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Agricultural land abandonment in Mediterranean environment provides ecosystem services via soil carbon sequestration

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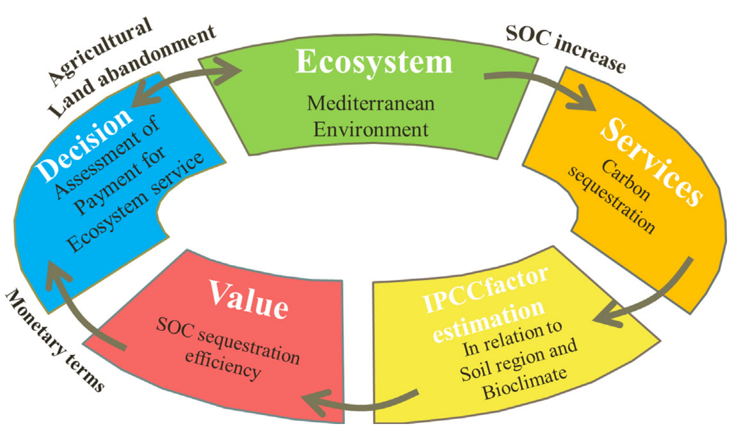
HIGHLIGHTS

- SOC after agricultural land abandonment was affected by Soil Region and Bioclimate.
- IPCC factors were calculated for Soil Region ∗ Bioclimate interaction.
- C stored in abandoned soil would offset of 6% of the agriculture Sicilian emissions.
- Agro Environmental measures must be site specific to improve payments efficiency.

GRAPHICAL ABSTRACT



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ABSTRACT

Abandonment of agricultural land leads to several consequences for ecosystem functions. Agricultural abandonment may be a significant and low cost strategy for carbon sequestration and mitigation of anthropogenic CO_2 emissions due to the vegetation recovery and increase in soil organic matter. The aim of this study was to: (i) estimate the influence of different Soil Regions (areas characterized by a typical climate and parent material association) and Bioclimates (zones with homogeneous climatic regions and thermotype indices) on soil organic carbon (SOC) dynamics after agricultural land abandonment; and (ii) to analyse the efficiency of the agri-environment policy (agri-environment measures) suggested by the European Commission in relation to potential SOC stock ability in the Sicilian Region (Italy). In order to quantify the effects of agricultural abandonment on SOC, a dataset with original data that was sampled in Sicily and existing data from the literature were analysed according to the IPCC (Intergovernmental Panel on Climate Change) methodology. Results showed that abandonment of cropland soils increased SOC stock by 9.03 Mg C ha^{-1} on average, ranging from 5.4 Mg C ha^{-1} to 26.7 Mg C ha^{-1} in relation to the Soil Region and Bioclimate. The estimation of SOC change after agricultural use permitted calculation of the payments for ecosystem service (PES) of C sequestration after agricultural land abandonment in relation to environmental benefits, increasing in this way the efficiency of PES. Considering the 14,337 ha of abandoned lands in Sicily, the CO_2 emission as a whole was reduced by 887,745 Mg CO_2.

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Therefore, it could be concluded that abandoned agricultural fields represents a valid opportunity to mitigate agriculture sector emissions in Sicily.

1. Introduction

Worldwide land use changes are altering the fate of landscapes, and land abandonment is one of the processes responsible for these changes (Arnáez et al., 2015; García-Ruiz and Lana-Renault, 2011; Parras-Alcántara et al., 2013). Land abandonment has occurred mainly in developed countries as a consequence of the intensification of agriculture and the reduction of the agriculture land necessary to feed the population (Alonso-Sarría et al., 2016; Kou et al., 2016). This is mainly found in Europe, where numerous research studies have been published (Hatna and Bakker, 2011; MacDonald et al., 2000). This abandonment is most extensive and studied in the European Mediterranean belt (Plieninger et al., 2014; Romero-Díaz et al., 2016; Sheffer, 2012), and most of the research focuses on the mountainous regions that were abandoned as a consequence of the low income and loss of population (Lasanta et al., 2015a). The abandonment of land not only results in changes to the soil system, but also in the hydrological cycle and fauna and flora resources (Dixon-Coppage et al., 2005; de Araújo et al., 2015; Keesstra et al., 2016).

Agricultural land abandonment was the most important change in Mediterranean ecosystems over the last centuries and probably no other change in land use has been more important since the expansion of agriculture from the eastern to the western Mediterranean ten millennia ago (Petanidou et al., 2008; Rühl et al., 2005). Abandonment of agricultural land leads to several consequences for ecosystem functions and ecosystem service benefits (Cammeraat et al., 2010; Lasanta et al., 2015a; Parras-Alcántara et al., 2016; Rey Benayas et al., 2007). On the other hand, abandonment may be a significant and low cost strategy for C sequestration and mitigation of anthropogenic CO_2 emissions (Post and Kwon, 2000). Abandonment in Mediterranean ecosystems results in the recovery of vegetation (Lasanta et al., 2015b; Molinillo et al., 1997; Nadal-Romero et al., 2016), changes in water and sediment discharges (Keesstra, 2007; López-Vicente et al., 2016), soil erosion reduction (García-Ruiz and Lana-Renault, 2011), and increased biodiversity in the initial stages of plant succession (Suárez-Seoane et al., 2002; Zaravali et al., 2007).

Depletion of soil C occurs within the first few decades of agricultural practices (Fernández-Romero et al., 2014; Murty et al., 2002), but several years are necessary for soil C recovery after agriculture abandonment (Alberti et al., 2008; Rühl et al., 2015). Agricultural soils are a source of CO_2 emission around the world, and this is accompanied by mismanagement that results in high erosion rates, soil aggregate loss, low infiltration rates, and changes in the soil biota (Bruun et al., 2015; Choudhury et al., 2016; de Moraes Sá et al., 2015; de Oliveira et al., 2015; Frossard et al., 2016; Gelaw et al., 2015; Leifeld and Mayer, 2015). The impact of CO_2 on global warming has resulted in a growing interest in reducing emissions and increasing sequestration, and soil can be a good sequestration option under appropriate management (Carr et al., 2015; Ferreira et al., 2016; Hu et al., 2015; Hombegowda et al., 2016; Poeplau et al., 2016).

Rates of change in soil C following agricultural land abandonment have been estimated through chronosequence studies, comparing soil C in sites with long term agricultural land abandonment (SOC steady state) with adjacent agricultural fields (DeGryze et al., 2004; Del Galdo et al., 2003; La Mantia et al., 2013; McLauchlan, 2006; Novara et al., 2014, 2013; Rühl et al., 2015; Saiano et al., 2013). The chronosequence approach is frequently used to evaluate plant succession after disturbance, comparing sites that differ only in time since agricultural abandonment (Novara et al., 2014; Rühl et al., 2005). The climatological gradient approach is also applied in soil science, hydrology and geomorphology (Campos et al., 2014; Cerdà, 1998a; Lozano-García et al., 2016; Parras-Alcántara et al., 2015).

The potential and the rate of C sequestration due to agricultural land abandonment varies widely (Post and Kwon, 2000), depending on soil and climate characteristics of sites that result in differences in vegetation succession, ranging from the development of prairie to forests (Alberti et al., 2011; La Mantia et al., 2013; Rühl et al., 2015; Van Eerd et al., 2014). Soil C accumulation is strongly dependent on management strategies and therefore land use decisions can change the fate of SOC stocks (Novara et al., 2012; Teshome et al., 2014). Over the last few decades, substantial areas of the European Union, particularly the southern regions, have been affected by agricultural land abandonment (Renwick et al., 2013) due to the loss of productivity and/or to obtain payment for environmental purposes. In particular, the abandonment process was supported by the introduction, since the late 1980s, of agricultural policy measures designed to reduce crop production in a period of structural surpluses. According to these regulations, member states were obliged to implement a national program including a list of measures included in article 2, among which was the introduction of agricultural land abandonment for at least 20 years. Farmers who withdrew agricultural land from production received a subsidy over those twenty years to compensate them for the income loss. Very few empirical studies have assessed the impact of abandonment on the environmental side (Hodge et al., 2006), most of the research has focused on the socio-economic approach and on the farmer and stakeholder's perceptions (Pereira et al., 2016). The rationale used to promote abandonment was strongly based in environmental ideas to promote afforestation, reduce soil losses, and restore degraded soils (Cerdà, 1997). In this context, exploring the relationships between the implementation of agricultural land abandonment measures and their environmental benefits helps in assessing the efficiency of this political instrument. There are substantial limitations in knowledge of the effect of agricultural land abandonment on soil C sequestration and a long-term study is required to determine the pattern and rate of C sequestration across a full chronosequence after agricultural land abandonment.

According to a large chronosequence survey and the available bibliographic data, the aim of this study was: (i) to evaluate the effect of different Soil Regions and Bioclimates on soil C dynamics after agricultural land abandonment; and, (ii) to study the efficiency of the Agro Environmental Measures (AEM) in the Sicilian Region in relation to potential SOC stock.

