Scientific Research Publishing

Open Journal of Soil Science, 2024, 14, 210-226
https://www.scirp.org/journal/ojss
ISSN Online: 2162-5379
ISSN Print: 2162-5360

Variations in Soil Organic Matter Content in Cultivated and Uncultivated Calcareous Soils from the Mediterranean Island of Malta after 15 Years of Cultivation

Anthony T. Sacco[1*], Marcelle Agius[1], Clara Didier[2]

[1]Institute of Earth Systems, Division of Rural Sciences and Food Systems, University of Malta, Msida, Malta
[2]École Nationale Supérieure Agronomique de Toulouse, Auzeville-Tolosane, France
Email: *anthony.sacco@um.edu.mt

How to cite this paper: Sacco, A.T., Agius, M. and Didier, C. (2024) Variations in Soil Organic Matter Content in Cultivated and Uncultivated Calcareous Soils from the Mediterranean Island of Malta after 15 Years of Cultivation. *Open Journal of Soil Science*, **14**, 210-226.
https://doi.org/10.4236/ojss.2024.144012

Received: February 2, 2024
Accepted: April 12, 2024
Published: April 15, 2024

Abstract

The soils of Malta are calcareous and generally undeveloped. Organic matter (OM) in these soils is low and farmers are constantly urged to increase it. The objective of this study was to evaluate any temporal variation in soil OM after 15 years of cultivation, and determine whether soil series, soil depth, and cultivation influence variation. OM was determined in the topsoil and subsoil of 7 agricultural and 4 non-agricultural sites. The sites represented 7 different soil series that are present on the island. In sampling periods 1 (t = 0 years) and 2 (t =15 years), the OM content in the collective (all soil series) bulk (topsoil and subsoil) uncultivated soil was 3.9 % and 3.8 % respectively. This was significantly greater than that of the collective bulk cultivated soil (2.4% and 2.3%). The OM in the collective uncultivated topsoil was 5.4% and 5.2% in periods 1 and 2 and was significantly higher than that of the cultivated topsoil (2.5% in both periods). The OM content in the collective uncultivated subsoil was 2.3% and 2.5% in periods 1 and 2 respectively but only that measured in period 2 was significantly higher than that of the cultivated subsoil (2.2% in both periods). On an individual soil series basis, the OM in the uncultivated topsoils was significantly higher than that of their cultivated counterparts. The differences in the subsoils were not significant. Across the uncultivated soil series, OM was significantly higher in the topsoil than in the subsoil but in the cultivated soil series the differences between topsoil and subsoil were not significant. There was no significant difference in OM between the uncultivated soils of different series, but in the cultivated the OM content was higher in soils that were more mature. After 15 years, no significant change in OM occurred in both the collective cultivated and uncultivated bulk soils, the collective topsoil and subsoil, and in most of the individual series. The OM content of each soil series was also similar to what was reported 60 and 50 years earlier by other researchers.

Keywords

Soil Organic Carbon, Agricultural Land, Non-Agricultural Land, Land Management

1. Introduction

Soil organic matter (SOM) is an important soil constituent. It is a major source of plant nutrients, especially in non-agricultural soil [1] and a source of carbon (C) and energy to the soil microbial population. It improves soil physical conditions such as water holding capacity [2], structure stability [3], water infiltration [4], porosity and aeration [5], and cation exchange capacity [6]. SOM also plays a crucial role in mitigating global warming [7] as it locks up C in soil [8]. In fact, soil can store up to 3 times more C than that present in the atmosphere [9].

The level of organic matter (OM) in soil is an indirect measure of soil health, and its decline often results in a decrease in soil fertility [10]. In the past 30 years, there has been an increasing concern for the stability of SOM. In fact, the European Union recognizes the decline of OM as one of the main threats to the soils in Europe [11], and the maintenance of SOM now forms an integral part of the farmers' financial support policy.

The level of OM in the soil varies and is a function of several factors such as the input of organic material, the characteristics and degradation potential of the soil, climate [12] topography [13] and cultivation practices [14]. The main input sources in uncultivated land are indigenous plant and animal waste whereas in cultivated land, cropping waste and farmyard manure (FYM) are the main contributors.

Cultivation has a substantial impact on SOM, where generally, the conversion of non-agricultural land into cultivated land, results in a loss of OM [15] [16]. It has been estimated that between 50 to 100 Pg of SOM have been lost worldwide over the past 200 years through the conversion of uncultivated land to agricultural land [17]. The long-term effect of cultivation on the distribution and dynamics of OM in agricultural soil has been investigated by several studies, where contrasting conclusions have been reached. Lal [18], Xia *et al.* [19]; Dai, *et al.* [20] and Abegaz *et al.* [21] reported a decrease in OM over time in soils under cultivation, while Liu *et al.* [22], Rahman *et al.* [23], and Adhikari and Hartemink [24], reported an increase.

Worldwide, the OM level in soils varies from very low in soils of arid regions, to very high in soils of wet and cold regions. In the soil of the Maltese islands, the OM content is low, averaging about 2.2% [25]. The soils of Malta are undeveloped, calcareous, shallow, and scarce and up to a few years ago, almost all the available land was used for cultivation. In areas where ground water is available, cultivation is practiced all year-round while in other areas it is only undertaken during the winter, and during the summer months, the soil is left bare and exposed. FYM is applied in early autumn before the rainy season, and tillage is generally conventional, utilizing moldboard plows and mechanical rotavators. During the past 30 years, the importance of maintaining a high and stable level of OM in soil has been highlighted to farmers who are encouraged to maintain and increase its level.

