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Research Article

Numerical Modelling and Economics of Agricultural Land Degradation in the Maltese Islands

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Abstract. The study applies a new GIS-based numerical modelling approach to calculate the economic burden agricultural land owners suffer through soil erosion land degradation. Numerically modelled soil erosion volumes in Maltese agricultural areas were estimated at 766 278 m^3/yr costing 7.98 M€/yr to replace. The model calculates that the average owner incurs 1170 €/0.01 km^2/yr on soil replacement and soil improvement requirements. With average yearly economic revenue of 1720 €/0.01 km^2/yr, this cost benefit imbalance may force agricultural land owners to not replace eroded soils. Over time, as a result of soil erosion, an increasingly large proportion of agricultural land may no longer suitable for agricultural purposes. Over 50 years, 1.53 km^2 (0.5% of Maltese area) of agricultural land may be depleted of soil, incurring an average national agricultural revenue loss of 0.26 M€ per year.

Soil erosion rates, and associated economic implications, may be mitigated with cost effective management practices. Two such practices include conservation tillage, which offers various economic advantages to farmers, and the restoration of breaches in slope-facing rubble walls in areas subject to soil erosion. The latter may require an investment of 11.94 M€ at the National scale or €1,600 by the average agricultural land owner. Both measures contribute towards the sustainable use of Maltese agricultural areas and maintaining key associated ecosystems services.

Keywords: Malta, agriculture, rUSLE soil erosion, GIS land degradation modelling, economics of land degradation, land use management

1 Introduction

Land degradation is caused by various forces and leads to a significant reduction of the productive capacity of land (Amundson et al., 2015). Various human activities contribute and accelerate land degradation, chief amongst these are unsustainable land use practices and inadequate management of natural resources. Such activities degrade soil quality and reduce the ability of lands to provide various ecosystem services. Ecosystem services can be grouped into four main categories that often form the basis of various economic activities. These are the provisional services that include the production of food and water, regulatory services that control climate, supporting services that include nutrient cycles, and cultural services which offer recreational benefits (e.g. Barrios, 2007; Kibblewhite et al., 2008; Clothier, Hall, Deurer, Green & Mackay, 2011).

Extensive empirical evidence ties land degradation to reductions in the provision of ecosystems services (e.g. Pimentel et al., 1995). Such information has however rarely promoted policy action (Second Scientific Conference United Nations Convention to Combat Desertification (UNCCD), 2013). Rather, a systematic analysis of costs of land degradation and the benefits of preserving ecosystems services has been promoted decision-makers to take steps in achieving land degradation neutrality (e.g. Baumgartner, von Braun, Abebaw & Müller, 2015). This economic-based approach, termed economics of land degradation, provides an economic framework against which decision-makers can appreciate the value of taking action against land degradation (Yesuf, Mekonnen, Kassie & Pender, 2005).

The Maltese Islands are situated in the centre of the Mediterranean Sea, 93 km south of Sicily, 120 km east of the northern coast of Tunisia, and 355 km north of Tripoli (Libya). The Islands have a total land area of 320 km^2 consisting of three principal islands Malta, Gozo and Comino (Figure 1). The Maltese Islands have a semi-arid Mediterranean climate with an average an-

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nual rainfall of 524 mm and an average yearly temperature is 22.5 °C (Malta National Report, 2002).

Agricultural land use covers 48% of the Maltese islands and is its predominant land use (Rural Development Department, 2014). In 2011, the primary productive agriculture and fisheries sectors produced 1.8% of the National gross domestic product (GDP) and in 2010 the agricultural sector employed 10.6% of the financially active Maltese population (Axiak et al., 1998). Agriculture is therefore a key economic production centre and plays a key role in Malta's long-term food-provision (Ministry for Rural Affairs and the Environment, 2007).

Agricultural practices have a significant impact on an area's susceptibility to land degradation (Brasselle, Gaspart & Platteau, 2002). Appropriate management may sustain key ecosystem services and agricultural productivity while inadequate measures may degrade natural resources and reduce crop yields (Axiak et al., 1998).

The Maltese agricultural sector faces significant economic, social and physical challenges that limit agricultural revenue. Such challenges include the relatively small agricultural parcel sizes (an issue exacerbated by land fragmentation) and poor soil quality (Camilleri, 2005). In marginally profitable or entirely uneconomic situations agricultural land is abandoned. In Malta, such scenarios are common in valley margin terraced slopes. These areas require regular maintenance of rubble walls, are difficult to access and are of small size (Rural Development Department, 2014).

In Malta, significant expanses of sloping valley margins were reclaimed for agricultural use. The creation of valley margin terraced slopes involved the use of rubble material for levelling, infilling with soil and the construction of rubble walls to retain soil (Rural Development Department, 2014). The resulting anthropogenic landscape may be maintained under continued agricultural management. However, abandoned terraced fields do not receive the required rubble wall maintenance and consequently soils retained by these structures are rapidly eroded, transported and deposited downslope. This dynamic is eroding the thin soils artificially deposited in the flanks of valleys, and over time reducing the agricultural capacity of such areas. This dynamic demonstrates the importance and need for continued agricultural land management.

The paper aims to quantify the loss in Maltese agricultural provisionary services resulting from soil erosion and its economic consequences. The study provides an 5 economics of land degradation argument that highlights the costs and benefits of action versus inaction towards achieving sustainable agricultural land management. Various cost effective soil conservation methods and management policies aiming to achieve land degradation neutrality are proposed for areas subject to or susceptible towards agricultural land degradation.

2 Methods

2.1 Soil erosion (rUSLE)

The revised Universal Soil Loss Equation provides estimations of potential erosion rates, calculated from empirical and functional relationships between various factors [Equation (1)] (Renard, Foster, Weesies, McCool & Yoder, 1997). Sultana (2015) applies the rUSLE to estimate soil erosion by water in the Maltese Islands for the year 2013. Sultana applied rUSLE into a GIS-based model where input parameters - rainfall erosivity (R), soil erodibility (K), slope length and steepness (LS), cover and management practices (C) and conservation practices (P) (Wischmeier & Smith, 1978) - were prepared separately and stored as GIS vector layers with a cell size of 50×50 m. The aforementioned rUSLE factors were then converted to raster layers with a grid resolution of 50 metres. The reader is referred to Sultana (2015) for a detailed explanation of methods employed and justification of values applied for RUSLE factors.

$$A\left(\mathrm{t\,ha^{-1}\,yr^{-1}}\right) = R \times K \times LS \times C \times P, \tag{1}$$

where, A = average annual soil loss ($\mathrm{t\,ha^{-1}\,yr^{-1}}$), R = rainfall/runoff erosivity ($\mathrm{MJ\,mm\,ha^{-1}\,h^{-1}\,yr^{-1}}$), K = soil erodibility ($\mathrm{t\,h\,MJ^{-1}\,mm^{-1}}$), LS = slope length and steepness (dimensionless), C = cover management (dimensionless), and P = support practice (dimensionless).