2. Materials and methods

2.1. Study sites

In order to quantify the effects of agricultural land abandonment on SOC a dataset composed of original data sampled at different sites in Sicily (24 sites) and existing data collected from the literature (12 sites) was analysed. SOC dynamics in secondary succession areas (Alberti et al., 2011; La Mantia et al., 2013; Rühl et al., 2015) is strongly influenced by soil and climate, consequently the dataset was subdivided into: i) three bioclimatic groups (1. thermo-Mediterranean, 2. meso-Mediterranean, 3. supra-Mediterranean), representing the most typical bioclimatic belts occurring in Sicily; and, ii) four different Soil Regions (SR), named 1, 2, 3 and 4 (Fig. 1). The Soil Regions are areas characterized by a typical climate and parent material association (Costantini et al., 2004, 2013).

The classification proposed by Rivas-Martínez (Rivas-Martinez, 1994; Rivas-Martínez and Loidi Arregui, 1999) was used to designate

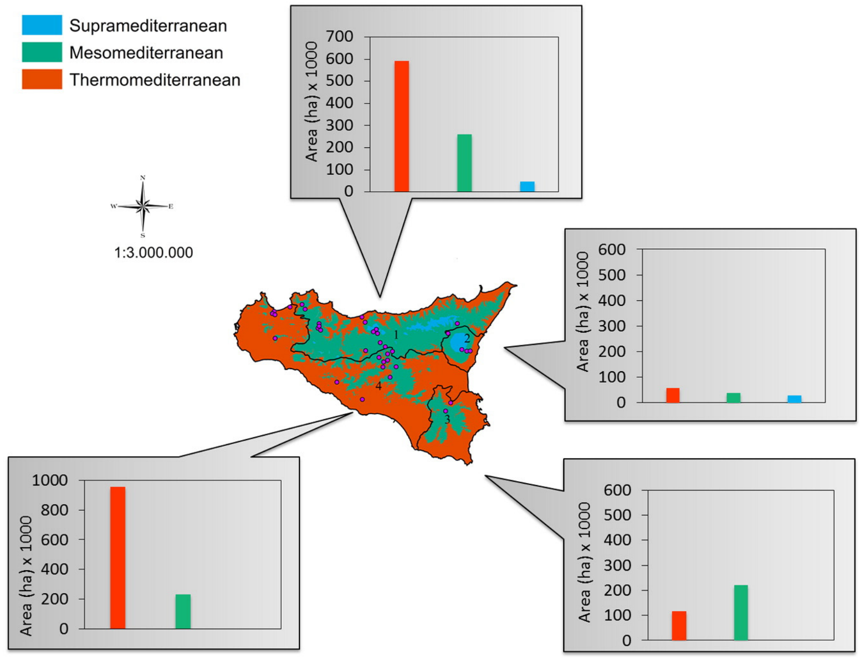

Fig. 1. Soil Regions in Sicily and Bioclimates. Bullets represent sampling points. The graphs represent the area (ha) of each bioclimatic group within the four soil regions.

the bioclimatic groups. The system of Rivas-Martinez is a hierarchical climate classification that subdivides the climate according to homogeneous climatic regions (Mediterranean for example) and thermotype indices. The thermotype index (tI) was calculated as follows:

$$\mathrm{tI} = (\mathrm{T} + \mathrm{M} + \mathrm{m}) \times 10 \tag{1}$$

where T is the yearly average temperature, m is the average minimum temperature of the coldest month(s) of the year, and M is the average maximum temperature of the coldest month(s) of the year.

2.2. Soil sampling data

Soil samples were collected at sites where different stages of secondary succession were present. Within all bioclimatic belts, we defined the following land use classes as successional stages: i) Ag = cultivated areas; and, ii) Ab = grasslands dominated by perennial grasses. The selected abandoned stages had reached C steady state equilibrium, because in these stages of the secondary succession the phytosociological relief showed equilibrium of the community. The supra-Mediterranean bioclimatic group was not present in SRs 3 and 4 (Fig. 1). Soil was sampled according to the protocol of the Italian National Inventory of Forests and Forest Carbon pools (Gasparini et al., 2008). After litter removal, mineral soil samples were collected at 0–30 cm depth using a 680-cm^3 cylinder. For each site and successional stage, three replicates were collected. The soil samples were passed through a 2 mm sieve, air dried, then analysed for C content using a CHN-Elemental Analyzer. SOC content was expressed as a percentage (g of C per 100 g of dry soil × 100) and converted to Mg per hectare using bulk density (BD) and soil depth (Blake and Hartge, 1986).

2.3. Literature data selection

Existing data from the SOC literature for Sicilian sites was screened for successional stage, bioclimatic group, and Soil Region. Data were taken during previous research carried out by Rühl et al. (2015). All data were indicated to the 30 cm depth. In some cases, BD was not measured, but was calculated (BD_{calc}) according to Post and Kwon (2000).

$$BD_{calc} = 100/\left(\frac{\frac{SOM}{10}}{0.224}\right) + \left(\left(100 - \frac{SOM}{10}\right)/1.64\right)$$

2.4. IPCC methods

The IPCC (Intergovernmental Panel on Climate Change) (2006) method has been used to evaluate SOC stock changes, consequent to the adoption of different agricultural land uses and management, in support of national GHGs inventories according to the UN Framework Convention on Climate Change. The adopted method evaluates SOC stock changes for the top 30 cm of a mineral soil profile over the first 20 years following changes in land use and land use management (VandenBygaart et al., 2004). For the present study, changes between cultivated croplands and uncultivated land, such as grasslands, have been analysed.

SOC inventory calculations were carried out for aggregated soil regions of Sicily.

Soil C stock change (ΔSOC) was calculated as follows:

$$\Delta SOC = (SOC_t - SOC_{t-20}) * A)/\mathrm{years} \tag{2}$$

where $SOC_{t\text{-}20}$ and SOC_t are the soil carbon stock at the start and after 20 years of the inventory period (Mg C ha^{-1}), respectively, and A is the area (ha) (IPCC, 2006). SOC_{t-20} corresponds to reaching C steady state during the stage of succession, as confirmed by phytosociological relief.

SOC (Mg C) was estimated using the equation:

$$SOC = SOCref * Mg * Fi * LUC * LA \tag{3}$$

where SOCref is the reference SOC stock (Mg C ha^{-1}), Mg is the management factor (dimensionless), Fi is the stock change factor for the input of organic matter (dimensionless), LUC is the land use change factor (dimensionless), and LA is the land area (ha) (IPCC, 2006).

In the original IPCC method, the SOCref is based on values from undisturbed native ecosystems. This approach was modified, according to Ogle and Breidt (2003), to use conventionally managed cropland as the reference (SOCref) instead of native conditions. In fact, SOC stock measurements are more reliable in soils under cultivated than natural conditions and agriculture management must be considered the reference SOC (SOCref). Therefore, in this study SOC under a long-term agriculture system (SOCag) corresponds to SOC under native condition (SOCref).

2.5. Data calculation

For each Soil Region (i), the IPCC factor (IPCCf) was calculated as follows:

$$\mathrm{IPCCf_i} = \mathrm{SOCab_i}/\mathrm{SOCag_i} \tag{4}$$

And for each Bioclimate (j), the IPCC factor (IPCCf) was calculated as follows

$$\mathrm{IPCCf_j} = \mathrm{SOCab_j}/\mathrm{SOCag_j} \tag{5}$$

where SOCab is the SOC content in the abandonment stage and SOCag is the SOC content in the agricultural cultivation stage. In the specific case of the abandonment processes, IPCCf was mainly affected by the LUC factor, considering the Mg and Fi factors equal to 1.

Then:

$$\mathrm{SOCab_i} = \mathrm{SOCag_i} * \mathrm{IPCCf_i} \tag{6}$$

and Bioclimate effect (j) over Soil Region (i) was calculated:

$$\mathrm{SOCab_j} = \mathrm{SOCag_j} * \mathrm{IPCCf_j} \tag{7}$$

After normal distribution of $\mathrm{IPCCf_i}$ and $\mathrm{IPCCf_{j,}}$ calculated on experimental data, the IPPCf in a specific Bioclimate of a Soil Region ($\mathrm{IPCCf_{ij}}$) was calculated using Eq. (8)

$$\mathrm{IPCCf_{\ ij}} = \mathrm{IPCCf_{\downarrow I}} + (\mathrm{IPCCf_{\ j}} * (\mathrm{IPCCf_{\downarrow j}} - \mathrm{xIPCCf_{\downarrow j}})/(\mathrm{xIPCCf_{\downarrow j}}) \tag{8}$$

where *x*IPCC*fj* is the IPCCf calculated for each bioclimate over a given Soil Region.

