age increases with depth (Gleixner 2013) in all soil types (Mathieu et al. 2015), leading to the assumption that sub-soil SOC is highly stable (Alcántara et al. 2016). Thus, the soil samples were collected with a 7-cm-diameter hand sediment corer down to 120 cm depth. The soil core was removed from the corer slowly, and it was immediately sectioned with a blade into samples each of 30 cm thick (0–30, 30–60, 60–90 and 90–120 cm) and packed in plastic containers. The sample containers were sealed with parafilm and stored on ice to minimize microbial activity until analysis (Bernal and Mitsch 2008).

2.3 Analysis of soil organic carbon

Each soil sample was oven-dried at 105 °C for 3 days, cooled down to room temperature in a desiccator, and weighed to determine the SBD (g cm^{-3}) following the method of Wilke (2005). Dry samples were ground and sieved to pass through 2-mm particle size, and the mass of fine soil was determined. Each sample was analyzed for SOC content by measuring soil organic matter (SOM) using loss-on-ignition method at 550 °C for 2 h as described in Jones (2001). SOC stock (kg C m^{-2}), expressed as a mass per unit surface area to a fixed depth of a profile, was calculated following the method of Poeplau et al. (2017). The carbon sequestration in crop land (for each crop type) was determined by subtracting the value of SOC stocks at virgin soil from the value of SOC stocks after 5, 15, 30 and 50 years' cultivation; and in fish farm was determined by subtracting the value of SOC stocks at virgin soil from the value of fish farm SOC stocks (15 years old) (Brar et al. 2013). The annual rate of SOC sequestration was calculated by changes in SOC stocks over total number of years.

2.4 Statistical analysis

Before performing the analysis of variance (ANOVA), the data were tested for their normality of distribution and homogeneity of variance, and when necessary, data were log-transformed. Two-way ANOVAs were used to identify statistically significant differences in SBD and SOC content among each of the land-use types and soil depth; cultivation histories and soil depth; and crop types and soil depth. Significant differences between means among the three land-uses, the five cultivation histories, the four crop types and the four soil depths were identified using the least significant difference (LSD) test at $P < 0.05$. The relationship between SOC content and SBD was examined with non-linear regression (Eid and Shaltout 2013, 2016; Eid et al. 2016). The significance of variation in SOC stock over the land-use types, cultivation histories and crop types was assessed using one-way ANOVA. The relationship between the cultivation history and its SOC stock for crop land was examined with a linear regression (Shrestha and

Lal 2010). All statistical analyses were performed using SPSS 15.0 software (SPSS 2006).

3 Results

Total mean of SBD increased non-significantly from 1.31 g cm^{-3} at depth 0–30 cm up to 1.33 g cm^{-3} at depth 30–60 cm, and then slightly decreased to 1.30 g cm^{-3} at depth 90–120 cm (Table 1). SBD of the virgin land (1.38 g cm^{-3}) was significantly higher than that of the crop land (1.30 g cm^{-3}) (Figs. 1, 2). Cultivation history significantly affected SBD and the minimum value was recorded in crop land cultivated for 50 years (1.28 g cm^{-3}). Crop type significantly affected SBD and the minimum value was recorded in crop land cultivated by clover (1.15 g cm^{-3}).

Total mean of SOC content declined significantly with depth from 9.7 g C kg^{-1} at depth 0–30 cm (43% of the SOC content was found in that depth) to 2.9 g C kg^{-1} at depth 90–120 cm (Table 1). The SOC content of the crop land (6.5 g C kg^{-1}) was significantly higher than that of the fish farm (5.2 g C kg^{-1}) and virgin land (3.8 g C kg^{-1}) (Figs. 3, 4). Cultivation history significantly affected the SOC content and maximum value was in crop land cultivated for 50 years (7.3 g C kg^{-1}). Crop type significantly affected the SOC content and maximum value was in crop land cultivated by rice (7.4 g C kg^{-1}). As expected, an exponential function was developed between SBD (g cm^{-3}) and SOC content (g C kg^{-1}) for Egyptian north Nile Delta soils where SOC content and SBD were negatively correlated (Table 2).

Significant differences in SOC stock were found related to land-use (Fig. 5). Considering the entire soil profile, 0–120 cm, virgin land (4.1 kg C m^{-2}) showed significantly lower values than fish farm (6.2 kg C m^{-2}) and crop land (6.6 kg C m^{-2}). Cultivation history significantly affected the SOC stock and maximum value was in crop land cultivated for 50 years (7.2 kg C m^{-2}). Crop type significantly affected the SOC stock and maximum value was in crop land cultivated by rice (7.5 kg C m^{-2}). There was a strong correlation between the cultivation history and SOC stock for crop land. Thus, SOC stock of crop land can be estimated from the cultivation history using this equation:

SOC stock (kg C m^{-2}) = 5.3 + 0.04 × cultivation history (years), $R^2 = 0.134$, F value = 54.4, $P < 0.001$.

The average CSR of crop land was 352, 134, 88 and 62 g C m^{-2} $year^{-1}$ for 5, 15, 30 and 50 years of cultivation, respectively. The highest CSR (545 g C m^{-2} $year^{-1}$) was observed in crop land cultivated for 5 years by rice, while the lowest (21 g C m^{-2} $year^{-1}$) was observed in crop land cultivated for 50 years by sugar beet. On the other hand, the average CSR of fish farm was 143 g C m^{-2} $year^{-1}$.

4 Discussion

Soil bulk density (SBD) is needed for estimating soil water retention characteristics and it is an essential input parameter for sediment, water and nutrient transport models (Boucneau et al. 1998). Furthermore, SBD is used as an indicator of site productivity, soil strength, porosity and/or mechanical resistance to plant growth, and can thus affect distribution of SOC (Drewry et al. 2008; Tamminen and Starr 1994). SBD influences agriculture by restricting air and water movement and has been recognized as a key soil quality indicator (Andrews et al. 2002). Land-use can affect SBD (Chen 2000), as reported in the present study. SBD of crop land was inversely related to the cultivation history, indicating a decrease in soil compaction with an increase in cultivation period. The decrease in SBD over the years could be attributed to the addition of roots (SBD has been found to correlate negatively with roots density, Salifu et al. 1999) and plant biomass, which might have increased the biological activities of the soil, and to the conversion of some micro-pores into macro-pores due to cementing action of organic acids and polysaccharides formed during the decomposition of organic residues by higher microbial activities (Shrestha and Lal 2010; Sombrero and de Benito 2010).

Field sampling and direct measurement of SBD is considered labor intensive, costly, time consuming, and often boring (Boucneau et al. 1998). To outdo this problem, Pedo Transfer Functions (PTFs) are frequently used to estimate SBD (De Vos et al. 2005). PTFs are empirically

Table 1 Total distribution (mean ± standard error) of soil bulk density (g cm^{-3}) and soil organic carbon (SOC) content (g C kg^{-1}) with soil depth in north Nile Delta, Egypt

Soil depth (cm)	Soil bulk density (g cm^{-3})	SOC content (g C kg^{-1})
0–30	1.31 ± 0.006a	9.7 ± 0.2a
30–60	1.33 ± 0.007a	5.6 ± 0.1b
60–90	1.31 ± 0.007a	4.4 ± 0.1c
90–120	1.30 ± 0.011a	2.9 ± 0.2d

Means in the same columns followed by different letters are significantly different at $P < 0.05$

