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Effects of land use changes and conservation measures on land degradation under a Mediterranean climate

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Abstract

Land degradation resulting from improper land use and management is a major cause of declined productivity in the arid environment. The objectives of this study were to examine the effects of a sequence of land use changes, soil conservation measures, and the time since their implementation on the degradation of selected soil properties. The climate for the selected 105 km^2 watershed varies from semi-arid sub-tropical to Mediterranean sub-humid. Land use changes were detected using aerial photographs acquired in 1953, 1978, and 2008. A total of 218 samples were collected from 40 sites in three different rainfall zones to represent different land use changes and different lengths of time since the construction of stone walls. Analyses of variance were used to test the differences between the sequences of land use changes (interchangeable sequences of forest, orchards, field crops, and range), the time since the implementation of soil conservation measures, and rainfall on the thickness of the A-horizon, soil organic carbon content, and texture. Soil organic carbon reacts actively with different combinations and sequences of land use changes. The time since stone walls were constructed showed significant impacts on soil organic carbon and the thickness of the surface horizon. The effects of changing the land use and whether the changes were associated with the construction of stone walls, varied according to the annual rainfall. The results help in understanding the effects of land use changes on land degradation processes and carbon sequestration potential and in formulating sound soil conservation plans.

1 Introduction

Rainfed farming is one of the main farming systems in a Mediterranean semi-arid and sub-humid climate. Increasing population and improper or intensive land use activities have resulted in various types of land degradation in many parts of the world (Cerdà et al., 2010). Land degradation caused by improper land use is a worldwide problem

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that has revived the issue of resources sustainability (Hurni, 1997). Degradation processes, such as soil erosion, salinization, crusting, and loss of soil fertility, affect the biological productivity of the land with subsequent impacts on the biodiversity of vegetation cover and/or its density (Le Houerou, 1996). Land degradation may result from the fragility of dryland ecosystems, which, under excessive human pressure or drastic changes in land use, reduce their productivity and resilience (Turkelboom, 2008).

Although degradation processes may occur without human interference (Stocking and Niamh, 2000), accelerated degradation is most commonly caused as a result of human intervention in the environment. Human-induced land degradation in semi-arid areas (such as population growth and urbanization, poverty, overgrazing, pollution, biodiversity, erosion and land use changes) is regularly cited as one of the principal causes of desertification (Parras-Alcántara et al., 2013; Abu Hammad and Tumeizi, 2012; Muñoz-Rojas et al., 2012; Lal, 1988). Socioeconomic factors, including poverty, land fragmentation, low standards of living and earning, a low level of education, and health condition, were cited as drivers contributing to an increased risk of degradation during the last few decades (Wakindiki and Ben-Hur, 2002). Biophysical factors, including rainfall variation and climate changes, geomorphologic features, and soil properties, also contribute significantly to land degradation (de Sherbinin, 2002). Land degradation processes are usually active in areas where the vegetation cover has been seriously damaged (Kok et al., 1995). In the Middle East and the Mediterranean, human interference has upset the natural balance and led to widespread removal of the soil cover (Cerdà et al., 2010; Beaumont and Atkinson, 1969).

For most landscapes, soil erosion by water is the most common process causing soil degradation. There is a distinct linkage between erosion and other types of degradation (Stocking and Niamh, 2000), and these are accelerated by deforestation, overgrazing, and the cultivation of unsuitable land (Lal, 1988; Beaumont and Atkinson, 1969).

Deforestation is considered as a major cause of cover loss, which accelerates land degradation, increases erosion, and exacerbates degradation of the physical and

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chemical properties of soil (Benneh et al., 1996). Deforestation and cultivation may result in an increased soil bulk density and penetration resistance, a decreased mean weight/diameter of aggregates, and a reduction of infiltration (Lal, 1988). The transition from forest to another agricultural use leads to a significant reduction in organic matter in the topsoil, or may induce substantial modifications in the quality and quantity of soil organic matter (Kocyigit and Demirci, 2012; Yimer and Abdelkadir, 2011; Riezebos and Loerts, 1998) as well as changes in soil properties (Wang et al., 2011; Tesfahunegn, 2013). Overgrazing may degrade rangelands, and increase the risk of soil erosion (FAO, 1999).

Land degradation in Jordan is attributed to periods of prolonged drought interrupted by more frequent extreme events (Cordova, 2000), or by a reduction in plant density associated with decreasing rainfall (Taimeh, 1999). The reduction in the vegetative cover was caused by the accelerated degradation coupled with misuse of the land, overgrazing, or the conversion of rangelands to croplands in marginal areas (Taimeh, 1999).

Improved soil management practices and associated technologies, such as soil conservation measures and land use management, can help reduce soil erosion, improve land productivity and sustain soil quality (Novara et al., 2013; Zhao et al., 2013; FAO, 1999). The land tenure system, land fragmentation and cost/benefit of implementing soil conservation interventions also have had a significant impact on land degradation (Bizoza and de Graaff, 2012; Tesfaye et al., 2014). The Mediterranean region has been affected by anthropic disturbance for thousands of years (Ore and Bruins, 2012) and, currently, is one of the most significantly altered hotspots in the world (Cerdà et al., 2010; Falcucci et al., 2007).

