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Effects of Temporal Variation in Long-Term Cultivation on Organic Carbon Sequestration in Calcareous Soils: Nile Delta, Egypt

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Abstract: Soil carbon sequestration is a riskier long-term strategy for climate mitigation than direct emissions reduction, but it plays a main role in closing carbon emission gaps. Effects of long-term cultivation on soil carbon sequestration were studied at the western edge of the Nile Delta near Alexandria, Egypt. Seven agricultural fields of different ages (0–50 years in use) were selected and compared with the surrounding desert (virgin soil) and desert shrub-land. Samples were taken at three horizons, 0–30, 30–60, and 60–90 cm, and tested for differences in physical and chemical properties. The results of long-term cultivation reveal that the European Commission (EC) value was 11.77 dS/m in virgin soil, while the EC values decreased to 5.82, 4.23, 3.74, 2.40, and 2.26 dS/m after 5, 10, 20, 30, and 50 years of cultivation, respectively. The calcareous rock fraction smaller than 50 μm in size revealed another phenomenon, where active calcium carbonate content increased with cultivation practices from 1.15% (virgin soil) to 5.42%, 6.47%, 8.38%, and 10.13% after 5, 10, 20, and 30 years of cultivation, respectively, while shrub-land also showed a low amount of active CaCO_3 with 1.38%. In fifty years of cultivation, soil bulk density decreased significantly from 1.67 to 1.11 g/cm^3 , and it decreased to 1.65, 1.44, 1.40, and 1.25 g/cm^3 after 5, 10, 20, and 30 years, respectively. These results reveal that the increase in soil carbon stock in the upper 90 cm amounted to 41.02 t C/ha after five years of cultivation, compared to virgin soil with 13.47 t C/ha. Soil carbon levels increased steeply during the five years of cultivation, with an average rate of 8.20 t C/ha per year in the upper 90 cm. After the first five years of cultivation, the carbon sequestration rate slowed, reaching 4.68, 3.77, 2.58, and 1.93 t C/ha per year after 10, 20, 30, and 50 years, respectively, resulting in sequestration-potential values of 46.78, 75.63, 77.43, and 96.45 t C/ha. These results indicate that potential soil carbon sequestration resembles a logarithmic curve until the equilibrium state between carbon application and decomposition by microorganisms is reached.

Keywords: cultivation age; soil organic carbon; climate mitigation; carbon sequestration

1. Introduction

Agricultural soils are a potential carbon sink that may be used to mitigate and decrease the global greenhouse effect causing climate changes [1–3]. Agriculture and land-use practices such as cultivation, plowing, and land shifting have always been a major source of greenhouse gas (GHG) emissions [4,5]. Soil stores about 1500 Pg of carbon in its upper horizons worldwide (0–100 cm), which is considered to be more than the amount of carbon found in the atmosphere or in crops [6–8]. The soil may be

stimulated as a carbon sink by the use of land-use practices that reduce organic matter decomposition rates (no-tillage) and/or by increasing the application rate of organic matter, i.e., using organic fertilizers. Soil carbon content is a function of parent material, vegetation, climate/environment, soil management, and time. In addition, land-use practices reveal an essential factor affecting the soil carbon sink: as land management practices, such as plowing for agriculture purposes, decompose the soil organic matter (SOM), the SOM levels rapidly decrease [9].