This paper focuses on agricultural areas. In view of this, soil erosion rates were exclusively calculated for agricultural areas. The five RUSLE factors – R, K, LS, C and P - were calculated on a cell-by-cell basis following equation (1) with the ArcGIS Spatial Analyst extension. The resulting layer defines average annual soil loss ($\mathrm{t\,ha^{-1}\,yr^{-1}}$) for each cell in the study area for the year 2013.

2.2 National soil depth

Soil depth, surface to bedrock, was measured at a grid distribution of between 0.5 to 1 km (Figure 4) using soil augers. Soil depth was measured in three hundred and thirty locations. In each location, soil depth was measured four times, each measure spaced 1 m east of the previous sampling point. The soil depth vales for each location were averaged and are displayed as point values in the average soil depth map (Figure 4). Average soil depth point values were used to interpolate soil depth between points using the ArcGIS kriging technique. The interpolation technique weighs the surrounding measured soil depth values to derive a predicted value for the unmeasured neighbouring locations. The weights applied in the kriging operation in this study are based

Figure 1: Map of the Maltese Islands (from Ezilon, 2009).

on the distance between the measured points, the values of the closest 8 point values and the prediction locations.

2.3 Soil volume and depth eroded per year

Eroded soil volume was calculated for each cell (50×50 m) [Equation (2)] from the eroded soil mass (variable tonne) obtained for each cell (50×50 m) through the rUSLE method [Equation (1)], and a common average soil density $\left(1.173\,\mathrm{g\,cm^3}\right)$ obtained as an average of 320 national bulk density values (MALta Soil Information System, 2003).

$$V = m \times D, \tag{2}$$

where V = volume $\left(\mathrm{m^3}\right)$, m = mass (kg), and D = density $\left(\mathrm{kg\,m^{-3}}\right)$.

Eroded soil depth was calculated for each cell (50×50 m) [Equation (3)] from the eroded soil volume [Equation (2)] with a common fixed area (50×50 m) for each GIS cell.

$$h = V/A, \tag{3}$$

where h = height (m), V = volume ($\mathrm{m^3}$), and A = area ($\mathrm{m^2}$).

Following the above method, soil erosion of $1\,\mathrm{t\,ha^{-1}\,yr^{-1}}$ (per 50×50 m unit cell) [Equation (1)] is equivalent to a volumetric loss of $0.852\,\mathrm{m^3}$ $\left(1000\,\mathrm{kg}/1173.1\,\mathrm{kg\,m^{-3}}\right)$ [Equation (2)] or a depth loss of 0.008 52 cm $\left(8.524 \times 10^{-10}\,\mathrm{km^3}/0.1\,\mathrm{km^2}\right)$ [Equation (3)]. The volumetric and depth values were applied in cost estimates associated with soil erosion.

3 Calculations and Results

3.1 rUSLE soil erosion model

The rUSLE soil erosion map (Figure 2) shows the spatial distribution of soil loss $\left(\mathrm{t\,ha^{-1}\,yr^{-1}}\right)$ in agricultural areas in the Maltese Islands for the year 2013 (Sultana, 2015). The soil erosion values were classified into eight categories of increasing soil loss severity: < 1 (none), 1 to 2, 2 to 5 (very low), 5 to 10 (low), 10 to 25 (moderate), 25 to 45 (high), 45 to 75 (very high), $> 75\,\mathrm{t\,ha^{-1}\,yr^{-1}}$ (severe). Erosion severity thresholds are in line with those presented by numerous authors (e.g. Šúri, Cebecauer, Hofierka & Fulajtár, 2002; Iraldo et al., 2013).

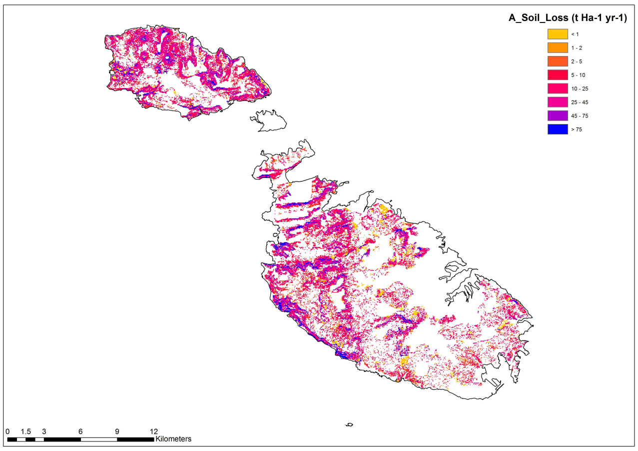


Figure 2: Average soil loss $\left(\mathrm{t\,ha^{-1}\,yr^{-1}}\right)$ in the Maltese Islands in 2013 following RUSLE equation (Sultana, 2015).

3.2 Soil volume lost/year and associated costs

The total calculated [Equation (2)] volume of eroded soil for Maltese agricultural areas in the year 2013 amounts to $766\,278\,\mathrm{m^3}$ (Figure 3). The total volume of soil eroded in 2013 in the local councils most affected by soil erosion has been calculated (Table 1). This information identifies localities that are subject to most severe soil volume loss and helps prioritise management initiatives seeking to reduce soil erosion.

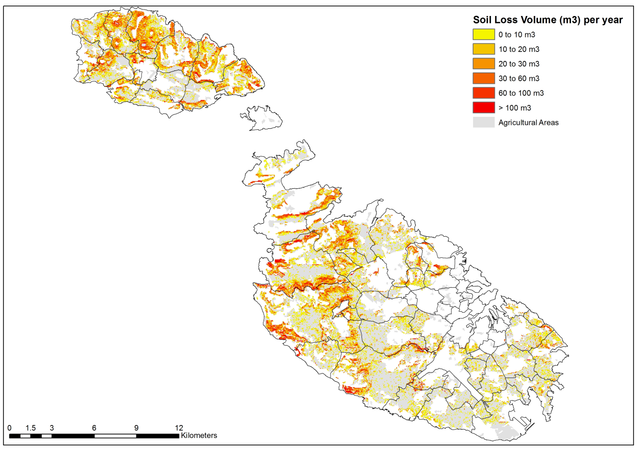


Figure 3: Soil erosion volumes $\left(\mathrm{m^2}\right)$ per cell $\left(0.0025\,\mathrm{km^2}\right)$ for the year 2013 in Malta.