Forest soils maintain high levels of organic matter compared with continuously cultivated soils, which also have lower organic matter contents than soils kept under prolonged fallow (Brown and Lugo, 1990). Erosion is significantly related to the soil's structural stability (Beaumont and Atkinson, 1969). Conversion of forest land to cultivated land seems to reduce the clay and increase the sand contents (Brown and Lugo, 1990) and some other physical and chemical properties (Mohawesh, 2002).

Assessment of land degradation is a complex process which involves many disciplines of the environmental and social sciences. Such assessment can be achieved using different methods, including assessment of the changes in soil fertility, rate of soil erosion, land productivity, physical and chemical indicators of soil quality, such as total organic carbon and aggregate stability (Parras-Alcántara et al., 2013; Muñoz-Rojas et al., 2012; García-Orenes et al., 2012). The methodology for assessing soil degradation, using detailed criteria for each type of biophysical degradation, was prepared by the FAO (1979).

The objectives of this study were to examine the effect of a sequence of land use changes, soil conservation measures, and the length of time that had passed since their implementation, on the degradation of selected soil properties in different rainfall regions under a Mediterranean climate.

2 Material and methods

The study was carried out in a 105 km^2 watershed, which is located between 32° 23″ and 32° 34″ N and 35° 33″ to 35° 50″ E (Fig. 1) and extends from the western part of the eastern plateau to the floor of the Jordan Valley. The elevation within the watershed varies from 1075 m a.s.l. at the upper south-eastern end of the watershed, to about 200 m below sea level at the lower western end of the watershed (Fig. 1). The current land use in the watershed includes range, olive orchards, cereals, and vegetables. Small scattered villages are found in the watershed (Banning et al., 1994).

The geology of the area is primarily marine sediments, dating from the Cretaceous age, consisting of limestone or limy material, with high calcium carbonate content (Bender, 1974; Beaumont and Atkinson, 1969). The climate within the watershed varies from semi-arid sub-tropical, at the western end, to Mediterranean sub-humid, at the eastern end. Rainfall varies according to elevation, from 524 mm, at the eastern parts, to 375 mm at the western part. Air temperature varies according to elevation. The mean annual maximum air temperature varies from 30.0 °C in the western end of the watershed, to 20.0 °C in the eastern end.

Deforestation, improper farming practices, overgrazing, conversion of rangelands to croplands, and uncontrolled expansion of urban and rural settlement are among the major drivers of land degradation (Khresat et al., 1998). Forest trees were cleared and replaced with fruit tree or urban areas (MoA, 2009). Land fragmentation hinders any efforts to improve land productivity. The historic desertification in the Decapolis, located close to the study area, was connected with severe soil degradation caused by agricultural mismanagement, and deforestation (Lucke and Schmidt, 2007).

The study area is dominated by soils classified as Haploxerepts (Typic Haploxerepts and Lithic Haploxerepts sub-groups), Haploxererts (Chromic Haploxererts and Vertic Haploxerepts sub-groups), and Xerorthents (Lithic Xerorthents and Typic Xerorthents). All these soil are derived from limestone. They are slightly to highly calcareous depending on the rainfall zone (MoA, 1995).

Different methods of soil conservation were introduced into the watershed a long time ago. The predominant soil conservation measure is stone walls. Small scattered areas with stone tree basins, terraces, contour lines, gradoni, and wadi control measures occasionally can be seen.

Aerial photographs, at a scale 1 : 10 000, for 1953 and 1978 and a satellite image of 0.60 m resolution for 2008 were used to map changes in land use. A soil map, at a scale of 1 : 50 000 (MoA, 1995) was used as the base map. Mapping of the land cover was carried out by classification and interpretation using aerial photographs from 1953, and 1978, and a 2008 satellite image. Similar approach was used by Alphan (2012). Land cover classification was carried out according to the CORINE system (Bossard et al., 2000). The classification was carried out by comparing the land cover for the three periods by overlaying and intersecting the 1953 land cover photograph with the 1978 one and the 1978 land cover photograph with the 2008 satellite image. Agricultural land use in the study area included field and vegetable crops (wheat, okra, onion, and

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bean), olive and fruit trees, range and shrubs, natural forest, and very small irrigated areas.

The watershed was divided into different zones, according to the elevation and land cover, using the satellite image of 2008, and annual rainfall records. These zone categories were: less than 400 mm rainfall (Zone1), 400 to 500 mm (Zone2), and more than 500 mm (Zone3).

Forty sites distributed throughout the watershed were selected. Each site was selected to include land segments whose use, as detected from the aerial photographs or the satellite image, had changed in 1953, or 1978, or 2008. The selected sites were checked in the field to ensure that each site included from two to four land uses to facilitate assessment of the impact of land use changes during the different periods on soil degradation. For example, some sites have had the same land cover and land use from 1953 until 2008, while other sites have experienced land use changes between 1953 and 1978, and/or 1978 and 2008 (Fig. 2).

Two to four samples were collected from each site that represents each land use. The total number of soil samples was 218. The objective was to include all land use categories and sequences of land use changes during the period 1953 to 2008 and to represent the dominant soil types in the study area. The sampling scheme representing the land use changes will be better demonstrated in tables provided in the result section.

