CHAPTER 13

Soil Quality Change in the Maltese Islands: A 10-Year Assessment (2003 to 2013)

Daniel Sultana

Introduction

Soils constitute a significant non-renewable geo-resource. Soil resources produce various ecosystem goods and services, chief amongst which are food production and the recycling or assimilation of wastes and other by-products (Arrouays, Marchant, Saby, Meersmans, Orton & Martin, 2012; deGroot, Wilson and Boumans., 2002). Healthy soils are therefore the foundation of our food system and merit our attention (Bot & Benites, 2005). Over the past few decades, various anthropogenic factors have increased the pressures on soil systems and associated ecosystem services. Amongst these pressures is a growth in global population and standards of living as well as climate change. These factors have significantly increased the global demand for food and have led to a widespread process of land use intensification.

Agricultural land use intensification may adversely affect soil physical, chemical and biological properties. The intensification process has occurred throughout the entire world and has lead to a significant decline in soil quality (Van Camp, Camp, Bujjarabal, Gentile, Jones, Montanarella, Olazabal & Selvaradjou., 2004). Supporting this claim is Steer's (1998) work that demonstrates that approximately 23% of the Earth's agricultural lands, pastures, forests and wild native lands have been degraded in the last decades of the last century. Soil erosion is a significant contributor towards soil quality loss and has been identified as a major threat to European agricultural soils (Virto et al., 2015). It is estimated 12% (115 million hectares) of Europe's total land area is affected by water erosion, a major threat to agricultural soil quality.

Soil degradation, which is a decline in soil quality, constitutes a serious global problem with important environmental and socio-economic consequences. Soil degradation limits soil's capacity to perform various ecosystem services, namely the provision of food, water, biodiversity and energy (Brevik et al., 2015). Consequently, soil quality is inexorably tied to national and global food safety, human health and sustainable economic and social development (Cheng, 2003; Liu, Herbert, Hashemi, Zhang & Ding, 2006). The increased awareness that soil is of critical importance has led to an interest in evaluating and monitoring its quality (Glanz, 1995; Doran & Parkin, 1996). Soil quality and its monitoring are a useful management tool through which soil conservation and sustainable development may be achieved (Banwart, 2011).

Soil management: policy, monitoring and selection of crops

Various soil management measures, falling under the description of "sustainable agriculture", have been proposed (Matson et al., 1997). These fundamentally seek to maintain high crop yields while preserving soil quality in agricultural areas. Such measures include: organic farming (van Leeuwen et al., 2015); terracing (Zhao, Mu, Wen & Wangand Gao, 2013); crop residue retention (Pittelkow et al., 2014); diversified crop rotations (Bhattacharyya, Prakash, Kundu & Gupta., 2006; Pittelkow et al., 2014; Abdollahi, Hansen, Rickson & Munkholm, 2015) and conservation tillage systems that include no-tillage (Kahlon & Ann-Varughese, 2013). These practices have been successful in reversing declines in soil organic matter and increasing soil fertility, water infiltration and water holding capacity.

Conservation and no-tillage practices preserve the soil quality by reducing soil erosion (Lal, 1993) and increasing the soil organic carbon content (Zotarelli et al., 2012), aggregate stability (Alvarez & Steinbach, 2009), biodiversity (Adl, Coleman & Read, 2005) and biological activity (Anken, Weisskopf, Zihlmann, Forrer, Jansa & Perhacova, 2004; Babujia, Hungria, Franchini & Brookes, 2010). In view of these benefits, conservation tillage is considered as on of the most important management practices enabling sustainable agricultural production. McGarry & Sharp (2001) support this claim. The authors measured a 47 and 40% increase in organic matter in the 20 to 30cm and 50 to 60cm layer of a field that had been under no-till for 12 years, relative to an adjacent conventionally tilled field. The relative increase in organic matter was matched with a measured decline in bulk density (23%) and an increase in water infiltration on the 0 to 5cm layer.

Since 1999 there has been a 250% increase in the agricultural areas applying no-tillage management measures; from 45million ha in 1999 to 111 million ha in 2009 (Derpsch et al., 2010). The rapid rise in global adoption of no-tillage by farmers may be tied to a number of significant advantages, namely; a reduction in fuel and labour consumption and soil erosion control (Lal, 1993).

The effects of tillage on soil physical properties are time, space and management dependent. In view of this, despite wide investigations on the impacts of no-tillage and other tillage systems on soil physical quality, correlations are highly variable and at times contradictory (Alvarez and Steinbach, 2009; Tangyuan et al., 2009; Wang and Shao, 2013; Munkholm, Heck & Deen, 2013; Derpsch, Friedrich, Kassam & Hongwen, 2014). Excessive soil compaction in untilled areas is still a concern in various agricultural regions, such as Europe (Anken et al., 2004; Soane., Ball, Arvidsson, Baschd, Moreno & Roger-Estrade, 2012; Dal Ferro, Sartori, Simonetti, Berti & Morari, 2014; López-Garrido, Madejón, León-Camacho, Girón, Moreno & Murillo, 2014). Soil compaction is undesired in agricultural areas since it leads to a reduction in total porosity, water infiltration capacity and hydraulic conductivity (Silva, Reichert, Reinert & Bortoluzzi, 2009).

An increase in soil bulk density also hinders root penetration capacity (Moraes, Debiasi, Carlesso, Franchini & Silva., 2014), which in turn limits the volume of soil roots have access to and reduces access to water and nutrients (Li et al., 2007). These changes may reduce crop yields, especially in dry years (Franchini et al., 2012). In this context of uncertainty of tillage system of soil quality, the use of crop rotations including plants with high potential for shoot and root biomass production has been suggested (Calonego & Rosolem, 2010; Munkholm et al., 2013; Silva et al., 2014). Such measures will prevent the formation of compacted layers and improve soil physical quality.

Soil management: soil quality indicators

The multidimensional concept of soil quality emerged as a result of the growing holistic approaches to land management and sustainable use systems (Mairura, Mugendi, Mwanje, Ramisch, Mbugua & Chianu, 2007; Villamil, Miguez & Bollero, 2008). The evaluation of soil quality is based on the use of indicators (Moebius-Clune, et al., 2011; Toledo, Galantini, Dalurzo, Vazquez & Bollero, 2013). The selection of soil quality indicators and their associated threshold values, maintained for the sustained functioning of soil, provides an ability to monitor changes and identify trends of improvement or deterioration in agro-ecological zones at various geographical and time scales.

