SOIL ORGANIC CARBON POOL'S CONTRIBUTION TO CLIMATE CHANGE MITIGATION ON MARGINAL LAND OF A MEDITERRANEAN MONTANE AREA IN ITALY

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Abstract

To evaluate the mitigation potential provided by the SOC pool, we investigated the impact of woody encroachment in the 0-30 cm depth of mineral soil across a natural succession from abandoned pastures and croplands to broadleaves forests on the central Apennine in Italy. In parallel, to assess the effect of the land use change (LUC) from cropland to pasture, a series of pastures established on former agricultural sites, abandoned at different time in the past, were also investigated.

Our results show that woody encroachment on former pastures and croplands contributes largely to mitigate climate change, with an increase of the original SOC stock of 45% (40.5 Mg C ha^{-1}) and 120% (66.5 Mg C ha^{-1}), respectively. Also the LUC from croplands to pastures, greatly contributes to climate change mitigation trough a SOC increase of about 80% of the original SOC (45.9 Mg C ha^{-1}).

The management of abandoned lands represent a crucial point in the mitigation potential of agriculture and forestry activities, and particularly the role of the SOC pool. A policy effort should focus on minimizing the risk of speculative management options, particularly when the value of woody biomass become convenient to supply new energy systems allowing monetizing a long term forests productivity.

In conclusion, despite both the land abandonment and the LUC can have a different impact on the SOC pool under different climatic conditions, these results can be useful to improve the SOC estimates in the National greenhouse gases Inventory at country level.

1. Introduction

In Europe, agricultural land abandonment is a common phenomenon since the beginning of the 20th century (Garcìa-Ruiz and Lana-Renault, 2011; MacDonald et al. 2000), and it is forecast to continue over the next decades (Pointereau et al. 2008; Rounsevell et al. 2006). The increase in abandonment of farmland is particularly severe on mountain areas of the southern and eastern countries of Europe (Estel et al. 2015; Terres et al. 2015). Lasanta (2014) observed that more than 75% of arable land is no longer worked in European mountains, a percentage that reaches 100% in some Mediterranean mountains. The phenomena is due to socio-economic aspects, climate change as well as the reflection of European policies carried out during several international negotiation on market and environment (Van Vliet et al. 2015; Renwick et al. 2013). In the last three decades, the Common Agricultural Policy (CAP) has promoted the reduction of production and, at the same time, has fostered more sustainable agricultural practices. The measures like set-aside and afforestation, introduction of the agro-environmental schemes, the decoupling of Agenda 2000, the definition of cross-compliance in the Middle Term Review of 2003 and the greening introduced by the CAP 2013 reform, have changed the production structure of European agricultural market and jeopardized environmental impacts (Kristensen et al. 2016; Passeri et al. 2016). The outline of the European agricultural policies has promoted, in many cases, more sustainable agricultural practices, but, at the same time, has resulted in some European contexts to an acceleration of the phenomenon of agricultural production deactivation, contributing over time to the abandonment of farmlands in marginal contexts, often classified as less favoured areas (Lasanta et al. 2017; MacDonald et al. 2000).

In connection with land abandonment, the woody encroachment is a widespread phenomenon throughout Europe (Piussi, 2000) and worldwide (Chiti et al. 2017; Eldridge et al. 2011; Zhang et al. 2010). In Italy, woody encroachment on abandoned lands characterizes both the Alps and the Apennines (Piussi, 2002; Corona et al. 2005).

The latest National greenhouse gases (GHG) Inventory, submitted by Italy in 2017 to the UNFCCC, shows a progressive contraction of cropland areas by 2 million ha over the last 25 years: from 10.8 million ha in 1990 to 8.8 million ha in 2015 (NIR, 2017). The causes of the cropland contraction are twofold: urbanization and/or abandonment. The abandoned agricultural area is subject to grass and woody encroachment, leading, in the long term, into forest establishment. Indeed, according to the National Inventory Report (NIR 2017), forest land has increased its surface over the last 25 years of nearly the same amount of cropland contraction: 1.7 million of hectares. In the NIR (2017) it is assumed that forest land is expanding exclusively on grassland, that therefore often represents an intermediate state of land cover between cropland and forest land in the woody encroachment process.

As a consequence, the woody encroachment on abandonment cropland can be considered as an indirect human induced land cover change, which causes an associated change in carbon (C) stocks at ecosystem level (Foley et al. 2005). The contribution of the abandonment of agricultural practices in favour of a grass and woody encroachment is likely to provide a large contribution in term of climate change mitigation, through the removal of CO_2 from the atmosphere and the consequent storage of the C in the above ground woody biomass (Risch et al. 2008) and in the soil. The balance between C inputs and outputs from soils controls the soil organic carbon (SOC) pool, and land use changes (LUC) may impact both the C input as well as output fluxes from an ecosystem (Guo and Gifford, 2002). Thus, after a LUC, soil can act as a source or a sink of C according to the ratio between inflows and outflows. Recent studies from montane areas of the Mediterranean basin, suggested a major role of soil in contributing to climate change mitigation trough SOC sequestration during the woody encroachment process (Novara et al. 2017; Nadal-Romero et al. 2016; Romero-Díaz et al. 2016).