The thickness of the A-horizon (AH) was measured in the field. Surface soil samples were collected for analyses of the soil texture and soil organic matter. The soil samples were air dried and sieved, using a 2 mm mesh, to remove stones, roots, and organic tissues. The particle size distributions were determined using the hydrometer method (Bouyoucos, 1951); the soil organic carbon (SOC) content was determined using the Walkley–Black method (Nelson and Sommers, 1982). An analysis of variance was used to determine the effect of land use changes and soil conservation measures (stone walls) on SOC, soil texture (clay, silt, and sand), and the thickness of the AH. Soil degradation was assessed by examining:

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– The effect of the change and the sequence of specific land use changes between 1953, 1978, and 2008.

– The effect of changing land use and the period of time that had elapsed since construction of the stone walls.

– The effect of rainfall, on SOC content, texture, and thickness of the AH.

3 Results

The results obtained after analyzing the land use changes under various conditions revealed several important patterns. In order to facilitate presentation of the results, the discussion will be presented in two parts. The first part covers general results, while the second part addresses specific results.

The analyses of the land cover indicated that, since 1953, land use had undergone various changes, such as land cultivated with field crops being converted to orchards, forest to orchards, and rangeland to orchards.

The analyses indicated that during the 1950s the land cover comprised 25 % rainfed field crops, 4 % fruit trees, 33 % forest, 37 % rangeland, and 1 % urban areas. According to analyses of the 2008 satellite images, the land cover comprised field crops 12.5 %, fruit trees 26.2 %, forest 29.4 %, and rangeland 23.7 %, and urban area and animal farms 8.1 %. Other non-agricultural land use was about 12 %.

3.1 General results

3.1.1 Differences between soils of unchanged land use

The analyses for lands whose land uses have not been changed since 1953 indicated that the average SOC content was 2.7 % for lands used for field crops, 3.4 % for lands used for orchards, 3.5 % for lands used for rangeland, and 4.5 %, for lands used for

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forests. The analyses of SOC content, AH, clay, sand, and silt distribution for soil samples withdrawn from one soil type, but cultivated with two different crops since 1953 indicated significant difference in values of these properties at the 0.01 and 0.05 level (Table 1).

Similar results were reported by other researchers (Riezebos and Loerts, 1998; Brown and Lugo, 1990). The high SOC content for the forest land use was attributed to the litter of the forest ecosystem (Chen et al., 2000). The average SOC content was slightly higher for soils cultivated with orchards as compared with those cultivated with field crops. This could be a result of the mixing of weeds and grasses with soil two times during the year or more plowing of the orchard. However, the SOC content for land cultivated with field crops was relatively lower than that of the rangelands because of the low grazing pressure in the watershed due to poor accessibility, since most of land cultivated with fields crops is scattered and separated by orchards or forest areas.

The average thickness of the AH was 14.6 cm for land cultivated with field crops, 12.7 cm for land cultivated with orchards, 10.3 cm for rangeland, and 9.8 cm for the forest areas. The results indicated significant differences in thickness of the AH for soils cultivated with field crops and forest, for soils cultivated with field crops and rangeland, and for soils cultivated with forest and orchards (Table 1). Frequent plowing of the soils in the orchards and field crops resulted in a thicker AH, as a result of the mixing of plant residues with the soil, as compared with the soils of the forest or rangelands. Soils cultivated with field crops had a thicker AH than those cultivated with orchards, because the slope of the land cultivated with field crops is less steep than that used for orchards. Forest lands occupy steep slopes which helps to explain why the AH for the forest soils was the thinnest among the land uses.

The analyses indicated significant differences in clay content between soils cultivated with field crop and forests, soils cultivated with field crops and range, and soils cultivated with orchards and rangeland. The average surface clay content was 57.5 % for soils for field crops, 60.4 % for soils for orchards, 50.4 % for forest soils, and 48.8 % for rangeland soils. As can be seen, the highest clay contents were obtained for soils

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cultivated with orchard and field crops. Soils used as range and forest occupy steep slopes and suffer from a higher rate of erosion than those used for field crops and orchards, which explains why they have a lower clay content. Other researchers have reported similar differences in soil texture as a consequence of the influence of land use types (Yao et al., 2010).

3.1.2 Effects of land use changes on soil properties

The analyses indicated that, during the period 1953 to 1978, there was a clear increase in the areas used for orchards at the expenses of that used for forest, field crops, or rangeland (Table 2).

Soil organic matter content decreased when forest lands were converted to orchards. The change of land use from field crops to orchards did not affect the SOC content or the thickness of the AH, regardless of the length of time that had elapsed since the land use changed. Similar results were reported by other researchers (Riezebos and Loerts, 1998). However, converting forest land to orchards resulted in a substantial reduction of SOC content (4.5 to 2.6 %) within a short period of time after the conversion. However, the magnitude of the SOC reduction was lower for land subjected to conversion before 1953. This suggests that the SOC content for the land used for orchards could be recovered when the same land use was adopted for a long time. The analyses indicated that when forest and rangelands were converted to orchards, the SOC content was significantly reduced, while the thickness of the AH was significantly increased (Table 2). The thickness of the AH did not seem to be related to the length of time that had elapsed since the conversion. The clay content was higher for land converted from field crops, forest, and range to orchards. These changes were affected by the length of time that had elapsed since the conversion, as suggested by the difference in their values for areas converted after 1953 as compared with those converted after 1978 (Table 2).