Soil quality indicators should be selected according to the scope of, the monitoring programme, the environmental context and the soil types of the region under study (Cantú, Becker, Bedano & Schiavo, 2007). It is essential to check the utility of soil quality indicators for each local agricultural ecosystem to prevent improper practices (Dalurzo, 2002). Productivity has traditionally been the indicator selected to quantify soil quality (Karlen, Mausbach, Doran, Cline, Harris & Schuman, 1997). Recently, however, soil quality indicators have been tied to aspects of soil sustainability. In particular, indicators should quantify the capacity of soil to absorb, store and recycle water, minerals and energy in such away that production of crops can be maximised and environmental degradation minimised (Tóth, Stolbovoy, V., & Montanarella, 2007). To this extent, typical soil quality indicators and monitoring programmes include soil organic matter, bulk density, electric conductivity, moisture content, pH, nitrates, phosphates and potassium, heavy metal concentrations and soil depth (Gao, Wang, Xu, Kong, Zhao & Zeng, 2013).

Soil monitoring and the early detection of changes in soil quality are essential to conserve soil for sustainable use. Soil quality monitoring are thus an effective method for evaluating the environmental sustainability of land use and management activities (Hamblin, 1991). Various countries have identified the benefits of soil monitoring and have introduced various monitoring programs. In fact, Europe has carried out a number of official soil monitoring frameworks for several years (such as the soil monitoring network, SMN). European SMNs include soil fertility monitoring, heavy metal monitoring, environmental soil surveys, soil erosion surveys, soil organic matter monitoring assessed through a variety of sampling strategies (Morvan, Saby, Arrouays, Le Bas, Jones & Verheijen, 2008).

In his report on Agriculture in Malta, Shepherd (1920) remarks that a precise national soil survey is not available. Lang (1960) later carried out a detailed survey where differences in soil chemistry, physical properties and biology constituents were mapped. The study by Lang (1960) provided a detailed description of the soils types and their distribution that aimed to facilitate agricultural planning.

Due to the rapid increase in urban areas since the 1960's and the shift of topsoil within and around new urban areas, the Lang (1960) map was considered as unsatisfactory for contemporary use. As a result, the Malta Soil Information System (MALSIS) project was carried out in 2003. Through MALSIS Malta – which until that point in time did not have a tradition of soil survey and monitoring – sought to describe, assess, monitor and manage National soils in a sustainable way (Vella, 2003). MALSIS consists of a national grid-based soil inventory at 1km intervals. A total of 280 sites were assessed between June 2002 and August 2003 in Malta, Gozo and Comino. The surveying methodology followed the FAO Guidelines for Soil Description. Sites were assessed in terms of agricultural land use, height of terrace, cropping pattern, irrigation, slope and soil chemical and physical properties. The MALSIS results identify six soil reference groups; leptosols, vertisols, calcisols, luvisols, cambisols and regosols. Calcisols were recognised as the dominant soil group. Results also demonstrate that National spatial patterns of soil types are very intricate. In fact, different soil types were often observed to occur within a single field or within a distance of a few metres (Vella, 2003). Refer to MEPA website (https://www.mepa.org.mt/soil-definition).

The study presented here assesses various soil chemical properties for sites corresponding to those studied in the 2003 MALSIS survey. The chemical properties – indicators of soil quality – obtained in this study may be directly compared against the MALSIS results. This allows a 10-year assessment in soil quality to be appraised. This information may serve to highlight important changes in soil quality and potential ecosystem functioning, all of which are important for National sustainable agricultural management.

Materials and Methods

Sampling methods and indicators

The sampling locations identified for this study are the same as those studied in MALSIS (2003) and are based on a 1km spaced grid distribution across Malta and Gozo. All grid points located within soil containing natural and agricultural areas were sampled in this study. The study present involved the survey of 280 sites across Malta and Gozo (Figures 1 to 6). The sampling of soils at the pre-selected geo-referenced target sites was initiated in June 2013 and was completed in September 2013. The timing of sampling is therefore similar to that of the MALSIS survey and corresponds to the Maltese dry season. Soil samples were gathered from a 0.2 meter depth below the soil surface. As with the MALSIS study, the soil survey methodology followed in this work follow the FAO Guidelines for Soil Description with minor adaptations to reflect local conditions.

The tools for assessing soil properties and health are taken from the VS-Fast methodology (McGarry, 1996) and selected VSA methods of Shepherd (2000). During field visits emphasis was placed on the qualitative and quantitative assessment of soil physical condition. The soil properties assessed in for each site in this study include the soil chemical measurements; organic carbon, pH, electrical conductivity and the soil physical measurements; bulk density, moisture and depth. The aforementioned soil properties were also assessed in the MALSIS study. Three results were calculated for each soil quality indicator in each site with the aim of obtaining average, range and standard deviation values. A justification for the choice of the aforementioned soil quality indicators is provided below.

Bulk density

Soil bulk density directly quantifies soil compaction and provides information on soil texture, organic matter levels, porosity and aggregation (Hernanz et al., 2000). In view of this, soil bulk density is a very useful parameter describing soil quality. Volumetric pore space is essential for sustainable soil use, both in terms of productivity and environmental well-being. Soil pores contain and allow the movement of water and air. Both of which are necessary for processes that produce and sustain the production of biomass. It is important to note that crop yields and the sustainability of farming families' livelihoods, are also closely linked with soil porosity (Shaxson & Barber, 2003). A change in bulk density is also a direct indicator suggesting change in other soil parameters. For instance, an increased soil organic carbon improves soil structure, which in turn leads to a decrease in bulk density, improves aggregate stability, increases pore size and increases the proportion of air and water filled pore space (Loveland & Webb, 2002).

Soil bulk density may increase when the total porosity is reduced. This may occur through a variety of compaction processes, either through direct compaction or through mechanical, chemical or biological breakdown of soil aggregates. The consequences of an increase in soil bulk density are numerous and significant. Severely compacted soil leads to a reduction in macropore volume, with a consequent reduction in water availability and poorer aeration. Compacted soils also slow drainage (hydraulic conductivity) which in turn reduces infiltration rates and water storage capacity, which increases overland flow, leads to the erosion of fertile topsoil and reduces crop production potential (biomass yields) (Li et al., 2007; Hernanz, Peixoto, Cerisola & Sanchez-Giron, 2000; Neves, Feller, Guimaraes, Medina, Tavares & Fortier, 2003). At the other extreme, soils with low bulk density and strength are susceptible to rapid soil erosion rates, a poor capacity to retain water and are subject to accelerated oxidation of soil organic matter with consequent loss of soil organic carbon (Sparling, Lilburne & Vojvodic-Vukovic, 2003).

The methods and standards followed in this study to obtain dry bulk density measures are that same as those adopted in MALSIS's (2003); Determination of dry bulk density British Standard 7755 – 5.6: 1999.

Electrical conductivity

Electrical conductivity of soil is a measure of the concentration of ions in solution. Electric conductivity is most often used as an indicator of salinity. It is however important to note that where soil nitrate levels are high, electric conductivity is also an indicator of soil nitrate status (Lewandowski, Zumwinkle & Fish, 1999).

The methods and standards followed in this study to obtain electrical conductivity measures are that same as those adopted in MALSIS's (2003); Determination of the specific electric conductivity ISO 11265 Soil Quality. This procedure specifies an instrumental method for the routine determination of the specific electrical conductivity in a water extract of soil samples. The determination is carried out to get an indication of the content of water-soluble electrolytes in a soil.