In Italy, the land use, land use change and forestry sector (LULUCF) is responsible of a net sink of 36,218 Gg CO_2eq in 2015, that increased on average by about 2,000 Gg CO_2eq per year, mainly due to the expansion of grassland and forest land (NIR, 2017). In particular, the conversion of 1.3

million ha from grassland to forest land between 1996 and 2015 led to a sink of 1,937 GgC yr^{-1}, of which 242 GgC yr^{-1} are attributed to the SOC pool. However, the SOC estimations in the National GHG Inventory are very poor due to lack of specific data at country level, using a single value of SOC content for the whole Italy in grassland, forest land and cropland categories respectively.

The aim of this research is to assess the variation in SOC levels due to the most representative LUC occurring in montane areas of Central Italy: a) natural successions from abandoned pasture and cropland to broadleaves forest; b) change in land use, from cropland to pasture.

Furthermore, the study gives policy recommendations on the management of rural development policies related to the increase in SOC and tries to draw some reflections on the overall impact of a "C oriented" agricultural policy for the rural areas and communities of the central Italian Apennine.

2. Materials and methods

2.1. Site description

The study area (44° 8' 16.9" N; 11°18' 57.5" E) is located on the Apennine ridge in the Mugello valley in Tuscany, 50 km north of Florence, at an average elevation of 800 m a.s.l. (Figure 1). The climate of the investigated area is temperate Mediterranean with a mean annual temperature of 9.2 °C and a mean annual precipitation of about 1000 mm. Since the 1950 both temperature and precipitation experienced a gradual decrease (Figure 2). According to Sanesi (1977), the soils of the area are generally classified as Cambisols, following to the FAO classification (IUSS Working Group WRB 2014). These soils are moderately depths or swallow, with a clay texture and sometime rich in gravel. The pH is moderately alkaline with carbonates only in the lower part of the profile.

Historical and census data concerning LUC dynamics for the Mugello valley indicate that over the last century the agricultural activities decreased substantially, particularly in the mountain areas, which are those more exposed at risks on land abandonment (Terres et al. 2015).

2.2. Experimental design

The study was conducted in 2012 considering three contiguous farms, one of which is active since the middle of the last century, while the other two closed their activity at the end of the 20th century. To investigate the effect of woody encroachment and of a shift in land use, both after land abandonment, we identified three chronosequences: a) from pasture to forest, b) from cropland to forest and, c) from cropland to pasture. Croplands are cultivated for fodder production that is consumed by cows during winter, while pastures are grazed by cows with a low intensity. In the first chronosequence, to have a strong baseline for SOC we considered three pastures currently grazed to represent the zero point. Then, were identified five pastures abandoned at different time in the past (6, 15, 30, 42, 54 years before), where woody encroachment is currently ongoing. A forest developed over a pasture abandoned 70 years before represents the final point of this chronosequence (Table 1). Similarly, in the second chronosequence were considered three croplands currently managed to represent the zero point. Then were considered two croplands abandoned at different time in the past (14 and 50 years before), and a forest developed on a cropland abandoned 64 years before (Table 1). The three croplands representing the zero point of the second chronosequence were also used as a baseline for the third choronsequence, where two pastures established on former croplands, abandoned 14 and 35 years before and always managed as pastures, were also considered. A pasture currently grazed was used as a final point of this choronsequence.

2.3. Soil sampling strategy

To determine the variations in SOC stocks following this natural LU change, it was adopted the soil sampling protocol proposed by the European Commission to certify changes in SOC (Stolbovoy et al. 2007). This sampling protocol is based on a randomized sampling template with a grid of 100 cells enabling a random sample collection with a distance threshold to be determined. The spatial parameters of the template are flexible and adjusted to the size and geographical coordinates of the sampling plot (e.g. pasture). To define the dimension of the template, the minimum and maximun X and Y axes of the area need to be known. Since all the selected sites were smaller than 5 ha, 3 plots per site were chosen (Stolbovoy et al. 2007) and located according to the above considerations. According to ISO 10381-4 standard (ISO, 2002), the number of sampling points for a composite soil sample should be 25. Hence, in each of the plots, soil samples were collected following a grid of 25 points. In each point the topsoil (0–30 cm depth of mineral soil) was sampled, to have 25 replicates per plot, which were mixed directly in the field to have one composite sample per plot. A sample from the organic horizon, namely the litter layer, was also collected in each plot using a frame 20 cm by 20 cm. Considering the three plots, there were three composite samples for the 0-30 cm depth and three for the litter at each site. In the middle of each plot, a trench was opened down to 100 cm depth and used for accurately evaluate the presence of stones with a size bigger than 2 mm, and to collect bulk density samples using a stainless steel cylinder of fixed volume (diameter=5 cm; height=5 cm), following the core method (Blake 1965). Considering the three soil trenches at each site, three samples of the bulk density were collected for the 0-30 cm layer.