The main objective of this study was to evaluate and compare any significant variations in the OM content between uncultivated and cultivated soil, between topsoil and subsoil of both cultivated and uncultivated soil, and between individual soils with similar and contrasting characteristics after a 15-year period in a Mediterranean climate.

2. Methodology

2.1. Experimental Design

Plots of land measuring between 2000 and 3000 m^2 were selected from across the islands in order to incorporate the different soil series that are present locally. As the findings from this study were going to be compared with what was reported 50 and 60 years earlier by other workers, for soil type classification purposes, together with the World Reference Base for Soil (WRBS), the Kubiena [26] classification system, as proposed by the study of Lang [27], is also referred to. The areas under study were relatively close to each other, and the maximum distance separating any two sites was not more than 20 km. This ensured that over the 15-year period, biases due to climatic differences were kept at a minimum. With regards to soil type, representatives of 7 soil series [27] having contrasting characteristics were selected. An effort was made to include a cultivated and an uncultivated soil from every series, however, as most of the soil on the island is used, or at some time had been used for cultivation, for some of the soil series, an uncultivated example could not be included. Cultivated and uncultivated soil sites belonging to the same series were selected close to each other, where, except for the Leptosol (Tax-Xagħra Series, Terra Rossa), the distance between two soils of the same series was less than 1000 m. **Table 1** gives a brief description of the sites and the soils used in this work. Following the first soil sampling session (referred to as Period 1), the agricultural land was cultivated according to local cultivation practices. These generally consisted of conventional tillage after the dry summer months followed by the addition of FYM and cultivation. Farm yard manure was applied to the land every 3 years. The crop types that were cultivated are given in **Table 1**. The sites were resampled after 15 years (referred to as Period 2) and in both occasions the soil samples were taken during winter.

2.2. Plot Setup and Soil Sampling Procedure

In each plot of land, 5 sub-plots, each measuring 9 m^2, were set in a W-shaped

Table 1. Characteristics of the soil and the plots used in this work.

Classification		Characteristics	Use	Site Properties and Vegetation
WRBS	Kubiena			
Arenosol*	Carbonate Raw Soil *Ramla Series** (RS)	A sandy soil with no aggregation and poor water holding capacity.	Cultivated	Part of a sand dune that during the time of the study period and before was used as an orchard.
Regosol	Carbonate Raw Soil *San Lawrenz Series* (SLS)	A clay soil originating from Blue clay parent material. It contains lithosolic colluvium material that originates from a coralline limestone stratum situated above the clay. The cultivated and the uncultivated sites were 800 m apart.	Cultivated	A rain-irrigated site that for the past 50 years has only been used to cultivate *Triticum aestivum* or occasionally *Hedysarum coronarium.*
			Uncultivated	A wood planted in the late 1600. The sampled area is dominated by *Populus alba* and short grass and shrubs. Due to the high clay content, the soil on site is moderately compacted.
Vertisol	Carbonate Raw Soil *Fiddien Series* (FS)	A heavy textured clay soil that is developed directly on Blue clay deposits. Unlike the SLS soil, this soil shows very little variation from the clay parent material. The cultivated and the uncultivated sites were 300 m apart.	Cultivated	Situated at the foot of the uncultivated FS slope. It is non-irrigated and is usually used to cultivate *Solanum lycopersicum* and other seasonal crops.
			Uncultivated	An East-facing slope that carries long grass type vegetation together with a number of *Eucalyptus tereticornis* trees.
Calcisol	Xerorendzina *San Biagio Series* (SBS)	A silty clay loam originating from the upper and middle layers of the globigerina limestone strata. The soil is not much differentiated from the surface to the bedrock and is greyish white in colour. The cultivated and the uncultivated sites were 500 m apart.	Cultivated	A non-irrigated site that is used mainly for the cultivation of *T. aestivum* and occasionally *H. coronarium*, *Vicia faba* and *Hordeum vulgare*.
			Uncultivated	A disused airfield that was converted into and used as a recreational park for the past 50 years. The vegetation is sparse and consists mainly of short grasses. The soil is hard and compacted in most places.
Luvisol*	Xerorendzina *Tal-Barrani Series** (TBS)	A clay loam that is similar to the Terra Rossa soils but not as much developed.	Cultivated	An irrigated site extensively cultivated with a variety of crops all year round. *S. tuberosum and S. lycopersicum* are most commonly cultivated.
Luvisol*	Terra Rossa *Tas-Sigra Series** (TS)	A heavy textured clay loam. Compared to the rest of the soils these are relatively decalcified and more mature.	Cultivated	An irrigated site used all year round mainly for the cultivation of *S. tuberosum.*
Leptosol	Terra Rossa *Tax-Xaghra Series* (TXS)	A typical clay loam Terra Rossa soil. The soils are stony and shallow. The cultivated and the uncultivated sites were 7000 m apart.	Cultivated	A non-irrigated site generally used to grow *T. aestivum*, and occasionally S. *tuberosum* and *V. faba.*
			Uncultivated	An exposed site carrying grasses and xerophytes.

arrangement across the site. From each sub-plot, 5 soil samples were taken from the soil surface down to 15 cm depth (referred to in this study as the topsoil), and then another 5 samples were taken from the 15 to 30 cm soil depth (referred to as the subsoil). Prior to sampling, the soil surface was cleared from all green and dry vegetation and stones. The 5 topsoil and 5 subsoil samples were separately mixed to produce separate composite topsoil and subsoil samples for each subplot. The topsoil and subsoil composite samples from each sub-plot were kept separate.

