Climate change mitigation and adaptation in agriculture: the case of olive

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Abstract

Agriculture might serve as a mitigation solution through carbon (C) sequestration in soil, in tree biomass and reducing GHG emissions. Increased C is also beneficial for some soil structures and functions improving the use of water resources and in turn the crop adaptation. This study aimed at improving knowledge on the synergy between mitigation and adaptation in agriculture through the paradigm of olive (*Olea europaea*). Through the analysis of the net ecosystem productivity and soil respiration, this paper reviewed the role of olive groves to store C in tree biomass occurring at a rate ranging from 0.36 to 2.78 t CO_2 ha^{-1} yr^{-1} and into soil (~8.5 t CO_2 ha^{-1} yr^{-1}). The influence of some practices (e.g., cover crops, no tillage, recycling of prunings) on that role is also discussed. The overall climatic impact of olive fruit and oil production has been evaluated also considering GHG emissions by upstream field operations (e.g., pruning, mulching of cover crop, fertilization, harvest, etc.) and by the extraction and bottling of oil.

The role of soil C as interface between climate change mitigation and adaptation has been delineated linking C-induced improvements in soil properties to increased water storage and reduced run-off and erosion. The outcomes presented may strengthen the environmental role of agriculture and promote synergistic mitigation and adaptation policies assisting in the conservation of soil and water resources.

Key words: biomass, carbon, erosion, macroporosity, *Olea europaea*, soil respiration, soil water

1. Introduction

The olive tree (*Olea europaea* L.) was domesticated more than 3,000 years ago in the Mediterranean area and represents an integral component (as fruit and oil) of the Mediterranean diet for millennia to the extent that a coevolution between Mediterranean inhabitants and olives has been proposed (Ortega 2006; Zeng *et al.* 2015). The specific drought tolerance mechanisms developed by olives as Mediterranean native species have greatly contributed to their longstanding success in dry and warm areas (Connor 2005; Dichio *et al.* 2013). In present, the recognition of olive products as functional food has renewed the interest for their consumption (Shahidi & Kiritsakis, 2017). However, olives are among the traditional Mediterranean crops which are now suffering the land abandonment because of environmental and socio-economic constraints (Rodrigo-Comino *et al.* 2017).

Up to 98% of the global olive growing area (10.2 Mha) is cultivated in the Mediterranean basin (FAOSTAT, 2017) under traditional cropping systems (80–100 p ha^{-1}) while a limited fraction (~1%) is recently shifting toward intensive (200-500 p ha^{-1}) or even super-intensive (up to 2,500 p ha^{-1}) cropping systems (Tous *et al.* 2010). The main reason boosting that change of grove design is the need to increase crop profitability through the reduction of costs per unit yield. However, the potential change of that crop design is limited because olive is cultivated mainly in marginal hilly areas (Xiloyannis *et al.* 2008) unsuitable for high density plantations. Hence, identifying alternative strategies to improve the profitability of olive groves is highly desirable for a socio-economic, ecological and landscape conservation.

Nowadays, an integrated view of agriculture combines the provision of food and fiber with additional functions and services to the extent that an ecosystem service approach has been proposed as the future of land evaluation (Dominati *et al.* 2016). The regulating services relevant to climate change mitigation that agriculture might provide include the overall reduction of emissions of greenhouse gases (GHG). Agriculture uses up to 70% of global fresh water through irrigation. Hence, increasing soil water reservoirs might contribute to reducing the irrigation need and increase productivity in rain-fed areas. The prevailing climate changes will increase the water demand by crops by 40-250% (Savé *et al.* 2012) contributing to increasing uncertainties for the future availability of fresh water. Hence, increasing soil water holding capacity might represent an adaptation strategy to face future water constraints.

This confirms that great opportunities for synergy between adaptation and mitigation measures exists in agriculture (Smith & Olsen 2010). Mitigation and adaptation are primary instruments to face climate change. However, they are often managed separately due to a poor integration of policies at international and national levels (Duguma *et al.* 2014). Therefore, this study aimed at improving awareness on synergy between mitigation and adaptation in agriculture through the paradigm of olive.