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3.1.3 Effects of soil conservation

For a long time, the construction of stone walls as a soil conservation measure was the most popular conservation intervention practiced by the government or local farmers in the watershed. Areas with stone walls constituted 21 % of the farmed land in 1953 and 1978 and increased to 31 % in 2008 (Table 3). The expansion of the orchard areas at the expense of areas cultivated with field crop was associated with an increase in the areas protected by stone walls. In 2008, about 66 % of the area used for the cultivation of field crops and about 88 % of the area cultivated with orchards were protected by stone walls.

The construction of stone wall clearly resulted in an increase in the SOC content of the soil, but the increase was slight for soils where the construction of the stone walls was recent (2008 or 1978). It was significantly higher when the construction was carried out before 1953 (Table 4). The influence of the construction of stone walls on the thickness of the AHs was slight. However, it should be stated that the soil conservation resulted in the thickness of the AH being maintained, which is an important benefit.

The variation in soil texture as a result of stone wall being constructed seemed to be negligible. This could be attributed to the influence of this measure in reducing runoff, consequently, reducing losses in the clay or silt fractions. A slight increase in the clay content resulted after the stone walls had been in place for an extended period. This suggests that it takes a long time to stabilize the soil surface following the construction of the walls (Table 4).

3.2 Specific results – effects of land use changes

The following summarizes the results obtained from comparing the effects of the different sequences of land use changes and the times since the construction of the stone walls on the soil properties for the different rainfall zones.

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Within each rainfall zone, different land uses, different sequences of land use changes, the construction of stone walls, and the elapsed time since construction were analyzed.

The analyses indicated that the SOC content varied according to the amount of annual rainfall. The SOC content was 2.56 % in Zone 1, 3.43 % in Zone 2, and 3.45 % in Zone 3. The differences between the less than 400 mm zone and other rainfall zones were significant (Table 5).

Soil organic matter (SOC) – general: land which had had a sustained forest cover had the highest SOC content (4.5 %). This was followed by land used for orchards (3.4 %) and land cultivated with field crops (2.7 %). Generally, the SOC content increased as the amount of rainfall increased. The SOC content increased with increasing elapsed time after conversion. (Lands converted after 1953 had higher SOC contents than those converted after 1978, Table 6). The effect of the length of time since the construction of the stone walls on the SOC content was limited to an increase in the SOC content for lands with stone walls constructed before 1953. The construction of stone walls had substantially increased the SOC content, especially for those areas where the stone walls were constructed before 1953. The SOC content was reduced as a result of converting forests lands to orchards, but it was increased, if the conversion was associated with the construction of stone walls. Conversion of rangeland to orchards reduced the SOC content even if stone walls had been constructed.

SOC by land use – field crops to orchards: the maximum increase in SOC content was identified for soil cultivated with field crops which had been converted to orchards and for which stone walls had been constructed before conversion. Generally, recent conversion of land cultivated with field crops to orchards resulted in a higher SOC content. This could be attributed to a reduction in erosion. However, in rainfall Zone 3 (more than 500 mm), the SOC content was higher than that of land converted before 1953, and the SOC content was higher for soils subjected to early land use changes in this zone (Table 6). The SOC increased, from 2.7 %, to 3.0 %, if stone walls had been constructed before 1953 on land that had been continuously cultivated with field crops

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(Table 7). The SOC content increased to 3.8 %, when the land had been converted and stone walls had been constructed before 1953 or 1979, but if the land was converted after 1978, the SOC was reduced to 2.8 %.

SOC by land use – forest to orchards: the SOC content was highest for soil with a sustained forest cover (4.5 %). The SOC was reduced when the forest land was converted to orchards (4.3 to 3.1 % in Zone 2, and from 4.6 to 3.4 % for Zone 3). The SOC content was reduced to 3.3 %, when the forest land was converted to orchards, after 1953, and when the land conversion took place after 1978, the SOC content was reduced to 2.6 %. For all zones, the length of time since the land was converted from forest to orchards did not affect the SOC content. Recent conversion resulted in a drastic reduction of the SOC content (2.6 %), even when stone walls had been constructed. However, when the land conversion was carried out before 1979 and was associated with the construction of stone walls, the reduction in the SOC content was substantially lower (3.6 %) than that of land which had been recently converted (after 1979). This suggests that rebuilding the SOC content after land has been converted requires a long time, but, eventually, a good SOC will be achieved in the soils (Table 7).

SOC by land use – rangeland to orchards: the SOC content was 3.5 % for land which had been continuously used as rangeland. This was reduced to 2.8 % when the rangeland was converted to orchards. The reduction was noticed in the three zones. This conversion had taken place rather recently. The SOC content did not seem to be affected by the time that had elapsed since the land was converted to orchards even if the conversion was associated with the construction of stone walls.