2.6. Uncertainty analysis and assumptions

Uncertainties were estimated using a Monte Carlo approach according to the IPCC method (IPCC, 2006) (Fig. 2). The probability density functions (PDFs) were determined by the standard error estimation. In this study, we simulated 10,000 estimates of soil C stock changes using the IPCC model and then summed the outputs of each run to produce an empirical distribution of 10,000 SOC changes for each Soil

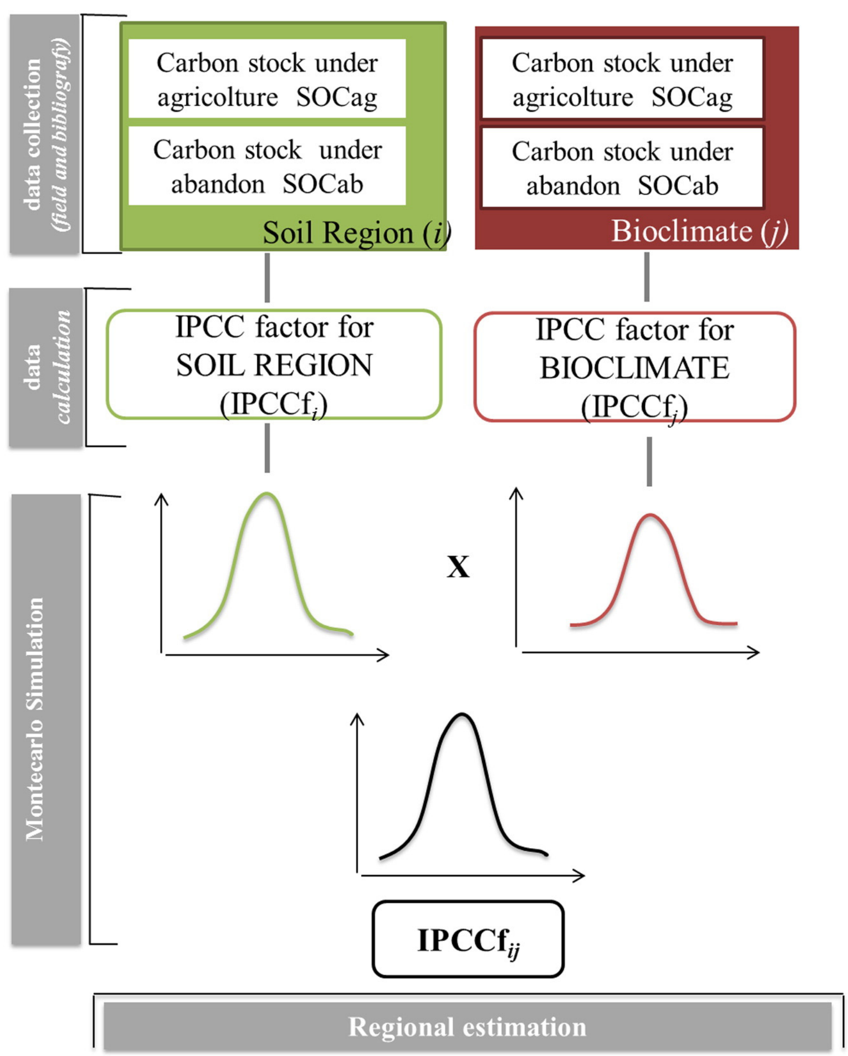

Fig. 2. Framework for IPCC uncertainty analysis.

Region (i) and Bioclimate (j). From these results, we estimated a 95% confidence interval for the change rate of SOC as the descriptor of uncertainty.

PDFs were truncated at 0 Mg C ha^{-1} and 150 Mg C ha^{-1} respectively. A sensitivity analysis was also performed to highlight contribution of the input to the variance output. This analysis was carried out using SPSS software (IBM, 2010).

2.7. Estimate of effectiveness of Premia scheme

The withdrawal of agricultural land for environmental purposes was an agro-environmental measure supported under the Rural Development Plan (RDP) of Sicily with the aim of safeguarding semi-natural areas and agricultural habitats favourable to wildlife and wild flora. The axe 2 of the RDP includes the agricultural measure 214 "Agri-environment payments" in order to ensure sustainable agricultural land use through the adoption of appropriate agricultural management practices. This measure also includes two actions, the F4A action (withdrawal of arable land for environmental purposes) and the F measure of Regulation 2078/92. At the end of December 2013 the surfaces regulated by these two actions amounted to 5271 ha (F4A RDP 2000–2006) and 8796 ha (Measure F 2078/92), respectively (Regione Siciliana, RAE, 2015). The annual premium obtained by farmers following the implementation of the abandonment measure shifted from 738.02 € (Measure F, Regulation 2078/92) to 600 € ha^{-1} $year^{-1}$ (Measure F4A, RDP 2000–2006) to 320 € ha^{-1} $year^{-1}$ (Measure 214, RDP 2007–2013). The premium calculation was estimated based on cost incurred and income foregone by the farmers who joined the agri-environmental measures, and in some circumstances an incentive payment of up to 20% may be paid.

In this work, the effectiveness of premiums was assessed through data acquisition on environmental benefits and by employing a budget following the land abandonment measure. According to Galati et al. (2016), the effectiveness of premiums (E_P) indicates that the amount of SOC sequestered per Euro per hectare (Mg C $€^{-1}$ ha^{-1}) could be calculated as follows:

$$E_P = \text{Premia}/\Delta SOC_{ij} \tag{9}$$

where, $\Delta SOC_{ij,}$ is the SOC sequestered in the first stage of succession after agricultural land abandonment for each Bioclimate (j) in a specific Soil Region (i), and is calculated as follows:

$$\Delta SOC_{ij} = SOC_{ag} * (IPCC_{ij} - 1) \tag{10}$$

Taking into consideration that the Ep changes with respect to the type of bioclimatic belt, the total budget of the land abandonment measure was redistributed at the regional level in relation to ecosystem service (carbon sequestration) as follows:

$$PES_{ij} = (RE_P/E_P) * \text{Premia} \tag{11}$$

where RE_P, which represents the payment efficiency at the regional level, is given by,

$$RE_P = \Delta SOC_R/\text{Total Budget} \tag{12}$$

where ΔSOC_R is the total SOC sequestered over all Soil Regions and the total budget is the budget provided by the regional government for this specific measure.

3. Results and discussion

3.1. SOC stock and SOC after abandonment in each Soil Region and Bioclimate

SOCag stocks were computed for each Soil Region and Bioclimate type using a survey and bibliographic data for a 30 cm soil depth. SOCag values ranged from 27.9 Mg ha^{-1} in SR3 to 47.3 Mg ha^{-1} in SR1 (Table 1, Fig. 3). SOCag was strongly affected by the type of Bioclimate, increasing from 16.7 Mg ha^{-1} in the thermo-Mediterranean to 54.5 Mg ha^{-1} in the supra-Mediterranean Bioclimate. The impact of climate on soil development, runoff generation, soil erosion, and plant cover is well-known (Anaya-Romero et al., 2015; Buendia et al., 2016; Cerdà, 1998b; Ochoa et al., 2016), but little is known about its impact on soil organic carbon, and this is why the results shown here shed light into the environmental impact of land abandonment. Our findings confirm the results of other investigations that are summarised in Köchy et al. (2015a, 2015b) and quantified by Pabst et al. (2016) in Africa or by Willaarts et al. (2016) in the Mediterranean.

SOCab increased in comparison to SOCag for all Soil Regions. The effect of abandonment on SOC change was higher in thermo- than in meso- and supra-Mediterranean bioclimates (Table 1, Fig. 4). Land abandonment favours the recovery of vegetation cover and the reestablishment of soil processes that contribute to restoration of soil properties (Cerdà et al., 2014). This leads to reduction of soil erosion, increased infiltration rates, soil biological activity, and biomass and enhanced plant diversity. The acceleration of the biological and hydrological cycles after land abandonment results in recovery of soil carbon stocks as found by other studies when land was abandoned (Brevik and Lazari, 2014), forests were transformed into crops (Wasak and Drewnik, 2015), or when degraded rangelands were restored (Zucca et al., 2016). There is a positive interaction in the soil system after abandonment that favours the recovery of the biota (fauna and flora) followed by litter and organic matter, which finally improves soil quality and as a consequence the diversity and mass of the biota (Certini et al., 2015; Chen et al., 2016; Frouz, 2016).

Among climate factors, precipitation is most frequently considered as one of the principal factors affecting SOC changes after land use change (Alberti et al., 2011; Guo and Gifford, 2002). Precipitation impacts the net primary production (NPP) and consequently the inputs of organic matter to the soil. Similar to our findings, Gabarrón-Galeote

Table 1
Average SOCag, SOCab and IPCCf calculated for the four Soil Regions and the three Bioclimates. Standard deviation (s.d), degrees of freedom (df), and best-fit distribution are reported for both SOCag and SOCab.