The reduction of GHG emissions and the sequestration of atmospheric CO_2 by means of crop photosynthesis and the increase of soil carbon stock is pivotal to mitigate climate changes (Smith *et al.* 2008). In this regard, the olive industry might contribute via (*i*) improving the main carbon stock pools (i.e., tree biomass, soil and litter) and (*ii*) reducing GHG emissions during olive cultivation and oil production.

The present study focuses on the impact of olive grove cultivation on carbon stock pools (ecological approach) and olive oil production chain on GHG emissions (Life Cycle Assessment – LCA- approach). The paper also examines the mitigation and adaptation synergy discussing the effect of increased SOC on soil water holding capacity and other regulating services (e.g., reduction of erosion risks).

ATMOSPHERIC CARBON SEQUESTRATION: IMPACT OF OLIVE GROVE ECOSYSTEMS

Monitoring and quantification of carbon (C), water and energy fluxes between cultivated ecosystems and atmosphere creates the basis for better knowledge of key processes related to climate change and agriculture relationship. According to the view of most ecologists, the imbalance between atmospheric CO_2 uptake through photosynthesis and loss by ecosystem respiration (both autotrophic and heterotrophic) is recognised as net ecosystem production (NEP). Hence, NEP is the balance of all CO_2 entering and leaving the ecosystem during a time frame (usually 1 year) (Smith *et al.* 2010). Hence, values of NEP reflect an ecosystem metabolism and its interaction with the environment (e.g. weather, soil water availability) (Chapin *et al.* 2006). There are also non-CO_2 exchanges of C (e.g., methane, volatile organic compounds, erosion, leaching of dissolved organic C) usually not included in NEP calculations. In addition, certain losses or gains of C related to anthropogenic activities (e.g., harvest, supply of organic row material or fertilisers) are also not included in NEP (Chapin *et al.* 2006).

As plants live, C is gained for new tissue formation (gross primary production, GPP) and lost for living tissue maintenance (including roots) as autotrophic respiration (R_a). Hence, the balance of that gain-loss represents the net gain in C (net primary productivity, NPP) allocated in the plant dry matter, NPP = GPP-R_a. A significant component of the ecosystem-atmosphere CO_2 fluxes is the heterotrophic respiration (R_h) of telluric organisms, thus the net C exchange is represented by NEP = NPP –R_h. The ecosystem is the reference for NEP calculations, thus positive values of NEP indicate that the ecosystem is a sink of CO_2, while negative ones indicate it as a CO_2 source. The net ecosystem exchange (NEE) is determined in micrometeorological based measurements of C exchange (e.g., eddy-covariance) considering the atmosphere as the reference, it follows that NEP is equivalent to -NEE.

Soil CO_2 efflux

Soil respiration (R_S) is a relevant component of terrestrial C cycle releasing CO_2 each year about 10-times that released from global fossil fuel combustion (Raich & Tufekcioglu, 2000). This supports the idea that a reduction of R_S through the stabilization of humic molecules might help to mitigate GHG emissions from soil (Piccolo *et al.* 2011). Emissions of CO_2 from soil depend on several factors including soil moisture, temperature, root density, abundance of C substrates and soil organism populations (Raich & Tufekcioglu, 2000). Some of these factors are involved in the spatial variability of soil respiration existing at a field scale. For example, in tree crops under localised irrigation, there is a soil moisture gradient between row (irrigated) and the inter-row (rain-fed) that generates a gradient in CO_2 soil emission (Montanaro *et al.* 2012).

Figure 1 reports the seasonal changes in R_S recorded at a traditional olive grove (156 p ha^{-1}) located in Southern Italy (40°29'N, 16°28'E) using portable gas analyser equipment according to the methodology reported in Montanaro *et al.* (2012). Measurements show that the increase of R_S detected early in the growing season is consistent with the increase in soil temperature. Thereafter, during the summer R_S conceivably declines because of the soil moisture reduction and the slowdown in root growth (Figure 1). However, eventual precipitation after the summer might promote a regrowth of roots and then an increase in R_S (Montanaro *et al.* 2012).