The 30 cm depth was chosen in line with the minimum depth required by the IPCC guidelines (IPCC, 2006) when reporting SOC stocks under different LU types. It also represents the compartment where SOC changes due to a LUC should be easy detectable also on the short term.

2.4. Laboratory analysis and SOC stock estimation

All samples were oven-dried (60 °C) to constant mass. The mineral soil was sieved at 2 mm mesh size; the organic horizon and the mineral soil samples were ground in a ball mill. Mineral soil samples were air-dried, then sieved at 2 mm to separate the fine earth (< 2 mm fraction) from the stones (> 2 mm fraction). All the analyses on mineral soil samples were performed on the fine earth only. The particle size distribution was determined by the pipette method after destruction of the organic cement by sodium hypochlorite adjusted at pH 9 (Mikutta et al. 2005). The pH was potentiometrically measured in deionised water with a soil–liquid ratio of 1:2.5. Total C was determined by dry combustion (ThermoFinnigan Flash EA112 CHN, Okehampton, UK) on finely ground aliquots of each sample. The possible occurrence of inorganic C was checked in all samples by a Dietrich-Fruhling volumetric calcimeter. Given its absence, total SOC is equal to total C. The SOC stock was calculated for the 0-30 cm depth according to Boone et al. (1999), considering the SOC concentration (kg C kg^{-1} soil), the soil bulk density (Mg soil m^{-3}), the depth of the layer (cm), and the percent in mass of rock fragments [1-(% rock volume/100)].

Statistical analyses

Differences in C concentrations and C stocks were determined among all the sites of each chronosequence using analysis of variance (ANOVA) with the R software (R Core Team 2016). When significant differences were observed a multiple comparisons test (Tukey HSD) was done. Statistical significance for the ANOVA and Tukey test were established at $p<0.001$.

3. Results

The investigated sites show a soil bulk density ranging from 1.0 to 1.2 Mg m^{-3}, a sandy clay loam to clay loam texture and a neutral pH, which are typical for the Cambisols in this area (Table 1; Sanesi 1977). Since soil features are known to affect SOC storage (Egli et al. 2009), the similarity of the main soil parameters support sites comparability within each chronosequence.

3.1 Variations in SOC concentrations and stocks

The three pastures show C concentrations in the topsoil ranging from 36.5±2.5 g C kg^{-1} to 43.0±2.3 g C kg^{-1} (Table 2). As soon as the woody encroachment begin, the C concentration does not increases significantly during all the intermediate stages, even after 42 years since the abandonment. A clear SOC increase is evident only when the forest vegetation is well established and the forest canopy closed, after about 50 and 70 years from the abandonment, with a C concentration of 48.5±2.8 g C kg^{-1} and 53.4±5.5 g kg^{-1}, respectively. The SON shows a similar trend with a significant increase only in the two final stages of forest colonization (Table 2).

Similarly, in the second choronosequence the three managed croplands show similar C concentrations in the topsoil, about 20.0 g C kg^{-1} (Table 2). As soon as the woody encroachment begins, the SOC increase is evident, being the concentration after 14 years 28.1±3.8 g C kg^{-1}. The concentration increases to 36.5±2.8 g C kg^{-1} after 50 years and reach 48.0±2.6 g C kg^{-1} after 64 years since the abandonment, when the forest is well established. Despite the significant increase in SOC already in the first stage of the succession, the SON does not follow the same trend, being significantly higher than the initial stage only in the forest stage (Table 2). The LUC from cropland to pasture cause as well an evident SOC increase (Table 2), with each stage being significantly different from the previous one, and with a SOC concentration in the pasture that is about 2.0 g C kg^{-1} higher than that in the cropland. Also in this chronosequence SON concentration does not follow the SOC trend, and the SON is significantly higher than the initial cropland only when the pasture is well established, several years after the abandonment (Table 2).