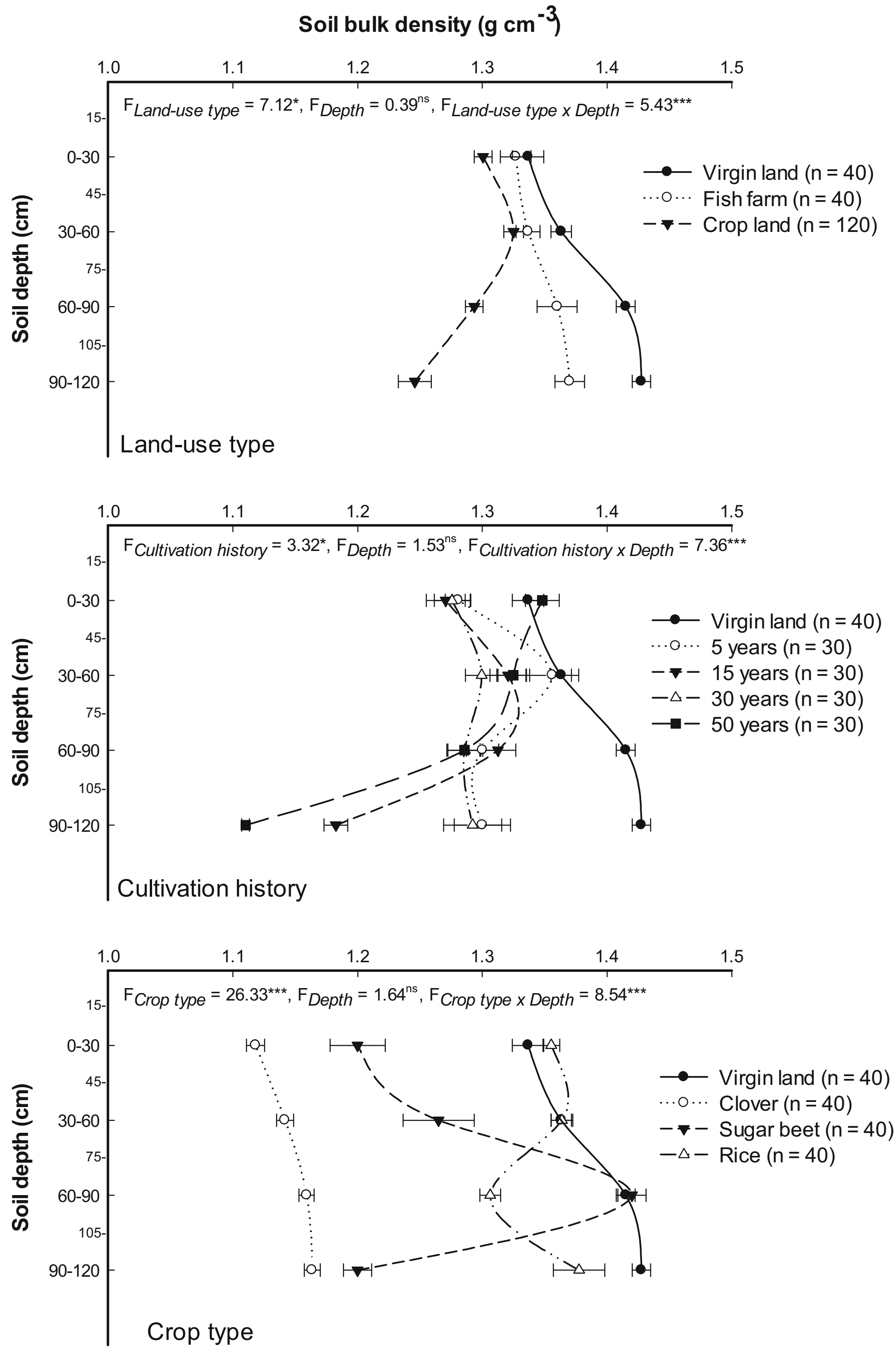

Fig. 1 Mean distribution of soil bulk density (g cm^{-3}) with soil depth (cm) in north Nile Delta, Egypt. *Horizontal bars* indicate the standard errors of the means. *F* values represent the two-way ANOVAs. $^{*}P < 0.05$, $^{***}P < 0.001$, *ns* not significant (i.e., $P > 0.05$)

determined by regression (Jalabert et al. 2010) where SBD generally has been based on SOC content only (Périé and Ouimet 2008; Kobal et al. 2011), and less commonly on further variables, such as soil texture (Bernoux et al. 1998; De Vos et al. 2005). In dataset of De Vos et al. (2005), models based on SOC content account for 55–57% of the total variation in SBD, while soil texture explains only 20–26% which in1dicates that SOC content alone accounted for twice as much variability as soil texture. Thus, simple models based on SOC content only are suitable and easy to use (De Vos et al. 2005). In the present study, we developed a negative exponential function for Egyptian north Nile Delta soils, where SBD increased and SOC content decreased with soil depth. It is similar to the

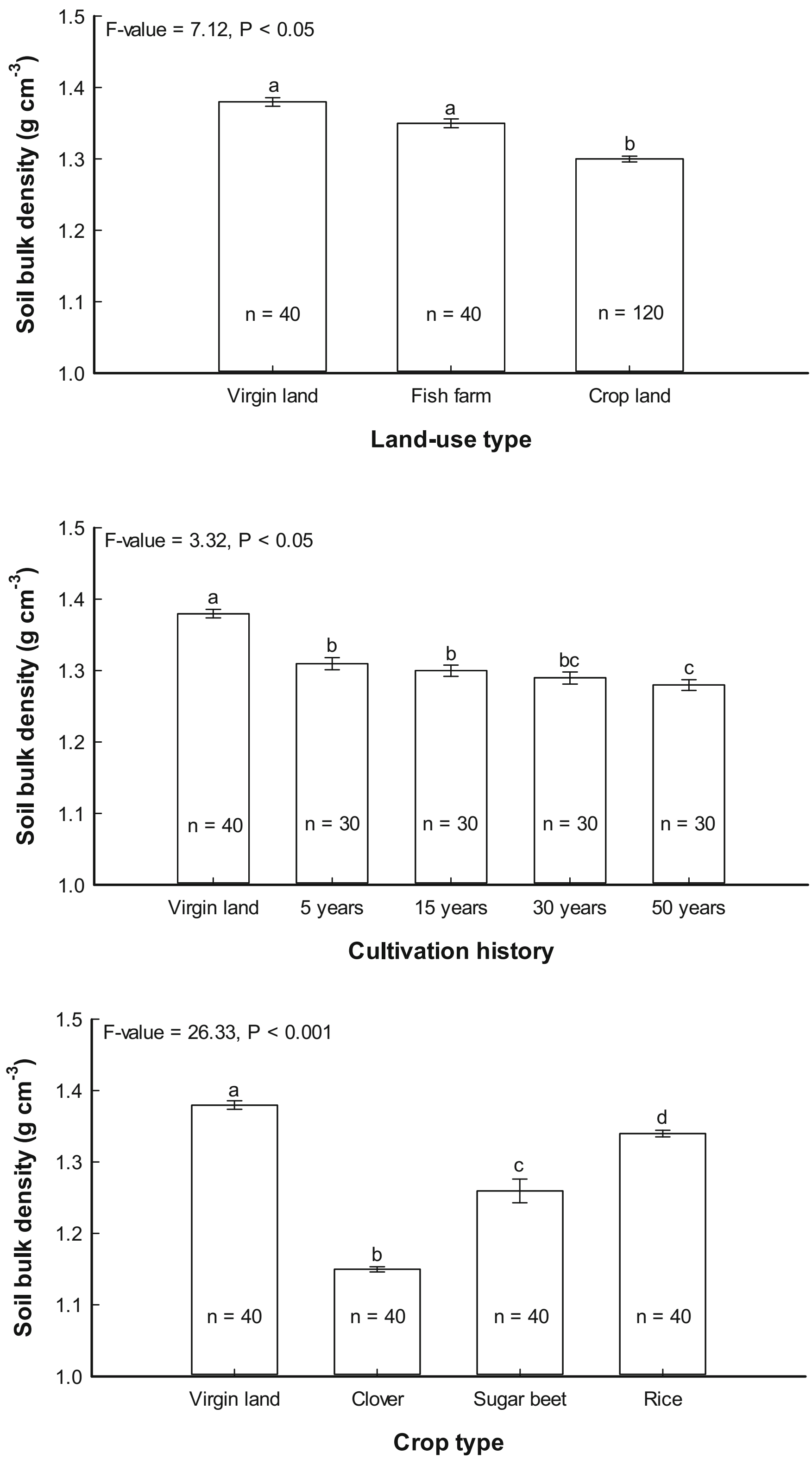

Fig. 2 Total mean ± standard error of soil bulk density (g cm^{-3}) considering the entire soil profile (0–120 cm) in north Nile Delta, Egypt. *F* values represent the one-way ANOVA