Despite the prominence of R_S for the determination of the ecological impact of olive groves (e.g., determination of net ecosystem productivity), information on annual soil CO_2 efflux is still limited. Almagro *et al.* (2009) measured the R_S under the canopy and at inter-canopy positions in an olive grove (10 × 10 m planting density) reporting soil emissions of approx. 30 and 12 t CO_2 ha^{-1} yr^{-1}, respectively. The soil CO_2 efflux reported in this study (Fig. 1) generates an annual emission close to 25 t CO_2 ha^{-1} yr^{-1} according to the integration curve procedure reported in Montanaro et al. (2017a). Soil emissions in olive groves might even be high at 43.2 t CO_2 ha^{-1} yr^{-1} under a higher plantation density (512 p ha^{-1}) likely because of a higher putatively root density (Bertolla *et al.* 2014). Soil management strategy (e.g., cover crops, tillage) might be influential on R_S in olive groves showing higher CO_2 effluxes from soil under cover crops (Chamizo *et al.* 2017; Turrini *et al.* 2017). Similarly, Saadi *et al.* (2007) measured the increased CO_2 emissions from soil supplemented with olive mill wastewater in the laboratory. This might be due to higher C substances available for microorganisms after cover crop mulching and mill wastewater supply (Raich & Tufekcioglu, 2000). Hence, increased R_S could possibly be interpreted as an acceptable environmental cost compensated by other positive benefits derived from increased C supply (see below).

Net ecosystem productivity

The carbon sequestration role of tree crops is recognised to the extent they have been listed among the natural climate solutions able to potentially mitigate climate change (Zomer *et al.* 2016; Griscom *et al.* 2017).

Table 1 reports some available information on NEP in various tree crops showing that olive groves have a fairly high ability to remove C from the atmosphere. This ability seems to decline with tree age likely due to the limited growth of old trees (see last entry in Tab. 1) (Chamizo *et al.* 2017). Several natural, climatic (e.g., variations in growing-season length or cloudiness, precipitation) and anthropogenic factors (e.g., cover crops, management of pruning residuals, tillage) might influence C uptake and respiration and in turn generate seasonal and inter-annual variabilities in NEP (Barford *et al.* 2001; Allard *et al.* 2008) making comparisons among sites and species difficult to assess. However, olive and citrus trees are evergreen crops which might differ in terms of leaf C economy compared to deciduous ones (Reich *et al.* 1995). In addition, considering that the longevity of leaf has been explained in terms of improved C balance and adaptation to environmental stresses

(Chabot & Hicks 1982), olive groves might be a suitable natural climate solution *sensu* Griscom *et al*. (2017).

Biomass carbon stock

Apart from annual newly formed biomass (i.e., fruit, leaves, new shoots and roots) which is the basis for NEP determination, perennial woody crops have a significant potential in terms of climate change mitigation mainly because the C permanently stored in above and belowground structures. However, tree crops are not yet considered key contributors to global and national C budgets to the extent that they are "*historically, generally missing*" in GHG inventory reports (Blujdea *et al.* 2016; Zomer *et al.* 2016).

Quantification of the biomass of pruning residuals and permanent structures removed at the end-of-life of the orchard in perennial crops including olive has been the core of several energy use studies (e.g., Velázquez-Martí *et al.* 2014; Ruiz *et al.* 2017). Pruning residues in olive groves might reach 2.4 t ha^{-1} dry matter (annual pruning) or even 4.6 t ha^{-1} (biannual pruning) (Velázquez-Martí et al. 2011; Palese *et al.* 2013) equal to approx. 0.7 and 1.4 t CO_2 ha^{-1} yr^{-1}. However, pruning residues are considered unstable sequestration of CO_2 because of their relatively fast turnover, thus they are not listed in climate change mitigation procedures (IPCC, 2006).