The trend in SOC stock variations during woody encroachment on pastures mirrors that of concentrations with the stock being significantly high only in the final stages of forest succession, namely after about 50 and 70 years when the forest is well established (Figure 3). Compared to the currently managed pasture, the SOC stock in the forest, the final point of the succession, increases of about 40 Mg C ha^{-1}. Litter layer start to accumulate from 42 years on (1.5±0.3 Mg C ha^{-1}) and its amount increase with time being 2.9±0.4 Mg C $ha^{-1}$and 4.8±0.5 Mg C ha^{-1}after 54 years and when the forest is well established, respectively. In the cropland chronosequence the trend in SOC accumulation is remarkable. Compared to the initial stage, after 14 years the topsoil already shows a SOC stock increase of 18.3 Mg C ha^{-1}. The increase is even more evident after 50 years (40.2 Mg C ha^{-1}), and 64 years (66.5 Mg C ha^{-1}) following the abandonment. In this chronosequence litter start to accumulate on mineral soil after 50 years, 3.2±0.3 Mg C ha^{-1}, and the amount increases to 5.1± Mg C ha^{-1} in the final forest stage. Finally, the LUC from cropland to pasture lead to an increase of the SOC stock in the pasture that is about 45 Mg C ha^{-1} higher than the cropland.

3.2 Impact on SOC fluxes

Taking into account the time since abandonment and the difference in SOC stocks between the different stages of each chronosequence, average annual SOC fluxes for the 0–30 cm depth were derived (Table 3). During the first 6 years since the abandonment of pastures, the soil start to emit C at a rate of 1 Mg C ha^{-1} yr^{-1}, amount that decline with time from 6 to 15 years since the abandonment, 0.3 Mg C ha^{-1} yr^{-1}. After 15 years since abandonment the trend is inverted and the soil start to accumulate C with a rate that increases with time, reaching about 1.0 Mg C ha^{-1} yr^{-1} when the forest is well established (Table 3).

On the contrary, after the abandonment of the croplands the soil immediately start to sequester SOC at a high rate during the first 14 years, 1.3 Mg C ha^{-1} yr^{-1}. The rate decreases slightly from 14 to 50 years, 0.6 Mg C ha^{-1} yr^{-1}, and increases again when the forest is well established, 1.3 Mg C ha^{-1} yr^{-1}. Changing the LU from cropland to pasture without ceasing the land management, leads as well to an immediate SOC sequestration of about 0.9 Mg C ha^{-1} yr^{-1} during the first 14 years. Then the SOC sequestration rate remains stable from 14 to 35 years, about 0.8 Mg C ha^{-1} yr^{-1}.

4. Discussion

4.1. Impact of land abandonment and of management on SOC stocks

Climatic conditions, such as precipitation and temperature, are considered to have a great influence on SOC following a land use change (Poeplau et al. 2011). Jackson et al. (2002) and Guo and Gifford (2002) found a negative relationship between precipitations and SOC changes after woody plant invasion on abandoned lands, with the SOC levels decreasing in areas of high precipitation (>1200 mm), and increasing in areas with low precipitation. Alberti et al. (2011) and La Mantia et al. (2013) found same pattern in some sites along the Italian peninsula. Our study area, with an average precipitation of 1000 mm could be classified at the limit where the SOC changes are uncertain. Looking at the trend following woody encroachment on former pastures, the increase in SOC stock is evident only when the forest is well established and the forest canopy is closed, 54 years after the abandonment (+28% of original SOC). In a study by Paul et al. (2002), it is suggested that after an initial SOC loss, after 30 years following the conversion from pastures to forest the initial SOC stock is fully recovered. In our case, considering the mineral soil, no SOC loss is observed in the first decades following the beginning of the woody encroachment, and after 54 years the SOC start to be significantly higher than the pasture the forest replaced. In the final point of the succession, the SOC stock in the topsoil is 44% higher than pastures and, when the litter layer is included, the C increases up to 50%. It is worth noting that litter start to accumulate on mineral soil from 42 years since abandonment and its amount increases in the following forest stages in connection with an increase of SOC in the mineral soil. The C inputs arriving to soil via litter deposition are thought to be the main responsible for the SOC increase in the long term, due to an increase in the recalcitrance of the C inputs from herbaceous vegetation to woody species (Marin-Spiotta et al. 2008), which leads to a longer persistence of the C in the soil system (Gleixner et al. 2001).

A different trend is observed when a cropland is no longer used for cultivation and allowed to revert to natural vegetation. The SOC amounts is significantly higher (+34%) than the managed cropland already 14 years after the abandonment of the agricultural practices and continue to increase until the forest is well established, as observed also by other authors (Novara et al. 2017; Blaser et al. 2014; Post and Kwon, 2000). The forest establishment following the abandonment of a cropland shows a higher mitigation potential compared to forests established on former pastures, due to the lower SOC concentration present under the initial situation. The final increase in SOC observed in mature forests replacing croplands, about 120% of the original SOC stock, is much higher than the 44% observed for the conversion of pasture. Litter contribution start to be relevant from 50 years on, when the SOC stock is already two fold the stock of the initial stage. This indicate that in this succession the most important role in SOC sequestration is played by the end of the agricultural practices, which stimulate SOC decomposition, and by the C inputs provided by herbaceous species, which are the prevalent species along the succession for many decades.