result of Yang et al. (2007) who developed a negative exponential function with SOC content for Chinese soils. In addition, Abdelbaki (2016) evaluated the performance of 48 published PTFs that required inputs of OM and SOC contents and particle size distribution for predicting SBD. He found that the exponential PTF ($SBD = 1.838 \times e^{-0.006 \times \text{SOC content}}$) which required input of SOC contents only is the best PTF which demonstrated best performance

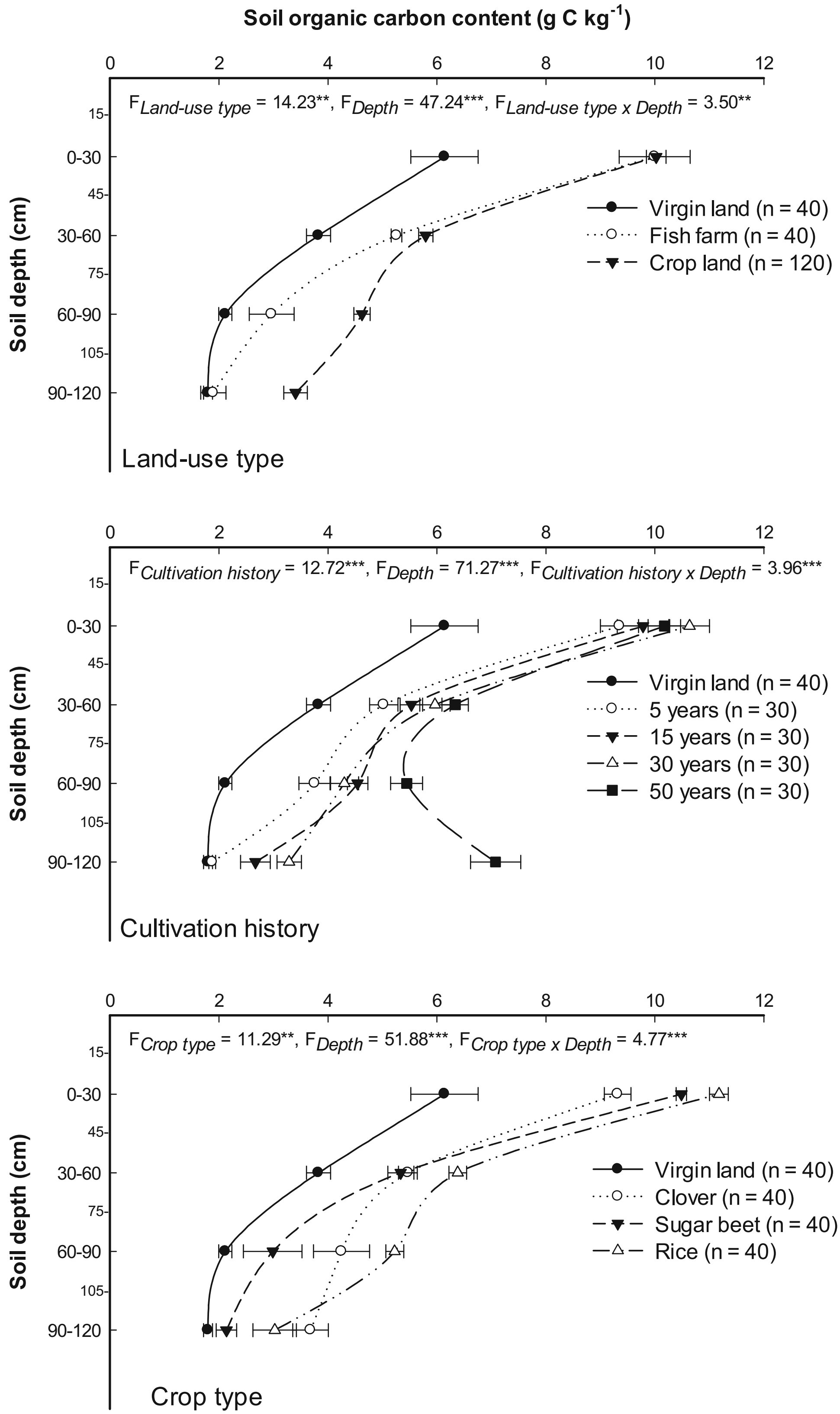

Fig. 3 Mean distribution of soil organic carbon content (g C kg^{-1}) with soil depth (cm) in north Nile Delta, Egypt. *Horizontal bars* indicate the standard errors of the means. *F* values represent the two-way ANOVAs. $^{**}P < 0.01$, $^{***}P < 0.001$