On the contrary, the C content in permanent structures (e.g., trunk, branches and coarse roots) available at the end of the life cycle of perennial tree crops represents a C pool that can be reported within the Kyoto Protocol commitments (IPCC, 2006). However, the fate of that biomass might be relevant for a CO_2 flux to the atmosphere. That is, the renewable biomass resource could be mulched and deposited on the orchard floor, or taken to a biomass power plant, or it could be used in the production of furniture, etc. creating uncertainty for the global warming potential determinations within LCA assessment (Fiore *et al.* 2018 and reference therein).

Table 2 reports the data on C stored in permanent biomass of various olive groves as compared with default IPCC values for dry regions (400-800 mm yr^{-1} precipitation) (IPCC, 2006). Considering that a refinement of the IPCC guidelines with updated default values is expected to be issued by 2019 (Montanaro G., pers. com.), increasing data availability would be in favour of a more accurate future GHG report for perennial crops. In addition, taking into account the longevity of olive groves (>80-100 years) compared to other tree crop orchards (15-20 years) specific information on olive would be highly valued.

Soil carbon stock

Recent estimates have quantified the global soil organic carbon (SOC) stock (1 m depth) at approx. 1500 Pg C representing the largest terrestrial C pool (Scharlemann *et al.* 2014). Soil has a potential to further store C through appropriate management practices trapping atmospheric CO_2 in soil (Lal, 2016). This provided the basis for the "4 per mille" initiative launched at the 21st Conference of the Parties to the United Nations (UN) Framework Convention on Climate Change in Paris (December 2015). The proposal would boost the adoption of strategies to enhance global SOC stock (0.4 m depth) at the rate of 0.4% per year to offset the current annual increase of atmospheric CO_2 (Lal, 2016). The evaluation of the factual achievement of the "4 per mille" initiative is under debate (Minasny et al. 2017, de Vries, 2018). However, increasing C content is affordable through the adoption of best management practices aimed at increasing C input (e.g., recycling of pruning residuals, supply of compost or manure, adoption of cover crops) and reducing soil disturbance (e.g. no or minimum tillage) (Lal, 2015). Generally, in woody species SOC accumulation rates in the top 10 cm soil layer is somewhat 50% greater than that under herbaceous ones presumably due to a higher C input from leaf-litter (Chimento *et al.* 2016).

Certain agricultural practices (e.g., no tillage, cover crops, supply of organic raw material, recycling of pruning residuals) might increase soil carbon stock and in turn enhance the climate change mitigation potential of agricultural soils (Lal, 2015). Aguilera *et al.* (2013) published a meta-analysis on soil carbon sequestration at various Mediterranean cropping systems as influenced by the typology of practices adopted. The highest mean carbon sequestration rate (~5 t C ha^{-1} yr^{-1}, 27 cm depth) was achieved by those practices applying the largest amounts of carbon input (exceeding 10 t C ha^{-1} yr^{-1}). At a traditional olive grove in Southern Italy, the change of management practices from tillage and burning of pruning residues to no-tillage, the adoption of spontaneous cover crops and the mulching of pruning residues had a beneficial effect of soil carbon concentration (from 1.1 up to 1.4%) and in turn on the stock of carbon (0-30 cm depth) at a mean rate of 2.4 t C ha^{-1} yr^{-1} (equal to 8.8 t CO_2 ha^{-1} yr^{-1}) (Figure 2). The beneficial increase of SOC due to certain soil management practices strengthens the relevance of groves as managed ecosystems to face climate change mitigation.

GHG EMISSIONS DURING UPSTREAM AND CORE PROCESSES OF OLIVE OIL PRODUCTION

Life cycle assessment (LCA) is broadly adopted to assess the impact of agricultural food production and processing on global warming potential supporting the identification of alternatives to reduce that impact in both annual and perennial crops (e.g., Cerutti *et al.* 2014; Goglio *et al.* 2017, Fiore *et al.* 2018).