2.3. Sample Treatment and Method of SOM Determination

Soil samples were transported to the laboratory at ambient temperature, air dried and crushed using pestle and mortar to pass through a 2 mm sieve. During sieving, soil aggregates were broken and any undecomposed vegetation was discarded. A sub-sample from each sieved sample was dried overnight at 105˚C. OM was determined in the oven-dried 2 mm soil fraction according to the Walkley and Black protocol [28] without supplemental heating, using 5 replicates from each sieved sub-sample. Statistical analysis of the data was carried out using Sigma Plot Version 14 statistical package (Systat Software Inc., San Jose, CA).

3. Results and Discussion

The level of OM in the soil samples varied from 0.5 %, recorded in a cultivated RS (Arenosol) soil plot, to 6.8 %, recorded in an uncultivated SBS (Calcisol) soil plot. Differences in OM content were observed between topsoil and subsoil, and between cultivated and uncultivated soil, both when the soil was considered collectively (all soil series together) and as individual series. Variations in OM content were also observed between soils of different series. The OM content of the collective uncultivated and cultivated soil, and of the collective topsoil and subsoil soil for both periods 1($t = 0$) and 2 ($t = 15$ years) are presented in **Table 2**. **Table 3** and **Table 4** show the mean OM level in the topsoil and subsoil of every subplot of the cultivated and uncultivated soil respectively. Each value in **Table 3** and **Table 4** is the mean of 5 replications.

3.1. Variation in OM between Cultivated and Uncultivated Soil and between Topsoil and Subsoil

In both sampling periods, the mean OM content of the collective uncultivated soil (FS, SLS, SBS, TXS) was significantly higher ($p < 0.001$) than that of all the collective cultivated soils and of the group of cultivated soils comprising only of FS, SLS, SBS and TXS (**Figure 1(a)**) (**Table 2**). The OM content of the collective uncultivated topsoil was significantly greater ($p < 0.001$) than that of the collective cultivated topsoil and the cultivated topsoil of the FS, SLS, SBS, TXS group (**Figure 1(b)**). The differences between the collective uncultivated and cultivated subsoil were not significant in both periods, however in period 2, the OM in the uncultivated subsoil was significantly higher than that of the cultivated subsoil of the FS, SLS, SBS, TXS group ($p = 0.009$) (**Figure 1(b)**).

Table 2. Characteristics of the soil and the plots used in this work.

	Cultivated All soil plots collectively*	**Cultivated** FS, SLS, SBS, TXS soils*	**Uncultivated** FS, SLS, SBS, TXS soils*	**Cultivated** All soil plots collectively		**Cultivated** FS, SLS, SBS, TXS soils		**Uncultivated** FS, SLS, SBS, TXS soils	
		Period 1				**Period 1**			
				Top Soil	**Sub Soil**	**Top Soil**	**Sub Soil**	**Top Soil**	**Sub Soil**
Mean	**2.4**	**2.3**	**3.9**	**2.5**	**2.2**	**2.5**	**2.1**	**5.4**	**2.3**
SD(+/−)	1.15	0.85	1.9	1.23	1.0	0.93	0.73	1.19	0.91
		Period 2				**Period 2**			
				Top Soil	**Sub Soil**	**Top Soil**	**Sub Soil**	**Top Soil**	**Sub Soil**
Mean	**2.3**	**2.3**	**3.8**	**2.5**	**2.2**	**2.5**	**2.1**	**5.2**	**2.5**
SD(+/−)	1.0	0.82	1.7	1.03	1.0	0.77	0.73	1.44	0.59

*The value is the mean of the topsoil and subsoil. Period 1 (t = 0 years). Period 2 (t = 15 years).

Table 3. Organic matter content (%) in the cultivated soil plots in sampling periods 1 and 2.

	Ramla Series (RS) (Arenosol)		**Fiddien Series (FS) (Vertisol)**		**San Lawrenz Series (SLS) (Regosol)**		**San Biagio Series (SBS) (Cacisol)**		**Tal-Barrani Series (TBS) (Luvisol)**		**Tax-Xaghra Series (TXS) (Leptosol)**		**Tas-Sigra Series (TSS) (Luvisol)**	
							Period 1							
Sub-Plot	**Top Soil**	**Sub Soil**	**Top Soil**	**Sub Soil**	**Top Soil**	**Sub Soil**	**Top Soil**	**Sub Soil**	**Top Soil**	**Sub Soil**	**Top Soil**	**Sub Soil**	**Top Soil**	**Sub Soil**
1	0.8	0.6	2.0	1.3	2.2	1.8	2.2	2.1	5.0	4.2	4.1	3.2	3.2	3.1
2	0.4	0.5	1.7	1.5	2.2	1.9	2.4	2.6	3.6	3.4	4.2	3.1	3.0	2.8
3	0.4	0.5	1.8	1.3	2.2	1.8	1.9	1.8	3.7	3.4	3.9	3.1	3.2	2.9
4	0.6	0.7	1.7	1.1	2.2	1.8	1.9	1.7	3.8	3.4	4.1	3.3	3.1	2.7
5	0.5	0.6	1.7	1.5	2.1	1.5	1.7	1.7	4.3	3.9	3.8	3.0	3.4	2.9
Mean	**0.54**	**0.58**	**1.78**	**1.34**	**2.18**	**1.76**	**2.02**	**1.98**	**4.08**	**3.66**	**4.02**	**3.14**	**3.18**	**2.88**
SD (+/−)	0.17	0.08	0.13	0.17	0.04	0.15	0.28	0.38	0.58	0.37	0.16	0.11	0.15	
							Period 2							
Sub-Plot	**Top Soil**	**Sub Soil**	**Top Soil**	**Sub Soil**	**Top Soil**	**Sub Soil**	**Top Soil**	**Sub Soil**	**Top Soil**	**Sub Soil**	**Top Soil**	**Sub Soil**	**Top Soil**	**Sub Soil**
1	1.2	0.8	1.7	1.5	2.0	1.5	2.4	2.1	3.3	2.9	3.7	3.3	3.0	3.1
2	1.0	0.7	3.0	1.8	1.9	1.5	2.1	1.8	4.3	4.0	3.7	3.4	2.9	2.5
3	0.9	0.7	2.7	1.4	1.9	1.6	2.1	1.7	3.9	3.2	3.7	3.4	2.9	2.9
4	0.7	0.6	1.7	1.4	1.8	1.6	1.9	1.6	3.6	3.5	3.6	3.8	3.0	2.7
5	0.6	0.7	2.0	1.3	1.8	1.4	2.0	1.7	4.1	2.8	3.5	3.2	3.4	3.1
Mean	**0.88**	**0.7**	**2.22**	**1.48**	**1.88**	**1.52**	**2.1**	**1.78**	**3.84**	**3.28**	**3.64**	**3.42**	**3.04**	**2.86**
SD (+/−)	0.24	0.07	0.60	0.19	0.08	0.08	0.19	0.19	0.40	0.49	0.09	0.23	0.21	0.26