Croplands are a major terrestrial C reservoir that can sequester a carbon stock of 2500 Gt worldwide, consisting of 1550 and 950 Gt of organic and inorganic carbon, respectively, in its first one-meter depth [10]. Deterioration in this C pool would have substantial effects on future carbon dioxide concentrations in the surrounding environment and, hence, also on GHG emissions [11]. Correlations between the surface-soil organic carbon pool (SOCP), land-use, and site parameters are the main factors in developing soil organic carbon (SOC) models and evaluating their impact on land-use and climate [12]. One study [13] analyzed SOC dynamics in terms of climatic variable impacts on local sequestration rates. Although soil texture, drainage condition, and slope did not correlate well with climatic parameters, these parameters varied in close connection with changes in land-use and SOC. These characteristics are responsible for 50%, 51%, and 54% of SOCP values in forest, grassland, and cropland, respectively [14]. Such variables become significant on a regional scale for assessing SOCP variations in which climatic change is not identified [15,16]. The initial role of soil texture in SOC sequestration was attributed to the consistence scale of passive C [17]. Nevertheless, its secondary role was due to its effect on the hydrologic properties of the soil surface [15]. Moreover, [16] showed that land-use had marked effects on the SOCP on a large scale, considering the soil pedon cells that increase with clay content. Transformation in agriculture with the effect of decreasing inputs of organic matter and/or increasing soil erosion leads to a degradation of SOC [18]. Another study [19] observed that this degradation was permanent in the top 30 cm of soil, in which the SOCP was reduced by 50%, and by 20% to 30% in the top 100 cm horizon. In addition, [3] investigated changes in land-use techniques, which are useful practices for enhancing C sequestration that would consequently reduce atmospheric CO₂ levels. West and Post (2002) [20] reported $20 \pm 12 \text{ g C m}^{-2} \text{ year}^{-1}$ was sequestered in the upper 30 cm horizon with crop rotation systems associated with increasing crop numbers. These efficient land management practices lead to increased SOC sequestration, and [21] found that improving cropland management resulted in SOC sequestration increasing from 80 to 208 Tg C year⁻¹ (Tg = 10¹² g). In cultivated lands, [22] also investigated the impact of land-use techniques on SOC sequestration, and found an increase from 60 to 70 Tg C year⁻¹ in carbon potential. Land management changes affecting the SOCP scales could involve temporal and spatial variability, which influences SOC levels to a large extent. Similarly, [10] revealed important changes in SOCP values at a 30-cm soil depth that were associated with land-use changes and influenced by soil texture and drainage.

The carbon sequestration potential of arid soils in Egypt is a relevant issue that has appeared together with land reclamation activities on a large scale. Arid desert soil, compared to other soils, has relatively high potential to act as a carbon sink, as its initial carbon stock is usually minimal [23,24]. While conventional farming practices still apply common methods, reclaimed lands in the northwestern deserts in Egypt are increasingly used for food production. The land was reclaimed using drip irrigation and is commonly fertilized with compost. Over the years, Burg El Arab has expanded in size, and hence, a mosaic of cultivated fields of different ages has gradually emerged, providing a relevant environment for carbon sequestration in such arid soils due to their management over time. SOC sequestration in soils reclaimed using irrigation and compost, considering temporal variations, may offer a methodology for generating carbon credits in desert regions like Egypt. Although the hydro-physical properties and resulting beneficial effects of using compost on soil structure in arid soils have been investigated [25,26], the influence of temporal variations on the SOCP potential in reclaimed soils remains unknown. Cultivation leads to soil development from its natural state to a transformed one through long-term intensive agricultural use [27,28]. This was the main aim, especially regarding uncultivated lands with calcareous soils, which is the situation in the northwestern part of Egypt, with soils dominated

by calcium carbonate. In addition to the overall calcium carbonate content, active calcium carbonate, the separated fraction of calcareous rock smaller than 50 μm in size, plays an essential role in forming the soil properties and the soil capacity to enhance its physical properties. This carbonate fraction is susceptible to rapid mobilization, and it is chemically active [29]. Active carbonate influences the extent and reactivity of the surfaces of the carbonates and constitutes an important reserve of exchangeable Ca^{2+} . Exchangeable Ca^{2+} comes mostly from carbonated rock, whose rate of dissolution depends on the hardness and size of its particles; the dissolution speed increases as the size decreases [29,30]. Soil CaCO_3 is an important criterion in the soils of the Mediterranean region [31]. Carbonate accumulations follow a sequence of morphologic development, starting as horizon features such as carbonate coats, masses, and fine nodules. Calcareous soils originate mainly from carbonate-rich parent materials.