However, LCA methodology needs further improvement for standardisation of methods (Cerutti *et al.* 2014; Notarnicola *et al.* 2017). LCA studies in the olive production chain might differ in terms of boundary layer, functional unit, scenario considered and the focussed production process (e.g., field, oil extraction and bottling, recycling of waste material, etc.) (Rinaldi *et al.* 2014, Tsarouhas *et al.* 2015, Christoforou & Fokaides 2016, Romero-Gámez *et al.* 2017, Proietti *et al.* 2017). The life cycle inventory might also represent a source of variability because it is influenced by the type of management adopted (e.g., irrigation, rainfed, tillage, cover crops, density plantation) (Russo *et al.* 2015).

The comparison of various LCA studies was not the purpose of the present paper. In this study, the impact on global warming potential (GWP) of olive cultivation, oil extraction and bottling has been inferred from similar LCA studies (Rinaldi *et al.* 2014, Tsarouhas *et al.* 2015, Proietti *et al.* 2017). In these studies, orchards were rainfed and planted traditionally (average 260 p ha^{-1} plantation density). The upstream operations identified were pruning, mulching of pruning residuals and cover crops, fertilization, pesticide applications, harvest and transportation of olive fruit to the mill. The downstream processes were the extraction and bottling of oil (Tab. 3). Considering these olive ecosystems, the mean annual values of upstream emissions sheared approx. 55% of the total CO_2eq emitted from cultivation to bottling. Interestingly, the amount of C sequestered in permanent structures and soil overcome emissions due to downstream operations (Tab. 3). This supports the idea that biogenic and soil carbon changes might be included in agricultural LCA (Goglio *et al.* 2015, Fiore *et al.* 2018) for a more accurate environmental impact assessment of olive fruit and oil production.

OLIVE GROVE AND SOIL WATER RESOURCE

Olive is mainly cultivated in low-rainfall environment and its survival depends on tree physiological characteristics and some grove management practices. For example, canopy management under water scarcity has been modelled to maximise grove productivity through the regulation of the canopy cover which is relevant for water evaporation from soil and in turn for tree water availability (Connor, 2005). However, improving collection and storage of rainwater in soil is pivotal to maintain the moisture (and yield) as optimal as possible and to minimize some environmental impacts (e.g., soil erosion, run-off).

Soil management is influential on various soil properties (e.g., porosity, bulk density) and processes (e.g., CO_2 emissions) which are related to climate change issues (Montanaro *et al.* 2012; Mangalassery *et al.* 2015). Conservative agricultural practices (including reduced tillage, no-till, permanent organic soil cover by retaining crop residues, cover crops) have been developed as both mitigation (reduction of GHG emissions) and adaptation tools (reduction of runoff, enhancement of water retention preventing soil erosion) (Mangalassery *et al.* 2015).

The relationship between soil management and the ability of soil to deliver a set of ecosystem services (including water supply to crop) is mediated by its carbon content, consequently under low SOC concentration some soil structure and functions are impaired (Palm *et al.* 2014; Demestihas *et al.* 2017; Montanaro *et al.* 2017b). Hence, increasing SOC would be beneficial for soil water storage and in turn for crops.

For example, at a Mediterranean rainfed olive grove under soil tillage SOC values were approx. 40% lower than that at a sustainable one (no tillage, cover crops and recycling of pruning residuals) affecting soil macroporosity and in turn soil saturated hydraulic conductivity (Fig. 3). As a consequence of the lower infiltration rate the amount of water stored in the soil (2 m depth) was ~25% reduced in tilled plots compared to sustainable ones (Fig. 3). Soil management (e.g., tillage *vs* cover crops) has an impact on run-off and in turn on soil erosion which is reasonably low in undisturbed soils where SOC tends to be high (Fig. 3).

CONCLUSIONS

This study provides a view on effective synergy between mitigation and adaptation to climate change in olive. Olive ecosystems might contribute to mitigate climate change through sequestration of atmospheric CO_2 in tree biomass and soil serving as a natural climate solution. This in turn provides an adaptation benefit due to the enhanced soil functions relevant for storage of rainwater.

The results also emphasise the opportunity to combine information on biome (field stage) and anthropogenic (field and mill stage) GHG emissions/removals if a more detailed environmental impact of olive fruit and oil production is to be determined. This study demonstrated the benefits of a synergistic approach to mitigation and adaptation in olive grove which might increase its resilience and support the implementation of environmentally friendly policies to face climate changes to preserve soil and water.