Thickness of the AH – general: the thickness of the AH was not affected by the time since the construction of the stone walls. Land cultivated with field crops had the highest AH thickness (15.6 cm), followed by orchards (12.7 cm) and forest (9.8 cm). Recent construction of stone walls on land cultivated with field crops resulted in a reduction in the thickness of the AH, but the thickness of AH was increased if the stone walls had been constructed before 1953.

Thickness of the AH by land use – field crops to orchards: recent conversion of land cultivated with field crops to orchards resulted in a thicker AH. The amount of time that had elapsed following construction of stone walls did not have any influence on the thickness of the AH when the land had been recently converted to orchards. Generally, no distinct pattern was noticeable for the thickness of the AH following a land conversion from field crops to orchards, if no intervention was implemented. This might be related to the rainfall zone. The thickness of the AH increased following conversion of land from the cultivation of field crops to orchards, because of the presence of stone walls and changes in the plowing regime. A slight increase in the thickness of the surface horizon was noticed for land with stone walls which had been constructed before 1978.

Thickness of the AH by land use – forest to orchards: the thickness of the AH for soil which had been continuously used for forest was 9.8 cm. This was thinner than that for soils of other land uses. This was expected since the natural forest in this catchment occupies a very steep slope. The thickness of the AH was substantially increased when the forest land was converted to orchards regardless of when the stone walls had been constructed. Farming practices such as plowing, clearing of mobile surface rocks, mixing of plant residues with soils, and reducing erosion by constructing stone walls, contributed to increasing the thickness of the AH to 16.4 cm when the forest land was converted to orchard after 1978, and to 16.0 cm for conversion after 1953. The older stone walls were in poor condition in comparison with those in areas converted after 1978. This again substantiates the positive role of stone walls.

Thickness of the AH by land use – rangeland to orchards: the thickness of the AH increased from 10.3 to 14.5 cm, when rangeland was converted to orchards. The conversion of either forest or rangeland to orchards resulted in increasing the thickness of the AH in all zones. Conversion of rangelands to orchards resulted in increasing the thickness of the AH regardless of when stonewalls had been constructed. The construction of stone walls after 1979 did not result in any significant increase in the thickness of the AH as compared with lands with no stone walls.

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Soil texture – general: the soil texture of the surface horizon did not show any distinct pattern, which could result from the inherited soil variation, or the effect of slope rather than the influence of the rainfall. The time since the construction of the stone walls had no effect on soil texture.

Soil texture by land use – forest to orchards: the clay content of the AH increased when forest land was converted to orchards. This could be attributed to the mixing of the surface soil with the sub-surface soil as a consequence of the plowing of the orchards.

4 Discussion

The analyses revealed important results relevant to land use in semi-arid Mediterranean and sub-tropical environments, its contribution to carbon pools, and its impact on land degradation. Other factors, such as types of farm management, plowing along contours enforced after the construction of stone walls and the maintenance of soil conservation interventions play an important positive role.

The soil organic matter content of land, for which the land use has never been changed, was, in descending order of magnitude, forest, rangeland, orchards, and field crops. The influence of the time that has elapsed since the construction of stone walls seemed to be limited to increasing the soil organic content for land where the stone walls were constructed a long time ago. However, the length of time did not seem to influence the thickness of the surface horizons and soil texture.

The soil organic matter content decreased when forest lands was converted to orchards not long after the time of the conversion. Conversion of land use from field crops to orchards did not affect the soil organic matter content or the thickness of surface horizon, regardless of the length of the time after the land use change. However, the magnitude of the soil organic matter content reduction was lower for a land use conversions made before 1953. This suggests that the soil organic matter content for land used as orchards should recover when the same land

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use was maintained for long time and given that proper conservation measures were implemented in the orchard fields. The analyses indicated that when forest and rangelands were converted to orchards, the soil organic matter content was significantly reduced while the thickness of the surface horizon was significantly increased.

The average thickness of the surface horizon was highest for field crops, followed by orchards, rangeland, and forest. The frequent plowing of the orchards and crop fields resulted in a thicker AH because of the mixing of the plant residues with the soil; a process that does not occur in the forests or rangelands. Soil cultivated with field crops had a thicker surface horizon than that cultivated with orchards, because land cultivated with field crops is less steep than that cultivated with orchards. The addition of oat straw to soil was considered as an effective technology to improve soil quality in the semiarid Mediterranean agro-ecosystems (García-Orenes et al., 2010).

The construction of stone walls clearly resulted in an increase in the organic matter content of the soil, the magnitude of the increase was slight for soils with recently constructed stone walls, but was significantly higher when such construction had been carried out before 1953. Stone wall construction influences the thickness of the surface horizon. It was noted that the soil conservation measures resulted in the maintenance of the thickness of the surface horizon, which is very important for maintaining soil fertility. Xu et al. (2012) showed that the implementation of three conservation measures significantly increased saturated hydraulic conductivity, aggregate stability, SOM and available N, P, K, but decreased the soil bulk density.

A slight increase in the clay content resulted a long time after the construction of the stone wall. This suggests that a long time needs to pass after the construction to stabilize the soil surface which is usually disturbed following the construction of the stone walls. The variation in soil texture as a result of stone wall construction seemed to be negligible. This could be attributed to the stone walls reducing runoff and, consequently, reducing losses of the clay or silt fractions. Li et al. (2014) showed that

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the construction of terrace combined with vegetation measures is effective in controlling runoff and soil erosion.