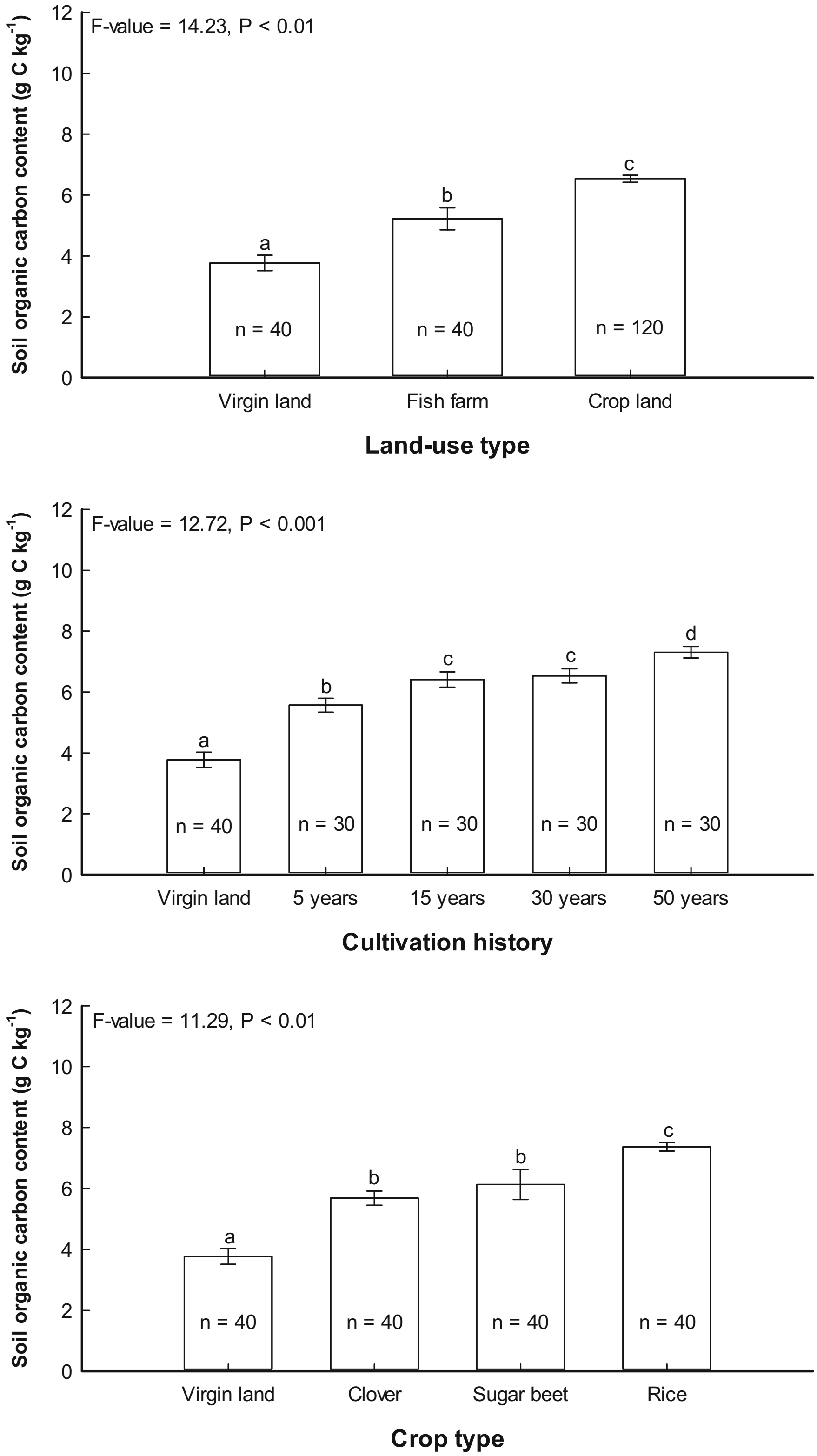

Fig. 4 Total mean ± standard error of soil organic carbon content (g C kg^{-1}) considering the entire soil profile (0–120 cm) in north Nile Delta, Egypt. *F* values represent the one-way ANOVA

and this indicated the great effect of the SOC contents on SBD predictions. Estimation of SBD in organic soils through PTFs is particularly problematic, and sometimes no relationship has been found between SBD and SOC content (Vanguelova et al. 2016). Thus, in the present study, despite the statistical significance of exponential functions, most *r* coefficients are often very low (Table 2). As reported in some previous studies (Howard et al. 1995;

Table 2 Equations used for the predicting of soil bulk density, SBD (g cm^{-3}) using soil organic carbon (SOC) content (g C kg^{-1}) in north Nile Delta, Egypt

Case	Equation	*r*	*P*
Land-use type			
Virgin land	$SBD = 1.351 + 0.998\ e^{-1.597 \times SOC\ content}$	−0.411	<0.001
Crop land	$SBD = 1.287 + 0.448\ e^{-0.989 \times SOC\ content}$	−0.111	<0.01
Fish farm	$SBD = 1.359 - 0.219\ e^{-1.537 \times SOC\ content}$	−0.244	<0.01
Cultivation history			
5 years	$SBD = 1.252 + 0.118\ e^{-0.146 \times SOC\ content}$	−0.182	<0.01
15 years	$SBD = 1.301 - 0.198\ e^{-0.673 \times SOC\ content}$	−0.131	<0.01
30 years	$SBD = 1.259 + 0.780\ e^{-0.882 \times SOC\ content}$	−0.192	<0.01
50 years	$SBD = 1.296 + 0.842\ e^{-1.168 \times SOC\ content}$	−0.251	<0.01
Crop type			
Clover	$SBD = 1.072 + 0.178\ e^{-0.179 \times SOC\ content}$	−0.736	<0.001
Sugar beet	$SBD = -31.770 + 33.100\ e^{-0.001 \times SOC\ content}$	−0.349	<0.01
Rice	$SBD = 1.331 + 0.549\ e^{-0.949 \times SOC\ content}$	−0.126	<0.01

De Vos et al. 2005; Yu et al. 2007; Périé and Ouimet 2008; Eid and Shaltout 2013, 2016; Eid et al. 2016), SOC content and SBD were negatively correlated. This indicates that this negative relationship between SBD and SOC content is valid across varying soil types and geographical regions.

The comparison of SOC content between virgin land, crop land and fish farm gives a unique opportunity to compare the SOC stocks under different land-use types and to evaluate the long-term carbon sequestration in crop lands and fish farms over time. The present study shows that the effect of land-use types and soil depth, as well as their interaction on SOC contents as well as SOC stocks are significant, and these results were consistent with previous relevant studies (Chen et al. 2007; Fang et al. 2012). We found that SOC content is greatest in the surface soil where most carbon inputs occur, and decreases with depth. This is so in agreement with previous studies which indicated that the surface soil is more active for SOC sequestration (Munoz-Rojas et al. 2012; Zhang et al. 2013), while only few soils show a different pattern. Land-use and degree of development of the soil as well as the soil type are the important factors influencing the vertical distribution of SOC in the soils (Parras-Alcántara et al. 2015; Vanguelova et al. 2016). Moreover, this variation could also be a result of interaction of complex processes such as decomposition, land management, biological cycling, leaching, illuviation, soil erosion, weathering of minerals, atmospheric deposition and application of manure (Lorenz and Lal 2005; Girmay and Singh 2012).

The content of SOC in the 0–30 cm soil depth accounts for 43% of the total content of SOC in the soil indicating the importance of topsoil layers as good sources of carbon sink, but also as a potential for large amount of CO_2 emission upon conversion and mismanagement. Similar results were reported by Yimer et al. (2006) in Ethiopia who found that 45% of the SOC content was in the top 30 cm of the soil profile, and by Batjes (2002) who indicated that about 44% of the total SOC stock down to 100 cm soil depth was situated within the top 30 cm of the soil, where as a corresponding 55–65% was measured by De Vos et al. (2015) for European forest soils.

In the present study, SOC content and SOC stock in virgin land is about 42 and 38% lower than in the crop land in North Nile Delta. The high mean SOC content as well as SOC stock for soils under agricultural land-use can be attributed to a decrease in soil erosion because of vegetation protection and agricultural practices, such as fertilization, irrigation, addition of manure, which can increase plant production and the rate of plant residue return into soil (Rasmussen and Collins 1991; Han et al. 2010; Fallahzade and Hajabbasi 2012). On the other hand, the high SOC content and SOC stock in the fish farm soils could be ascribed to the prolonged saturation (anoxic conditions) of soils under this land-use, which have slower decomposition rates of litter and soil organic matter (Bouchard and Cochran 2006).

Further, the current study points out that, high SOC content and SOC stock under rice compared with clover and sugar beet may be attributed to greater aboveground biomass production and favorable water regime under rice fields (Kukal et al. 2009). In the study of Chiti et al. (2012) in Italy, the rice field soils showed a higher mean SOC stock than the other arable land soils. In China, the results of Huang et al. (2012) showed that rice cropping significantly increased SOC stocks by 9%. Pan et al. (2010) reported that rice paddies not only held higher SOC stocks compared with dry croplands in China, but showed greater sequestration rates. Sahrawat (2004) concluded that there is preferential accumulation of OM in submerged rice soils as compared with aerobic soils due to incomplete decomposition of organic materials, and decreased humification of OM under flooded conditions. In addition, Hanke et al.