	SOCag				SOCab				IPCCf
	Mg ha^{-1}	sd	df	Best distribution	Mg ha^{-1}	sd	df	Best distribution	
Soil Region									
1	47.3	14.6	27	Lognormal	52.9	16.6	27	Gamma	1.12
2	39.8	10.5	17	Weibull	45.1	10.7	17	Weibull	1.13
3	27.9	5.7	28	Weibull	34.6	3.8	28	Weibull	1.24
4	35.2	8.2	36	Weibull	50.7	14.0	36	Lognormal	1.44
Bioclimate									
Thermo	16.7	8.7	39	Normal	25.6	9.3	39	Normal	1.53
Meso	42.7	14.1	46	Normal	44.8	15.9	46	Normal	1.05
Supra	54.5	22.3	22	Weibull	55.9	29.7	22	Weibull	1.10

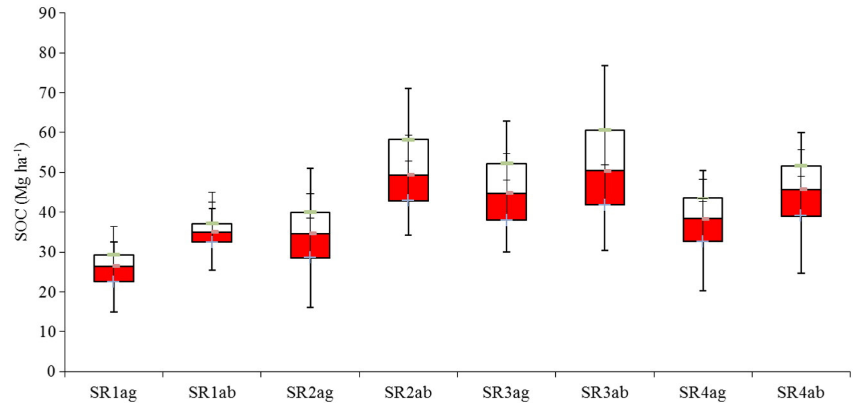

Fig. 3. Soil organic carbon stock variability (Mg ha^{-1}) under agricultural (ag) and abandoned (ab) land use for the Soil Regions.

et al. (2015) found a strong correlation between Bioclimate and SOC change after abandonment; their results showed an increase at the wettest site (precipitation > 650 mm), while there was no SOC gain at the driest sites (precipitation < 450 mm). Climate has also been found to exert control on soil organic carbon stocks and rainfall level is the key factor controlling organic carbon accumulation and shows similar results to the geomorphological response found under different climates (Cerdà, 1998a).

3.2. IPCC factors

Results showed that land use change from cultivated croplands (ag) to grasslands (ab) increased SOC stocks in the top 30 cm of the soil by a factor of 1.23 (average of all paired sites); this represented a 23% increase in overall SOC stock. The positive use of grasslands to restore degraded land and recover soil organic matter stocks has also been found in other regions, and the grasslands are very efficient even under grazing pressure (Lu et al., 2015; Orgill et al., 2016). The four Soil Regions were characterized by different IPCC factors ($IPCCf_i$) related to agricultural abandonment that ranged from 1.12 to 1.44 in SR1 and SR4, respectively (Table 1). The thermo-Mediterranean climate showed the highest values while the supra-Mediterranean Bioclimate showed the lowest values of $IPPCf_j$. Higher C stocks have been recorded in moist and cool temperate regions than in dry and warm temperate regions (Alberti et al., 2011). The IPCC factors for each type of Bioclimate and each Soil Region are shown in Table 2. As expected, the new $IPCCf_{ij}$, calculated according to Eq. (8), showed on average values for both Soil Regions and Bioclimates very close to $IPCCf_i$ and $IPCCf_j$.

3.3. Regional SOC sequestration and sensitivity analysis

After neglecting cropland soils, the SOC sequestered (ΔSOC) in Sicilian soils increased on average of 9.03 Mg C ha^{-1}, ranging from 5.4 Mg C ha^{-1} to 26.7 Mg C ha^{-1} depending on Soil Region and Bioclimate (Table 3). Considering the 14,337 ha of abandoned lands, the CO_2 emissions as a whole were reduced by 887,745 Mg CO_2 (Table 3).

The highest rate of increase in SOC occurred in SR4, followed by SR3, due to the combination of a high sequestration rate and area distribution. Among bioclimates, the thermo-Mediterranean Bioclimate sequestered the highest amount of CO_2 (759,504.7 Mg CO_2) due to the highest rate of SOC sequestration and area distribution (9509 ha) (Table 3). About 70% of the abandoned area was in the thermo-Mediterranean Bioclimate, whereas 21% and 9% fell within the meso- and supra-Mediterranean Bioclimates, respectively (Table 3).

Sensitivity analysis indicated that uncertainty in the thermo-bioclimate contributed almost 6% of the variability in the output as compared to about 10 and 13% contributions from the meso- and supra-bioclimates (Fig. 5). According to our findings, it is clear that more effort is needed in order to minimize the uncertainty of the input coefficients. This could be obtained by increasing the surveys in Sicily and by improving our sampling methods.

The SR4 showed about 44% of variance contribution to the total soil C change due to abandonment processes on the island even in the absence of supra areas, while SR2, including all Bioclimate typology, contributed only 24%. The other Soil Regions (3 and 1) were only involved in 10% of soil C change.

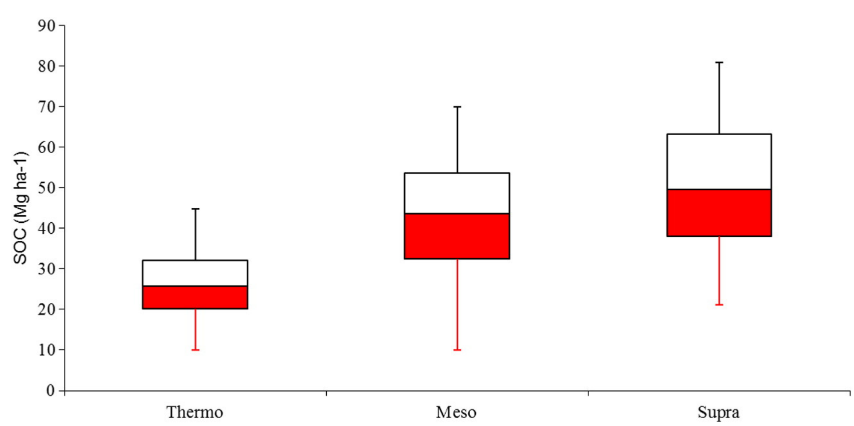

Fig. 4. Soil organic carbon stock variability (Mg ha^{-1}) under agricultural (ag) and abandoned (ab) land use for the three Bioclimates.

Table 2
Calculated $IPCCf_{ij}$ factors and interactions between Soil Regions and Bioclimate according to Eq. (8); sd = standard deviation.

Bioclimate	Soil Region							
	1		2		3		4	
	$IPCCf_{ij}$	Sd	$IPCCf_{ij}$	sd	$IPCCf_{ij}$	sd	$IPCCf_{ij}$	sd
Thermo	1.50	0.16	1.51	0.24	1.52	0.158	1.72	0.10
Meso	0.97	0.28	0.98	0.32	1.04	0.33	1.24	0.21
Supra	1.01	0.30	1.02	0.46	–	–	–	–

3.4. Effectiveness of payments for land abandonment measure

The impact of subsidies from the European Union on Mediterranean agriculture are relevant to understand changes in agricultural management (Shelef et al., 2016), but there are also environmental impacts such as changes in the hydrologic cycle and alterations in soil organic matter and biota that need more research (Bisantino et al., 2015; de Araújo et al., 2015). The effectiveness of the premiums, calculated as the rate between the overall value of payments obtained by the farmers over twenty years (Eq. (9)) and the SOC sequestered in the same period, showed that the value of C sequestered changed in relation to the Bioclimate in each specific Soil Region (Fig. 6, blue line). Due to the wide variability of potential C sequestration in the four Soil Regions and Bioclimates, the value of C sequestered (€ C Mg^{-1}) ranged from 590.61 € C Mg^{-1} for the farm located in the thermo bioclimate of SR4, to 3032.54 € C Mg^{-1} in the *meso* bioclimate in SR2. The different values observed show that the adoption of an egalitarian fairness criterion, (equal distribution of payments (red dotted line, Fig. 6) among all providers independent of the level of ecosystem service provision, leads to an unfair distribution of premiums. Therefore, in order to ensure an equitable distribution of the premiums in relation to the ecosystem service provided, the total budget of the set-aside measure was redistributed taking into account the changes of EP in the different bioclimatic areas. According to this criterion the value of C sequestered is constant and in our case study is equal to 1746.31 € C Mg^{-1} ha^{-1} (Fig. 6, blue dotted line) and the amount of total budget for twenty years of the set-aside measure ranged from 9080.82 € for the land user who produced low C sequestration levels (5.2 Mg C ha^{-1}) to 46,626.54 € for the land user who produced high C sequestration levels (26.7 Mg C ha^{-1}) (Fig. 6, red line).

New approaches might be investigated aimed at achieving a better payment efficiency and differentiating payment levels, following procedures for the provisioning of environmental services or/and introducing an ecosystem service payment. In this case study, premia calculations usually considered variable costs or income forgone resulting from agri-environmental program agreement.

Payment levels based on regional averages result in simplicity and low administrative costs, but create infra-marginal producer rents. However, the effectiveness of agro-environmental measures is site specific and the consideration of several factors should be taken into account: i) agro-environmental scheme introductions must be site specific to ensure the highest response to local conditions; ii) agro-environmental payments can create good results together with less favoured area (LFA) payments with particular attention to combating land abandonment and marginalisation; iii) because the effect of the agro-environmental measures is heterogeneous, variable and complex, their evaluation requires a long-term study approach.