Organic carbon

Soil organic matter is soil material that originates from organisms that were once or are currently living (Magdoff, 2004). Soil organic matter is comprised of approximately 50% carbon and is rich in various nutrients including nitrogen and phosphorus. Soil organic matter content is dependent on a variety of parameters, namely; organic matter inputs and decomposition, temperature, aeration, physical and chemical properties and leaching. Soil organic matter strongly influences most of the functions associated with soil quality (Weil, Islam, Stine & Samson-Liebig, 2003). Organic carbon rapidly decreases with cultivation and cropping (Su, Zhao, Zhang & Zhao, 2004; Bot & Benites, 2005). A decrease in organic carbon has negative effects on various soil properties necessary to maintain soil quality and crop productivity and leads to an increase in bulk density, a decrease in water infiltration and water holding capacity and a decrease in aggregate stability (Matson, Parton, Power & Swift, 1997).

There are many advantages to increasing or maintaining high levels of soil organic matter, namely; reducing bulk density, increasing soil resistance to erosion and reducing green house gasses by carbon sequestration. Soil organic matter and agricultural productivity potential have also been directly and positively correlated. Soil organic matter and by extension soil fertility, is increased in most agricultural soils by retaining crop residue on the soil surface, by rotating crops with pasture or perennials, or by adding organic residues (Krull, Skjemstad & Baldock, 2004). Levels of soil organic carbon reflect the total quantity of soil organic matter.

The methods and standards followed in this study to obtain organic carbon measures are that same as those adopted in MALSIS (2003). Determination of Organic Matter according to Walkley & Black (Nelson & Sommers, 1982) quantifies organic carbon in soil samples according to a wet oxidation procedure. This procedure is applicable to all types of air-dry soil samples pre-treated according to PROT 003.

pH

The analysis of mixed soil pH is necessary in soil quality assessment. The chemical reactions that occur in soil are significantly influenced by soil pH. Nutrients demonstrate diverse ranges of pH thresholds within which the highest proportion of nutrients are in a plat-available form. Optimal pH ranges exist for each crop and soil inhabiting organism. Various parameters influence soil pH, key amongst these are climate, parent material and fertiliser use. pH significantly influences various soil processes, key amongst these are; nutrient availability, biogeochemical cycling, contaminant sorption, structural stability and biological activity (scho0306bkiq-e-e pp14). Base saturation quantifies the percentage of the total cation exchange capacity occupied by the basic cations, calcium, magnesium, potassium and sodium. Base saturation is positively correlated to pH; with an increase in pH there is an increase in the amount of basic cations (Lewandowski et al., 1999). The methods and standards followed in this study to obtain pH measures are that same as those adopted in MALSIS (2003). The procedure followed is an instrumental method for the routine determination of pH using a glass electrode in a 1:5 (V/V) suspension of soil in water (pH-H2O); ISOIDIS 10390 Soil quality - Determination of pH.

Moisture content

Plants can use water holding capacity is the quantity of water soil can retain that. Water holding capacity is influenced by soil texture, structure and organic matter (Lewandowski et al., 1999). The amount of water present in soil is referred to as soil moisture content. Soil moisture is not constant with time and may vary. The management of soil moisture is important for sustained and improved crop productivity and water supply (Shaxson & Barber, 2003). The methods and standards followed in this study to obtain soil moisture measures are that same as those adopted in MALSIS (2003). The procedure followed is the determination of moisture in soil by oven drying; PROT 003, preparation and pre-treatment of soil samples for physico-chemical analysis.

Soil depth

Soil depth measures the depth from soil surface to a root restrictive layer, typically stone, water table, or hardpan. Shallow soils reduce water holding capacity and root development (Lewandowski et al., 1999).

The soil depth indicator was not assessed in MALSIS (2003). In this study, soil depth measures depth from surface to bedrock. The depth was measured at a grid distribution of between 0.5 to 1km (Figure 6) using soil augers in a total of three hundred and thirty locations. Due to significant differences in soil depth within the same sampling location, soil depth was measured three to four times; each measure was spaced 1meter east of the previously sampled point. The soil depth vales for each location are presented as an average of the four soil depth values (Figure 6).

Results Andand Discussions

Bulk density (g/cm3)

The average soil bulk density for the 254 assessed Maltese soils in 2003 (MALSIS 1) fell within the following ranges; ≤0.5g/cm3, 0%; 0.51 to 1.00g/cm3, 16%; 1.01 to 1.25g/cm3, 65%; 1.26 to 1.50g/cm3, 18%; 1.51 to 2.00g/cm3, 1%; ≥2.01g/cm3, 0%. The average soil bulk density for the 109 assessed Maltese soils in 2013 (MALSIS 2) fell within the following ranges; ≤0.5g/cm3, 0%, 0.51 to 1.00g/cm3, 11%; 1.01 to 1.25g/cm3, 70%; 1.26 to 1.50g/cm3, 18%; 1.51 to 2.50g/cm3, 0%; 2.51 to 3.00g/cm3, 1%; >3.00g/cm3, 0% (Figure 1a).

Change in soil bulk density was also assessed for sites where measures in bulk density were carried out in 2003 (MALSIS 1) and 2013 (MALSIS 2). MALSIS 2 values were subtracted from MALSIS 1, such that a positive change demonstrates an increase in soil bulk density and a negative change suggests a fall in soil bulk density. Bulk density change has been calculated in 97sites and exists within the following ranges; ≤ -0.40g/cm3, 1%; -0.39 to -0.2g/cm3, 6%, -0.19 to -0.01g/cm3, 32%; 0 g/cm3, 2%; 0.01 to 0.20g/cm3, 58%; 0.21 to 0.40g/cm3, 6%; 0.41 to 0.60g/cm3, 3%; 0.61 to 1.00g/cm3, 0%; >1.00g/cm3, 1% (Figure 1b). Results suggest that 59% of the locations assessed in 2013 had a greater average bulk soil density than the same locations in 2003 i.e. soil compaction is prevalent. It is worth noting that 82% of the locations subject to compaction have an increase in soil bulk density within the range of 0.01 to 0.20g/cm3; 0.01 to 0.1g/cm3, 44% and 0.11 to 0.2g/cm3, 38%.