Similarly, the conversion of cropland to pasture leads to a SOC increase, which is evident soon after the change. The final increase in SOC, assessed when the pasture is managed since several decades, suggests that also a less intensive management system can lead to great mitigation potential due to a substantial SOC increase, about 84% higher than the original SOC stock.

Since the SOC increase is strictly related to the decrease in precipitation (Alberti et al. 2011; Jackson et al. 2000), a further SOC increase could be predicted for the investigated LUC, considering the decreasing trend in mean annual precipitation observed in the Mugello valley during the last 60 years (Figure 2), although possible changes in vegetation productivity should be also considered. This fact highlight the need to find the best management options for the marginal land such those considered in this study, to correctly manage to huge amount of C stored as a consequence of this LUC.

The overall mitigation potential of woody encroachment over abandoned cropland is more clearly understood in the context of the C stored in above ground biomass of pastures and forest systems. In pastures from the same area, the aboveground C stocks can vary widely due to the extent of tree cover and shrubs, from 0.5 Mg C $ha^{-1}$where trees are absent, to over 10 Mg C ha^{-1} where there is substantial presence of trees and shrubs (Pellis, 2017). On the contrary, mature forests from the same area show an amount of C in the aboveground biomass of about 115 Mg C ha^{-1} (Pellis, 2017), hence about 10 to more than 100 times higher than pastures.

Our findings show that once the land is subject to a LUC due to abandonment, the SOC content continue to change over a time period longer than the 20 years period considered by the IPCC as the time needed for the SOC stocks to reach the equilibrium, when changing from a LU category to another one (IPCC 2006 vol. 4, chapter 2, eq. 2.24, 2.25). In case of cropland and pasture land abandonment, the SOC continue to accumulate for a longer time period and this can be attributed to the slow evolution of the vegetation cover that changes the biomass inputs into the soil over time, keeping the SOC fluxes dynamic (Table 3). On the other side in case of LUC from cropland to pasture, the transition can be considered from one stable LU category to another. In this case the

SOC appears to continuously increase over time (at least up to 35 years, and most likely for a longer time) well beyond the 20 year IPCC default period used in the National GHG Inventory (NIR, 2017). This may result in an underestimation at National level of the potential C sink of such conversions. In fact, within the NIR the transition from cropland to pasture land, that for Italy occurred on about 1.3 million ha in the period 1990-2015, implies an annual SOC accumulation rate of about 1.11 Mg C ha^{-1} yr^{-1} for 20 years, while results from this study indicate a similar annual SOC accumulation rate (0.85 Mg C ha^{-1} yr^{-1}) but over a time period longer than 35 years.

4.2. Implications for climate change mitigation options in abandonment agricultural areas

Woody encroachment can reduce soil erosion, increase biodiversity and contribute to climate change mitigation trough the storage of C in soil and woody vegetation (Vallejo et al. 2006). However, it can also impact significantly the landscape, biodiversity, the ecosystems dynamics and sustainability of a region trough the reduction in open habitats that were formerly maintained by traditional land management (Kleijn et al. 2009). Considering climate change mitigation, in a long-term the forest can accumulate a greater amount of C than pastures and transitional phases. Nevertheless, the main part of the additional C is stored in tree biomass, which constitute a less stable C pool due to external disturbances, such as management, harvesting and environmental modifications, compared with C stored in the mineral soil (Guidi et al. 2014). The LUC occurring trough woody encroachment can have important environmental and socio-economic impacts (Beilin et al. 2014), which can be positive or negative depending on local factors and the aims of conservation (Höchtl et al. 2005). Taking into account social needs and community's perceptions about the forest and their role in the production of ecosystem's services, forest conservation in the Mediterranean region should be promoted (Scarascia-Mugnozza et al. 2000). Nevertheless, the regulation of many Regions (Authority Management of Rural Development Programme - RDP), among which Tuscany, allows to restore the pastures and croplands, where woody encroachment is on going or where tree were planted, subject to the provision of a prove that the land was previously under agriculture/pasture management. In our study area, aerial photos from 1954 demonstrate that the sites were not forested at that time, thus per regulation previous conditions of pasture or cropland can be restored (d.p.g.r. 48/R/2003 art. 80 bis), potentially allowing the release in the atmosphere of a huge amount of C trough vegetation clearings and delayed SOC emissions. Making a practical example for the Mugello valley, between 1982 and 2010 the utilized agricultural area has been reduced by 35% (ISTAT 2010), meaning that 14,660 ha are currently in transition to forest and can be potentially reconverted into grassland or cropland. A policy effort should focus on minimizing the risk of speculative management options, particularly when the value of woody biomass become convenient to supply new energy systems (Astiacio Garcia, 2017), allowing monetizing a long term natural forests productivity.