3.3 Soil depth and soil depth lost 1, 10, 50 and 100 years

An interpolation between average soil depth points was carried out via GIS kriging and is calculated on the basis of the closest 8 point values. The resulting National soil depth map (Figure 4) is displayed below.

The depth of soil eroded yearly (2013) in agricultural areas has been calculated at a cell ($50\times50\,\mathrm{m}$) level. The value is obtained from rUSLE defined soil erosion rate $\left(\mathrm{t\,ha^{-1}\,yr^{-1}}\right)$ [Equation (1)], its conversion to soil erosion volume [Equation (2)], and its conversion to depth [Equation (3)]. The calculated yearly soil depth eroded (MSDE) and the National soil depths (NSD) (Figure 4) were superimposed and divided. The resulting value is a proportion (percent) indicating total soil depth eroded (TSDE) relative to initial soil depth [Equation (4)]. The greater the resulting value (the higher the percent value) the less soil remains.

$$TSDE = (MSDE/NSD) \times 100, \tag{4}$$

where $TSDE$ = Total Soil Depth Eroded (%), $MSDE$ = Modelled Soil Depth Eroded (cm), and SD = National Soil Depth (cm).

When the minimum soil depth for agricultural practice is reached, $< 15\,\mathrm{cm}$ soil depth (The National Environment, minimum standards for management of soil quality regulations, 2001), the area is identified as no longer being suitable for agricultural practice. The method defines the aerial extent of agricultural land that will, provided no soil is added, not contain sufficient soil depth to support agricultural practices. The agricultural area will thus be degraded to the point of agricultural unsuitability and be of no agricultural economic revenue (marked as black areas in Figure 5). The analysis has been carried out at various time scales, 1, 100 and 500 years (Figure 5). The resulting reduction in agricultural area has been calculated (Figure 5 and associated tables).

4 Discussion

Maltese central, south-eastern and north-eastern agricultural areas show the lowest erosion risk (Figures 2 and 3). These areas are characterised by relatively flat topographies and adequately maintained soil erosion structures. The ***Maltese north-western and Gozitan*** areas are most susceptible to soil erosion. These zones are characterised by a large range in erosion rates (Figure 2). Within the area, low erosion risk occurs in plateaus comprising low topographic gradients, and the application of good land management and soil erosion control measures. Plateau flanks and valley sides typically demonstrate exceptionally high erosion rates and are characterised by high topographic gradients, inadequate cultivation practices and poor erosion control

Table 1: Local councils and total soil volume eroded by council per year (m^3/yr) in the year 2013 (MT: Malta; GZ: Gozo).

Rabat MT	116502	Kercem	20590	Rabat GZ	9536	Marsaxlokk	4220
Mgarr	86966	Zebbug MT	15317	Ghajnsielem	9342	Iklin	4151
Siggiewi	55514	Mosta	14440	Marsascala	7949	Luqa	3698
Zebbug GZ	49557	Dingli	13834	Zabbar	7635	Xewkija	3593
Mellieha	47386	Gharb	13055	Qrendi	7193	Mdina	3466
Sn Pawl Bhr	43330	Swieqi	11621	Zurrieq	7019	Attard	3441
Nadur	35678	Munxar	11400	Ghargur	6922	Birzebbugia	3162
Xaghra	28408	Sn Lawrenz	11299	Sannat	6644	Ghaxaq	3103
Ghasri	27113	Mqabba	10515	Zejtun	5594	San Gwann	2960
Qala	24908	Naxxar	10295	Qormi	4607	Mtarfa	2483