Period 1 (t = 0 years). Period 2 (t = 15 years).

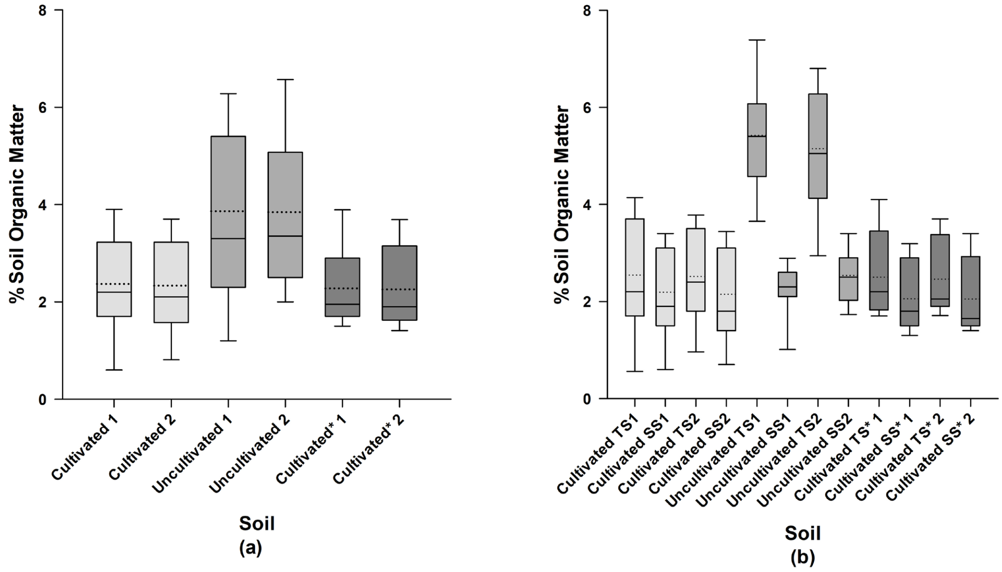
Table 4. Organic matter content (%) in the uncultivated soil in sampling periods 1 and 2.

	Fiddien Series (FS) (Vertisol)		San Lawrenz Series (SLS) (Regosol)		San Biagio Series (SBS) (Cacisol)		Tax-Xaghra Series (TXS) (Leptosol)	
Period 1								
Sub-Plot	**Top Soil**	**Sub Soil**	**Top Soil**	**Sub Soil**	**Top Soil**	**Sub Soil**	**Top Soil**	**Sub Soil**
1	3.0	1.0	6.1	2.3	5.2	2.1	4.8	2.3
2	3.6	1.0	4.5	2.3	5.2	2.2	7.3	2.4
3	5.6	2.1	5.7	2.8	6.0	2.6	6.3	2.9
4	4.2	1.1	5.4	2.4	5.9	2.6	7.4	5.2
5	4.1	1.1	7.4	2.6	5.4	2.3	5.4	2.7
Mean	**4.1**	**1.26**	**5.82**	**2.48**	**5.5**	**2.36**	**6.24**	**3.1**
SD (+/−)	0.96	0.47	1.06	0.22	0.39	0.23	1.15	1.20
Period 2								
Sub-Plot	**Top Soil**	**Sub Soil**	**Top Soil**	**Sub Soil**	**Top Soil**	**Sub Soil**	**Top Soil**	**Sub Soil**
1	6.6	2.7	6.8	1.6	3.3	2.2	6.3	3.4
2	6.8	3.4	6.1	2.4	5.1	2.9	4.7	3.2
3	5.0	2.0	8.1	2.2	4.2	2.5	4.3	3.8
4	3.9	1.7	5.1	2.1	2.9	2.0	2.7	2.0
5	6.0	2.7	4.8	2.5	4.1	2.5	6.2	2.9
Mean	**5.66**	**2.5**	**6.18**	**2.16**	**3.92**	**2.42**	**4.84**	**3.06**
SD (+/−)	1.21	0.67	1.34	0.35	0.86	0.34	1.49	0.68

Period 1 (t = 0 years). Period 2 (t = 15 years).