Figure 1a: Average bulk density values for M1 (2003) as the smaller circles and M2 (2013) values as the larger circles surrounding the smaller (M1) circles

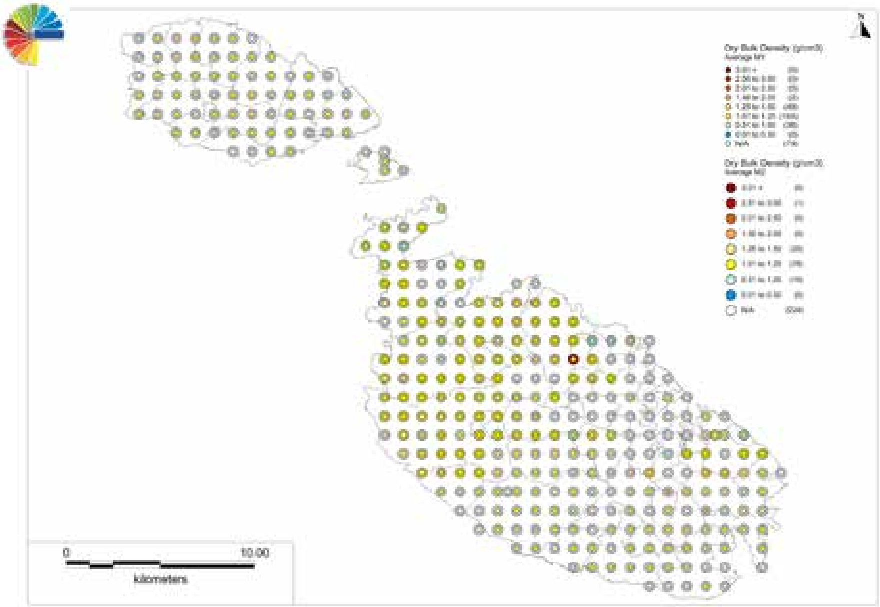
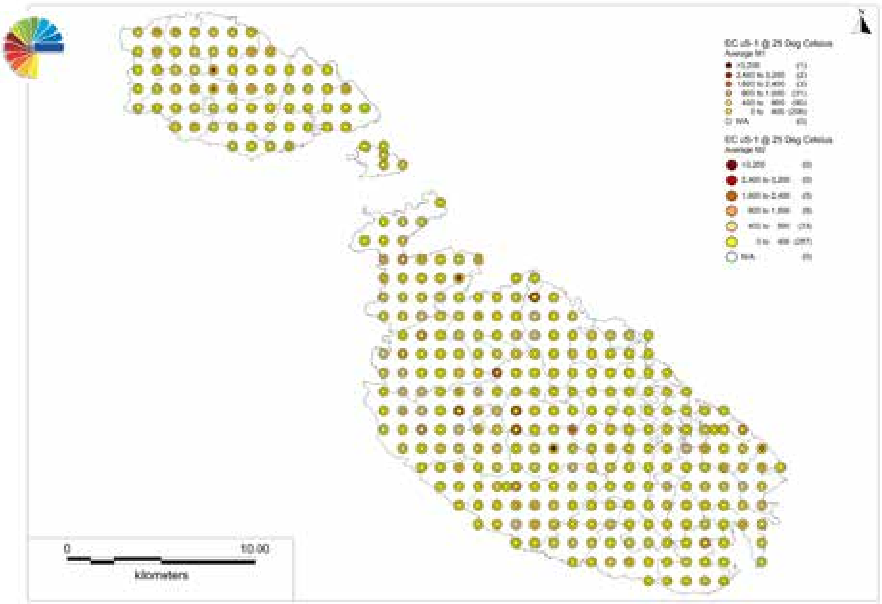


Figure 1b: Change in bulk density between 2003 and 2013 (M2-M1)



The average bulk density of all the sites assessed in 2003 is 1.14g/cm3. The average soil bulk density for the sites assessed in both 2003 and 2013 (97 sites in total) was of 1.12g cm3 for 2003 and 1.17g cm3 for 2013. In view of the national average soil bulk density, the increase in soil bulk density observed in 59% of the studied sites is significant. An increase in soil bulk density over time signifies soil compaction. This leads to a decrease in total soil porosity (macro-porosity in particularly) and hydraulic conductivity which influences the water release curve. Various chemical and biological parameters, namely soil organic carbon and mineralisable nitrogen, are also influenced by a change in soil bulk density (scho0306bkiq-e-e pp36).

3.1.2. Electrical conductivity (uS-1) (at 25°C)

The average electrical conductivity (uS-1) for the 270 assessed Maltese soils in 2003 (MALSIS 1) fell within the following ranges; ≤400uS-1 (non-saline), 53%, >400 to 800uS-1 (slightly saline), 33%; >800 to 1600uS-1 (moderately saline), 11%; >1600 to 2400uS-1 (moderately saline), 1%; >2400 to 3200uS-1 (very saline), 1%; >3200uS-1 (extremely saline), 0%. The average electrical conductivity for the 143 assessed Maltese soils in 2013 (MALSIS 2) fell within the following ranges; ≤400uS-1, 69%, >400 to 800uS-1, 22%; >800 to 1600uS-1, 6%; >1600 to 2400uS-1, 3%; >2400uS-1, 0% (Figure 2a).

Change in soil electrical conductivity was also assessed for sites where measures in electrical conductivity were carried out in 2003 (MALSIS 1) and 2013 (MALSIS 2). MALSIS 2 values were subtracted from MALSIS 1, such that a positive change demonstrates an increase in electrical conductivity and a negative change suggests a decrease in electrical conductivity. Change in electrical conductivity has been calculated in 141 sites and exists within the following ranges; ≤ -2500uS-1, 1%; >-2500 to -200uS-1, 0%, >-2000 to -1500uS-1, 1%; >-1500 to -1000 uS-1, 1%; >-1000 to -500uS-1, 9%; >-500 to -250uS-1, 13%; >-250 to -1uS-1, 42%; 0uS-1, 0%; 1 to 250uS-1, 20%; >250 to 500uS-1, 7%; >500 to 1000uS-1, 3%; >1000 to 1500uS-1, 0%; >1500uS-1, 3% (figure 2.B). Results suggest that 67% of the locations assessed in 2013 had a lower electrical conductivity than the same locations in 2003. It is worth noting that 82% of the locations subject to reduced conductivity levels have a decrease in electrical conductivity within the range of -1 to -500uS-1.

Figure 2a: Average electrical conductivity values for M1 (2003) as the smaller circles and M2 (2013) values as the larger circles surrounding the smaller (M1) circles.