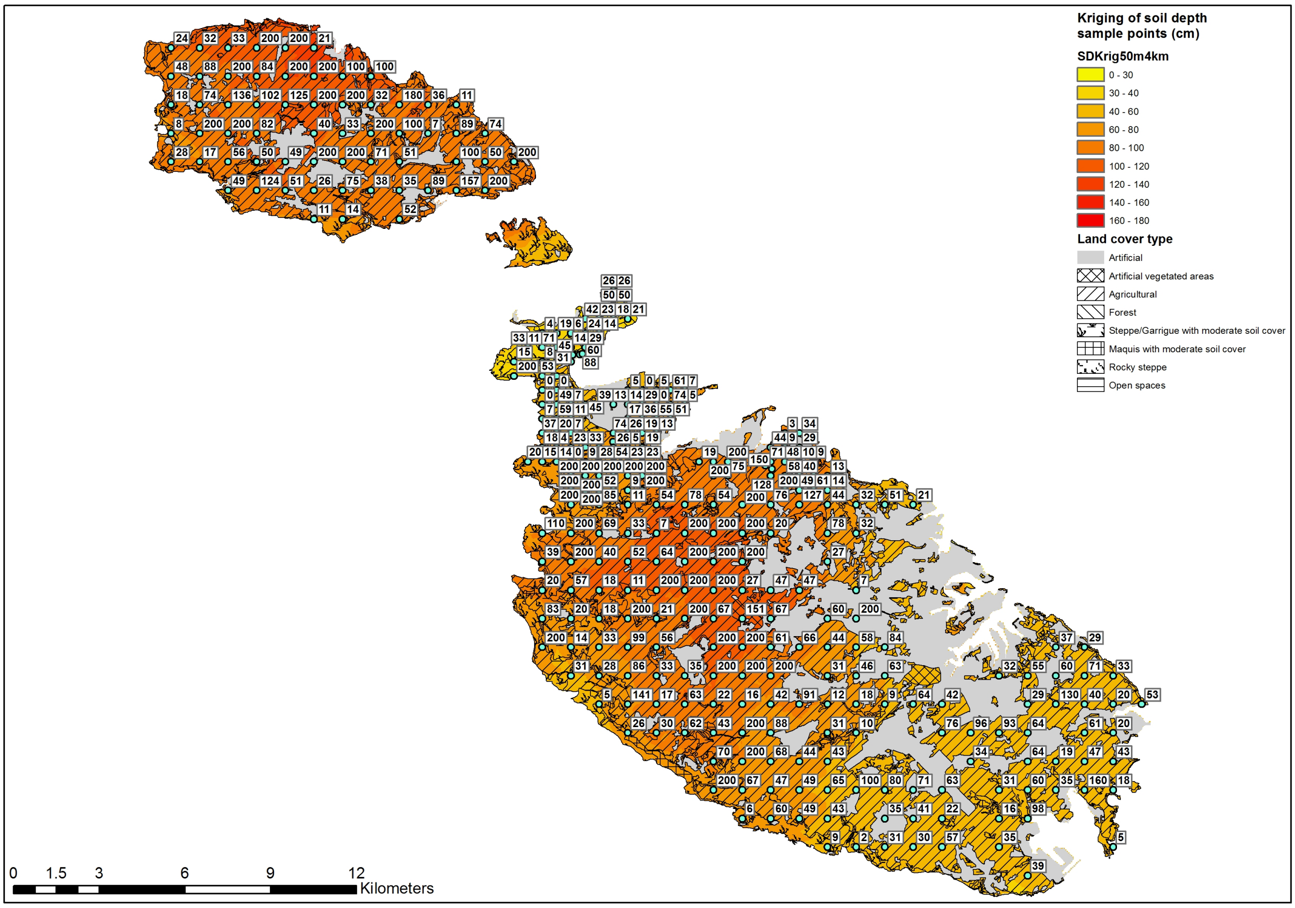
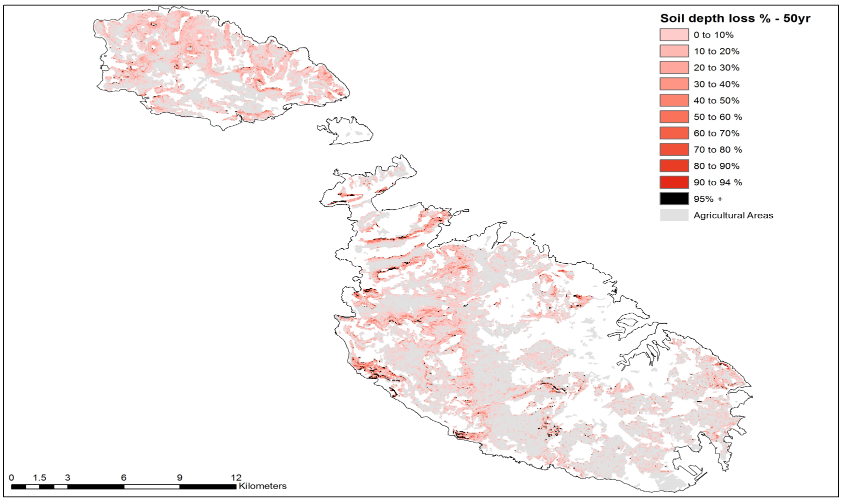


Figure 4: Malta soil depth map. Point values are average soil depth calculated in location. Values between points are interpolated soil depths using ArcGIS kriging technique. *Note, maximum measurable soil depth is* 200 cm*, point values of* 200 cm *indicate soil depths are greater than* 200 cm.

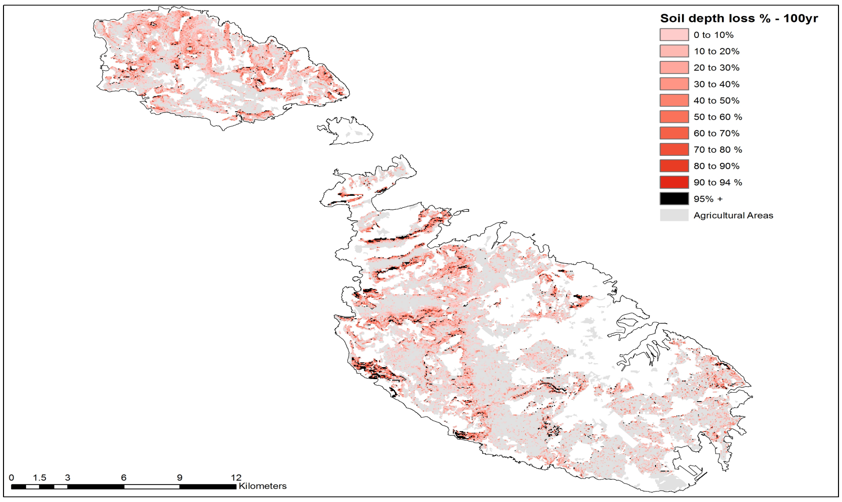
measures.

Maltese agricultural land is subject to various socio-economic conditions that constrain net farm income. Such hindering conditions include increased international agricultural price competition of cheaper costing imported foreign goods. Small agricultural holding size, exacerbated by land fragmentation, and an Agricultural Leases (Re-letting) Act, that does not facilitate the change of land ownership, further constrain potential agriculture income.

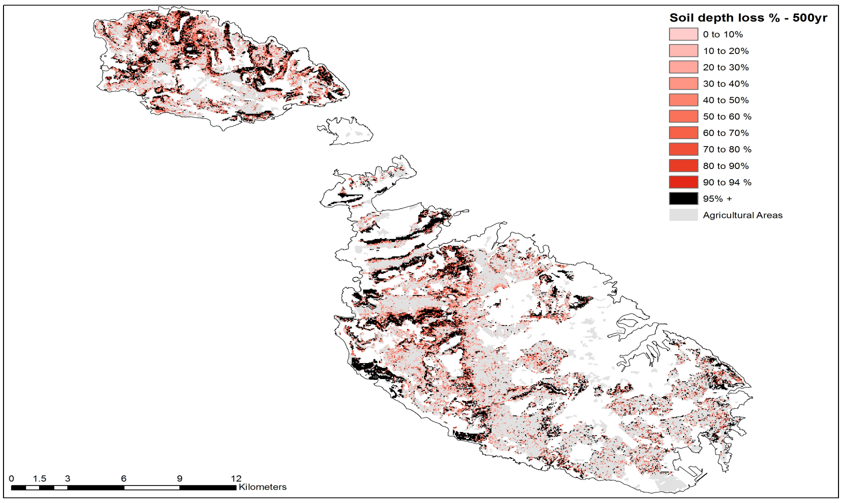
As a consequence of the aforementioned traditional and modern economic constraints, a number of agricultural areas, once financially viable, are now less so. Having lost their economic potential, marginally profitable agricultural areas were abandoned. In Malta, such areas are common in valley margin terraced slopes which