The role of land use sector in the GHG balance it is recognized at the EU level with the decision no. 529/2013/EU, which requires the Member States to account for emissions and removals of GHG resulting from the LULUCF sector (EU, 2013), broadening the obligatory accounting of the sector to grazing land and cropland activities. Italy has also decided to elect these two activities under article 3.4 of the Kyoto Protocol for the second commitment period (2013-2020), decision that leads to a wider consideration of the land sector beyond the forests. The management of abandoned land could represents a crucial point in the mitigation potential of agriculture and forestry activities, and particularly the role of the SOC pool (Novara et al. 2017; Nadal-Romero et al. 2016; Romero-Díaz et al. 2016), which is also recognized into the Thematic Strategy for Soil Protection (European Commission, 2013), where it is defined that the maintenance of SOC stocks is essential for the fulfilment of present and future emission reduction commitments at EU level. The strengthening of the RDP can play a crucial role in this purpose, promoting extensive agricultural practices and environmental protection measures. In the Tuscany Region, RDP includes the maintenance and management of pastures, recognizing the hedge costs or the related income loss for farmers engaged in pro-mitigation practices as defined in the EU Reg. 1305/2013 of the RDP.

5. Conclusions

Woody encroachment on former pastures and croplands contributes to mitigate climate change leading to a SOC increase, which is varying depending on the previous LU. Nevertheless, in the central Italian Apennine, the mitigation potential of soil from pasture and cropland subject to woody encroachment can be effective only in the long term.

Correct management solutions for marginal areas in montane and subalpine regions of Europe, can avoid a huge loss of C in case the original land use is restored. Given the important function of forest, a correct landscape management should incentivize the protection function of new-formed forests over the conversion back to the economic production. However the role of this land is not fully reflected in the Italian GHG inventory due to lack of data at country level.

In conclusion, to preserve the C stock either in the woody biomass or soil, new management options should be deeply examined. In this context it will be essential to have the necessary information to estimate with high accuracy the overall C budget due to possible changes of land use and land cover, so as to exert more consciously active land management and improve national GHG inventory estimations.

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Tables and Figures

Table 1 – Physical (bulk density, rock fragment content and texture) and chemical (pH) soil parameters for the 0-30 cm depth of each stage from the three chronosequences.

Table 2 – Soil organic carbon (SOC) and Nitrogen concentrations for the 0-30 cm depth of each stage from the three chronosequences (n=3 composite sample per stage).

Table 3 – SOC fluxes of the sites from the different chronosequences. Fluxes are obtained as the difference between the SOC stocks from two consecutive stages of the chronsequence dived by the number of years. For fluxes, negative numbers means “emissions”, positive numbers “absorption”.

Figure 1 – Map of Italy with the indication of the three different parts of the Apennine ridge. The square indicates the Mugello valley, within the Tuscany region, were the study was performed,.

Figure 2 – a) Mean annual temperature and b) annual precipitation from 1950 to 2012 for the Mugello valley (Data provided by the Euromediterranean Center on Climate Change).

Figure 3 – SOC stock variations of the 0-30 cm depth in the three chronosequences: a) from pasture to forest; b) from cropland to forest and c) from cropland to pasture. Numbers below each bar represent the time since the abandonment. Different letters indicate significant differences within the same chronosequence (Anova $p<0.001$).

Figure 1
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Figure 2

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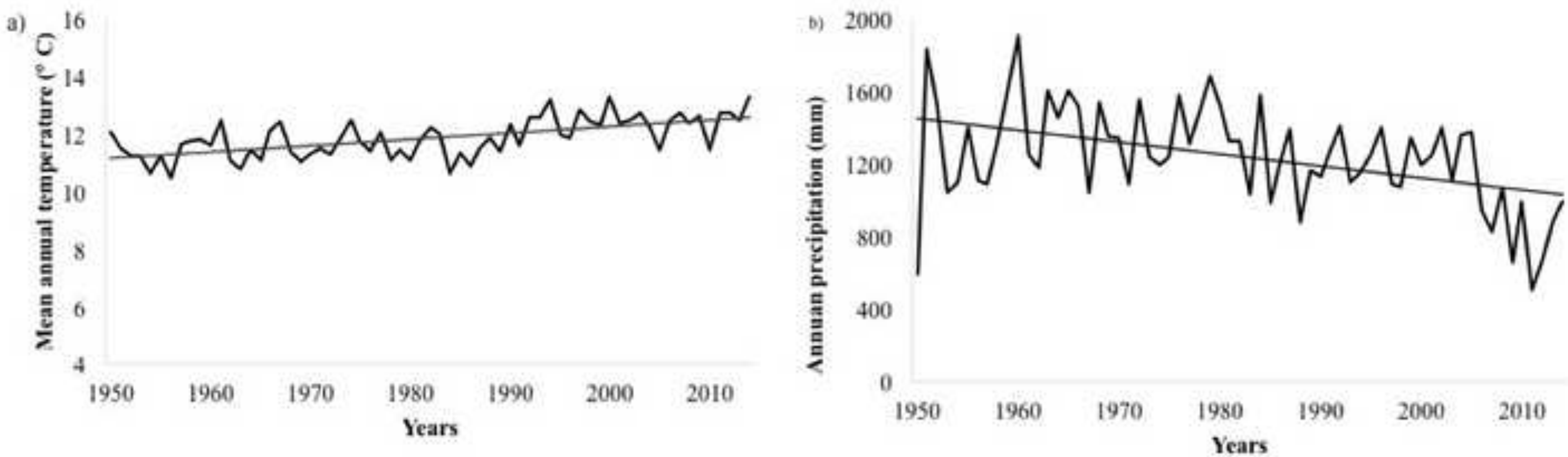