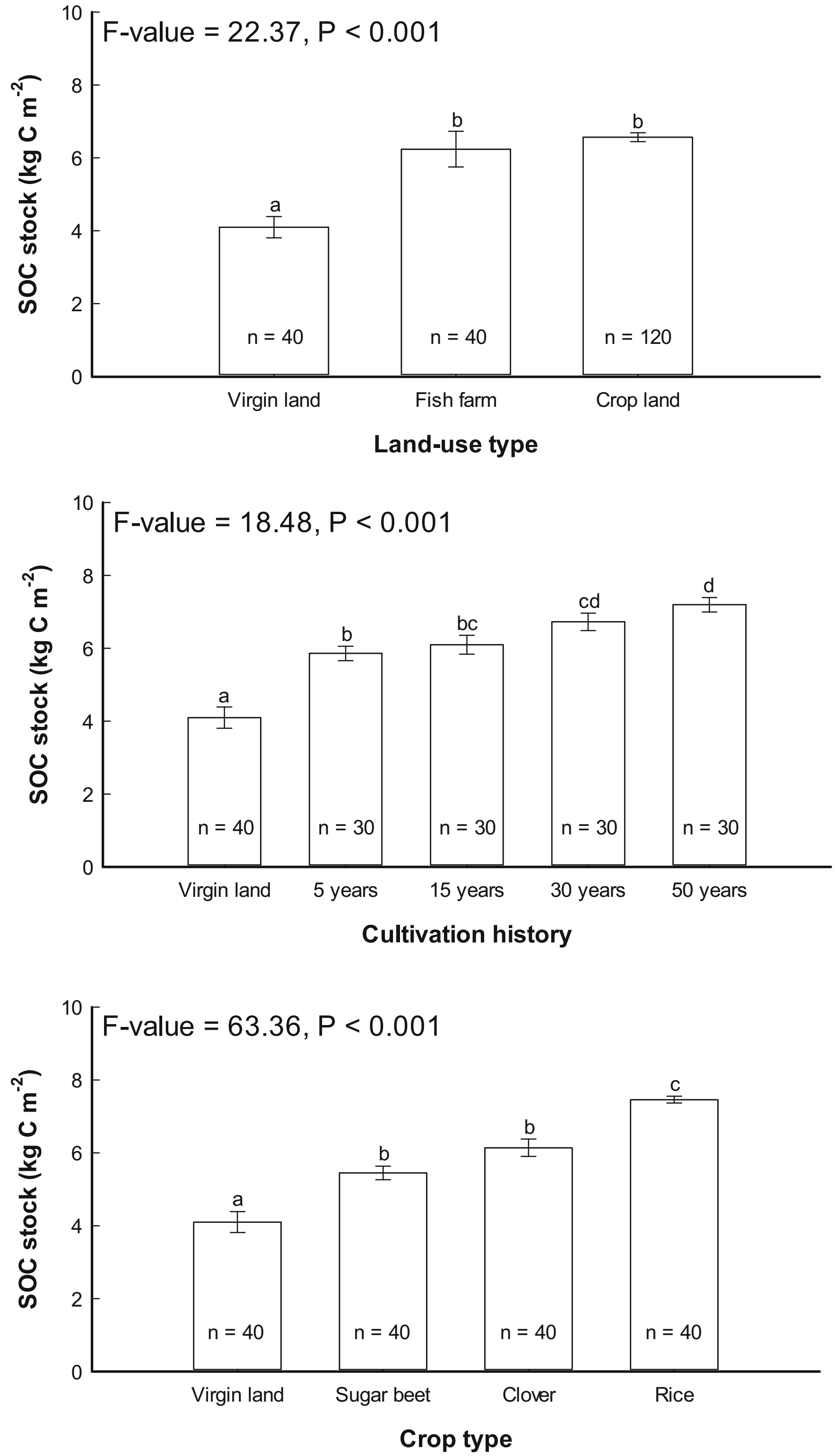

Fig. 5 Total summation (mean ± standard error) of soil organic carbon stock (kg C m^{-2}) considering the entire soil profile (0–120 cm) in north Nile Delta, Egypt. *F* values represent the one-way ANOVA

(2013) in their investigation reported that carbon accumulation in rice soils may result from a microbial community well adapted to anoxic conditions, but less efficient in mineralizing carbon during transient oxic periods. Hence, the increased SOC content and SOC stock with time in rice soils is probably due to less degradation under oxic conditions (Bossio and Scow 1995).

Our results show that when virgin land was converted into crop land or fish farm, SOC stock to a 120-cm depth increased by 60 or 52%. The study of Zhang et al. (2014)

Table 3 Soil organic carbon (SOC) stock (kg C m^{-2}) in the crop land soil of north Nile Delta, Egypt, compared with those reported in other studies

Country	Region	SOC stock (kg C m^{-2})	References
Egypt	Mediterranean	6.6	Present study
USA	Subtropical	2.2	Ross et al. (2013)
India	Subtropical	3.7–5.9	Singh et al. (2011)
India	Tropical	1.9–3.1	Kukal et al. (2009)
India	Tropical	3.4–5.9	Mandal et al. (2012)
China	Temperate	8.8	Liu et al. (2011)
India	Temperate	10.1–12.6	Singh et al. (2011)
UK	Temperate	8.4	Smith et al. (2000)
Denmark	Temperate	14.0	Krogh et al. (2003)
Germany	Temperate	9.0	Wiesmeier et al. (2013)

Table 4 Soil organic carbon (SOC) accumulation rate (g C m^{-2} $year^{-1}$) in the soil of north Nile Delta, Egypt, compared with those reported in other studies

Country	Habitat	Cultivation history (year)	Soil depth (cm)	SOC accumulation rate (g C m^{-2} $year^{-1}$)	References
Egypt	Cultivated land	5–50	120	62–352	Present study
China	Cultivated land	20	20	140	Yu et al. (2009)
Russia	Short grass steppe	77	20	30	Lopes de Gerenyu et al. (2008)
Belgium	Cultivated land	40	24	23	Sleutel et al. (2003)
Canada	Grass land	5–12	15	60–80	Mensah et al. (2003)
USA	Tall grass prairie	40	10	62	McLauchlan et al. (2006)
USA	Restored prairie	6–60	60	45	Potter et al. (1999)
USA	Cultivated land	15	30	90	Eve et al. (2002)
USA	Grazing land	15	30	22	Eve et al. (2002)

suggested that converting virgin land to crop land in arid region of the Yanqi Basin, China, not only enhances SOC stocks, but also leads to longer-term SOC storage. Converting virgin land to crop land in the north Nile Delta results in an increase of SOC stock (0–120 cm) by 2.5 kg C m^{-2}. Zhang et al. (2014) reported that conversion from virgin land to irrigated crop land increased SOC stock (0–100 cm) by 3.7 kg m^{-2}, while Zhang et al. (2012) reported that conversion from desert steppe to crop land in China led to increase in SOC stock from 3.9 to 5.1 kg m^{-2} in the top 100 cm as a result of 20 years of cropping. These results imply that the longer the cropping is, the greater the SOC stock increase will become.

In general, SOC content and SOC stock increased with the increase in cultivation history of crop land. Similar increase in SOC content and SOC stock with increase in cultivation history under cultivated land was reported in the Netherlands (Reijneveld et al. 2009), under forest in Germany (Fettweis et al. 2005) and under forest in USA (Shrestha and Lal 2010). Estimates in this study show that, after 50 years of cultivation, SOC stock increased by 76% in crop land compared with those of the initial stock (virgin land). The cultivation history is important to understand temporal changes in ecosystem carbon stock in reclaimed soils (Knops and Tilman 2000), especially because initial soil properties are often unknown. Several cultivation history studies (Rumpel et al. 1999; Maharaj et al. 2007; Shrestha and Lal 2010) have reported accumulation of SOC stock over time in cultivated soils. However, ecosystem processes and the long-term changes in SOC stock in cultivated soil land-uses are poorly understood. Shrestha and Lal (2010) found an increase in SOC stock with increase in the cultivated history in forest and pasture ecosystems. Some studies carried out in Europe indicated an increase of SOC stock with increasing cultivation history (see Nieder and Richter 2000). Increase in SOC content as well as SOC stock with cultivation history may be due to increase in soil microbial biomass (Sourkova et al. 2005), accumulation and incorporation of the aboveground biomass, litter and roots (Shrestha and Lal 2010).