50 year % soil depth removed	Area (km^2)
0–10%	41.32
10–20%	17.19
20–30%	6.66
30–40%	3.20
40–50%	1.81
50–60%	1.14
60–70%	0.74
70–80%	0.52
80–90%	0.42
90–94%	0.10
95%+	**1.53**
% MT agric. area lost	**0.5**



100 year % soil depth removed	Area (km^2)
0–10%	19.62
10–20%	21.75
20–30%	10.83
30–40%	6.35
40–50%	3.97
50–60%	2.67
60–70%	1.97
70–80%	1.23
80–90%	1.05
90–94%	0.29
95%+	**4.90**
% MT agric. area lost	**1.6**



500 year % soil depth removed	Area (km^2)
0–10%	0.10
10–20%	1.82
20–30%	5.19
30–40%	6.10
40–50%	6.41
50–60%	5.58
60–70%	5.02
70–80%	4.34
80–90%	3.43
90–94%	1.36
95%+	**35.28**
% MT agric. area lost	**11.2**

Figure 5: 50, 100, 500 year (top to bottom) erosion maps showing % (of total) soil depth eroded. Area in black marks agricultural land with 95%+ soil eroded; considered as containing insufficient soil depth to support agricultural practices. Tables to the right of images indicate the total National land area affected by the soil loss percentage category.

contain soil retaining rubble walls. These structures require regular maintenance, which is no longer carried out when agricultural land is abandoned. As soil retaining rubble walls on sloping surfaces deteriorate they are breached and gravitational processes rapidly transport the retained soils downslope to more stable areas. As a consequence of the above interacting factors, soil erosion has been identified as a prevailing land degradation process that poses a significant threat to continued agricultural land use (Tanti, Role, Borg. C. & Calleja, 2002; Sultana, 2015).

Eroded soil can be deposited downslope, either in low gradient areas or in valleys, particularly where water retaining structures are present. Soil deposited in dams and reservoirs reduce water retention capacity and require dredging. These activities incur a cost; termed off-site cost (Section 4.1). To ensure continued sustainable agricultural land use, eroded soils need to be replaced. This process increases farming costs and reduces net agricultural earnings. In addition to soil replenishment, soil erosion degrades the remaining *in situ* soil requiring the addition of chemical soil supplements to maintain crop yields (Pimentel et al., 1995). These costs are termed on-site costs (Section 4.2).

4.1 Off-site costs

Between the years 2011 to 2013 the National valley management unit cleared 12 708 m^3 of rubble type material and 9492 m^3 of soil sediment eroded from catchment areas and deposited in valleys, dams and reservoirs. The sediment clearing works represent a fraction of the total sediment deposited yearly in various sediment depocenters. These works carry a direct cost, associated with the dredging of such material, and an indirect cost, tied to reduced drainage capacity and consequent flood related damages. While the National dredging works budget is not known, it is clear that should soil erosion rates be reduced, the budgetary allocations to maintenance works on previously dredged areas is less required. Funds could instead be redirected to dredging previously unmaintained channels.

4.2 On-site costs

4.2.1 Volume of soil erosion

A number of local private agencies were contacted by the authors enquiring on the price of 1 m^3 of soil. The author was informed that soil prices ranged depending on; soil quality (most often soil is described as a mixture of soil present in various construction sites), whether soil shall be transported to location by seller or buyer, and accessibility of deposition site (if less accessible, smaller transport vehicles and more journeys may be required). Quoted soil prices per meter cubed, including VAT, ranged from 7.34 €/m^3 when the buyer transports, 10.42 €/m^3 when the seller transports, and 12.80 €/m^3 when the seller transports soil to locations of limited accessibility (personal communication). A 10.42 €/m^3 soil price, likely to represent costs incurred by farmers, is applied in our calculations.

The calculated total soil volume eroded annually in National agricultural areas amounts to 766 278 m^3. Applying the 10.42 €/m^3 soil prices, the national cost for replacing eroded soil in agricultural areas is 7.98 M€/yr. Applying the same soil price, the average soil volume $\left(\mathrm{m}^3\right)$ eroded per unit area $\left(0.0025\,\mathrm{km}^2\right)$ (Table 2, column B) in the most affected agricultural areas (Table 2, column A) has been calculated. The standard deviation of soil erosion volumes $\left(\mathrm{m}^3\right)$ for the listed affected agricultural area is also provided (Table 2, column C). The average soil volume $\left(\mathrm{m}^3\right)$ eroded per unit area value (Table 2, column B) allows agricultural land owners to calculate the average monetary costs (Table 2, column D) incurred to replace eroded soil per 0.0025 km^2 in zones affected by erosion (Figure 3). The replacement of eroded soil is necessary to maintain agricultural areas subject to erosion.

The 2010 Malta agricultural census indicates that 74% of total utilised agricultural area (UAA) consists of agricultural holdings covering less than 0.01 km^2, and 24% consists of medium-size holdings with a land area between 0.01 to 0.05 km^2 (Rural Development Department, 2014). Applying the 10.42 €/m^3 soil prices, the average monetary cost to replace eroded soil per average agricultural holding/parcel size $\left(0.01\,\mathrm{km}^2\right)$ is calculated (Table 2, column E) for the areas most affected by soil erosion (Figure 3).

The average agricultural land owner, managing an average sized agricultural field $\left(0.01\,\mathrm{km}^2\right)$ in an area subject to soil erosion (Figure 3), suffers a yearly expense ranging from 400 €/0.01 km^2/yr to 2585 €/0.01 km^2/yr (Mtarfa) averaging at of 994.56 €/0.01 km^2/yr on soil replacements (Table 2).

4.2.2 Erosion negatively affects soil quality

The impact soil erosion has on productivity and non-point source pollution is well known (Lal, 2003). Soil erosion by water removes valuable topsoil, rich in low density organic carbon, nitrates, phosphates and potassium. With increased soil erosion soil quality, associated with nutrient quantity, decreases. This has significant adverse impacts on agricultural yield (Verity & Anderson, 1990).