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FIGURE LEGENDS

Figure 1 – Seasonal changes of soil respiration (μmol m^{-2} s^{-1}) (●) and soil temperature (○) measured midday at an intermediate position between row and inter-row in an olive grove (156 p ha^{-1}, Southern Italy), DOY = day of year. Each point is the mean (±SE) of 30 measurements.

Figure 2 – Variation of the soil carbon stock (0-30 cm depth) recorded at an olive grove after the shift from conventional (tillage, burning of pruning residues) to sustainable practices (*in situ* mulching of pruning residues, cover crop).

Figure 3 –Variations (%) of some soil parameters and functions occurring after a 40% increase of SOC (soil organic carbon) induced by shifting from tillage and burning of pruning redisues to cover crops and mulching of pruning residues). Redrawn from Montanaro *et al.* 2017b and references therein.

Table 1 - Annual Net Ecosystem Productivity (NEP) in various tree crops, olive and vineyard. Note that values might have been converted from net ecosystem exchange (NEE) to NEP based on the relation NEP = -NEE.

Tree crop	NEP ($t\ CO_2\ ha^{-1}\ yr^{-1}$)	density ($p\ ha^{-1}$)	age (years)	reference
olive	**45.9**	227	12-16	Nardino *et al.* 2013
vineyard	29.9	3077	17	Meggio & Pitacco 2016
olive	**28.0**	408	4	Testi *et al.* 2008
apple	15.2	3333	9	Zanotelli *et al.* 2013
peach	11.7 - 17.4	500	14	Montanaro *et al.* 2017a
apple	13.9	2632	10	Panzacchi *et al.* 2012
olive	**13.4**	285	20	Brilli *et al.* 2016
orange	4.0*	494	14	Liguori *et al.* 2009
orange	7.9*	1000	12	Liguori *et al.* 2009
olive	**2.5 - 5.1**	**204**	80	Chamizo *et al.* 2017

*Assuming 0.75 heterotrophic/total soil respiration ratio (Montanaro *et al.* 2017a)

Table 2 – Amount of CO_2 stored in above and belowground biomass in olive trees (various references) and default IPCC value for that biomass in dry areas (see Tab. 5.1, Chapter 5, Vol 4 of the IPCC, 2006). Note that for the IPCC value a standard 1:1 ratio between above and belowground biomass has been considered.