Regional variations in SOC stocks could be related to a number of natural factors (climate, parent material, landscape position and elevation, site-specific conditions such as soil texture, soil mineralogy, pH and drainage; Tan et al. 2004; Leifeld et al. 2005; von Lützow et al. 2006; Yu et al. 2007) and human activities (land-use type, management intensity; Somaratne et al. 2005). Considering the entire soil profile (0–120 cm), the range SOC stock in the north Nile Delta crop land was 5.5–7.5 kg C m^{-2} which compared to the range reported for crop land soils from China (Table 3). In contrast, it is higher than those reported for tropical and subtropical crop land soils from India and for subtropical crop land from USA. In addition, it is lower than those reported for temperate crop land soils from Europe. The highest SOC stock in temperate climates in Europe may be attributed to the low soil temperature that probably supported high vegetative growth and rapid root proliferation (Singh et al. 2011). In addition, Chiti et al. (2012) reported a decrease of the SOC stock from the temperate regions toward the Mediterranean ones. The lowest SOC stock in tropical and subtropical climates may be attributed to the greater decomposition due to high temperature (Eid et al. 2014). Worldwide, SOC stocks generally increase as mean annual temperature decreases (Post et al. 1982).

Our study calculated an SOC accumulation rate of about 62 g C m^{-2} $year^{-1}$ in the 120 cm for 50 years of cultivation; this finding supports previous results such as those by Yu et al. (2009) who suggested a large potential for organic carbon sequestration in the cultivated soils. The previous results (Table 4) reflect a high variability in SOC accumulation rates, which depend on several factors such as the climate zone, crop species, biomass accumulation rates, cultivation history, time of restoration and soil type (Post and Kwon 2000; Guo and Gifford 2002).

5 Conclusion

The aims of the present study are: (1) to quantify the vertical distribution of the soil bulk density (SBD) and SOC content in the soil of north Nile Delta, Egypt, under different types of land-use; (2) to provide estimates of the carbon sequestration rate (CSR) of those soils under different types of land-use; and (3) to establish a baseline data on SOC stocks for future studies on SOC dynamics. Effect of crop type was significant on SBD, SOC content, and SOC stock. Soil bulk density decreases as soil organic carbon content increases. SOC stock under crop land and fish farm were 1.6 and 1.5 times as that of virgin land. SOC stock increases as the number of years of cultivation increases. Rice was the crop with less SBD and more soil organic carbon stock. Conversion of virgin land into crop land or fish farm contributed to SOC sequestration. In conclusion, crop lands may be the optimal choice for SOC sequestration in the north Nile Delta. Crop land with rice and clover are also recommended for their great contribution to SOC storage in the area.

Acknowledgements We thank two anonymous reviewers and the editor for their useful comments on an earlier version, and Dr. Amir H.Y. Salama, Department of English, Faculty of Al-Alsun (Foreign Languages), Kafr El-Sheikh University for the English revision. The senior author extends his appreciation to the Deanship of Scientific Research at King Khalid University for funding this work.

References

Abdelbaki AM (2016) Evaluation of pedotransfer functions for predicting soil bulk density for US soils. Ain Shams Eng J. doi:10.1016/j.asej.2016.12.002

Abu Al-Izz MA (1971) Land forms of Egypt. Dar AI-Maaref, Cairo

Alcántara V, Don A, Well R, Nieder R (2016) Deep ploughing increases agricultural soil organic matter stocks. Glob Change Biol 22:2939–2956

Alfiky A, Kaule G, Salheen M (2012) Agricultural fragmentation of the Nile Delta; a modeling approach to measuring agricultural land deterioration in Egyptian Nile Delta. Procedia Environ Sci 14:79–97

Aly AM, Kitamura Y, Shimizu K (2013) Assessment of irrigation practices at the tertiary canal level in an improved system—a case study of Wasat area, the Nile Delta. Paddy Water Environ 11:445–454

Andrews SS, Karlen DL, Mitchell JP (2002) A comparison of soil quality indexing methods for vegetable production systems in Northern California. Agric Ecosyst Environ 90:25–45

Batjes NH (2002) Carbon and nitrogen stocks in the soils of Central and Eastern Europe. Soil Use Manage 18:324–329

Batjes NH (2014) Total carbon and nitrogen in the soils of the world. Eur J Soil Sci 65:10–21

Bernal B, Mitsch WJ (2008) A comparison of soil carbon pools and profiles in wetlands in Costa Rica and Ohio. Ecol Eng 34:311–323

Bernoux M, Arrouays D, Cerri C, Volkoff B, Jolivet C (1998) Bulk densities of Brazilian Amazon soils related to other soil properties. Soil Sci Soc Am J 62:743–749

Bossio DA, Scow KM (1995) Impact of carbon and flooding on the metabolic diversity of microbial communities in soils. Appl Environ Microbiol 61:4043–4050

Bouchard V, Cochran M (2006) Wetland and carbon sequestration. In: Lal R (ed) Encyclopedia of soil science. CRC Press, Boca Raton, pp 1887–1890

Boucneau G, Van Meirvenne M, Hofman G (1998) Comparing pedotransfer functions to estimate soil bulk density in northern Belgium. Pedologie Themata 5:67–70

Brar BS, Singh K, Dheri GS, Balwinder-Kumar (2013) Carbon sequestration and soil carbon pools in a rice-wheat cropping system: effect of long-term use of inorganic fertilizers and organic manure. Soil Till Res 128:30–36

Chen JY (2000) Study on the relation between under vegetation biomass and soil bulk density of *Cunninghamia lanceolata* plantation. J Fujian For Sci Technol 27:56–60

Chen LD, Gong J, Fu BJ, Huang ZL, Huang YL, Gui LD (2007) Effect of land use conversion on soil organic carbon sequestration in the loess hilly area, Loess Plateau of China. Ecol Res 22:641–648

Chiti T, Gardin L, Perugini L, Quaratino R, Vaccari FP, Miglietta F, Valentini R (2012) Soil organic carbon stock assessment for the different cropland land uses in Italy. Biol Fert Soils 48:9–17

Cicuzza D, De Nicola C, Testi A, Pignatti S, Zanella A (2015) Which is the contribution to the carbon sequestration of the forest ecosystems in the Castelporziano Reserve? Evidences from an integrated study on humus and vegetation. Rend Fis Acc Lincei 26:403–411

De Vos B, Van Meirvenne M, Quataert P, Deckers J, Muys B (2005) Predictive quality of pedotransfer functions for estimating bulk density of forest soils. Soil Sci Soc Am J 69:500–510

De Vos B, Cools N, Ilvesniemi H, Vesterdal L, Vanguelova E, Carnicelli S (2015) Benchmark values for forest soil carbon stocks in Europe: results from a large scale forest soil survey. Geoderma 251(252):33–46

Drewry JJ, Cameron KC, Buchan GD (2008) Pasture yield and soil physical property responses to soil compaction from treading and grazing - a review. Aust J Soil Res 46:237–256