The objectives of this study are (1) to investigate the development of the soil organic carbon pool (SOCP) in a mosaic of cultivated fields of different ages, with reclaimed arid soils near Alexandria in northwestern Egypt, (2) to trace the effects of cultivation periods over the long term (50 years) on the chemical properties and organic carbon sequestration in soil, which mainly originated from calcareous parent material (geological age), and (3) to determine the carbon sequestration potential in different layers of arid desert soils in Egypt and the impacts on the potential of their physical–chemical properties.

2. Materials and Methods

2.1. Experimental Site Specification

The study was conducted in the region west of the Nile Delta, in the Burg El Arab catchment area south-west of Alexandria City, Egypt, ($31^{\circ}20' \text{ N}$, $29^{\circ}30' \text{ E}$) with an area of 34,650 ha, as shown in Figure 1. The region is characterized by Mediterranean climatic conditions, with high oscillations between the minimum and maximum daily temperatures. The results of a three-year climatic data survey (2017–2020) conducted at Burg El Arab Meteorological Station show that the average annual rainfall (mainly in winter seasons) is 210.6 mm. Moreover, the mean annual temperature is 21.4°C , with a maximum temperature of 35.66°C and a minimum temperature of 9.5°C . The surface of the area is created mainly of various Tertiary and Quaternary sedimentary deposits [32]. The study area is characterized by a series of three parallel Pleistocene limestone ridges, ranging in elevation up to 35 m and separated by shallow depressions. The Quaternary deposits constitute the main groundwater source in the area. These ridges and depressions in the Burg El Arab area control the groundwater flow pattern. The irrigation water source is El Aqarya Canal, a line branch from El Nubaria Canal, which receives its water directly from the Nile.

Figure 1. Sample location of the studied arable fields west of the Nile Delta, Burg El Arab, southern Alexandria City, Egypt.

2.2. Selected Soil Data and Laboratory Analysis

Seven arable fields of different ages (Table 1) were selected in the western desert area of the Nile Delta, near Burg El Arab city. Seven soil profiles sites were selected to represent the variations in a mosaic of cultivated fields of different ages, reclaimed using the drip irrigation method. Profile 1 represents the uncultivated soils (control), while Profile 2 represents the soil in zones dominated by shrubs. Profiles 3, 4, 5, 6, and 7 (Figure 1) represent the state of cultivated soils after 5, 10, 20, 30, and 50 years.

The soil profile of every field was studied down to a 90-cm depth. The fields were sampled for analysis in three line transects. Each transect consisted of five sample locations where samples were collected at three horizons (0–30, 30–60, and 60–90 cm deep). The representative soil samples for each horizon were air-dried for the physical and chemical analyses. At the indicated locations and soil depths, bulk density samples were prepared for measurements, which were taken by hammering sample rings with a fixed volume (100 cm³) into the soil.

The soil samples were air-dried at room temperature and were ground to pass through a 2-mm sieve. Soil pH (1:2.5) was measured using a Hanna model PH211 microprocessor-based pH-meter. Electrical conductivity (EC) was assessed in soil paste extract using a conductivity meter. For active carbonate determination, exchangeable cations of Ca²⁺ and total CaCO₃ (equivalent carbonate) were measured according to the methods of [33]. Active carbonate (carbonate extractable with ammonium oxalate) was likewise determined according to [33]. Organic matter was determined using the Walkley and Black method [34]; cation exchange capacity (CEC) was determined using the ammonium acetate method [35]; available N was extracted with K₂SO₄ and quantified by means of the steam-distillation procedure using MgO-Devarda alloy according to the Bremner and Keency method, as described by [34]. Available P was extracted with 0.5 N NaHCO₃ at pH 8.5 [36] and quantified colorimetrically using the ascorbic acid method [37], and available K was extracted with 1.0 N ammonium acetate at pH 7.0 and quantified using a flame photometer [38]. Particle-size analysis was performed using the international pipette method [39]. Saturation percentage and soil density calculations were carried out according to [33].

Table 1. Physico-chemical properties of different layers in investigated soil after longer cultivation periods.