The analyses indicated that the soil organic content increased as the amount of rainfall increased; the soil organic content of the rangeland also increased with increasing amounts of rainfall. However, the soil organic content was reduced in all rainfall zones when rangeland was converted to orchards.

The analyses indicated that differences in the thicknesses of the surface horizons in the different rainfall zones were not significant. However, the surface horizon was thicker for soils cultivated with field crops than for those of forests or orchards.

The highest clay content was observed in soils cultivated with orchards and field crops. The clay content was highest in the highest rainfall zone and for soils where the land use was converted from forest or range to orchards. This could be attributed to the better conditions of the recently constructed stone walls on land used for orchards as compared to the old and poorly maintained stone walls constructed on land cultivated with field crop.

5 Conclusions

Forest land seemed to have the highest SOC content. The SOC content and the thickness of the surface horizon depend on the length of a sustained specific land use. Conversion of land use may lead to higher or lower SOC content and the thickness of the surface horizon. Such changes depend on the long-term annual rainfall, construction of soil conservation measures – such as stonewalls – and how much time has elapsed since the construction of such measures. The outcomes of soil conservation measures seemed to be related to the time needed for the land to recover from any disturbance associated with the construction of stonewalls after the conversion of the land. This applied to lands converted from a sustained land use, such as forest or range to a new farming system. The significance of such results provide valuable information about the factors governing the carbon sequestration potential of soils, the impacts of land use changes, and the implementation of soil conservation measures. The results also provide information about the effects of these factors on the thickness and texture of the surface horizon in different rainfall zones. Such results will help in understanding the impact of land use changes on land degradation processes, which, ultimately, will aid in formulating means to mitigate their negative effects.

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Table 1. Soil properties of lands where the land use has not been changed.

Land use[c]	Organic carbon (%)	Thickness of A-horizon (cm)	Clay (%)	Silt (%)	Sand (%)	No. of samples
Field crop	2.7	14.6	57.5	31.3	11.2	53
Forest	4.5[b]	9.8[b]	50.4[b]	31.3	18.3[b]	55
Field crop	2.7	14.6	57.5	31.3	11.2	53
Orchard	3.4	12.7	60.4	26.3[a]	13.3	6
Field crop	2.7	14.6	57.5	31.3	11.2	53
Range	3.5[b]	10.3[b]	48.8[b]	34.9[a]	16.3[a]	24
Forest	4.5	9.8	50.4	31.3	18.3	55
Orchard	3.4[b]	12.7[a]	60.4	26.3[b]	13.3	6
Forest	4.5	9.8	50.4	31.3	18.3	55
Range	3.5[b]	10.3	48.8	34.9[a]	16.3	24
Orchard	3.4	12.7	60.4	26.3	13.3	6
Range	3.5	10.3	48.8[a]	34.9[b]	16.3	24

[a] Significant $P < 0.01$.
[b] Significant $P < 0.05$.
[c] Indicates that at each site there were two types of land use on the same soil.

Table 2. Properties of soils subjected to land use changes since 1953.

Sequence of land use[a] 1953→1978→2008	Organic carbon (%)	Thickness of A-horizon (cm)	Clay (%)	Silt (%)	Sand (%)	No. of samples
Fc1 → Fc2 → Fc3	2.7	14.6	57.5[b]	31.3	11.2[c]	53
Fc1 → O2 → O3	2.7	14.4	63.4	30.7	06.0	16
Fc1 → Fc2→Fc3	2.7	14.6	57.5	31.3	11.2	53
F1 → Fc2 → O3	2.7	14.3	56.1	31.3	12.5	35
Fc1 → Fc2→O3	2.7	14.3	56.1[c]	31.3	12.5[b]	35
Fc1 → O2 → O3	2.7	14.4	63.4	30.7	06.0	16
F1 → F2→F3	4.5[b]	09.8[b]	50.4[c]	31.3[c]	18.3[b]	55
F1 → F2 →O3	2.6	16.4	66.1	27.2	06.6	10
F1 → F2 →F3	4.5[b]	09.8[c]	50.4	31.3[c]	18.3[c]	55
F1 → O2 →O3	3.3	16.0	60.1	31.3	08.8	05
F1 → F2 →O3	2.6	16.4	66.1	27.2	06.6	10
F1 → O2 →O3	3.3	16.0	60.1	31.3	08.8	05
R1 → R2→R3	3.5[c]	10.3[b]	48.8	34.9	16.3	24
R1 → R →O3	2.8	14.6	52.8	34.1	13.1	14

[a] Sequence of land use changes, during 1953 (1), 1978 (2), and 2008 (3), Fc – field crop, O – orchards, F – Forest, R – range
[b] Significant $P < 0.01$.
[c] Significant $P < 0.05$.

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Table 3. Cultivated area covered with stone walls (ha).

Land use	Soil conservation	1953		1978		2008	
		Area	%	Area	%	Area	%
Field crop	No stone wall	832	7.9	793	7.6	415	4.3
	Stone wall	1814	17.3	1456	13.9	886	8.4
Olive tree	No stone wall	125	1.2	181	1.7	329	3.1
	Stone wall	274	2.6	675	6.4	2416	23.0
Other		7450	71.0	7390	70.4	6449	61.1
Total		10 495	100	10 495	100	10 495	100

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Table 4. Soil properties for soil according to the year of stone wall construction.