3.5. Implications for management

The quantification of the potential for and rates of C sequestration across Sicilian climatic regions aids in predicting the sequestered C stock in abandoned agricultural land at a larger scale. Overall, although there are numerous uncertainties, the knowledge of the influences of land-use change on SOC could contribute to future modelling work, which will require both a mechanistic understanding of C cycling as well as data for calibration. The adoption of agro-environmental measures promoted by the European Commission and transposed by the Sicilian Region was very effective for soil C sequestration and the perspective seems to be interesting regarding implications for Kyoto Protocol reporting.

Total emissions of GHGs from the agricultural sector in Sicily in 2000 were about $0.7 * 10^9$ kg CO_2eq (Beccali et al., 2007). The CO_2 stored in abandoned cropland (44,387 Mg CO_2 $year^{-1}$; Table 3) as determined in this analysis represents an offset of about 6% of the annual emissions attributed to agriculture in Sicily. Some aspects, however, assume great importance for planners: i) what measures could be taken when the abandonment period lasts longer than planned and the succession continues to maquis, and potentially turn into woods; ii) how to consider the effects of secondary succession on biodiversity; iii) how to handle any rehabilitation of agriculture; and iv) how the abandonment will

Table 3
SOC change (ΔC) after agricultural land abandonment and long term prospective following the application of agri-environmental measures in the Sicilian region.

Soil Region	Bioclimate	ΔC	Area	Agricultural land abandonment		
				CO_2		
		(Mg ha^{-1})	(ha) (under AEM)	(Mg)	(Mg ha $^{-1}$ $year^{-1}$)	(Mg $year^{-1}$)
1	Thermo	8.4	453	12,937.7	1.4	646.9
	Meso	5.4	262	4838.8	0.9	241.9
	Supra	5.7	112	2153.8	1.0	107.7
2	Thermo	8.0	721	19,618.6	1.4	980.9
	Meso	5.2	300	5297.9	0.9	264.9
	Supra	5.4	103	1893.2	0.9	94.7
3	Thermo	10.2	510	17,659.1	1.7	883.0
	Meso	7.0	150	3553.7	1.2	177.7
	Supra	–	–	–	–	–
4	Thermo	26.7	7825	709,289.3	4.5	35,464.5
	Meso	8.3	3912	110,503.0	1.4	5525.2
	Supra	–	–	–	–	–
Total			14,348	887,745.1	15.3	44,387.3
	Thermo	14.4	9509	759,504.7	4.5	2510.8
	Meso	6.3	4624	124,193.4	3.0	684.5
	Supra	5.6	215	4047	1.9	202.3

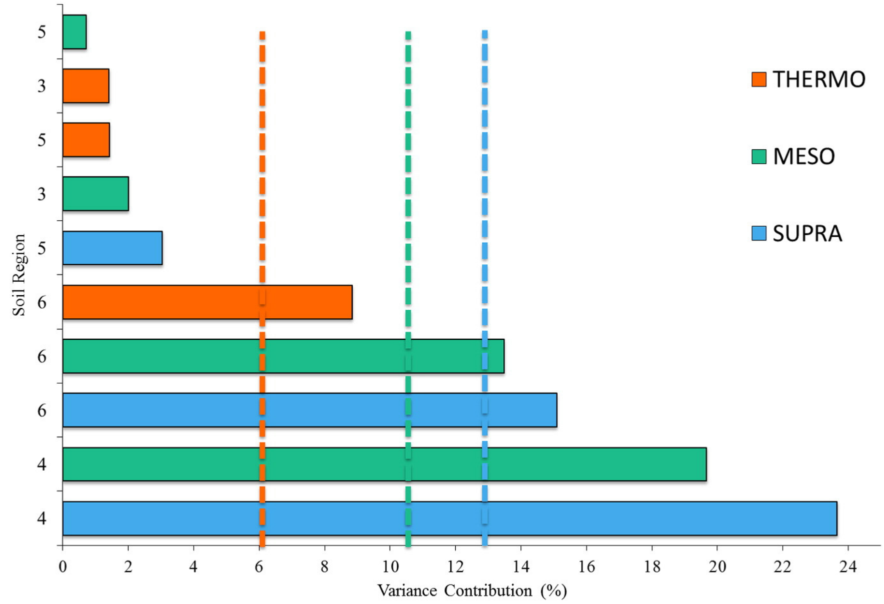

Fig. 5. Contributions of variable inputs of the model to the output of Monte Carlo analysis for Sicily. Vertical lines are the average contribution of Bioclimate.

affect the forest fire regime and if this will reduce or increase soil organic matter content.

Regarding secondary succession impacts on biodiversity, the abandoned agricultural land will advance to forms of arboreal vegetation, maximizing the benefits related to C storage. This would suggest that the community should take the responsibility to reward those farmers for decades of abandonment or encourage alternative approaches of exploitation, such as through the sale of C credits certified by the public body that carries out the surveys. Closely connected with this aspect is the management of biodiversity, in fact, in the Mediterranean rare or endangered species are linked to open spaces, including agricultural or natural grasslands (Pasta and La Mantia, 2013). For this reason, the maintenance of the prairie stage would allow maximization of benefits in terms of biodiversity but also in the proportion of C in the soil. To assess how to manage a possible rehabilitation of agriculture to avoid losing soil C, accurate experimental data or partial data on this aspect are necessary. More research is also needed into the role forest fires will play in the C cycle and vegetation recovery (Hedo et al., 2015; Shaw et al., 2016).

Abandoned agricultural fields represent a valid opportunity to mitigate agricultural sector emissions in Sicily. Further studies should be carried out to promote agro- ecological systems. Considering the findings of this study, payments should be diversified based on site-specific characteristics. Moreover, the estimated potential SOC sequestration, through the use of specific $IPCCf_{ij}$, could aid the prediction of the true value of the ecosystem services furnished by abandoned agricultural lands as suggested by agro-environmental measures and additionally to estimate the PES more accurately. To quantify the effects of agricultural land abandonment on SOC and to evaluate the efficiency of payments delivered by the abandonment measure, a dataset created by combining original data sampled in various Sicilian sites and literature data was analysed. For its size and great pedoclimatic variability, Sicily can be considered quite representative of most of the Mediterranean countries. Sicily is an island with a unique environmental history, and can be used as a laboratory to quantify the impact of land abandonment on carbon dynamics and the methodology and the findings can be exported to other regions (Galati et al., 2016; Smith et al., 2015).

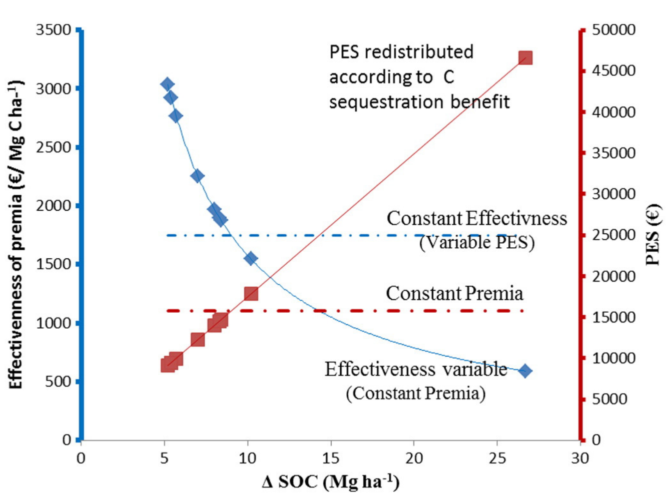

Fig. 6. Effectiveness of premiums and PES in relation to sequestered SOC.

4. Conclusions

The abandonment of agricultural land in the Mediterranean belt contributes to increased soil C stocks. This was found under different bioclimatic and Soil Regions and allowed us to evaluate the efficiency of the agro environmental measures undertaken in Sicily. Our calculations show that the abandonment of cropland soils increased SOC stock an average of 9.03 Mg C ha^{-1}, ranging from 5.4 Mg C ha^{-1} to 26.7 Mg C ha^{-1}. This dataset permitted us to determine the payments for the C sequestration ecosystem service after agricultural land abandonment. In Sicily, and due to the land abandonment, the CO_2 emissions were reduced by 887,745 Mg CO_2, and this demonstrated that abandonment is a key strategy to mitigate greenhouse gas emissions and flight against climate change.

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References

Alberti, G., Leronni, V., Piazzi, M., Petrella, F., Mairota, P., Peressotti, A., Piussi, P., Valentini, R., Gristina, L., La Mantia, T., Novara, A., Rühl, J., 2011. Impact of woody encroachment on soil organic carbon and nitrogen in abandoned agricultural lands along a rainfall gradient in Italy. Reg. Environ. Chang. 11, 917–924.

Alberti, G., Peressotti, A., Piussi, P., Zerbi, G., 2008. Forest ecosystem carbon accumulation during a secondary succession on eastern Prealps (Italy). Forestry 81, 1–11.

Alonso-Sarría, F., Martínez-Hernández, C., Romero-Díaz, A., Cánovas-García, F., Gomariz-Castillo, F., 2016. Main environmental features leading to recent land abandonment in Murcia region (Southeast Spain). Land Degrad. Dev. 27 (3):654–670. http://dx.doi.org/10.1002/ldr.2447.