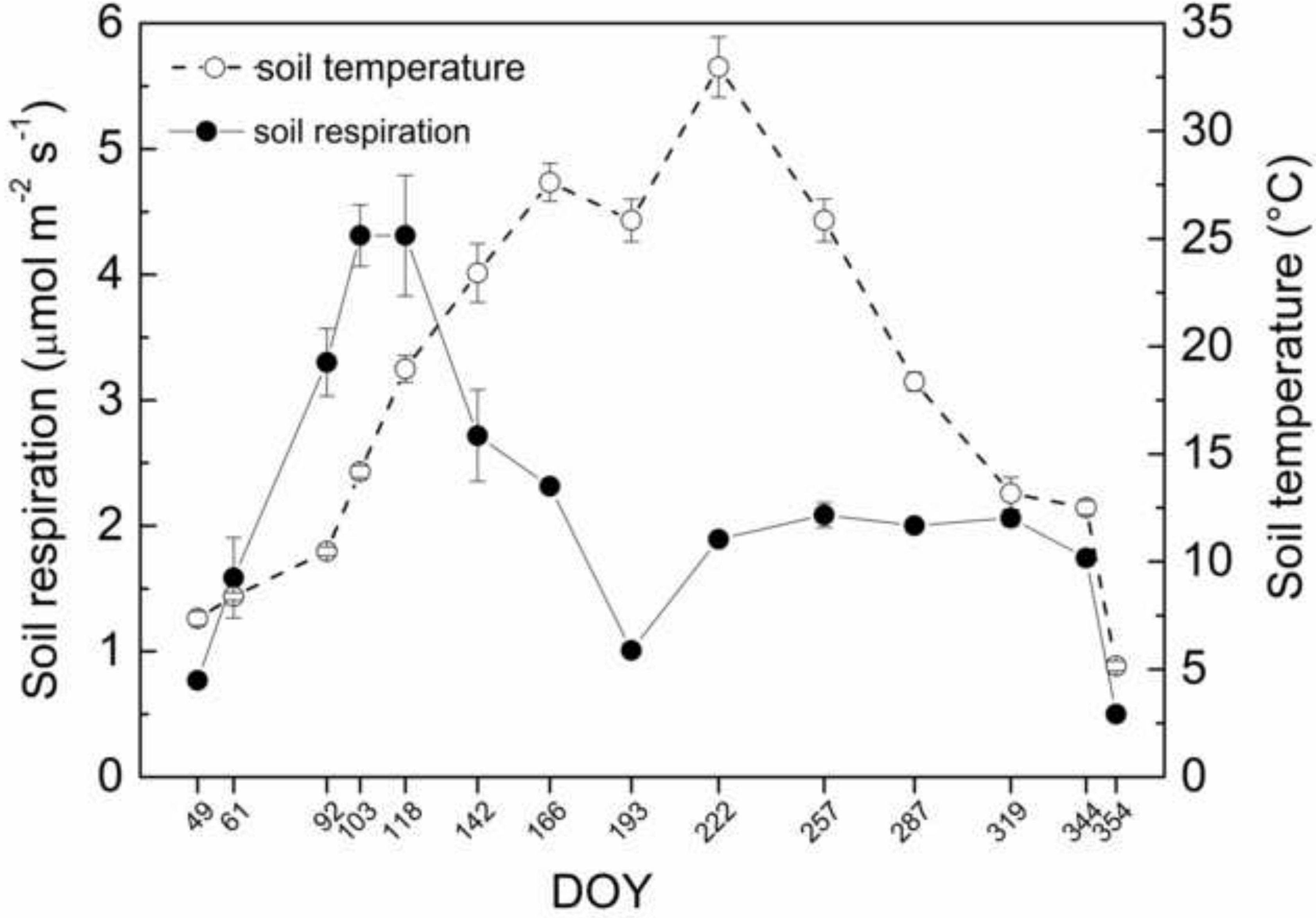
Description	t CO_2 ha^{-1}	t CO_2 ha^{-1} yr^{-1}	Reference
60-year old, 100 p ha^{-1}	91.4	1.52	Nuzzo V. in preparation
5-year old, n.a.	66.1	13.2	IPCC, 2006
100-year old, 107 p ha^{-1}	36.4	0.36	Almagro *et al.* 2010
11-year old, 330 p ha^{-1}	30.6	2.78	Proietti *et al.* 2014
11-year old, 330 p ha^{-1}	20.5	1.86	Ilarioni *et al.* 2013

Table 3 – Annual carbon sequestration rates (t CO_2 ha^{-1} yr^{-1}) measured in soil and above and belowground permanent structures of an olive grove, and emission rates (t CO_2 ha^{-1} yr^{-1}) occurring during field operations (pruning and mulching of pruning residuals and cover crop, fertilization, pesticides application, harvest and transport of olive fruit to the mill) and during the extraction and bottling of oil. Note that the atmosphere has been considered the reference thus + and - signs indicate net emissions to and removals from the atmosphere, respectively.