Cultivation Period	Horizon Depth, cm	pH (1:2.5)	Coarse Sand %	Fine Sand %	Total Sand %	Silt %	Clay %	Texture	Ava. N, mg/kg	Ava. P, mg/kg	Ava. K, mg/kg	FC %
Virgin Soil	0–30	8.34	15.22	68.76	83.98	3.50	12.52	Loamy sand	5.76	2.87	31.87	8.72
	30–60	8.41	12.76	70.22	82.98	2.50	14.52	Sandy loam	4.12	1.09	30.87	9.34
	60–90	8.43	8.87	71.89	80.76	1.50	17.74	Sandy loam	2.67	1.00	29.32	10.27
Desert shrubs	0–30	8.26	12.22	55.76	67.98	17.40	14.62	Sandy loam	9.87	2.87	41.98	9.66
	30–60	8.33	13.31	51.56	64.87	15.89	19.24	Sandy clay loam	3.76	1.65	38.98	9.48
	60–90	8.37	16.74	44.76	61.50	15.78	22.72	Sandy clay loam	2.11	1.58	30.55	8.49
5 years cultivation	0–30	8.11	12.67	46.87	59.54	14.80	25.66	Sandy clay loam	11.76	5.87	62.98	15.11
	30–60	8.13	14.22	48.76	62.98	13.60	23.42	Sandy clay loam	9.87	3.67	60.98	13.78
	60–90	8.19	21.76	43.22	64.98	16.98	18.04	Sandy loam	3.90	2.78	46.12	10.37
10 years cultivation	0–30	8.03	19.53	33.87	53.40	17.89	28.71	Sandy clay loam	39.78	15.87	176.98	15.78
	30–60	8.09	21.35	35.65	57.00	24.87	18.13	Sandy loam	38.33	14.87	166.76	10.94
	60–90	8.13	30.22	46.76	76.98	15.22	7.80	Loamy sand	29.57	10.65	140.00	4.11
20 years cultivation	0–30	7.76	5.68	45.99	51.67	20.00	28.33	Sandy clay loam	29.20	14.70	192.50	17.38
	30–60	7.87	8.94	41.60	50.54	20.12	29.34	Sandy clay loam	25.40	14.60	191.20	17.61
	60–90	8.15	8.58	35.98	44.56	21.44	34.00	Sandy clay loam	19.33	8.54	166.00	18.67
30 years cultivation	0–30	7.61	18.66	30.32	48.98	19.76	31.26	Sandy clay loam	44.98	18.98	189.98	18.84
	30–60	7.72	23.14	29.76	52.90	17.45	29.65	Sandy clay loam	42.87	17.87	187.44	17.99
	60–90	7.93	19.78	41.78	61.56	15.78	22.66	Sandy clay loam	38.55	12.87	166.87	13.78
50 years cultivation	0–30	7.27	26.75	41.23	67.98	3.12	28.90	Sandy clay loam	47.14	18.50	165.50	15.95
	30–60	7.34	28.69	37.98	66.67	4.43	28.90	Sandy clay loam	41.11	17.00	161.60	16.44
	60–90	8.37	22.37	38.19	60.56	4.22	35.22	Sandy clay	37.89	9.34	147.65	19.22

2.3. Physicochemical Parameters of Soil Samples and Soil Organic Carbon Pool Calculation

Soil coarse fraction content (particles > 2 mm in diameter) was determined according to [40]: gravel content (%) = (weight of coarse materials/weight of coarse and fine materials) × 100.

Calculation of the SOCP was carried out as a parameter of SOC concentration [3,41]. The content of soil organic matter (SOM) for each horizon was first converted to SOC percentage by multiplying the SOM by a factor of 0.58 [42,43]. For each soil horizon, SOCP (kg C m^{-2}) was calculated by multiplying the SOC percentage by the soil depth (30 cm), soil bulk density (Mg m^{-3}), and soil fraction (<2 mm in size) [42]:

$$\text{SOCP} = [L * B.D * \text{SOC} * (1 - F/100)]/10$$

where SOCP is the soil organic carbon pool for each soil horizon (kg m^{-2}), L is the thickness of the soil layer (30 cm), SOC is soil organic carbon content (wt %), $F > 2$ mm coarse soil fragment (wt %), and BD is the soil dry bulk density (Mg m^{-3}).