Anaya-Romero, M., Abd-Elmabod, S.K., Muñoz-Rojas, M., Castellano, G., Ceacero, C.J., Alvarez, S., Méndez, M., De la Rosa, D., 2015. Evaluating soil threats under climate change scenarios in the Andalusia region, southern Spain. Land Degrad. Dev. 26 (5):441–449. http://dx.doi.org/10.1002/ldr.2363.

Arnáez, J., Lana-Renault, N., Lasanta, T., Ruiz-Flaño, P., Castroviejo Arnaez, J., 2015. Effects of farming terraces on hydrological and geomorphological processes. A review. Catena 128, 122–134.

Beccali, M., Cellura, M., Mistretta, M., 2007. Environmental effects of energy policy in Sicily: the role of renewable energy. Renew. Sust. Energ. Rev. 11, 282–298.

Bisantino, T., Bingner, R., Chouaib, W., Gentile, F., Trisorio Liuzzi, G., 2015. Estimation of runoff, peak discharge and sediment load at the event scale in a medium-size Mediterranean watershed using the AnnAGNPS model. Land Degrad. Dev. 26 (4):340–355. http://dx.doi.org/10.1002/ldr.2213.

Blake, G.R., Hartge, K.H., 1986. Bulk density. In: Klute, A. (Ed.), Methods of Soil Analysis, Part 1, 2nd edition Agronomy Monograph vol. 9. American Society of Agronomy, Madison, WI, pp. 363–375.

Brevik, E.C., Lazari, A.G., 2014. Rates of pedogenesis in reclaimed lands as compared to rates of natural pedogenesis. Soil Horizons:55 http://dx.doi.org/10.2136/sh13-06-0017.

Bruun, T.B., Elberling, B., de Neergaard, A., Magid, J., 2015. Organic carbon dynamics in different soil types after conversion of forest to agriculture. Land Degrad. Dev. 26 (3): 272–283. http://dx.doi.org/10.1002/ldr.2205.

Buendia, C., Batalla, R.J., Sabater, S., Palau, A., Marcé, R., 2016. Runoff trends driven by climate and afforestation in a Pyrenean Basin. Land Degrad. Dev. 27 (3):823–838. http://dx.doi.org/10.1002/ldr.2384.

Cammeraat, E., Cerdà, A., Imeson, A.C., 2010. Ecohydrological adaptation of soils following land abandonment in a semi-arid environment. Ecohydrology 3, 421–430.

Campos, A.C., Etchevers, J.B., Oleschko, K.L., Hidalgo, C.M., 2014. Soil microbial biomass and nitrogen mineralization rates along an altitudinal gradient on the cofre de perote volcano (Mexico): the importance of landscape position and land use. Land Degrad. Dev. 25 (6):581–593. http://dx.doi.org/10.1002/ldr.2185.

Carr, P.M., Brevik, E.C., Horsley, R.D., Martin, G.B., 2015. Long-term no-tillage sequesters soil organic carbon in cool semi-arid regions. Soil Horizons 56 (6). http://dx.doi.org/10.2136/sh15-07-0016.

Cerdà, A., 1997. Soil erosion after land abandonment in a semiarid environment of southeastern Spain. Arid Soil Res. Rehabil. 11 (2), 163–176.

Cerdà, A., 1998a. Relationships between climate and soil hydrological and erosional characteristics along climatic gradients in Mediterranean limestone areas. Geomorphology 25 (1–2):123–134. http://dx.doi.org/10.1016/S0169-555X(98)00033-6.

Cerdà, A., 1998b. Effect of climate on surface flow along a climatological gradient in Israel: a field rainfall simulation approach. J. Arid Environ. 38 (2):145–159. http://dx.doi.org/10.1006/jare.1997.0342.

Cerdà, A., Giménez Morera, A., García Orenes, F., Morugán, A., González Pelayo, Ó., Pereira, P., Novara, A., Brevik, E.C., 2014. The impact of abandonment of traditional flood irrigated citrus orchards on soil infiltration and organic matter. In: Arnáez, J., González-Sampériz, P., Lasanta, T., Valero-Garcés, E.L. (Eds.), Geoecología, cambio ambiental y paisaje: homenaje al profesor José María García Ruiz. Instituto Pirenaico de Ecología, Zaragoza, pp. 267–276.

Certini, G., Vestgarden, L.S., Forte, C., Tau Strand, L., 2015. Litter decomposition rate and soil organic matter quality in a patchwork heathland of southern Norway. Soil 1: 207–216. http://dx.doi.org/10.5194/soil-1-207-2015.

Chen, X., Duan, Z., Tan, M., 2016. Restoration affect soil organic carbon and nutrients in different particle-size fractions. Land Degrad. Dev. 27 (3):561–572. http://dx.doi.org/10.1002/ldr.2400.

Choudhury, B.U., Fiyaz, A.R., Mohapatra, K.P., Ngachan, S., 2016. Impact of land uses, agrophysical variables and altitudinal gradient on soil organic carbon concentration of north-eastern Himalayan region of India. Land Degrad. Dev. 27 (4):1163–1174. http://dx.doi.org/10.1002/ldr.2338.

Costantini, E.A.C., Urbano, F., L'Abate, G., 2004. Soil Regions of Italy. http://www.soilmaps.it/ita/cartadeisuoli3.html.

Costantini, E.A.C., Barbetti, R., Fantappiè, M., L'Abate, G., Lorenzetti, R., Magini, S., 2013. Pedodiversity. In: Costantini, E.A.C., Dazzi, C. (Eds.), The Soils of ItalyWorld Soils Book Series. Springer, Berlin, Germany.

de Araújo, A.S.F., Eisenhauer, N., Nunes, L.A.P.L., Leite, L.F.C., Cesarz, S., 2015. Soil surface-active Fauna in degraded and restored lands of Northeast Brazil. Land Degrad. Dev. 26 (1), 1–8.

de Moraes Sá, J.C., Séguy, L., Tivet, F., Lal, R., Bouzinac, S., Borszowskei, P.R., Briedis, C., et al., 2015. Carbon depletion by plowing and its restoration by no-till cropping systems in oxisols of subtropical and tropical agro-ecoregions in Brazil. Land Degrad. Dev. 26 (6):531–543. http://dx.doi.org/10.1002/ldr.2218.

de Oliveira, S.P., de LaCerdà, N.B., Blum, S.C., Escobar, M.E.O., de Oliveira, T.S., 2015. Organic carbon and nitrogen stocks in soils of northeastern Brazil converted to irrigated agriculture. Land Degrad. Dev. 26 (1):9–21. http://dx.doi.org/10.1002/ldr.2264.

DeGryze, S., Six, J., Paustian, K., Morris, S.J., Paul, E.A., Merckx, R., 2004. Soil organic carbon pool changes following land-use conversions. Glob. Chang. Biol. 10, 1120–1132.

Del Galdo, I., Six, J., Peressotti, A., Cotrufo, M.F., 2003. Assessing the impact of land-use change on soil C sequestration in agricultural soils by means of organic matter fractionation and stable C isotopes. Glob. Chang. Biol. 9, 1204–1213.

Dixon-Coppage, T.L., Davis, G.L., Couch, T., Brevik, E.C., Barineau, C.I., Vincent, P.C., 2005. A forty-year record of carbon sequestration in an abandoned borrow-pit, Lowndes County, GA. Soil and Crop Science Society of Florida Proceedings. vol. 64, pp. 8–15.

Fernández-Romero, M.L., Lozano-García, B., Parras-Alcántara, L., Collins, C.D., Clark, J.M., 2014. Effects of land management on different forms of soil carbon in olive groves in Mediterranean areas. Land Degrad. Dev. 2014. http://dx.doi.org/10.1002/ldr.2327.

Ferreira, A.C.C., Leite, L.F.C., de Araújo, A.S.F., Eisenhauer, N., 2016. Land-use type effects on soil organic carbon and microbial properties in a semi-arid region of Northeast Brazil. Land Degrad. Dev. 27 (2):171–178. http://dx.doi.org/10.1002/ldr.2282.

Frossard, E., Buchmann, N., Bünemann, E.K., Kiba, D.I., Lompo, F., Oberson, A., Tamburini, F., Traoré, O.Y.A., 2016. Soil properties and not inputs control carbon: nitrogen: phosphorus ratios in cropped soils in the long term. Soil 2:83–99. http://dx.doi.org/10.5194/soil-2-83-2016.

Frouz, J., 2016. Effects of soil development time and litter quality on soil carbon sequestration: assessing soil carbon saturation with a field transplant experiment along a post-mining chronosequence. Land Degrad. Dev. http://dx.doi.org/10.1002/ldr.2580.

Gabarrón-Galeote, M.A., Trigalet, S., van Wesemael, B., 2015. Soil organic carbon evolution after land abandonment along a precipitation gradient in southern Spain. Agric. Ecosyst. Environ. 199, 114–123.

Galati, A., Crescimanno, M., Gristina, L., Keesstra, S., Novara, A., 2016. Actual provision as an alternative criterion to improve the efficiency of payments for ecosystem services for C sequestration in semiarid vineyards. Agric. Syst. 144:58–64. http://dx.doi.org/10.1016/j.agsy.2016.02.004.