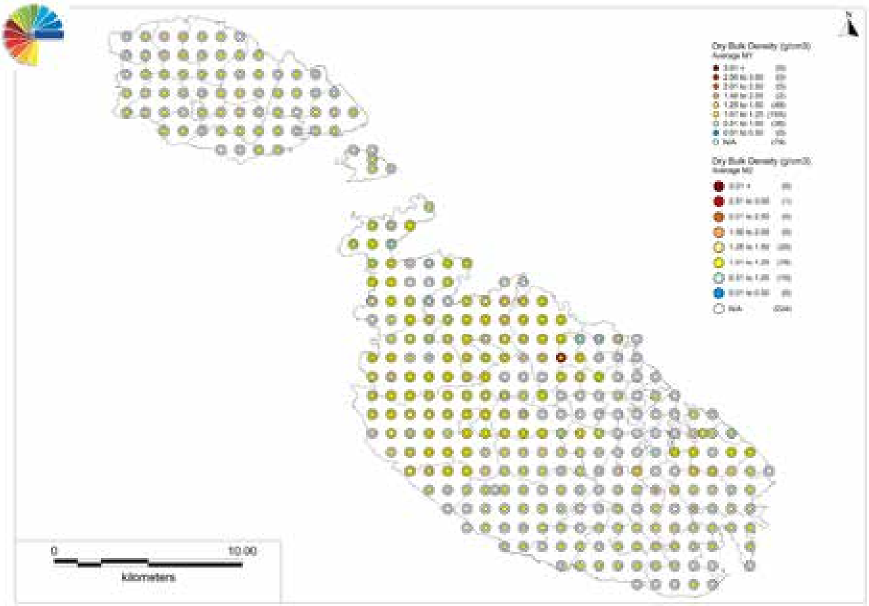
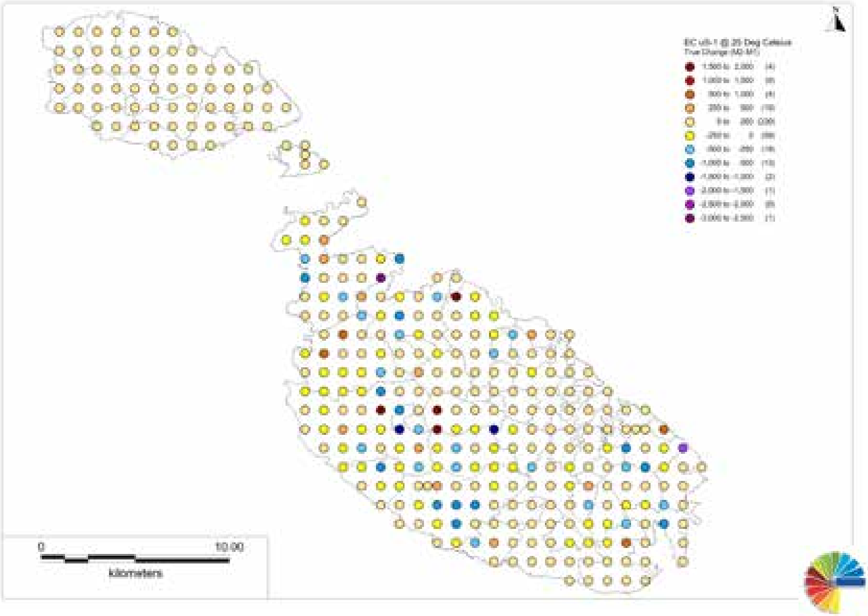


Figure 2b: Change in electrical conductivity between 2003 and 2013 (M2-M1)



The average electrical conductivity of all the sites assessed in 2003 is 518uS-1. The average electrical conductivity for the sites assessed in both 2003 and 2013 (141 sites in total) was of 512uS-1 for 2003 and 430uS-1 for 2013. In view of the national average electrical conductivity, the decline in electrical conductivity observed in 67% of the studied sites is significant. Electrical conductivity is a measure of salinity and is also influenced by soil nitrate levels (Lewandowski et al., 1999). Maltese aquifers are subject to seawater intrusion that results in high levels of chloride concentrations in aquifers (MRA, 2005). Thirteen of the fifteen aquifers have also been reported as being heavily polluted by nitrates, sourced primarily from the excessive use of natural and artificial fertilisers in arable agricultural practices (WCMP for the Maltese Islands, 2011). In view of the treat to aquifer water quality, various programmes were established with the aim of achieving good water quality status. Key amongst these programmes is the Nitrates Action Programme (2011), which proposes various measures that seek to govern the period during which fertilisers are applied and reduce the quantity of fertilisers used in the agricultural sector. Such initiatives may, in part, be an explanation for lower soil electrical conductivity recorded in 2013.

Organic carbon (%)

The organic carbon (%) for the 271 assessed Maltese soils in 2003 (MALSIS 1) fell within the following ranges; ≤1% (very low), 13%; >1 to 1.5 (low), 25%; >1.5 to 2%, 24%; >2 to 5.5% (moderate), 37%; >5.5%, 1%. The average organic carbon for the 70 assessed Maltese soils in 2013 (MALSIS 2) fell within the following ranges; ≤1% (very low), 4%; >1 to 1.5 (low), 17%; >1.5 to 2%, 30%; >2 to 5.5% (moderate), 45%; >5.5%, 4% (Figure 3a).

Change in organic carbon was also assessed for sites where measures in organic carbon were carried out in 2003 (MALSIS 1) and 2013 (MALSIS 2). MALSIS 2 values were subtracted from MALSIS 1, such that a positive change demonstrates an increase in organic carbon and a negative change suggests a decrease in organic carbon. Change in organic carbon has been calculated in 70 sites and exists within the following ranges; ≥2.19%, 3%; <2.19 to 1.20%, 6%, <1.2 to 0.6%, 19%; <0.6 to 0.01%, 31%; 0%, 0%; -0.01 to >-0.6%, 27%; -0.06 to >-1.2%, 9%; -1.2 to >-2.2%, 4%; ≤-2.2%, 1% (Figure 3b). Results suggest that 59% of the locations assessed in 2013 had higher organic carbon content than the same locations in 2003. The average organic carbon of all the sites assessed in 2003 is 1.98%. The average for soil organic carbon content for the sites assessed in both 2003 and 2013 (70 sites in total) was of 2.11% for 2003 and 2.30% for 2013.

Figure 3a: Average organic carbon values for M1 (2003) as the smaller circles and M2 (2013) values as the larger circles surrounding the smaller (M1) circles