Figure 3

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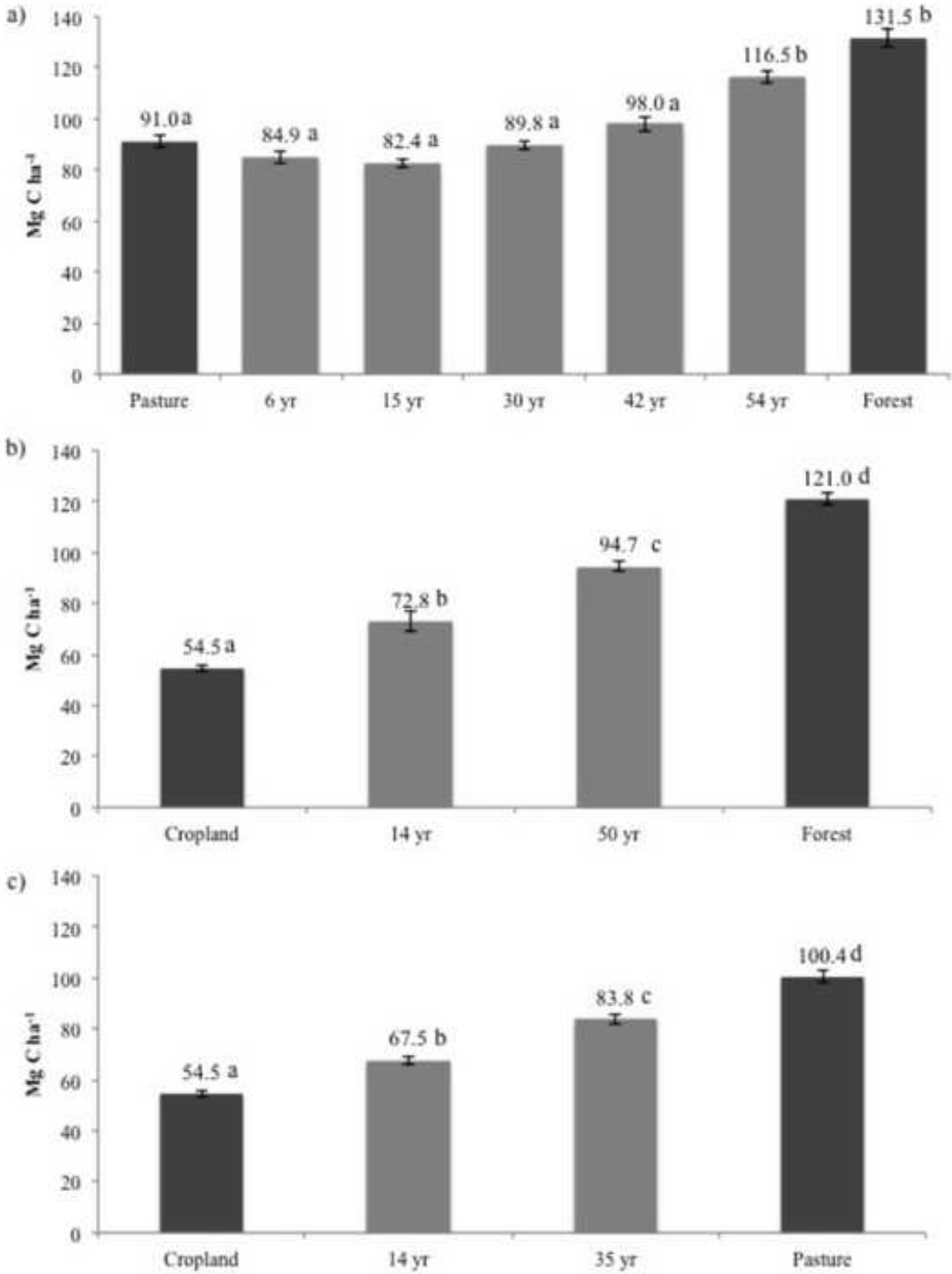

Table 1
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Table 1 – Physical (bulk density, rock fragment content and texture) and chemical (pH) soil parameters for the 0-30 cm depth of each stage from the three chronosequences (n=3 for each stage).