García-Ruiz, J.M., Lana-Renault, N., 2011. Hydrological and erosive consequences of farmland abandonment in Europe, with special reference to the Mediterranean region - a review. Agric. Ecosyst. Environ. 140, 317–338.

Gasparini, P., Di Cosmo, L., Morelli, S., Paletto, A., Tosi, V., Huez, B., Gregori, E., Rodeghiero, M., Frizzera, L., Tonolli, S., 2008. Manuale di campagna per il rilievo degli attributi integrativi (Fase 3+) INFC. http://mpf.entecra.it/node/1008 (accessed 13/03/16).

Gelaw, A.M., Singh, B.R., Lal, R., 2015. Organic carbon and nitrogen associated with soil aggregates and particle sizes under different land uses in Tigray, northern Ethiopia. Land Degrad. Dev. 26 (7):690–700. http://dx.doi.org/10.1002/ldr.2261.

Guo, L., Gifford, R.M., 2002. Soil carbon stocks and land use change: a meta-analysis. Glob. Chang. Biol. 8, 345–360.

Hatna, E., Bakker, M.M., 2011. Abandonment and expansion of arable land in Europe. Ecosystems 14, 720–731.

Hedo, J., Lucas-Borja, M.E., Wic, C., Andrés-Abellán, M., De Las Heras, J., 2015. Soil microbiological properties and enzymatic activities of long-term post-fire recovery in dry and semiarid Aleppo pine (*Pinus halepensis* M.) forest stands. Solid Earth 6 (1): 243–252. http://dx.doi.org/10.5194/se-6-243-2015.

Hodge, I., Reader, M., Revoredo, C., Crabtree, B., Tucker, G., King, T., 2006. Project to assess future options for set-aside. Final Report for the Department for Environment, Food and Rural Affairs. University of Cambridge, Department of Land Economy, Cambridge.

Hombegowda, H.C., van Straaten, O., Köhler, M., Hölscher, D., 2016. On the rebound: soil organic carbon stocks can bounce back to near forest levels when agroforests replace agriculture in southern India. Soil 2:13–23. http://dx.doi.org/10.5194/soil-2-13-2016.

Hu, Y.L., Niu, Z.X., Zeng, D.H., Wang, C.Y., 2015. Soil amendment improves tree growth and soil carbon and nitrogen pools in Mongolian pine plantations on post-mining land in Northeast China. Land Degrad. Dev. 26 (8):807–812. http://dx.doi.org/10.1002/ldr.2386.

IBM Corp. Released, 2010. IBM SPSS Statistics for Windows, Version 19.0. IBM Corp, Armonk, NY.

IPCC, 2006. In: Eggleston, H.S., Buendia, L., Miwa, K., Ngara, T., Tanabe, K. (Eds.), IPCC guidelines for national greenhouse gas inventories, agriculture, forestry and other land use, prepared by the National Greenhouse Gas Inventories Programme vol. 4. Institute for Global Environment Strategies (IGES), Japan . http://www.ipcc-nggip.iges.or.jp/public/2006gl/ (accessed 20.12.2014).

Keesstra, S.D., 2007. Impact of natural reforestation on floodplain sedimentation in the Dragonja basin, SW Slovenia. Earth Surf. Process. Landf. 32 (1):49–65. http://dx.doi.org/10.1002/esp.1360.

Keesstra, S.D., Bouma, J., Wallinga, J., Tittonell, P., Smith, P., Cerdà, A., Montanarella, L., Quinton, J.N., Pachepsky, Y., van der Putten, W.H., Bardgett, R.D., Moolenaar, S., Mol, G., Jansen, B., Fresco, L.O., 2016. The significance of soils and soil science towards realization of the United Nations Sustainable Development Goals. Soil 2:111–128. http://dx.doi.org/10.5194/soil-2-111-2016.

Köchy, M., Don, A., van der Molen, M.K., Freibauer, A., 2015a. Global distribution of soil organic carbon – part 2: certainty of changes related to land use and climate. Soil 1: 367–380. http://dx.doi.org/10.5194/soil-1-367-2015.

Köchy, M., Hiederer, R., Freibauer, A., 2015b. Global distribution of soil organic carbon – part 1: masses and frequency distributions of SOC stocks for the tropics, permafrost regions, wetlands, and the world. Soil 1:351–365. http://dx.doi.org/10.5194/soil-1-351-2015.

Kou, M., Jiao, J., Yin, Q., Wang, N., Wang, Z., Li, Y., Yu, W., Wei, Y., Yan, F., Cao, B., 2016. Successional trajectory over 10 Years of vegetation restoration of abandoned slope croplands in the Hill-Gully region of the Loess Plateau. Land Degrad. Dev. 27 (4):919–932. http://dx.doi.org/10.1002/ldr.2356.

La Mantia, T., Gristina, L., Rivaldo, E., Pasta, S., Novara, A., Rühl, J., 2013. The effects of post-pasture woody plant colonization on soil and aboveground litter carbon and nitrogen along a bioclimatic transect. iForest 6, 238–246.

Lasanta, T., Nadal-Romero, E., Errea, P., Arnáez, J., 2015a. The effect of landscape conservation measures in changing landscape patterns: a case study in Mediterranean mountains. Land Degrad. Dev. http://dx.doi.org/10.1002/ldr.2359.

Lasanta, T., Nadal-Romero, E., Arnáez, J., 2015b. Managing abandoned farmland to control the impact of re-vegetation on the environment. The state of the art in Europe. Environ. Sci. Pol. 52, 99–109.

Leifeld, J., Mayer, J., 2015. ^{14}C in cropland soil of a long-term field trial – experimental variability and implications for estimating carbon turnover. Soil 1:537–542. http://dx.doi.org/10.5194/soil-1-537-2015.

López-Vicente, M., Nadal-Romero, E., Cammeraat, E.L.H., 2016. Hydrological connectivity does change over 70 years of abandonment and afforestation in the Spanish Pyrenees. Land Degrad. Dev. http://dx.doi.org/10.1002/ldr.2531.

Lozano-García, B., Parras-Alcántara, L., Brevik, E.C., 2016. Impact of topographic aspect and vegetation (native and reforested areas) on soil organic carbon and nitrogen budgets in Mediterranean natural areas. Sci. Total Environ. 544:963–970. http://dx.doi.org/10.1016/j.scitotenv.2015.12.022.

Lu, X., Yan, Y., Sun, J., Zhang, X., Chen, Y., Wang, X., Cheng, G., 2015. Short-term grazing exclusion has no impact on soil properties and nutrients of degraded alpine grassland in Tibet, China. Solid Earth 6 (4):1195–1205. http://dx.doi.org/10.5194/se-6-1195-2015.

MacDonald, D., Crabtree, J.R., Wiesinger, G., Dax, T., Stamou, N., Fleury, P., Gutierrez Lazpita, J., Gibon, A., 2000. Agricultural abandonment in mountain areas of Europe: environmental consequences and policy response. J. Environ. Manag. 59 (1), 47–69.

McLauchlan, K., 2006. The nature and longevity of agricultural impacts on soil carbon and nutrients. A review. Ecosystems 9, 1364–1382.

Molinillo, M., Lasanta, T., García-Ruiz, J.C., 1997. Managing mountainous degraded landscape after farmland abandonment in the central Spanish Pyrenees. Ecol. Manag. 176, 147–160.

Murty, D., Kirschbaum, M.U.F., McMurtrie, R.E., McGilvray, H., 2002. Does conversion of forest to agricultural land change soil carbon and nitrogen? A review of the literature. Glob. Chang. Biol. 8, 105–123.

Nadal-Romero, E., Cammeraat, E., Pérez-Cardiel, E., Lasanta, T., 2016. Effects of secondary succession and afforestation practices on soil properties after cropland abandonment in humid Mediterranean mountain areas. Agric. Ecosyst. Environ. 228, 91–100.

Novara, A., Gristina, L., La Mantia, T., Rühl, J., 2013. Carbon dynamics of soil organic matter in bulk soil and aggregate fraction during secondary succession in a Mediterranean environment. Geoderma 193–194, 213–221.

Novara, A., La Mantia, T., Barbera, V., Gristina, L., 2012. Paired-site approach for studying soil organic carbon dynamics in a Mediterranean semiarid environment. Catena 89, 1–7.

Novara, A., La Mantia, T., Rühl, J., Badalucco, L., Kuzyakov, Y., Gristina, L., Laudicina, V.A., 2014. Dynamics of soil organic carbon pools after agricultural abandonment. Geoderma 235-236, 191–198.

Ochoa, P.A., Fries, A., Mejía, D., Burneo, J.I., Ruíz-Sinoga, J.D., Cerdà, A., 2016. Effects of climate, land cover and topography on soil erosion risk in a Semiarid Basin of the Andes. Catena 140:31–42. http://dx.doi.org/10.1016/j.catena.2016.01.011.

Ogle, S., Breidt, F.J., 2003. Uncertainty in estimating land use and management impacts on soil organic carbon storage for US agricultural lands between 1982 and 1997. Glob. Chang. Biol. 9, 1521–1542.