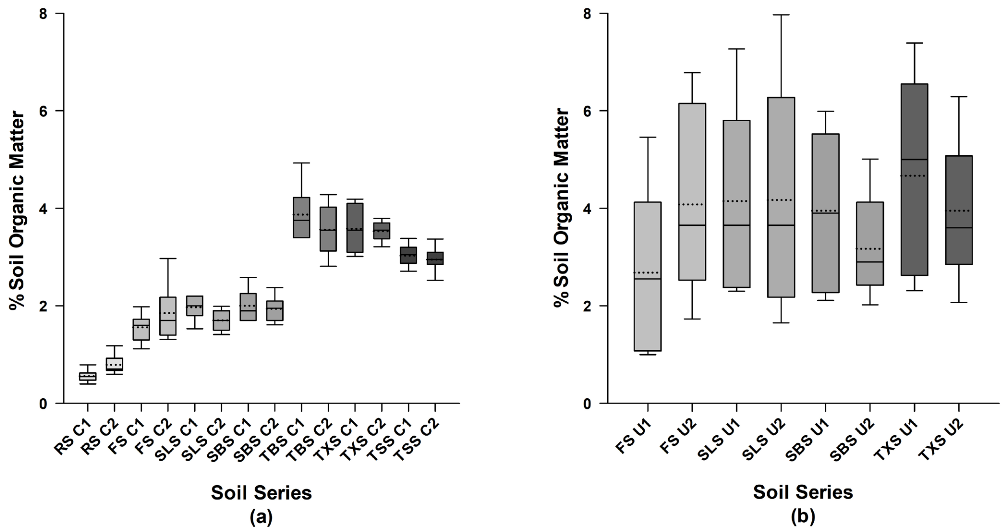
The level of OM in individual soil series is shown in Figure 2. The soils of the uncultivated plots (Figure 2(b)) were always richer in OM than their cultivated counterpart (Figure 2(a)), however, for the TXS soil, this difference was not statistically significant. Similar differences were also observed in the topsoil (Figure 3 and Figure 4), however, in period 1, the difference between the TXS cultivated and uncultivated topsoil was then significant ($p = 0.003$). In the subsoil, the differences were less marked than in the topsoil, and were only significant in the SLS soil in both sampling periods ($p < 0.001$; 0.004), and in the FS and SBS soils; both in period 2 ($p = 0.007$; 0.011). OM was lower in the uncultivated subsoil than in the cultivated, in the FS soil in Period 1, and in the TXS soil in both periods; however, these differences were not statistically significant.

Variations in OM content were also observed between the topsoil and the subsoil (Figure 1(b), Figure 3 and Figure 4), especially in the uncultivated soils (Figure 1(b), Figure 4(a) and Figure 4(b)). In the cultivated soil, the OM in the collective topsoil was higher than that in the collective subsoil (Figure 1(b)); however, the difference was not significant. Except for the RS soil in period 1, the OM in each individual cultivated subsoil (Figure 3) was lower than that in the topsoil, however the difference was only significant in the TXS soil in period 1 ($p < 0.001$) and in the FS soil in period 2 ($p < 0.001$). In period 1, the OM in the RS subsoil was higher than that in the topsoil, but the difference was not statistically significant. In the uncultivated soil, the OM in the collective topsoil was significantly higher ($p < 0.001$) than that in the collective subsoil in both periods (Figure 1(b)). In individual uncultivated soil series, the OM in the subsoil was always less than that of the topsoil (Figure 4(a) and Figure 4(b)), and compared to the cultivated soil the differences were more marked. In period 1 this difference was significant ($p < 0.001$) for all soil type but in period 2, it was only significant in the SLS and FS soils ($p < 0.001$).



Dotted line denotes the mean; Solid line denotes the median; 1 and 2 represent the sampling period; *Cultivated FS, SLS, SBS and TXS soil.

Figure 1. Soil organic matter content in (a) cultivated and uncultivated soil in periods 1 and 2; and (b) cultivated and uncultivated topsoil (TS) and subsoil (SS) in periods 1 and 2.



Dotted line denotes the mean; Solid line denotes the median.

Figure 2. Soil organic matter content in (a) individual cultivated (C) soil series in periods 1 and 2; and (b) uncultivated (U) soil series in periods 1 and 2.

These differences in OM content in the soils reflect the effect of cultivation or the lack of it. In agricultural land, more organic material is removed from the soil than it is returned, and intensive tillage practice decreases OM stability and accelerates its oxidation and breakdown [29] [30]. This is well demonstrated here, as non-agricultural soils were richer in OM both when the soils were considered collectively and also when compared on same series basis. As tillage mixes the topsoil with subsoil, the OM in agricultural soil is distributed in the bulk soil and becomes diluted. This effect will be more significant in shallow soils like those of Malta, where in most places the soil is barely 30 cm deep and the whole soil profile is generally affected by tillage. Although the OM content in the cultivated topsoil was higher than that of the subsoil, this difference was not significant, both when the soils were considered collectively and also when considered as an individual series. The difference in the uncultivated soil highly contrasts with this, as the OM in the uncultivated topsoil was much higher than that in the subsoil and the differences were significant both when the soils were considered collectively and in most of the individual soil series. Uncultivated soil is not tilled, and OM tends to accumulate on the soil surface and in the upper level of the topsoil, creating a sharp contrast with the OM level in the subsoil. The incorporation of dead leaves and other organic detritus into the lower soil layers from the topsoil by the soil fauna is not enough to reduce this sharp contrast. Except for the RS soil, the soils used in this study are high in clay, and thus, natural mixing between the surface layers and sub layers is difficult, especially in an arid climate. Moreover, OM is also stabilized and locked by the high clay content [31] in the topsoil and very little tends to move down to lower levels, especially in these soils that are dry and compact for most part of the year and where free drainage is somehow restricted.