Eid EM, Shaltout KH (2013) Evaluation of carbon sequestration potentiality of Lake Burullus, Egypt to mitigate climate change. Egypt J Aquat Res 39:31–38

Eid EM, Shaltout KH (2016) Distribution of soil organic carbon in the mangrove *Avicennia marina* (Forssk.) Vierh. along the Egyptian Red Sea Coast. Reg Stud Mar Sci 3:76–82

Eid EM, Shaltout KH, Al-Sodany YM (2014) Decomposition dynamics of *Phragmites australis* litter in Lake Burullus, Egypt. Plant Species Biol 29:47–56

Eid EM, El-Bebany AF, Alrumman SA (2016) Distribution of soil organic carbon in the mangrove forests along the southern Saudi Arabian Red Sea coast. Rend Fis Acc Lincei 27:629–637

El Nahry AH, Ibraheim MM, El Baroudy AA (2008) Assessment of soil degradation in the northern part of Nile Delta, Egypt, using remote sensing and GIS techniques. Egypt J Remote Sens Space Sci 11:139–154

El Shimi SA (2005) Design and cost analysis of agriculture wastes recycling alternatives for Sinbo Village, Gharbiya Governorate. Ministry of water resources and irrigation. United States Agency for International Development, Cairo

Elbasiouny H, Abowaly M, Abu_Alkaeir A, Gad A (2014) Spatial variation of soil carbon and nitrogen pools by using ordinary Kriging method in an area of north Nile Delta, Egypt. Catena 113:70–78

Elhag M, Psilovikos A, Sakellariou-Makrantonaki M (2013) Land use changes and its impacts on water resources in Nile Delta region using remote sensing techniques. Environ Dev Sustain 15:1189–1204

El-Nahrawy MA (2011) Country pasture/forage resource profiles: Egypt. FAO, Rome

EMA (Egyptian Meteorological Authority) (1980) Climatic normals for the Arab Republic of Egypt up to 1975. Ministry of Civil Aviation, Meteorological Authority, General Organization for Governmental Printing Offices, Cairo

Eve MD, Sperow M, Paustian K, Follett RF (2002) National-scale estimation of changes in soil carbon stocks on agricultural lands. Environ Pollut 116:431–438

Fallahzade J, Hajabbasi M (2012) The effects of irrigation and cultivation on the quality of desert soil in Central Iran. Land Degrad Dev 23:53–61

Fang X, Xue Z, Li B, An S (2012) Soil organic carbon distribution in relation to land use and its storage in a small watershed of the Loess Plateau, China. Catena 88:6–13

Feller C, Bernoux M (2008) Historical advances in the study of global terrestrial soil organic carbon sequestration. Waste Manage 28:734–740

Fettweis U, Bens O, Hüttl RF (2005) Accumulation and properties of soil organic carbon at reclaimed sites in the Lusatian lignite mining district afforested with *Pinus* sp. Geoderma 129:81–91

Girmay G, Singh BR (2012) Changes in soil organic carbon stocks and soil quality: land-use system effects in northern Ethiopia. Acta Agric Scand Sect B 62:519–530

Gleixner G (2013) Soil organic matter dynamics: a biological perspective derived from the use of compound-specific isotopes studies. Ecol Res 28:683–695

Guo LB, Gifford RM (2002) Soil carbon stocks and land use change: a meta analysis. Glob Change Biol 8:345–360

Han F, Hu W, Zheng J, Du F, Zhang X (2010) Estimating soil organic carbon storage and distribution in a catchment of Loess Plateau, China. Geoderma 154:261–266

Hanke A, Cerli C, Muhr J, Borken W, Kalbitz K (2013) Redox control on carbon mineralization and dissolved organic matter along a chronosequence of paddy soils. Eur J Soil Sci 64:476–487

Hay WW (2014) The accelerating rate of global change. Rend Fis Acc Lincei 25:29–48

Howard PJA, Loveland PJ, Bradley RI, Dry FT, Howard DM, Howard DC (1995) The carbon content of soil and its geographical-distribution in Great Britain. Soil Use Manage 11:9–15

Huang S, Sun Y, Zhang W (2012) Changes in soil organic carbon stocks as affected by cropping systems and cropping duration in China's paddy fields: a meta-analysis. Clim Change 112:847–858

Jalabert SSM, Martin MP, Renaud JP, Boulonne L, Jolivet C, Montanarella L, Arrouays D (2010) Estimating forest soil bulk density using boosted regression modelling. Soil Use Manage 26:516–528

Jobbagy EG, Jackson RB (2000) The vertical distribution of soil organic carbon and its relation to climate and vegetation. Ecol Appl 10:423–436

Jones JB (2001) Laboratory guide for conducting soil tests and plant analysis. CRC Press, Boca Raton

Khattab AF, El-Gharably ZA (1984) The problem of aquatic weeds in Egypt and methods of management. In: Proc. 3rd symposium on weed problems in the Mediterranean area, Portugal, pp 335–344

Knops JMH, Tilman D (2000) Dynamics of soil nitrogen and carbon accumulation for 61 years after agricultural abandonment. Ecol 81:88–98

Kobal M, Urbancic M, Potocic N, De Vos B, Simoncic P (2011) Pedotransfer functions for bulk density estimation of forest soils. Sumarski List 135:19–27

Krogh L, Noergaard A, Hermanen M, Greve MH, Balstroem T, Breuning-Madsen H (2003) Preliminary estimates of contemporary soil organic carbon stocks in Denmark, using multiple datasets and four scaling-up methods. Agric Ecosyst Environ 96:19–28

Kukal SS, Rehana-Rasool, Benbi DK (2009) Soil organic carbon sequestration in relation to organic and inorganic fertilization in rice–wheat and maize–wheat systems. Soil Till Res 102:87–92

Lal R (2004) Soil carbon sequestration to mitigate climate change. Geoderma 123:1–22

Leifeld J, Bassin S, Fuhrer J (2005) Carbon stocks in Swiss agricultural soils predicted by land-use, soil characteristics, and altitude. Agric Ecosyst Environ 105:255–266

Liu Z, Shao M, Wang Y (2011) Effect of environmental factors on regional soil organic carbon stocks across the Loess Plateau region, China. Agric Ecosyst Environ 142:184–194

Lopes de Gerenyu VO, Kurganova IN, Kuzyakov Y (2008) Carbon pool and sequestration in former arable Chernozems depending on restoration period. Ekologija 54:232–238

Lorenz K, Lal R (2005) The depth distribution of soil organic carbon in relation to land use and management and the potential of carbon sequestration in subsoil horizons. Adv Agron 88:35–66

Maharaj S, Barton CD, Karathanasis TAD, Rowe HD, Rimmer SM (2007) Distinguishing "new" from "old" organic carbon in reclaimed coal mine sites using thermogravimetry: II. Field validation. Soil Sci 172:302–312

Mandal KG, Baral U, Padhi J, Majhi P, Chakraborty H, Kumar A (2012) Effects of cropping on soil properties and organic carbon stock in Deras region, India. Reg Environ Change 12:899–912

Mathieu JA, Hatté C, Balesdent J, Parent É (2015) Deep soil carbon dynamics are driven more by soil type than by climate: a worldwide meta-analysis of radiocarbon profiles. Glob Change Biol 21:4278–4292

McLauchlan KK, Hobbie SE, Post W (2006) Conversion from agriculture to grassland builds soil organic matter on decadal time scales. Ecol Appl 16:143–153

Meersmans J, van Wesemael B, De Ridder F, Dotti MF, De Baets S, van Molle M (2009) Changes in organic carbon distribution with depth in agricultural soils in northern Belgium, 1960–2006. Glob Change Biol 15:2739–2750