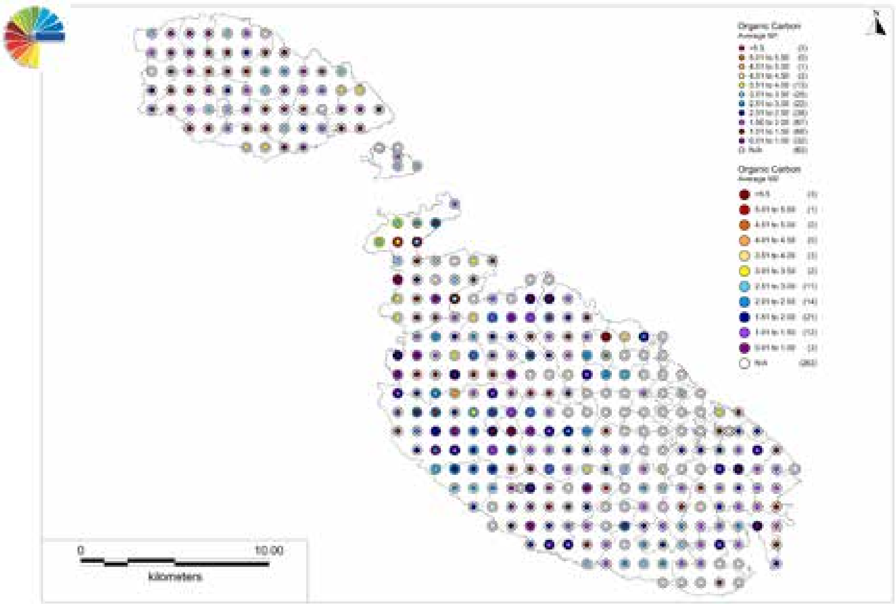
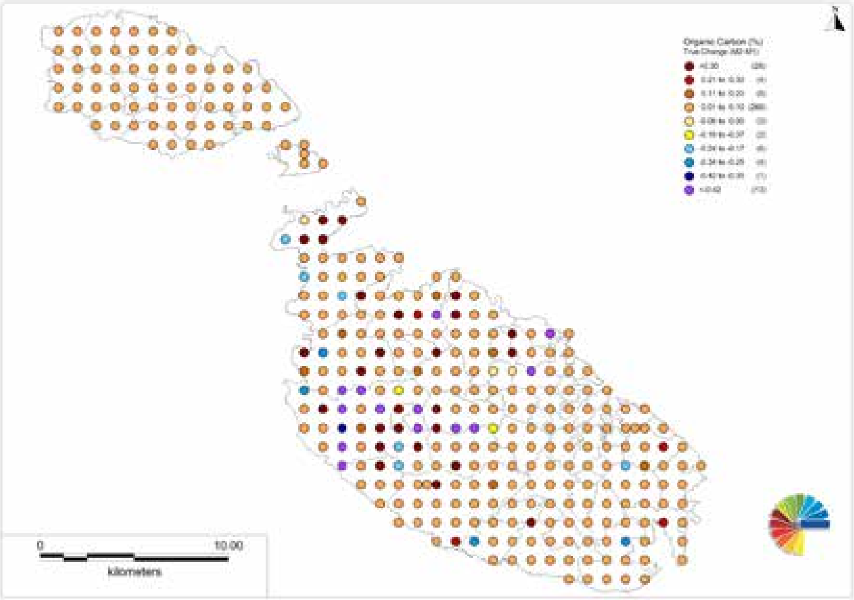


Figure 3b: Change in organic carbon between 2003 and 2013 (M2-M1)

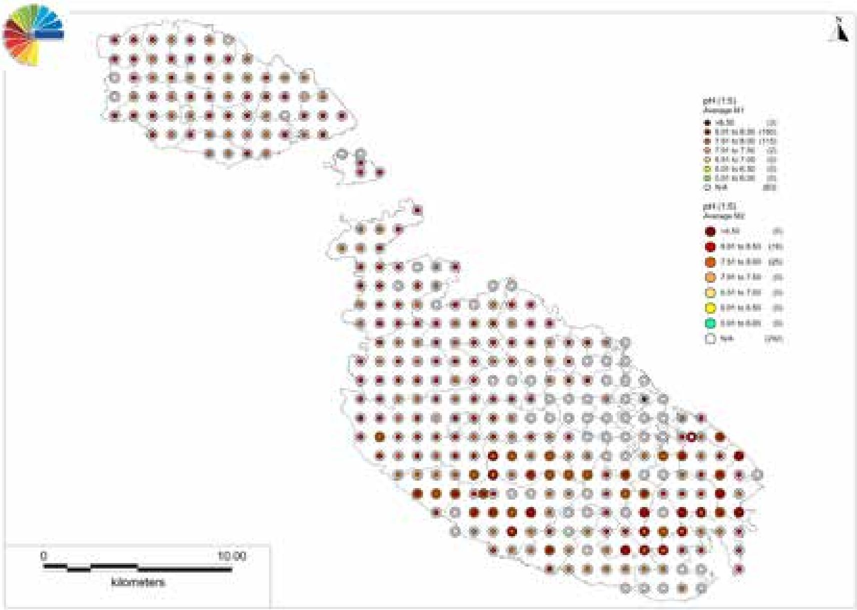


The increase in soil organic carbon strongly and positively influences most of the functions associated with soil quality (Weil et al., 2003). The Rural Development Programme for Malta proposes a number of measures that aim to combat soil degradation, especially in terms of the decline of organic matter and to reduce the level of input of chemical fertiliser. The observed increase in soil organic matter may in part be the result of such initiatives. An additional benefit of an increase in soil organic carbon is that, through carbon sequestration, soil represents a significant sink for atmospheric carbon dioxide (CO2). Climate change mitigation may be enhanced by storing carbon in plant biomass and soils and by reducing emissions from agriculture (Jenkinson & Johnston, 1977; Schlesinger, 1990).

pH (1:5)

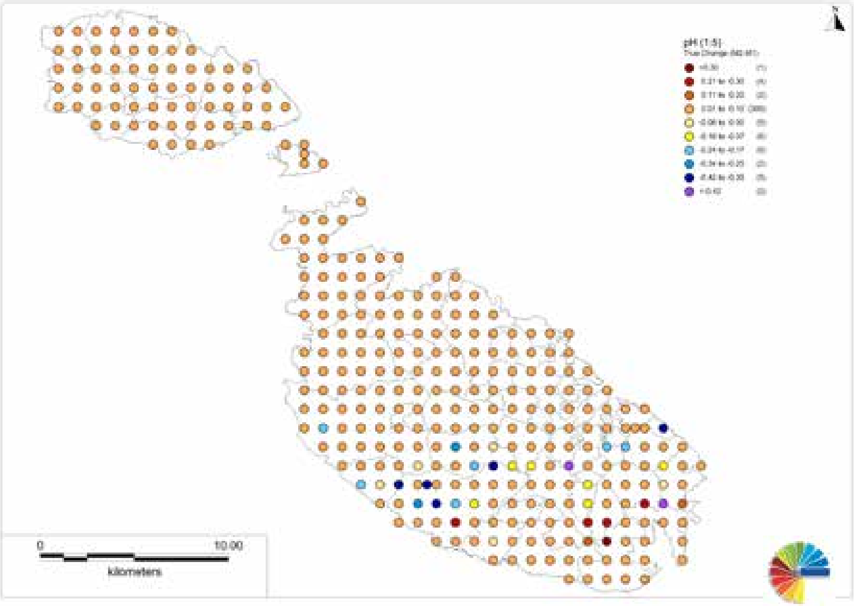
Soil pH (1:5) for the 270 assessed Maltese soils in 2003 (MALSIS 1) fell within the following ranges; >8.5 (alkaline), 1%; 8.5 to >8 (slightly alkaline), 56%; 8 to >7.5, 43%; <7.5, 1%. The average organic carbon for the 41 assessed Maltese soils in 2013 (MALSIS 2) fell within the following ranges; >8.5 (alkaline), 0%; 8.5 to >8 (slightly alkaline), 39%; 8 to >7.5, 61%; <7.5, 0% (Figure 4a).