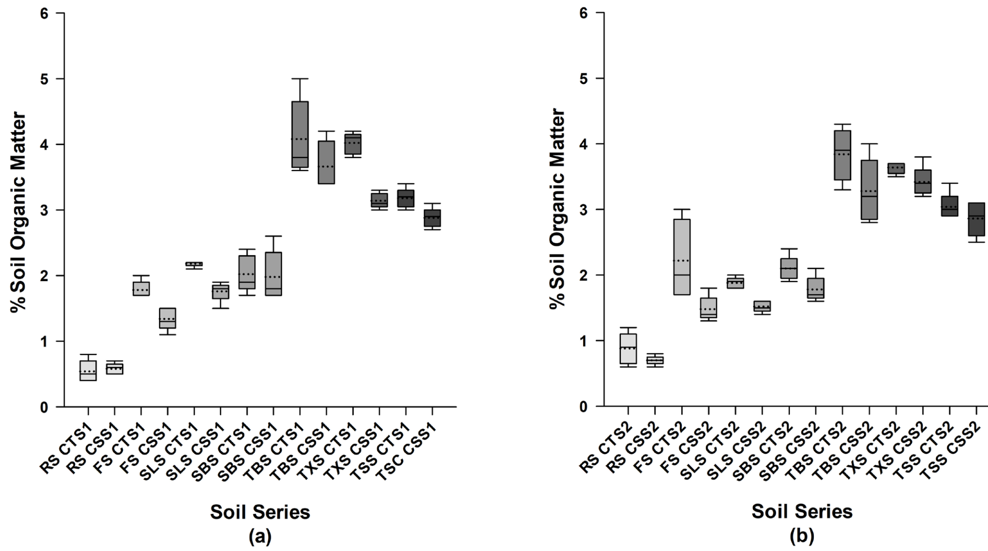
3.2. Variation in OM Content among Different Soil Series

In both sampling periods, differences in OM content were recorded between some of the soil series (**Table 3**, **Table 4**; **Figure 2**). These differences were more pronounced in the cultivated than in the uncultivated soils. In the individual cultivated soil plots, the mean OM content ranged from 0.6% to 3.9%. The TBS and the TXS soil plots were significantly richer ($p < 0.05$ Kruskal Wallis ANOVA on Ranks) in OM than all the other soil types except from the TSS soil plot, however, the OM in the TSS soil was significantly higher than that in the RS and FS soil plots. The differences in OM content between the RS, the FS, the SLS and the SBS soil plots were not significant. In the uncultivated soil, no significant difference in OM content was observed between the four soil series plots.

A similar pattern in OM variation was also observed in the cultivated topsoil and subsoil (**Figure 3(a)** and **Figure 3(b)**), where in both periods, OM was highest in the TSS, TBS and the TXS series plots. However, in this case, in the topsoil the difference was only significant between (TBS and TXS vs RS and FS) and (TS vs RS) in period 1; and (TB vs RS and SLS), and (TXS and TSS vs RS) in period 2. In the subsoil, the differences were statistically significant between (TBS and TXS vs RS and FS) and (TS vs RS) in period 1, and (TXS vs RS, FS and SLS), (TBS and TSS vs RS) in period 2. In the uncultivated soil (**Figure 3(c)** and **Figure 3(d)**), the differences were not statistically significant except in period 1, where the OM in the TXS topsoil and subsoil was significantly higher than that in the FS.

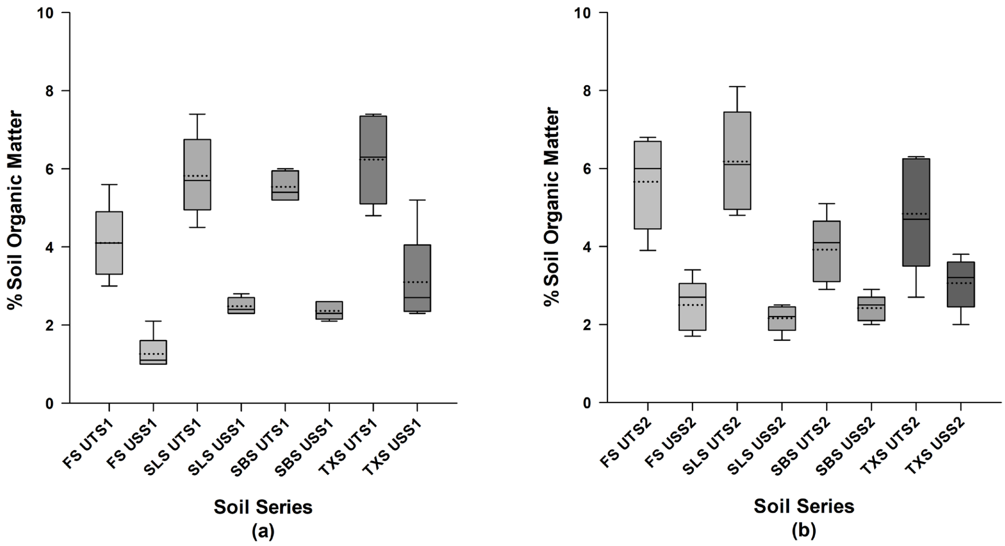
Based on their OM content, the cultivated soil types used in this study can be grouped into three categories; a group representing soil with an OM content less than 1%, another for soils with OM content ranging between 1% and 2%, and another group for soil with an OM content greater than 2%. The lowest OM level (<1.0%) was recorded in the RS soil (Arenosol). This soil type is found only in one location on the islands, and is produced from contemporary or Quaternary dune beds of calcareous weakly glauconitic sand, and is thus very permeable [27]. The low OM content in this soil could be attributed to a number of factors such as its sandy texture, loose structure, low clay content, high water percolation rate and cultivation practice. During the study period and before, this site was used as an orchard and consequently, very little organic material was returned to the soil during the years from the crop. FYM was applied in small portions close to the trees. The loose sandy structure keeps the soil aerobic for most of the year thus accelerating the degradation of the little organic material that is added. Moreover, as the leaching factor in such soils is high, products of decomposition are easily leached out. The low OM content in this soil type agrees with studies on soils that are rich in sand [32] [33] [34], and low in clay [35].