Site	Bulk Density ($Mg\ C\ m^{-3}$)	Rock fragments on total mass (Percentage)	Sand ($g\ kg^{-1}$)	Silt ($g\ kg^{-1}$)	Clay ($g\ kg^{-1}$)	pH
Pasture	1.08±0.08	33	538±37	169±28	293±32	7.2±0.2
Pasture	1.13±0.03	30	498±28	152±24	350±25	7.3±0.2
Pasture	1.10±0.07	32	585±32	167±32	248±29	7.0±0.1
6	1.12±0.05	28	494±29	215±38	291±35	7.1±0.3
15	1.07±0.06	29	552±28	231±24	217±41	7.1±0.3
30	1.15±0.07	33	522±36	182±27	296±33	7.0±0.2
42	1.19±0.06	32	532±27	175±38	293±26	6.7±0.3
54	1.14±0.04	30	472±32	210±34	318±29	6.8±0.3
Forest	1.17±0.06	32	473±30	287±25	240±32	6.6±0.3
Cropland	1.24±0.05	27	493±19	213±32	294±31	6.9±0.2
Cropland	1.21±0.06	20	481±21	195±28	324±27	7.3±0.3
Cropland	1.23±0.06	25	524±28	157±35	319±26	7.2±0.3
14	1.14±0.07	24	505±18	222±39	273±32	6.8±0.2
50	1.14±0.05	24	496±17	183±34	321±28	6.5±0.3
Forest	1.14±0.07	23	542±23	165±43	293±25	6.4±0.3
Cropland[a]	1.23±0.06	24	499±26	188±26	313±29	7.1±0.3
14	1.20±0.05	26	486±24	223±26	291±32	7.0±0.2
35	1.18±0.06	27	534±38	192±32	274±36	6.9±0.2
Pasture	1.17±0.06	21	518±27	215±38	267±28	6.9±0.3

[a] The cropland values are the average of the three croplands from the chronosequence cropland to forest

Table 2
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Table 2 – Soil organic carbon (SOC) and nitrogen (N) concentrations for the 0-30 cm depth of each stage from the three chronosequences (n=3 composite sample per stage). Within each column different letters indicate significant differences within the same chronosequence (Anova and Tukey test p<0.001).

Site	SOC	SON
	g C kg^{-1}	g C kg^{-1}
Pasture	38.9±5.24a	2.8±0.73ab
Pasture	43.0±2.33a	3.5±0.34a
Pasture	36.5±2.52a	3.6±0.45a
6	36.0±4.43a	2.6±0.54a
15	36.6±2.31a	2.10.53b
30	36.9±2.21a	2.2±1.02b
42	39.4±4.33a	2.6±0.43a
54	48.5±2.84b	3.5±0.42b
Forest	53.4±5.56b	3.8±0.64b
Cropland	22.0±2.94a	2.4±0.43a
Cropland	20.7±2.25a	2.9±0.62ab
Cropland	20.3±2.02a	1.9±0.41a
14	28.0±3.81b	3.3±0.52b
50	36.5±2.83c	1.9±0.22a
Forest	48.0±2.62d	2.8±0.41b
Cropland[a]	21.0±2.43a	2.2±0.52a
14	26.0±1.72b	2.7±0.23a
35	32.3±1.45c	2.9±0.31a
Pasture	43.0±3.51d	4.5±0.31b

[a] The cropland values for C and N are the average of the three croplands from the chronosequence cropland to forest.

Table 3

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Table 3 – SOC fluxes of the sites from the different chronosequences. Fluxes are obtained as the difference between the SOC stocks from two consecutive stages of the chronsequence dived by the number of years. For fluxes, negative numbers means "emissions", positive numbers "absorption".

Time since abandonment	ΔSOC	SOC flux
	Mg C ha^{-1}	Mg C ha^{-1}yr^{-1}
Pasture vs Forest		
6 yr	-6.06	-1.01
15 yr	-2.57	-0.29
30 yr	7.40	0.53
42 yr	8.20	0.66
54 yr	18.53	1.29
Forest	15.01	1.13
Cropland vs Forest		
14 yr	18.34	1.31
50 yr	21.17	0.59
Forest	26.36	1.32
Cropland vs Pasture		
14 yr	12.97	0.93
35 yr	16.31	0.78