National soil erosion by water reduces soil quality and consequently reduces crop yield. Farmers aiming to maintain agricultural productivity incur costs to artificially restore eroded soil nutrients. National records indicate that Maltese farmers have spent 1.90 M€ (2010), 1.93 M€ (2011) and 2.00 M€ (2012) on fertilisers and soil improvers (National Statistics Office, 2012). Assum-

Table 2: Forty four (of the sixty seven) localities affected by highest soil erosion rates. A: localities affected by soil erosion; B: yearly average soil loss volume (m^3) per unit area $(0.0025\,km^2)$ in affected eroded areas; C: standard deviation of soil erosion volumes per affected area in the locality; D: average monetary costs incurred by the farmers to replace lost eroded soil per $0.0025\,km^2$ in zones affected by erosion; E: average monetary cost incurred by agricultural land owner to replace eroded soil per average agricultural holding/ parcel size cell $(0.01\,km^2)$ located within affected eroded areas. *Agricultural owners tending areas subject to soil erosion incur an average yearly soil replacement cost of* 248.64 €/0.0025 km^2/yr *(minimum* 100.04 €/0.0025 km^2/yr, *maximum* 646.28 €/0.0025 km^2/yr*) and an average yearly cost on soil improvers, necessary to artificially maintain soil quality, of* 43.67 €/0.0025 km^2/yr.

A	B	C	D	E	A	B	C	D	E
Mtarfa	62.08	60.61	646.28	2,585.12	Sn Gwann	23.12	44.95	240.72	962.86
Mqabba	59.74	147.25	621.94	2,487.78	Sn Pawl Bhr	23.05	23.99	239.93	959.71
Marsa	50.20	32.30	522.54	2,090.16	Ghajnsielem	22.68	23.87	236.05	944.20
Swieqi	48.22	128.58	501.96	2,007.83	Santa Lucija	22.42	42.06	233.44	933.74
Fgura	38.31	22.25	398.83	1,595.33	Sannat	22.07	51.38	229.76	919.05
Mgarr MT	35.67	49.60	371.34	1,485.34	Qrendi	21.73	75.70	226.21	904.84
Sn Lawrenz	35.20	98.84	366.41	1,465.64	Zebbug MT	21.63	40.07	225.21	900.84
Rabat GZ	33.23	43.13	345.89	1,383.57	Mdina	21.53	21.90	224.12	896.48
Rabat MT	29.61	53.14	308.28	1,233.14	Kirkop	19.47	16.34	202.65	810.59
Mellieha	29.32	50.35	305.25	1,221.02	Kalkara	19.14	17.04	199.21	796.83
Nadur	28.96	34.87	301.47	1,205.88	Zejrun	18.59	60.01	193.48	773.91
Siggiewi	28.90	51.20	300.83	1,203.32	Gharb	17.83	20.17	185.66	742.63
Fontana	28.30	35.55	294.58	1,178.31	Iklin	17.66	31.55	183.89	735.56
Gharghur	27.80	25.86	289.40	1,157.60	Zabbar	16.74	18.45	174.30	697.18
Mosta	27.40	106.12	285.24	1,140.96	Luqa	16.43	17.87	171.08	684.32
Zebbug GZ	27.21	27.69	283.30	1,133.21	Birkirkara	16.26	19.57	169.23	676.93
Dingli	27.02	68.36	281.28	1,125.12	Xewkija	16.04	21.88	166.98	667.93
Munxar	25.79	36.62	268.48	1,073.92	Marsascala	15.40	19.78	160.37	641.46
Qala	25.26	26.15	262.98	1,051.91	Marsaxlokk	15.40	31.76	160.32	641.29
Xaghra	25.21	45.69	262.40	1,049.62	Qormi	15.15	17.65	157.74	630.97
Ghasri	25.06	31.65	260.86	1,043.44	Pembroke	15.03	16.35	156.48	625.91
Kercem	24.54	32.99	255.47	1,021.89	Xghajra	15.00	15.87	156.10	624.40

ing an even application of fertilisers and soil improvers throughout the Maltese utilised agricultural area (UAA) $(114.5\,km^2)$, an average cost of 17 467.25 €/km^2 is calculated. The average cost on fertilisers and soil improvers incurred by the typical agriculture land owner $(0.01\,km^2)$ is 174.67 €/0.01 km^2/yr. Should management practices, reducing soil erosion, be introduced, these costs could be diminished.

4.2.3 Costs of action; maintain state of affair in affected areas

To maintain the current state of affairs - in terms of quantity and quality - in agricultural areas affected by soil erosion, eroded soil must be replaced and soil quality maintained. The average agricultural land owner $(0.01\,km^2)$, managing an average sized agricultural field in an area subject to soil erosion (Figure 3), suffers an average yearly expense of 1169.24 €/0.01 km^2/yr on replacing eroded soil (minimum 400.18, average 994.56 and maximum 2585.12 €/0.01 km^2/yr) and artificially maintaining soil quality (average 174.68 €/0.01 km^2/yr).

The yearly cost incurred by the average agricultural farmer to replace eroded soils and artificially maintain soil quality in erosion affected areas amounts to 1169.24 €/0.01 km^2/yr. The average yearly economic revenue from Maltese UAA is 1719.65 €/0.01 km^2. Therefore the gain of an agricultural land owner who undertakes measures to address soil erosion would be 550 €/0.01 km^2/yr. In view of this cost and benefit imbalance, various agricultural land owners may consider the price tied to replacing eroded soils in areas subject to soil erosion too high in relation to economic revenue. As a result, the owners of agricultural land in erosion prone areas (Figure 3) may choose not to replace soil lost through erosion. Over time, dependent on soil erosion rate and soil depth present, the agricultural area may be degraded to such an extent as to no longer be suitable for agricultural purposes. The effects of no soil replacement scenarios – *do nothing scenario* (Section 4.2.4) - on total agricultural area over various times scales are shown in Figure 5.

4.2.4 Costs of inaction; the do nothing scenario

Soil is formed over long periods of time and is therefore considered a finite resource. Nationally, soil is of moderate depth in agricultural areas (Figure 4). In situations where eroded soil is not replaced (do nothing scenario), soil resource will eventually be depleted and consequently unsuitable for agricultural production. The time taken for soil depletion depends on *in situ* soil depth and soil erosion rate. To calculate the economic costs of the do nothing scenario, associated with the loss of agricultural land through soil erosion, a number of assumptions must be made (i) UAA produce equal income, (ii) no soil is added to the eroded agricultural areas, and (iii) only registered agricultural income is considered. Following these assumptions, an average agricultural cost can be attributed for a defined agricultural area.