The OM content in the FS (Vertisol), the SLS (Regosol) and the SBS (Calcisol) soil plots was higher than that in the RS soil plot, and falls between 1.0% to 2.0%. Like the RS soil, these are undeveloped raw soils with very little differentiation from their parent material and contain high levels of $CaCO_3$ (29% - 65%) and clay. The FS and SLS soils are greyish heavy clay soils developed from clay parent material that still dominates the soil profile especially in the FS soil. Their low level of OM, despite the high clay content, could be attributed to the soils' raw and immature nature and to their management. The SBS soil are whitish silty clay soils developed from the upper layers of the globigerina limestone layer [27]. These are also undeveloped soils and contain a relatively high content of $CaCO_3$ inherited from the limestone parent material. With regards to cultivation and management, apart from the FS site, these soils are used mainly for the cultivation of *Triticum aestivum* and *Hordeum vulgare*, although occasionally the SBS soil site is used to cultivate *Vicia fava* or *Hedysarum coronarium*. These crops are used as fodder and bedding material for animals, and most of the aboveground plant material is harvested and apart from the roots, very little plant residue is incorporated back into the soil. These high clay-content soils retain a substantial amount of water during the winter, but are then very dry, extremely hard and compacted in summer and also develop surface crust and cracks. The extensive tillage required to break the massive aggregates prior to cultivation, is a significant factor in the oxidation and degradation of the OM.



Dotted line denotes the mean; Solid line denotes the median.

Figure 3. Soil organic matter content in individual soil series cultivated topsoil (CTS) and subsoil (CSS) in periods (a) 1 and (b) 2; and in individual soil series uncultivated topsoil and subsoil in periods (c) 1 and (b) 2.



Dotted line denotes the mean; Solid line denotes the median.

Figure 4. Soil organic matter content in individual soil series of uncultivated topsoil and subsoil in periods 1 (a) and 2 (b).

The OM level in the TBS and the TSS soils (Luvisol), and the TXS (Leptosol) was close to or greater than 3% in both sampling periods, and except from the TSS soil, this concentration occurred in both the topsoil and subsoil. These soils are typical Mediterranean Terra Rossa type soils and are more developed than the rest of the soils used in this study. These sites are used for the production of a variety of crops but mainly include *S. tuberosum*, *S. lycopersicum*, *Allium cepa*, and *Cucurbita pepo*. The fact that this cultivation system returns a substantial amount of above ground residue to loam type soils that are more developed and mature than the other soils used in this study, might partially explain the relatively higher OM content. Moreover, Luvisols and Leptosols are more developed and more decalcified than the other soil series and this might also account for their greater OM content. In the uncultivated soil plots, the mean OM concentration ranged from 2.7% to 4.7% (**Figure 2(b)**; **Figure 4(a)** and **Figure 4(b)**); however, in both sampling periods, the differences between the four soil types were not statistically significant. In sampling period 1 however, the difference between the TXS and the FS was significant in both the topsoil and the subsoil.

The OM content in the individual cultivated soil types observed in this study, is similar to what was reported in a survey by Sivarajasingham in 1971 [36] and to a lesser extent to that by Lang in 1960 [27] (**Table 5**). Based on their OM content, the soils surveyed by Sivarajasingham can also be grouped into the 3 categories referred to earlier, and those reported by Lang into 2, as the mean OM content in the RS soils was higher than 1%. The sample size in both these past surveys was far larger than the sample size of this study as these were nationwide studies. This similarity in OM content and distribution pattern in soils of the same series over the years might reflect the effect inherent soil properties, such as texture and nature of the parent material, have on the level of OM, especially in soils that are under constant cultivation. It can be seen here that raw, immature soils with high clay and high carbonate content that are cultivated contain less OM than soils that are more mature and decalcified. In both 1960 and 1970, most, if not all of the soil on the islands was used for cultivation, thus the results obtained 60 years earlier can be soundly compared with the results obtained for the cultivated soil of this study. On the other hand, in uncultivated soils the lack of cultivation seems to override the effect of soil properties, especially in the topsoil, since no major difference in OM content was observed between the soils. However, a larger soil sample of uncultivated soil, would have been needed to produce a more valid conclusion.

3.3. Temporal Variation

After 15 years, no significant change in the mean OM content was recorded in the collective cultivated and uncultivated soil (**Figure 1(a)**), and in the collective cultivated topsoil and subsoil (**Figure 1(b)**). A slight change from 5.4% to 5.2% and from 2.3% to 2.5% was noted in the collective uncultivated topsoil and subsoil respectively; however, both differences were not statistically significant.