3. Results and Discussion

3.1. Effect of Cultivation Period on Soil Physico-Chemical Properties

The results in Table 1 reveal that soil pH decreased from alkaline in virgin soil (8.39) to slightly alkaline in cultivated soil 8.14, 8.08, 7.93, 7.75, and 7.66 after 5, 10, 20, 30, and 50 years, respectively. This could be attributed to the addition of fertilizers and manures over long periods. Generally, it was observed that pH values increased in deeper horizons (Table 1) compared to the upper soil horizons, which could be attributed to the movement of soluble salts and increasing calcium carbonate content (parent material). Our results are consistent with [44,45], in that increasing pH values of alkaline soils need special management practices such as the addition of acidifying materials and gypsum. In addition, the pH of calcareous soils is inversely proportional to CO_2 pressure, and while soils can contain 1% to 25% CaCO_3 with pH from 7.6 to 8.4, calcareous soils may have pH up to 8.6 [46].

With respect to soluble salt content, the data indicate that cultivated soils have lower electrical conductivity (EC) values than uncultivated soil (virgin soil). The results of long-term cultivation reveal that the EC value was 11.77 dS/m in the virgin soil, and then, the EC values decreased to 5.82, 4.23, 3.74, 2.40, and 2.26 dS/m after 5, 10, 20, 30, and 50 years of cultivation, respectively. In addition, the obtained results indicate that the salinity distribution increased in the deeper soil layers compared to the upper layer (Figure 2). On the other hand, the salt distribution in shrub-land soil reveals another phenomenon, i.e., that the upper layer (0–30 cm) contains high salinity (13.67 dS/m) compared to the lower soil layers 30–60 and 60–90 cm with 7.51 and 6.11 dS/m, respectively (Figure 2). The decrease in EC values is attributed to continuous leaching processes in light-textured calcareous soils through long cultivation periods, whereby there is less intensive leaching in shrub-land soil [44,45].

Figure 2. Impact of cultivation period on salinity distribution (dS/m) in different soil layers.

Calcium carbonate content is the main indicator of the calcareous soils in northwestern Egypt, and this reveals interesting results about long-term cultivation. CaCO_3 content was found to be extremely high (40.88%) in the uncultivated soils (virgin soil), while the values of calcium carbonate concentrations were affected by the length of cultivation periods, decreasing to 29.22% after five years of cultivation (Figure 3). Continuous cultivation in this region has resulted in the CaCO_3 content decreasing to moderate values (25.32%) after 20 years and low values (12.76%) after 50 years of cultivation (Figure 3). This could be attributed to the effect of organic matter decomposition as a consequence of manure application during cultivation. In addition, the distribution of calcium carbonate with depth reveals that the CaCO_3 content increased with depth in all the investigated soil samples over the different cultivation periods. In calcareous soils, calcium carbonate was efficiently stored in the deeper layers, and the acidity created through the nitrification process was neutralized through accelerating CaCO_3 depletion [47]. Dissolution of CaCO_3 via this anthropogenic source of acidity leads to CO_2 efflux and loss of CaCO_3 from the soil surface [48]. The application of acidifying fertilizers, such as ammonia and sulfur, reduced soil carbonate content during the cultivation process [49]. These conclusions are in agreement with the results of [50], who found significant differences in soil carbonate content between continuously cropped fields.

Figure 3. Calcium carbonate distribution at different soil depths in successive cultivation periods.

In addition to the calcium carbonate content and its impact on the physico-chemical properties of calcareous soils, the active calcium carbonate attributed to the fraction of calcareous rock smaller than $50\ \mu\text{m}$ in size revealed another phenomenon (Figure 4). Active calcium carbonate contents increase with the duration of cultivation practices, whereby the concentration increased from 1.15% in virgin soil to 5.42%, 6.47%, 8.38%, and 10.13% after 5, 10, 20, and 30 years of cultivation, respectively (Figure 4). Shrub-land showed low amounts of active CaCO_3 , with just 1.38%. Furthermore, the results indicate that the differences in active CaCO_3 distribution among the investigated layers were pronounced, with higher values of active CaCO_3 in the upper layer (0–30 cm) than in the deeper layer (60–90 cm). Carbonate content is a true reflection of the effect of parent material of the soil. An absence of any distinct calcic horizons reflects the low intensity of soil-forming processes and the relatively short time of soil formation, as well as the dominance of the parent material [46]. Ref. [31] reported that soils under arid or semiarid conditions in the northern Mediterranean zone are mostly calcareous. Ref. [51] found that such land surfaces are mainly represented by Holocene deposits of coastal sand dunes, old lagoonal and alluvial accretions, and Pleistocene oolitic limestone ridges.