Fresh vegetables and fruit that passed through organised markets in 2012 amounted to 41.24 Mkg yielding a wholesale value of 19.69 M€ (National Statistics Office, 2012). Malta UAA covers 114.5 km^2. Based on these values each square kilometre of Maltese UAA generated on average 171 965 €/yr in 2012 (0.172 M€/km^2/yr).

Results defining the aerial extent of agricultural land that will, provided no soil is added (do nothing scenario), be agriculturally degraded to the point of agricultural unsuitability (marked as black areas in Figure 5). Three time scales were assessed; 1, 100 and 500 years. Over 50 years, 1.53 km^2 (0.5% of Maltese area) of agricultural land is depleted of soil, incurring a loss of national agricultural potential amounting to 0.263 M€/yr; over 100 years, 4.9 km^2 (1.6% of Maltese area) of agricultural land is depleted of soil, incurring a national agricultural loss of 0.843 M€/yr and over 500 years, 35.28 km^2 (11.2% of Maltese area) of agricultural land is depleted of soil, incurring a national agricultural loss of 6.067 M€/yr.

4.3 Cost effective soil conservation measures

Soil erosion rates, and associated economic implications, can be mitigated with cost effective agricultural cover and management practices. Soil conservation practices may be cheaper to set up and maintain than the continuous replacement of eroded soils. This approach increases the economic viability of agricultural exploits within areas subject to soil erosion and ensures sustainable, continued, use of such areas.

Soil degradation is the result of soil displacement, erosion, or soil chemical and physical degradation (Land and Water Development Division Soil Resources, Management and Conservation Service & of the United Nations, 1998). Water driven soil degradation is intensified when vegetation bare sloping soil surfaces are exposed to rainfall that exceeds infiltration rate. Such scenarios increase surface-water runoff and many researchers observe a direct link between soil erosion rate and runoff intensity (e.g. Pruski & Nearing, 2002; Keppeler, Lewis & Lisle, 2003; Safriel et al., 2003). Soil conservation measures seek to dissipate water-runoff energy or increase water infiltration rate and consequently reduce the effects of soil erosion (Food and Agriculture Organisation, 1983, 1994; Hudson, 1992, 1981; Morgan, 1986; Schwab, Frevert, Edminster & Barnes, 1981).

4.3.1 No till technique

The majority of farmers plough their land prior to sowing their crops. Tillage with a mouldboard plough for instance, commonly used in Maltese agriculture, overturns the top 15 to 25 cm of soil exposing soil to erosion by wind and water (Huggins & Reganold, 2008). Montgomery (2007) argues tillage is a principal cause of agricultural land degradation.

Conservation tillage and no-till farming techniques seek to minimise soil disruption and retain at least 30% of the previous crop residues. Crop residue, left on the fields after harvest, helps increase water infiltration and reduces run-off. This process protects soil from erosion and promotes soil productivity. By reducing evaporation, crop residues also facilitate water conservation. In water scarce situations, greater water availability can lead to higher crop yields (Huggins & Reganold, 2008). In 2004 close to 40% of American cropland was farmed through conservation tillage. Reports from the United States Department of Agriculture indicate that such practices enriched agricultural soil organic material, reduced soil erosion, and improved soil water balance (Huggins & Reganold, 2008).

In addition to higher crop production, conservation and no-till methods provide farmers with direct economic incentives. Conservation and no-till techniques require fewer passes over a field and consequently, less fuel (50 to 80%) and less labour (30 to 50%) are required. This may significantly lowering production costs increasing agricultural return on investment (Huggins & Reganold, 2008).

4.3.2 Retaining rubble walls

Through the construction of terraced fields, upheld by retaining dry rubble walls, traditional Maltese agricultural practices have decreases field gradients and reduced soil erosion (Role, 2002). When properly constructed rubble walls are highly effective at retaining large volumes of soil while allowing appropriate soil drainage (Role, 2002).

As evidenced by field observations of rubble wall state (Sultana, 2015), terraced fields that are not regularly maintained develop rubble wall breaches. Gravitational processes then transport large volumes of soils to more stable down-slope areas. If breaches are not attended to, they rapidly widen, develop large collapses and soil mass erosion follows. Terraced fields and associated rubble walls must be perceived as a necessary soil conservation method essential for the sustained production of agricultural capital in areas subject to soil erosion (Figure 3).

A 2013 rubble wall state survey (Sultana, 2015) indicates that the majority of contour parallel rubble walls within terraced fields are in a moderate to poor state (Figure 6). Agricultural rubble walls in terraced field in a moderate state contain between 1 to 3 breaches that expose half the soil profile, and rubble walls in a poor state either contain more than 3 breaches or contain 1 breach that exposes the entire soil profile (Sultana, 2015).

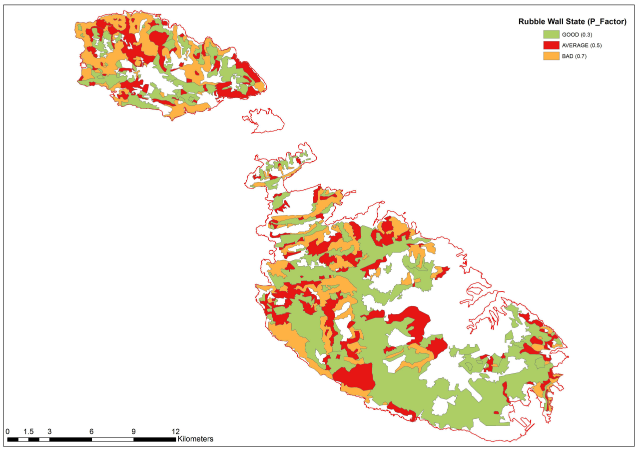


Figure 6: Map showing rubble wall state (Sultana, 2015). Note white areas represent urban areas that contain no rubble walls.

To be able to estimate the costs of restoring rubble walls in agricultural areas subject to soil erosion, a number of local rubble wall construction contractors were asked to supply a quotation based on the following specifications; (i) terraced fields (soil retained behind rubble wall) located in Rabat Malta, accessible through a countryside lane, (ii) rubble wall section to be built 5 m length, 0.5 m in width and 1.5 m in height, (iii) constructed following typical methods (outlined in Maltese L.N. 169 of 2004), and (iv) 50% of rubble material provided by contractor and transported to site. The quoted price averaged at €400 (personal communications).