Orgill, S.E., Condon, J.R., Conyers, M.K., Morris, S.G., Alcock, D.J., Murphy, B.W., Greene, R.S.B., 2016. Removing grazing pressure from a native pasture decreases soil organic carbon in Southern New South Wales, Australia. Land Degrad. Dev. http://dx.doi.org/10.1002/ldr.2560.

Pabst, H., Gerschlauer, F., Kiese, R., Kuzyakov, Y., 2016. Land use and precipitation affect organic and microbial carbon stocks and the specific metabolic quotient in soils of eleven ecosystems of Mt. Kilimanjaro, Tanzania. Land Degrad. Dev. 27 (3):592–602. http://dx.doi.org/10.1002/ldr.2406.

Parras-Alcántara, L., Lozano-García, B., Galán-Espejo, A., 2015. Soil organic carbon along an altitudinal gradient in the Despenaperros Natural Park, southern Spain. Solid Earth 6 (1):125–134. http://dx.doi.org/10.5194/se-6-125-2015.

Parras-Alcántara, L., Lozano-García, B., Keesstra, S., Cerdà, A., Brevik, E.C., 2016. Long-term effects of soil management on ecosystem services and soil loss estimation in olive grove top soils. Sci. Total Environ. http://dx.doi.org/10.1016/j.scitotenv.2016.07.016.

Parras-Alcántara, L., Martín-Carrillo, M., Lozano-García, B., 2013. Impacts of land use change in soil carbon and nitrogen in a Mediterranean agricultural area (Southern Spain). Solid Earth 4:167–177. http://dx.doi.org/10.5194/se-4-167-2013.

Pasta, S., La Mantia, T., 2013. Plant species richness, biogeographic and conservation interest of the vascular flora of the satellite islands of Sicily, patterns, driving forces and threats. In: “Islands and Plants, Preservation and Understanding Of Flora on Mediterranean islands”, 2nd Botanical Conference in Menorca. Proceedings and Abstracts (Cardona Pons, E., Estaun Clariso, I., Comas Casademont, M., and Fragai Arguimbau, P. (editors). Consell Insular de Menorca, Collecciò 20, 201–238. 2013 (ISBN, 978-84-95718-95-2).

Pereira, P., Mierauskas, P., Novara, A., 2016. Stakeholders' perceptions about fire impacts on Lithuanian protected areas. Land Degrad. Dev. 27 (4):871–883. http://dx.doi.org/10.1002/ldr.2290.

Petanidou, T., Kizos, T., Soulakellis, N., 2008. Socioeconomic dimensions of changes in the agricultural landscape of the Mediterranean Basin: a case study of the abandonment of cultivation terraces on Nisyros Island, Greece. Environ. Manag. 41, 250–266.

Plieninger, T., Hui, C., Gaertner, M., Huntsinger, L., 2014. The impact of land abandonment on species richness and abundance in the Mediterranean basin: a meta-analysis. PLoS One 9 (5), e98355.

Poeplau, C., Marstorp, H., Thored, K., Kätterer, T., 2016. Effect of grassland cutting frequency on soil carbon storage – a case study on public lawns in three Swedish cities. Soil 2: 175–184. http://dx.doi.org/10.5194/soil-2-175-2016.

Post, W.M., Kwon, K.C., 2000. Soil carbon sequestration and land-use change: processes and potential. Glob. Chang. Biol. 6, 317–327.

Regione Siciliana, 2015. Relazione Annuale di Valutazione al 2014. Agriconsulting.

Renwick, A., Jansson, T., Verburg, P.H., Revoredo-Giha, C., Britz, W., Gocht, A., McCracken, D., 2013. Policy reform and agricultural land abandonment in the EU. Land Use Policy 30, 446–457.

Rey Benayas, J.M., Martins, A., Nicolau, J.M., Schulz, J., 2007. Abandonment of agricultural land: an overview of drivers and consequences, CAB reviews. Perspect. Agr. Veter. Sci. Nutrit. Nat. Resour. 2, 1–14.

Rivas-Martinez, S., 1994. Bases para una nueva classificacion bioclimatica de la Tierra, Folia Bot. Madritensis. vol. 10 pp. 1–23.

Rivas-Martínez, S., Loidi Arregui, L., 1999. Bioclimatology of the Iberian Peninsula. In: Rivas-Martínez, S., Fernández-Gonzáles, F., Loidi, J. (Eds.), Checklist of Plant Communities of Iberian Peninsula, Balearic and Canary Islands to suballiance level, Itinera Geobotanica. 13, pp. 353–451.

Romero-Díaz, A., Ruiz-Sinoga, J.D., Aymerich, F.R., Brevik, E.C., Cerdà, A., 2016. Ecosystem responses to land abandonment in Western Mediterranean Mountains. Catena http://dx.doi.org/10.1016/j.catena.2016.08.013.

Rühl, J., Gristina, L., La Mantia, T., Novara, A., Pasta, S., 2015. Afforestation and reforestation: the Sicilian case study. In: Valentini, R., Miglietta, F. (Eds.), The Greenhouse Gas Balance of Italy - An Insight on Managed and Natural Terrestrial Ecosystems. Springer, pp. 173–184.

Rühl, J., Pasta, S., La Mantia, T., 2005. Metodologia per lo studio delle successioni secondarie in ex coltivi terrazzati, il caso di studio delle terrazze di Pantelleria (Canale di Sicilia), Foresta@. vol. 2 pp. 388–398.

Saiano, F., Oddo, G., Scalenghe, R., La Mantia, T., Ajmone-Marsan, F., 2013. DRIFTS sensor: soil carbon validation at large scale (Pantelleria, Italy). Sensors 13, 5603–5613.

Shaw, E.A., Denef, K., Milano de Tomasel, C., Cotrufo, M.F., Wall, D.H., 2016. Fire affects root decomposition, soil food web structure, and carbon flow in tallgrass prairie. Soil 2:199–210. http://dx.doi.org/10.5194/soil-2-199-2016.

Sheffer, E., 2012. A review of the development of Mediterranean pine-oak ecosystems after land abandonment and afforestation: are they novel ecosystems? Ann. For. Sci. 69 (4), 429–443.

Shelef, O., Stavi, I., Zdruli, P., Rachmilevitch, S., 2016. Land use change, a case study from southern Italy: general implications for agricultural subsidy policies. Land Degrad. Dev. 27 (4):868–870. http://dx.doi.org/10.1002/ldr.2343.

Smith, P., Cotrufo, M.F., Rumpel, C., Paustian, K., Kuikman, P.J., Elliott, J.A., McDowell, R., Griffiths, R.I., Asakawa, S., Bustamante, M., House, J.I., Sobocká, J., Harper, R., Pan, G., West, P.C., Gerber, J.S., Clark, J.M., Adhya, T., Scholes, R.J., Scholes, M.C., 2015. Biogeochemical cycles and biodiversity as key drivers of ecosystem services provided by soils. Soil 1:665–685. http://dx.doi.org/10.5194/soil-1-665-2015.

Suárez-Seoane, S., Osborne, P.E., Baudry, J., 2002. Responses of birds of different biogeographic origins and habitat requirements to agricultural land abandonment in northern Spain. Biol. Conserv. 105, 333–344.

Teshome, A., de Graaff, J., Ritsema, C., Kassie, M., 2014. Farmers' perceptions about the influence of land quality, land fragmentation and tenure systems on sustainable land management in the north western Ethiopian Highlands. Land Degrad. Dev. http://dx.doi.org/10.1002/ldr.2298.

Van Eerd, L.L., Congreves, K.A., Hayes, A., Verhallen, A., Hooker, D.C., 2014. Long-termtillage and crop rotation effects on soil quality, organic carbon, and total nitrogen. Can. J. Soil Sci. 94, 303–315.

VandenBygaart, A.J., Gregorich, E.G., Angers, D.A., Stoklas, U.F., 2004. Uncertainty analysis of soil organic carbon stock change in Canadian cropland from 1991 to 2001. Glob. Chang. Biol. 10, 983–994.

Willaarts, B.A., Oyonarte, C., Muñoz-Rojas, M., Ibáñez, J.J., Aguilera, P.A., 2016. Environmental Factors Controlling Soil Organic Carbon Stocks in Two Contrasting Mediterranean Climatic Areas of Southern Spain. Land Degrad. Dev. 27 (3), 603–611.

Wasak, K., Drewnik, M., 2015. Land use effects on soil organic carbon sequestration in calcareous Leptosols in former pastureland-a case study from the Tatra Mountains (Poland). Solid Earth 6 (4):1103–1115. http://dx.doi.org/10.5194/se-6-1103-2015.

Zaravali, M.P., Yakoulaki, M.D., Papansatasis, V.P., 2007. Effects of shrub encroachment on herbage production and nutritive value in semi-arid Mediterranean grasslands. Grass Forage Sci. 62, 355–363.

Zucca, C., Arrieta Garcia, S., Deroma, M., Madrau, S., 2016. Organic carbon and alkalinity increase in topsoil after rangeland restoration through *Atriplex nummularia* plantation. Land Degrad. Dev. 27 (3):573–582. http://dx.doi.org/10.1002/ldr.2378.