Figure 4. Active calcium carbonate in successive cultivation periods.

Cation exchange capacity was observed in cultivated soils compared to virgin soil (Figure 5). The results reveal that the CEC content of virgin soil was 6.20 cmolcl^{-1} , while the CEC values with increasing cultivation duration were 13.65, 24.28, 30.88, and $31.40 \text{ cmolcl}^{-1}$ after 5, 10, 30, and 50 cultivation years, respectively. In addition, the distribution of CEC values with soil depth in successive cultivation periods reveals that the CEC value was higher at the soil surface and decreased with soil depth, cation exchange capacity of shrub-land soil was lower than that in the cultivated surrounded soil with 6.78 cmolcl^{-1} , and its content at the soil surface was higher than in the deeper soil layers (Figure 5). The increase in cation exchange capacity in cultivated soils over longer periods was found to be related to clay and organic matter content. The obtained results are in agreement with those of [52], namely that CEC results are in parallel with the cultivation activities in the reclaimed desert areas and are considered as an indicator of soil fertility in supplying nutrients. High CEC indicates high clay and organic matter content since many plant nutrients are positively charged ions, so they are adsorbed on the colloidal surfaces of clay and organic matter [45].

Figure 5. Impact of cultivation period on cation exchange capacity (CEC) cmolcl^{-1} in different soil layers.

Soil bulk density results revealed that at a depth of 0–30 cm, it was significantly affected by agricultural practices (Figure 6). In 50 years of cultivation, the bulk density decreased significantly from 1.67 g/cm^3 to 1.11 g/cm^3 , while it declined to 1.65, 1.44, 1.40, and 1.25 g/cm^3 after 5, 10, 20, and 30 years, respectively. The same phenomena were observed in the second horizon (30–60 cm), i.e., that the soil bulk density decreased significantly from 1.66 g/cm^3 in virgin soil to 1.11 g/cm^3 in cultivated land

after 50 years. At a depth of 60–90 cm, however, the bulk density was not significantly affected by agricultural practices (Figure 6).

Figure 6. Impact of cultivation period on soil bulk density (g/cm³) in different soil layers.

3.2. Effect of Cultivation Period on Soil Organic Carbon Sequestration

3.2.1. Organic Carbon Content

The organic carbon content of virgin soil close to the city of Burg El Arab was 0.12% (0–30 cm), whereas the fields which were cultivated for 5, 10, 20, 30, and 50 years contained 0.42%, 0.55%, 0.92%, 0.98%, and 1.22% of carbon, respectively, in the upper (0–30 cm) layer of the soil. The second horizon (30–60 cm) showed interesting results, namely that the carbon content increased from 0.09% in uncultivated soil (virgin land) to 0.41%, 0.38%, 0.87%, 0.96%, and 1.10% in the cultivated lands after 5, 10, 20, 30, and 50 years, respectively. However, in the deeper layer (60–90 cm), the increase in carbon content was not significantly linked with the agricultural practices or the period of cultivation (Figure 7). In arid and semiarid regions, SOC plays an essential role in the global carbon cycle and climate change [2]. The results obtained here are in agreement with the findings of [53,54], who established that SOC stocks were greater in agricultural land than in nonagricultural land.

Figure 7. Impact of cultivation period on organic carbon distribution in different soil layers.