Year of stone wall construction 1953	1978	2008	Organic matter (%)	Thickness of A-horizon (cm)	Clay (%)	Silt (%)	Sand (%)	No. of samples
No	No	No	2.64*	14.61*	58.82*	30.51	10.67*	33
No	No	Yes	2.66*	14.63*	56.16*	32.32	11.47*	43
No	Yes	Yes	2.71*	15.12*	60.56*	30.29	09.15*	34
Yes	Yes	Yes	3.15*	14.00*	57.56*	30.56	11.78*	29

* Significant $P < 0.01$.
Note: Yes: means stone walls were observed on aerial photographs that year.
No: means no stone walls were observed on aerial photographs that year.

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Table 5. Variation in soil properties according to rainfall zones.

Rainfall (mm)	Organic matter (%)	Thickness A-horizon (cm)	Clay (%)	Silt (%)	Sand (%)	No. of samples
< 400 (Zone 1)	2.56	13.2	52.47	34.12*	13.45	40
400–500 (Zone 2)	3.43*	13.5	57.59	30.33*	12.03	72
> 500 (Zone 3)	3.45*	12.4	54.56	31.33*	14.10	106

* Significant $P < 0.01$.

Table 6. Distribution of soil properties and sequence of land use change, by rainfall zones.

Rainfall (mm)	Sequence of land use change 1953→11 978→2008	Organic carbon (%)	Thickness of A-horizon (cm)	Clay (%)	Silt (%)	Sand (%)	No. of samples
< 400	Fc1 → Fc2 → Fc3	2.5	16.2	54.0	32.7	13.3	13
< 400	Fc1 → Fc2 → O3	2.2	13.8	52.2	35.4	12.6	9
< 400	Fc1 → O2 → O3	2.0	13.7	61.2	31.5	7.4	3
< 400	F1 → F2 → F3	3.7	11.0	46.3	37.1	16.6	2
< 400	R1 → R2 → O3	2.1	13.3	55.5	34.9	9.6	3
< 400	R1 → R2 → R3	3.1	09.1	48.4	34.7	16.8	10
400–500	Fc1 → Fc2 → Fc3	2.9	13.8	58.8	31.4	9.8	16
400–500	Fc1 → Fc2 → O3	3.4	14.5	61.0	27.9	10.8	12
400–500	Fc1 → O2 → O3	2.3	14.5	53.8	36.7	9.6	4
400–500	F1 → F2 → F3	4.3	11.8	55.2	28.1	16.7	16
400–500	F1 → F2 → O3	3.1	16.7	65.2	27.9	6.9	6
400–500	F1 → O2 → O3	3.1	17.5	64.3	29.9	6.1	2
400–500	O1 → O2 → O3	3.4	12.7	60.4	26.3	13.3	6
400–500	R1 → R2 → O3	3.0	15.0	47.0	40.4	12.6	4
400–500	R1 → R2 → R3	4.0	09.8	50.8	34.2	14.9	6
> 500	Fc1 → Fc2 → Fc3	2.7	14.4	58.4	30.6	11.0	24
> 500	Fc1 → Fc2 → O	2.4	14.4	54.4	31.7	13.8	14
> 500	Fc1 → O2 → O3	3.1	14.7	68.4	27.7	3.9	9
> 500	F1 → F2 → F3	4.6	08.8	48.6	32.3	19.1	37
> 500	F1 → F2 → O3	2.0	16.0	67.6	26.2	6.1	4
> 500	F1 → O2 → O3	3.4	15.0	57.1	32.3	10.6	3
> 500	R1 → R2 → O3	3.1	14.9	54.9	30.2	14.9	7
> 500	R1 → R2 → R3	3.7	12.0	47.7	35.5	16.7	8

Land use: Fc1 – field crops, F – forest, O – orchards, and R – range.

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Table 7. Distribution of soil properties according to land use change by time of stone walls construction.