Mensah F, Schoenau JJ, Malhi SS (2003) Soil carbon changes in cultivated and excavated land converted to grasses in east-central Saskatchewan. Biogeochemistry 63:85–92

Munoz-Rojas M, Jordan A, Zavala LM, De la Rosa D, Abd-Elmabod SK, Anaya-Romero M (2012) Organic carbon stocks in Mediterranean soil types under different land uses (Southern Spain). Solid Earth 3:375–386

Nieder R, Richter J (2000) C and N accumulation in arable soils of West Germany and its influence on the environment—developments 1970 to 1998. J Plant Nutr Soil Sci 163:65–72

Pacala S, Socolow R (2004) Stabilization wedges: solving the climate problem for the next 50 years with current technologies. Science 305:968–972

Pan G, Xu X, Smith P, Pan W, Lal R (2010) An increase in topsoil SOC stock of China's croplands between 1985 and 2006 revealed by soil monitoring. Agric Ecosyst Environ 136:133–138

Parras-Alcántara L, Lozano-García B, Galán-Espejo A (2015) Soil organic carbon along an altitudinal gradient in the Despeñaperros Natural Park, southern Spain. Solid Earth 6:125–134

Périé C, Ouimet R (2008) Organic carbon, organic matter and bulk density relationships in boreal forest soils. Can J Soil Sci 88:315–325

Poeplau C, Vos C, Don A (2017) Soil organic carbon stocks are systematically overestimated by misuse of the parameters bulk density and rock fragment content. Soil 3:61–66

Post WM, Kwon KC (2000) Soil carbon sequestration and land-use change: processes and potential. Glob Change Biol 6:317–327

Post WM, Emanuel WR, Zinke PJ, Stangenberger AG (1982) Soil carbon pools and world life zones. Nature 298:156–159

Potter KN, Torbert HA, Johnson HB, Tischler CR (1999) Carbon storage after long-term grass establishment on degraded soils. Soil Sci 164:718–725

Rasmussen PE, Collins HP (1991) Long-term impacts of tillage, fertilizer, and crop residue on soil organic matter in temperate semiarid regions. Adv Agron 45:93–134

Reijneveld A, van Wensem J, Oenema O (2009) Soil organic carbon contents of agricultural land in the Netherlands between 1984 and 2004. Geoderma 152:231–238

Ross CW, Grunwald S, Myers DB (2013) Spatiotemporal modeling of soil organic carbon stocks across a subtropical region. Sci Total Environ 461(462):149–157

Rumpel C, Kögel-Knabner I, Hüttl RF (1999) Organic matter composition and degree of humification in lignite-rich mine soils under a chronosequence of *Pine*. Plant Soil 213:161–168

Sahrawat KL (2004) Organic matter accumulation in submerged soils. Adv Agron 81:169–201

Salifu KF, Meyer WL, Murchison HG (1999) Estimating soil bulk density from organic matter content, pH, silt and clay. J Tropic For 15:112–120

Shaltout KH, Galal TM, El-Komi TM (2010) Evaluation of the nutrient status of some hydrophytes in the water courses of Nile Delta. Ecol Mediterr 36:77–87

Shrestha RK, Lal R (2010) Carbon and nitrogen pools in reclaimed land under forest and pasture ecosystems in Ohio, USA. Geoderma 157:196–205

Singh SK, Pandey CB, Sidhu GS, Sarkar D, Sagar R (2011) Concentration and stock of carbon in the soils affected by land uses and climates in the western Himalaya, India. Catena 87:78–89

Sleutel S et al (2003) Carbon stock changes and carbon sequestration potential of Flemish cropland soils. Glob Change Biol 9:1193–1203

Smith P (2008) Land use change and soil organic carbon dynamics. Nutr Cycl Agroecosys 81:169–178

Smith P, Milne R, Powlson DS, Smith JU, Falloon P, Coleman K (2000) Revised estimates of carbon mitigation potentials of UK agricultural land. Soil Use Manage 16:293–295

Somaratne S, Seneviratne G, Coomaraswamy U (2005) Prediction of soil organic carbon across different land-use patterns: a neural network approach. Soil Sci Soc Am J 69:1580–1589

Sombrero A, de Benito A (2010) Carbon accumulation in soil. Ten-year study of conservation tillage and crop rotation in a semi-arid area of Castile-Leon, Spain. Soil Till Res 107:64–70

Sourkova M, Frouz J, Fettweis U, Bens O, Hüttl RF, Santruckova H (2005) Soil development and properties of microbial biomass succession in reclaimed post mining sites under Sokolov (Czech Republic) and Cottbus (Germany). Geoderma 129:73–80

SPSS (2006) SPSS base 15.0 user's guide. SPSS Inc., Chicago

Tamminen P, Starr M (1994) Bulk density of forested mineral soils. Silva Fenn 28:53–60

Tan ZX, Lal R, Smeck NE, Calhoun FG (2004) Relationships between surface soil organic carbon pool and site variables. Geoderma 121:187–195

UNESCO (1977) Map of the world distribution of arid regions. MAB Technical Notes, Paris

Vanguelova EI et al (2016) Sources of errors and uncertainties in the assessment of forest soil carbon stocks at different scales-review and recommendations. Environ Monit Assess 188:630

von Lützow M, Kögel-Knabner I, Ekschmitt K, Matzner E, Guggenberger G, Marschner B, Flessa H (2006) Stabilization of organic matter in temperate soils: mechanisms and their relevance under different soil conditions—a review. Eur J Soil Sci 57:426–445

Wang X, Zhu B, Hua K-K, Luo Y, Zhang J, Zhang A (2013) Assessment of soil organic carbon stock in the upper Yangtze River Basin. J Mt Sci 10:866–872

Wiesmeier M, Hübner R, Barthold F, Spörlein P, Geuss U, Hangen E, Reischl A, Schilling B, von Lülzow M, Kögel-Knabner I (2013) Amount, distribution and driving factors of soil organic carbon and nitrogen in cropland and grassland soils of southeast Germany (Bavaria). Agric Ecosyst Environ 176:39–52

Wilke BM (2005) Determination of chemical and physical soil properties. In: Margesin R, Schinner F (eds) Manual for soil analysis—monitoring and assessing soil bioremediation. Springer, Heidelberg, pp 47–95

Yang Y, Mohammat A, Feng J, Zhou R, Fang J (2007) Storage, patterns and environmental controls of soil organic carbon in China. Biogeochemistry 84:131–141

Yimer F, Ledin S, Abdelkadir A (2006) Soil organic carbon and total nitrogen stocks as affected by topographic aspect and vegetation in the Bale Mountains, Ethiopia. Geoderma 135:335–344

Yu DS, Shi XZ, Wang HJ, Sun WX, Chen JM, Liu QH, Zhao YC (2007) Regional patterns of soil organic carbon stocks in China. J Environ Manage 85:680–689

Yu Y, Guo Z, Wu H, Kahmann JA, Oldfield F (2009) Spatial changes in soil organic carbon density and storage of cultivated soils in China from 1980 to 2000. Global Biogeochem Cycl 23:1–6

Zhang L, Xie Z, Zhao R, Wang Y (2012) The impact of land use change on soil organic carbon and labile organic carbon stocks in the Longzhong region of Loess Plateau. J Arid Land 4:241–250
Zhang C, Liu G, Xue S, Sun C (2013) Soil organic carbon and total nitrogen storage as affected by land use in a small watershed of the Loess Plateau, China. Eur J Soil Biol 54:16–24
Zhang J, Wang X, Wang J (2014) Impact of land use change on profile distributions of soil organic carbon fractions in the Yanqi Basin. Catena 115:79–84