3.2.2. Potential Soil Carbon Sequestration

The effects of successive cultivation periods acted significantly on soil bulk density (Figure 6) and organic carbon content, which is mainly used for calculations of SOC stocks. The results in Figure 8 reveal that the increase in soil carbon in the upper 90 cm amounted to 41.02 t of C/ha after five years of cultivation compared to the virgin soil content of 13.47 t of C/ha. During five years of cultivation, the carbon levels increased steeply, with an average rate of 8.20 t C/ha per year in the upper 90 cm. After the first five years of cultivation, the carbon sequestration rate slowed, reaching 4.68, 3.77, 2.58, and 1.93 t C/ha per year after 10, 20, 30, and 50 years, respectively, resulting in sequestration potential values of 46.78, 75.63, 77.43, and 96.45 t C/ha (Figure 8). These results indicate that potential soil carbon sequestration resembles a logarithmic curve (Figure 8) until an equilibrium state between carbon application and decomposition by microorganisms is reached.

Figure 8. Potential soil carbon sequestration trend under the influence of successive cultivation periods.

These results are consistent with the findings of [3,18,54], in particular, that SOC stocks were greater in agricultural land than in nonagricultural land in arid and semiarid regions. The impact of agricultural management on SOC plays an important role in the global carbon cycle and climate change [53]. The increase in soil carbon sequestration initially takes place in the upper 0–30 cm of the soil and then shifts towards deeper soil layers. After five years of cultivation, the soil carbon sink was 18.86 t of C/ha compared to the lower layer (60–90 cm) amount of 4.02 t of C/ha. The same results were also reported for the next 50 years of cultivation. After 10, 20, 30, and 50 years of cultivation, the SOCP values were 21.20, 34.66, 30.20, and 36.68 t of C/ha, respectively, in the upper layer (0–30 cm) compared to the deeper layer (60–90 cm), in which SOCP values were 10.52, 4.91, 8.47, and 22.56 t of C/ha after 10, 20, 30, and 50 years of cultivation (Figure 8). Organic C content is important in determining the soil chemical properties, and it directly and indirectly influences soil properties in general [2,9,55].

The Kyoto Protocol states that carbon sinks and sources should be accounted for, “taking into account uncertainties, verifiability, and transparency in reporting”. However, [11] identified the issues surrounding the monitoring and verification of soil carbon sequestration. The significant generic problem of changes in terrestrial biospheric carbon relates to CO₂ resolution (the smallest detectable change). The rate of change in biospheric carbon pools is slow, especially in relation to the pool size, and measurable changes in carbon stock are not easily achieved for the larger soil carbon pools [4]. In a recent paper, the minimum detectable variation in soil organic carbon potential was calculated as a function of cultivation duration and sample size for SOC changes, and this is consistent with the findings of [56,57].

4. Conclusions

Efforts have been made to increase the productivity of newly-reclaimed soil in order to meet the urgent food demand from the growing world population. The productivity of such soils is directly linked to their inherent quality and to the new properties that have been developed by cultivation over a specific period of time. Improved agricultural management often has a range of other environmental and economic benefits in addition to climate mitigation potential, and such “win-win” strategies to improve soil carbon storage are attractive and should be implemented as part of integrated sustainability policies. This study demonstrates that carbonate content is a true reflection of the effect of parent material on soil characteristics and that soil active calcium carbonate content increases with long-term cultivation practices, while shrub-land tends to have lower amounts of active CaCO_3 . The effects of the cultivation period significantly affect soil carbon sink levels during the first cultivation years. Then, the increase in carbon sequestration declines with further continuous cultivation, and this soil carbon sink potential resembles a logarithmic curve as a function of agricultural duration. Therefore, due to the strong influence of land management and land-use on carbon sequestration, greater precision would be obtained if SOC sequestration on a regional scale was identified for the different land-use categories.

Author Contributions: This research article includes several contributions. Conceptualization was prepared by M.A.-H. M.A. performed the field survey. The data sample analysis and the investigations were prepared and analyzed by M.A. and M.A.-H. The original draft preparation of the article was done by M.A., M.A.-H., and M.Z. Review and editing of the text were finalized by M.A. and Z.V. The supervision and funding acquisition were supported by M.A.-H. and Z.V. The final version of the article was revised by M.A.-H. and M.Z. All authors have read and agreed to the published version of the manuscript.

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