Sequence of land use 1953–1978–2008	Sequence of stonewall construction 1953	1978	2008	Organic carbon (%)	Thickness of A-horizon (cm)	Clay (%)	Silt (%)	Sand (%)	No. of samples
Fc1 → Fc2 → Fc3	No	No	No	2.7	15.6	56.7	31.4	11.9	16
Fc1 → Fc2 → Fc3	No	No	Yes	2.7	13.2	55.1	33.7	11.1	11
Fc1 → Fc2 → Fc3	No	Yes	Yes	2.6	15.4	58.9	30.8	10.2	15
Fc1 → Fc2 → Fc3	Yes	Yes	Yes	3.0	13.6	58.9	29.6	11.5	11
Fc1 → Fc2 → O3	No	No	No	2.8	12.4	59.6	29.6	10.7	8
Fc1 → Fc2 → O3	No	No	Yes	2.3	14.1	51.0	34.7	14.3	8
Fc1 → Fc2 → O3	No	Yes	Yes	2.8	15.4	62.6	27.8	9.6	10
Fc1 → Fc2 → O3	Yes	Yes	Yes	2.8	14.9	50.3	33.8	15.6	9
Fc1 → O2 → O3	No	No	No	2.2	15.2	66.6	27.2	6.3	6
Fc1 → O2 → O3	No	No	Yes	3.2	16.0	49.0	38.0	13.0	2
Fc1 → O2 → O3	No	Yes	Yes	2.0	12.3	62.4	33.2	4.4	4
Fc1 → O2 → O3	Yes	Yes	Yes	3.8	14.8	66.8	29.7	3.5	4
F1 → F2 → F3	No	No	No	4.5	9.8	50.4	31.3	18.3	55
F1 → F2 → O3	No	No	Yes	2.6	16.4	66.1	27.2	6.6	10
F1 → O2 → O3	No	Yes	Yes	3.3	16.0	60.0	31.3	8.8	5
O1 → O2 → O3	Yes	Yes	Yes	3.4	12.7	60.4	26.3	13.3	6
R1 → R2 → O3	No	No	No	3.1	14.5	48.8	42.0	9.2	2
R1 → R1 → O3	No	No	Yes	2.8	14.6	53.4	32.8	13.7	12
R1 → R2 → R3	No	No	No	3.5	10.3	48.8	34.9	16.3	24

Sequence of land use for the three periods: 1953–1978-2008: Fc1 – field crops, F – forest, O – Orchards and R: range.
Yes: mean stone walls were recorded, No: mean no stone walls were recorded.

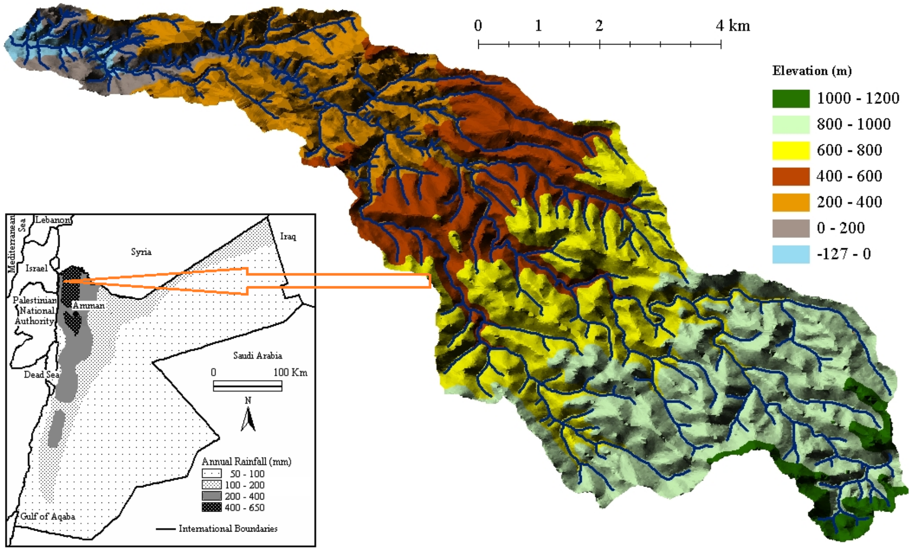

Figure 1. Location, boundary and elevations within the Wadi Ziqlab catchment.

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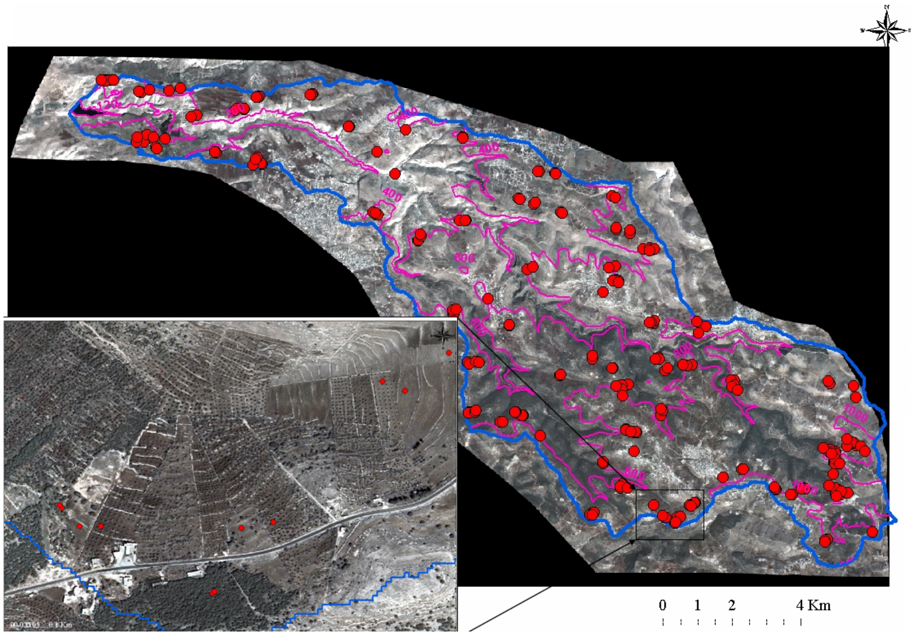

Figure 2. Distribution of sampling sites within the Wadi Ziqlab catchment.