Maltese sloping agricultural areas have been engineered into rectangular shaped terraced fields with contour parallel soil retaining rubble walls. Nationally, an area of 74.61 km^2 has been numerically identified as being subject to soil erosion. In the RUSLE model, amongst other factors, soil erosion is significantly influenced by management factor (rubble wall state) and slope factors (gradient). The affected areas likely represent sloping agricultural fields. Taking an average terraced field dimension of 100 m wide by 50 m deep and considering moderate state rubble walls, two breaches per terraced field, the Nation requires an investment of 11.94 M€ for the restoration of breaches in slope-facing rubble walls. The investment, while substantial, will reduce soil erosion in these areas thereby allowing agricultural practices to be continued and essential ecosystems services maintained.

The average Maltese farmer owns an agricultural field 0.01 km^2 in area. Taking an average terraced field dimension of 100 m long by 50 m wide, each farmer owns two tiers of terraced field containing a 200 m long section of slope-facing soil retaining rubble walls. Considering state rubble walls in a moderate state, two breaches per terraced field, the average agricultural farmer requires an investment of €1,600 for the restoration of four breaches in slope-facing rubble walls. The farmer may distribute these costs over time, and other than minor restorations from time to time, the farmer is unlikely to require such substantial investment in the future.

In view of the average yearly economic revenue from Maltese UAA $\left(1719.65\,€/0.01\,\mathrm{km}^2/\mathrm{yr}\right)$, the initial rubble wall restoration investment is considerable. The annual return on investment is however substantial. Rubble wall restoration will reduce an agricultural farmer's average yearly expense (in agricultural areas affected by soil erosion) by 1169.24 $€/0.01\,\mathrm{km}^2/\mathrm{yr}$. These reduced costs are associated with spared costs to replace eroded soils and artificially maintain soil quality. Also, on longer time scales (Figure 5), the investment in rubble wall restorations will also preserve agricultural areas subject to erosion for long term sustainable use.

5 Conclusions

Land degradation is caused by various forces and leads to a significant reduction of the productive capacity of land (Amundson et al., 2015). Various human activities contribute and accelerate land degradation, which degrade soil quality and reduce the ability of lands to provide various ecosystem services.

Extensive empirical evidence Information tying on land and soil degradation to reductions in the provision of ecosystems services has however rarely promoted policy action. An economic-based approach, termed economics of land degradation, has been shown to be more successful. Such an approach provides an economic framework against which decision-makers can appreciate the value of taking action against land degradation.

Maltese agricultural land is subject to various socio-economic conditions that constrain net farm income. As a consequence a number of agricultural areas, once financially viable, are now less so. Having lost their economic potential, with such changes in socio-economic dynamics, the economic incentive for tending these marginally profitable agricultural areas fields was lost and the fields were abandoned.

In Malta, such areas are common in valley margin terraced slopes which contain soil retaining rubble walls. These structures require regular maintenance, which is no longer carried out when agricultural land is abandoned. Sultana (2015) argues that various socio-economic factors contribute towards agricultural land abandonment and the consequent deterioration of soil retaining structures. As Once soil retaining rubble walls on sloping surfaces deteriorate they are breached and, natural dynamics dominate and gravitational processes rapidly transport the retained soils downslope to more stable areas. This process limits the national agricultural economic potential and also deteriorates associated ecosystem services.

The calculated total soil volume eroded annually in National agricultural areas at the nationally level amounts to $766\,278\,\mathrm{m}^3$. The national cost for replacing eroded soil in agricultural areas is 7.98 M€/yr. The yearly cost incurred by the average agricultural farmer to replace eroded soils and artificially maintain soil quality in erosion affected areas amounts to 1169.24 €/$0.01\,\mathrm{km}^2$/yr. The average yearly economic revenue from Maltese UAA is 1719.65 €/$0.01\,\mathrm{km}^2$ (Section 4.2.3). Therefore the gain of an agricultural land owner who undertakes measures to address soil erosion would be 550 €/$0.01\,\mathrm{km}^2$/yr. In view of this cost and benefit imbalance, various agricultural land owners may consider the price tied to replacing eroded soils in areas subject to soil erosion too high in relation to economic revenue. As a result, the owners of agricultural land in erosion prone areas (Figure 3) may choose not to replace soil lost through erosion. Over time, dependent on soil erosion rate and soil depth present, the agricultural area may be degraded to such an extent as to no longer be suitable for agricultural purposes.

Results defining the aerial extent of agricultural land that will, provided no soil is added (do nothing scenario), be agriculturally degraded to the point of agricultural unsuitability (marked as black areas in Figure 5). Three time scales were assessed; 1, 100 and 500 years. Over 50 years, $1.53\,\mathrm{km}^2$ (0.5% of Maltese area) of agricultural land is depleted of soil, incurring a loss of national agricultural potential amounting to 0.263 M€/yr; over 100 years, $4.9\,\mathrm{km}^2$ (1.6% of Maltese area) of agricultural land is depleted of soil, incurring a national agricultural loss of 0.843 M€/yr and over 500 years, $35.28\,\mathrm{km}^2$ (11.2% of Maltese area) of agricultural land is depleted of soil, incurring a national agricultural loss of 6.067 M€/yr.

Soil erosion rates, and associated economic implications, can be mitigated with cost effective agricultural cover and management practices. Soil conservation practices may be cheaper to set up and maintain than the continuous replacement of eroded soils. This approach increases the economic viability of agricultural exploits within areas subject to soil erosion and ensures sustainable, continued, use of such areas. Two cost-effective agricultural management methods are proposed to reduce soil erosion, maintain soil quality and preserve agriculture associated ecosystem services. The first, conservation tillage and no-till farming techniques, seek to minimise soil disruption and retain at least 30% of the previous crop residues. This process protects soil from erosion and promotes soil productivity and also provides farmers with various direct economic incentives.

The second is the restoration and maintenance of soil retaining rubble walls. Taking an average terraced field dimension of 100 m wide by 50 m deep and considering moderate state rubble walls, two breaches per terraced field, the Nation requires an investment of 11.94 M€ for the restoration of breaches in slope-facing rubble walls. Should the restoration be carried out by the average agricultural farmer, an investment of €1,600 would be required. In both cases, while the initial rubble wall restoration investment is considerable, the annual return on investment is substantial. The investment, while substantial, will reduce soil erosion in these areas thereby allowing agricultural practices to be continued and essential ecosystems services maintained.

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