Small variations were observed in individual cultivated and uncultivated soil series. In the cultivated plots (**Figure 2(a)**), a decrease was observed in the SLS, SBS, TBS, TXS and the TSS soil plots, however, the difference was only significant in the SLS soil ($p = 0.016$). A marginal increase occurred in the RS and the FS soil plots but only that in the RS soil plot was statistically significant ($p = 0.006$). Variations in the uncultivated soil plots (**Figure 2(b)**) were not statistically significant. Some variations were recorded in the cultivated topsoil (**Figure 3(a)** and **Figure 3(b)**), but these were only statistically significant in the SLS and TXS soil plots, where the OM decreased, and in the RS soil plot, where it increased. In the cultivated subsoil (**Figure 3(a)** and **Figure 3(b)**), the differences were only significant in the RS soil with an increase in OM, and the SLS soil plots where a decrease was recorded.

The differences in the individual uncultivated topsoil (**Figure 4(a)** and **Figure 4(b)**), over a period of 15 years, were greater than those in the cultivated; however, apart from that in the SBS soil, these were not statistically significant. The significant decline in OM in the uncultivated SBS topsoil from 5.5% to 3.9%, could be the results of a combination of factors, however the type of vegetation, the state of the soil and the use of the site could be very significant. The vegetation on this site is sparse and consists of a few *Pinus halepensis* trees, and patches of short grasses. During the years, the use of the area as a recreational park and picnic area had damaged and degraded the sparse vegetation and compacted the silty clay soil.

In the uncultivated subsoil, temporal variations were less marked than in the topsoil, which again reflects the lack of mixing between topsoil and subsoil in soils that are not tilled. Differences were not statistically significant except for those in the FS soil plot, where the OM increased from 1.3 % to 2.5 %. The OM

Table 5. Organic matter content (%) in the cultivated soil from this study compared to that reported in the surveys carried out by Lang in 1960 and by Sivarajasingham in 1971.

Soil Type		Organic Matter Content %			
Soil Series	**WRBS**	**Lang (Lang 1960)**	**Sivarajasingham (Sivarajasingham 1971)**	**This study**	
				Period 1	**Period 2**
Carbonate Raw Soil *Ramla Series* (RS)	Arenosol	1.4	0.5	0.6	0.8
Carbonate Raw Soil *San Lawrenz Series* (SLS)	Regosol	1.6	1.8	1.9	1.7
Carbonate Raw Soil *Fiddien Series* (FS)	Vertisol and Regosol	1.4	1.6	1.6	1.8
Xerorendzina *San Biagio Series* (SBS)	Calcisol	1.9	2.1	2.0	1.9
Xerorendzina *Tal-Barrani Series* (TBS)	Luvisol	3.0	4.6	3.9	3.6
Terra Rossa *Tas-Sigra Series* (TBS)	Luvisol	4.5	2.7	3.0	3.0
Terra Rossa *Tax-Xaghra Series* (TXS)	Leptosol	4.5	3.6	3.6	3.5

Period 1 (t = 0 years); Period 2 (t = 15 years).

in the FS topsoil also increased from 4.1 % to 5.7 % however this was not statistically significant (p = 0.055). The FS soil on this site is a relatively deep raw clay soil with high water holding capacity overlying clay parent material and, unlike the other uncultivated sites, carries a dense long grass type vegetation during winter through late spring. This type of vegetation might be a significant factor in enhancing SOM. Moreover, unlike the other uncultivated sites, this site is undisturbed.

The mean OM content found in the individual cultivated soil series, is similar to what was reported by Lang [27] and Sivarajasingham [36], for soils of the same series. This might indicate that over a span of 60 years, variation in OM in these soils might have also been minimal. This could be the effect of climate and cultivation practice that collectively are suppressing an increase in the level of OM in the soil. As pointed out earlier, in agricultural land in the Maltese Islands, the main input of organic material in the soil is FYM. This is applied and incorporated into the soil in late summer or early autumn, where the soil temperatures are still high following the hot summer months. The first torrential rains generally occur in September and October, and this sudden increase in water content in the soil together with the high soil temperature will accelerate the decomposition and mineralization of the organic material in the FYM. Further tillage action will aerate the soil and further accelerates OM mineralization.

4. Conclusions

This work has shown that cultivation and tillage have a major effect on the level and distribution of organic matter in the soil of Malta. The organic matter content in non-agricultural soil was higher than in the cultivated soil, in both the bulk soil and the topsoil, and the differences in organic matter content between topsoil and subsoil were more marked in soils that were uncultivated. This was not only observed when the soil was considered collectively but also in individual soils with similar characteristics. Contrary to uncultivated soil, in cultivated soil, soil properties such as texture, soil development, and the nature of the parent material seem to be significant factors in influencing organic matter content. In cultivated sites, more developed and mature loams were richer in organic matter than compacted raw calcareous clays and loose sand whose composition included large proportions of unweathered parent material. In uncultivated soils, despite the fact that the soils had different textural characteristics, the differences were negligible.

However, despite playing a major role in the distribution and level of organic matter in soil, cultivation, tillage and the constant application of farm yard manure failed to alter the concentration of organic matter in the soil after a 15-year period. Moreover, in the bulk cultivated soil and individual cultivated soil series, the level of organic matter was similar to what was reported 60 and 50 years earlier suggesting that changes in organic matter level in the dry calcareous cultivated soil of Malta under a Mediterranean climate are slow.

Acknowledgements

The authors would like to thank the farmers and landowners that made their land available for this study.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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