Figure 4: Average pH values for M1 (2003) as the smaller circles and M2 (2013) values as the larger circles surrounding the smaller (M1) circles



Change in pH was also assessed for sites where measures in pH were carried out in 2003 (MALSIS 1) and 2013 (MALSIS 2). MALSIS 2 values were subtracted from MALSIS 1, such that a positive change demonstrates an increase in pH (becoming alkaline) and a negative change suggests a decrease in pH (becoming acidic). Change in pH has been calculated in 40 sites and exists within the following ranges; ≥0.3%, 3%; <0.3 to 0.2, 8%, <0.2 to 0.12, 5%; <0.12 to 0.01, 20%; 0 to -0.06, 13%, <0.06 to -15, 10%; <-0.15 to -0.24, 18%; <-0.24 to -0.33, 8%; <-0.33, 18%. Results suggest that 65% of the locations assessed in 2013 were more acidic than the same locations in 2003. The average pH (1.5) of all the sites assessed in 2003 is 8.02. The pH (1:5) for the sites assessed in both 2003 and 2013 (40 sites in total) was of 8.01 for 2003 and 7.92 for 2013 (Figure 4b).

Figure 4b: Change in pH between 2003 and 2013 (M2-M1)



Moisture content (%)

Soil moisture for the 270 assessed Maltese soils in 2003 (MALSIS 1) fell within the following ranges; 0 to 2%, 9%; >2 to 4%, 52%; >4 to 6%, 30%; >6 to 10%, 9%; >10%, 0% (Figure 5a). The average organic carbon for the 41 assessed Maltese soils in 2013 (MALSIS 2) fell within the following ranges; 0 to 2%, 1%; >2 to 4%, 42%; >4 to 6%, 39%; >6 to 10%, 15%; >10%, 3% (Figure 5a).

Change in moisture content was also assessed for sites where measures in moisture content were carried out in 2003 (MALSIS 1) and 2013 (MALSIS 2). MALSIS 2 values were subtracted from MALSIS 1, such that a positive change demonstrates an increase in moisture and a negative change suggests a decrease in moisture. Change in moisture content has been calculated in 148 sites and exists within the following ranges; ≥9.2%, 1%; <9.2 to 8%, 1%, <8 to 4, 5%; <4 to 2%, 14%; <2 to 0%, 40%, <-0.01 to -2%, 29%; <-2 to -4%, 9%; <4%, 1% (Figure 5b). Results suggest that 61% of the locations assessed in 2013 had higher soil moisture content than the same locations in 2003. The average soil moisture of all the sites assessed in 2003 is 3.77%. The soil moisture for the sites assessed in both 2003 and 2013 (148 sites in total) was of 3.97% for 2003 and 4.50% for 2013.

Figure 5a: Average moisture content values for M1 (2003) as the smaller circles and M2 (2013) values as the larger circles surrounding the smaller (M1) circles

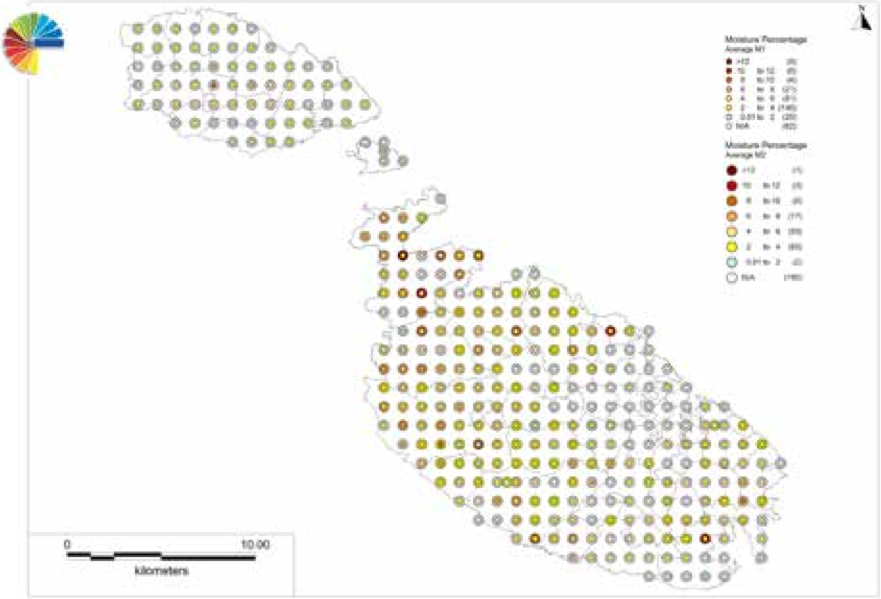
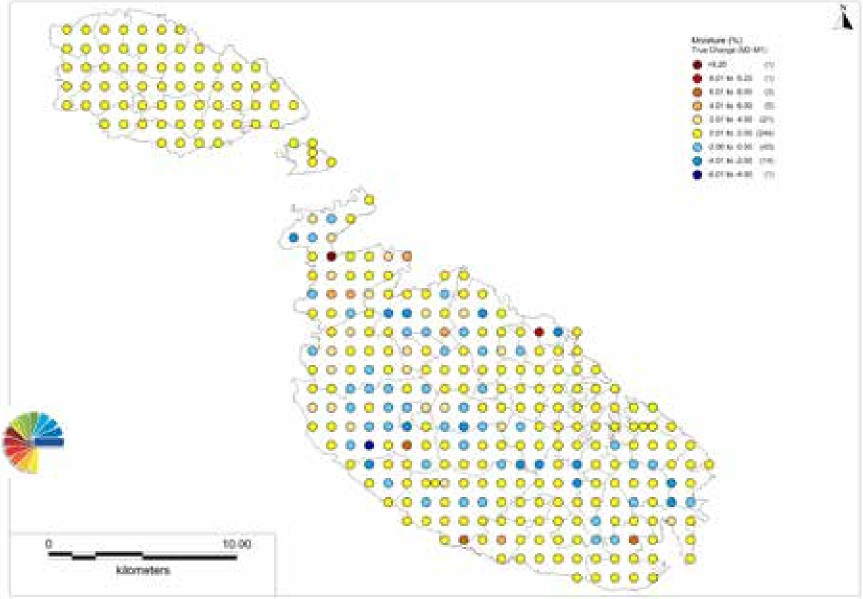


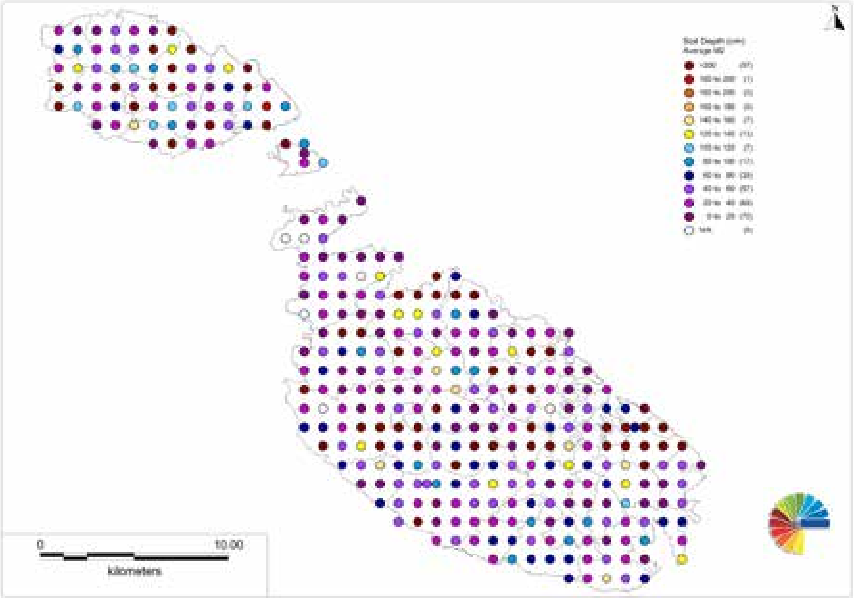
Figure 5b: Change in moisture content between 2003 and 2013 (M2-M1)



Soil depth

Soil depth was not measured in Maltese 2003 (MALSIS 1). In view of the significant lack of systematic quantitative National soil depth data, soil depth was assessed in 343 sites in 2013 (MALSIS 2). The recoded average values fell within the following ranges; 0cm, 2%; >0 to 10cm, 9%; >10 to 20cm, 12%, >20 to 40cm, 20%; >40 to 60cm, 17%; >60 to 100cm, 17%; >100 to <200cm, 7%; >200cm, 17% (Figure 6).

Figure 6: Top figure displays average soil depth values established in M2 (soil depth not calculated in M1)

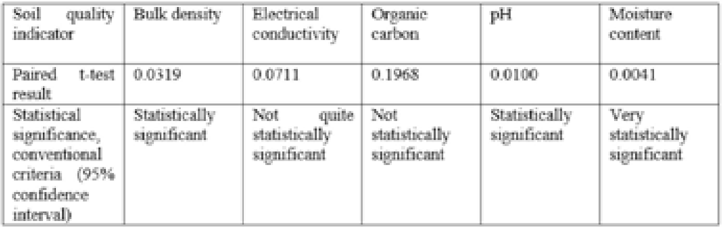


The average National soil depth in areas where soil was recoded and did not exceed 200cm, was of 47.76cm. Shallow soils, less than 10cm in depth, are often associated with plateaus and surfaces subject to soil erosion (e.g. inclined valley sides). Deeper soils, ranging from 10 to 100cm depth, are typically associated with agricultural areas on relatively flat and moderately include surfaces. Agricultural areas containing soil within the aforementioned depth range, located in included valley sides, often retain soil through the construction and maintenance of soil retaining rubble walls. These structures are paramount to maintain soil in place and where absent or not restored, rapid soil erosion ensues (Sultana, 2015). As suggested by Lang (1960), in this study soils deeper than 100cm were only observed in areas associated with valley beds where material eroded in with the catchment is deposited.

Statistical significance (paired t-test)

The paired t-test calculates the difference within each before-and-after pair of measurements, determines the mean of these changes and reports whether this mean of the differences is statistically significant. A paired t-test is used to compare two population means where you have two samples in which observations in one sample can be paired with observations in the other sample. In this study the paired t-test is applied to assess statistical significance of before (M1, 2003) and-after (M2, 2013) observations for each assessed soil indicator. The difference in soil bulk density results is statistically significant, for electrical conductivity is is not quite statistically significant, for organic carbon it is not statistically significant, and for moisture content it is very statistically significant. Results are displayed in Table 1.

Table 1: Statistical significance with the paired-t test



Soil quality indicator	Bulk density	Electrical conductivity	Organic carbon	pH	Moisture content
Paired t-test result	0.0319	0.0711	0.1968	0.0100	0.0041
Statistical significance, conventional criteria (95% confidence interval)	Statistically significant	Not quite statistically significant	Not statistically significant	Statistically significant	Very statistically significant

Conclusions

The sampling locations identified for this study are the same as those studied in MALSIS (2003) and are based on a 1km spaced grid distribution across Malta and Gozo. All grid points located within soil containing natural and agricultural areas were sampled in this study. The study present involved the survey of 280 sites across Malta and Gozo (Figures 1 to 6).

Bulk density change has been calculated in 97sites. Results suggest that 59% of the locations assessed in 2013 had a greater average bulk soil density than the same locations in 2003 i.e. soil compaction is prevalent. The average soil bulk density for the sites assessed in both 2003 and 2013 (97 sites in total) was of 1.12g cm3 for 2003 and 1.17g cm3 for 2013.

Change in electrical conductivity has been calculated in 141 sites. Results suggest that 67% of the locations assessed in 2013 had a lower electrical conductivity than the same locations in 2003. The average electrical conductivity for the sites assessed in both 2003 and 2013 (141 sites in total) was of 512uS-1 for 2003 and 430uS-1 for 2013.

Electrical conductivity is a measure of salinity and is also influenced by soil nitrate levels (Lewandowski et al., 1999). A number of national initiatives, key amongst which may be the Nitrates Action Programme (2011), may, in part, be an explanation for lower soil electrical conductivity recorded in 2013.

Change in organic carbon has been calculated in 70 sites. Results suggest that 59% of the locations assessed in 2013 had higher organic carbon content than the same locations in 2003. The average for soil organic carbon content for the sites assessed in both 2003 and 2013 (70 sites in total) was of 2.11% for 2003 and 2.30% for 2013. The increase in soil organic carbon strongly and positively influences most of the functions associated with soil quality (Weil et al., 2003). An additional benefit of an increase in soil organic carbon is that, through carbon sequestration, soil represents a significant sink for atmospheric carbon dioxide (CO2).

Change in pH has been calculated in 40 sites. Results suggest that 65% of the locations assessed in 2013 were more acidic than the same locations in 2003. The average pH (1.5) of all the sites assessed in 2003 is 8.02.

Change in moisture content has been calculated in 148 sites. Results suggest that 61% of the locations assessed in 2013 had higher soil moisture content than the same locations in 2003. The soil moisture for the sites assessed in both 2003 and 2013 (148 sites in total) was of 3.97% for 2003 and 4.50% for 2013.

Average National soil depth in areas where soil was recoded and did not exceed 200cm, was of 47.76cm. Shallow soils, less than 10cm in depth, are often associated with plateaus and surfaces subject to soil erosion (e.g. inclined valley sides). Deeper soils, ranging from 10 to 100cm depth, are typically associated with agricultural areas on relatively flat and moderately include surfaces. Agricultural areas containing soil within the aforementioned depth range, located in included valley sides, often retain soil through the construction and maintenance of soil retaining rubble walls.

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