Description		t CO_2eq ha^{-1} yr^{-1}
emissions	Upstream field operations[a]	+0.66
	Extraction, bottling (1 L) of oil[a]	+0.53
sequestrations	Permanent structures[b]	-1.60
	Soil[c]	-8.81

[a] averaged from Rinaldi *et al.* 2014, Tsarouhas *et al*. 2015 and Proietti *et al.* 2017; [b] see Table 2 for references; [c] own data redrawn from Fig. 2

Figure 1


soil temperature
soil respiration
Soil respiration (µmol m^{-2} s^{-1})
Soil temperature (°C)
DOY
0
1
2
3
4
5
6
0
5
10
15
20
25
30
35
49
61
92
103
118
142
166
193
222
257
287
319
344
354

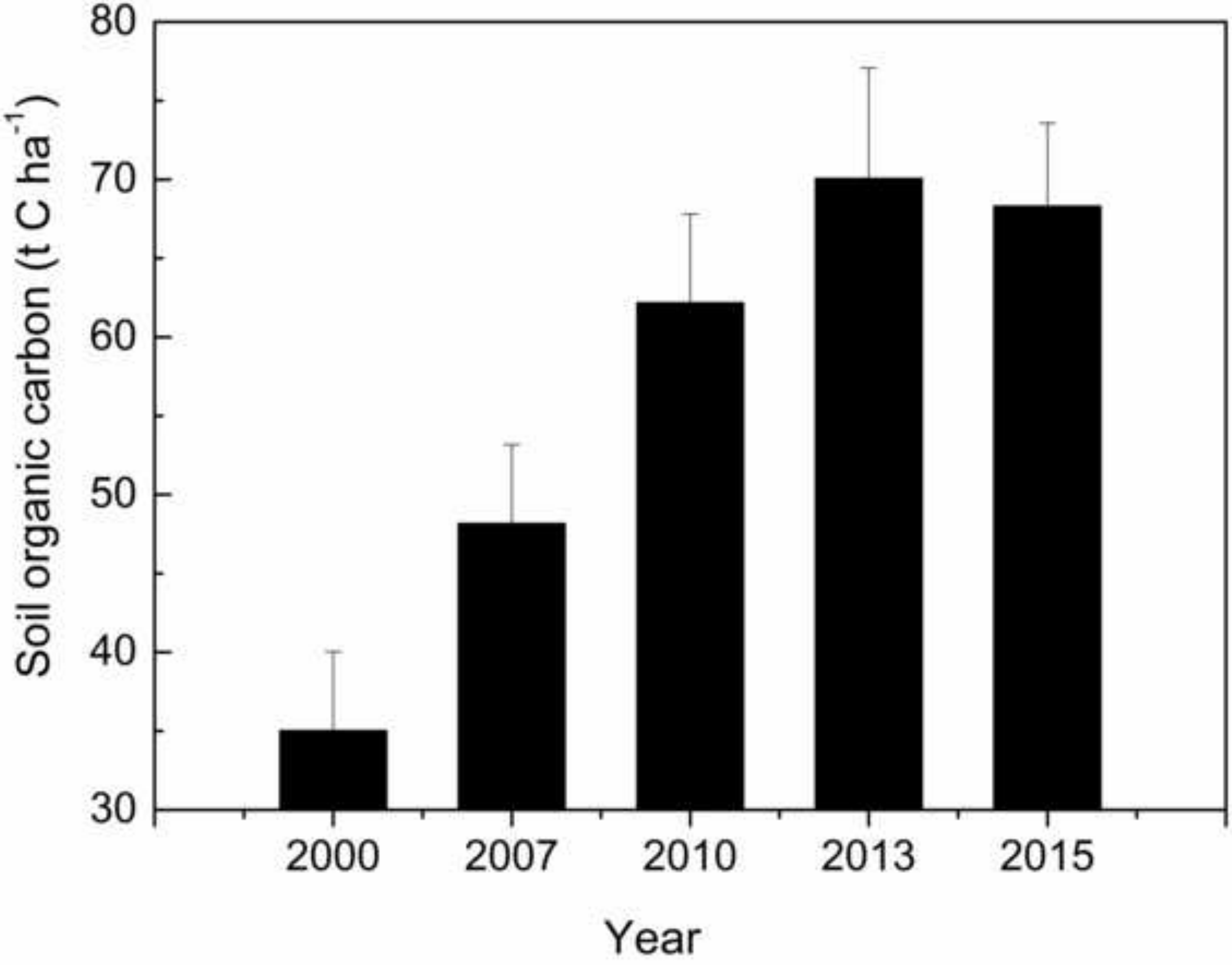
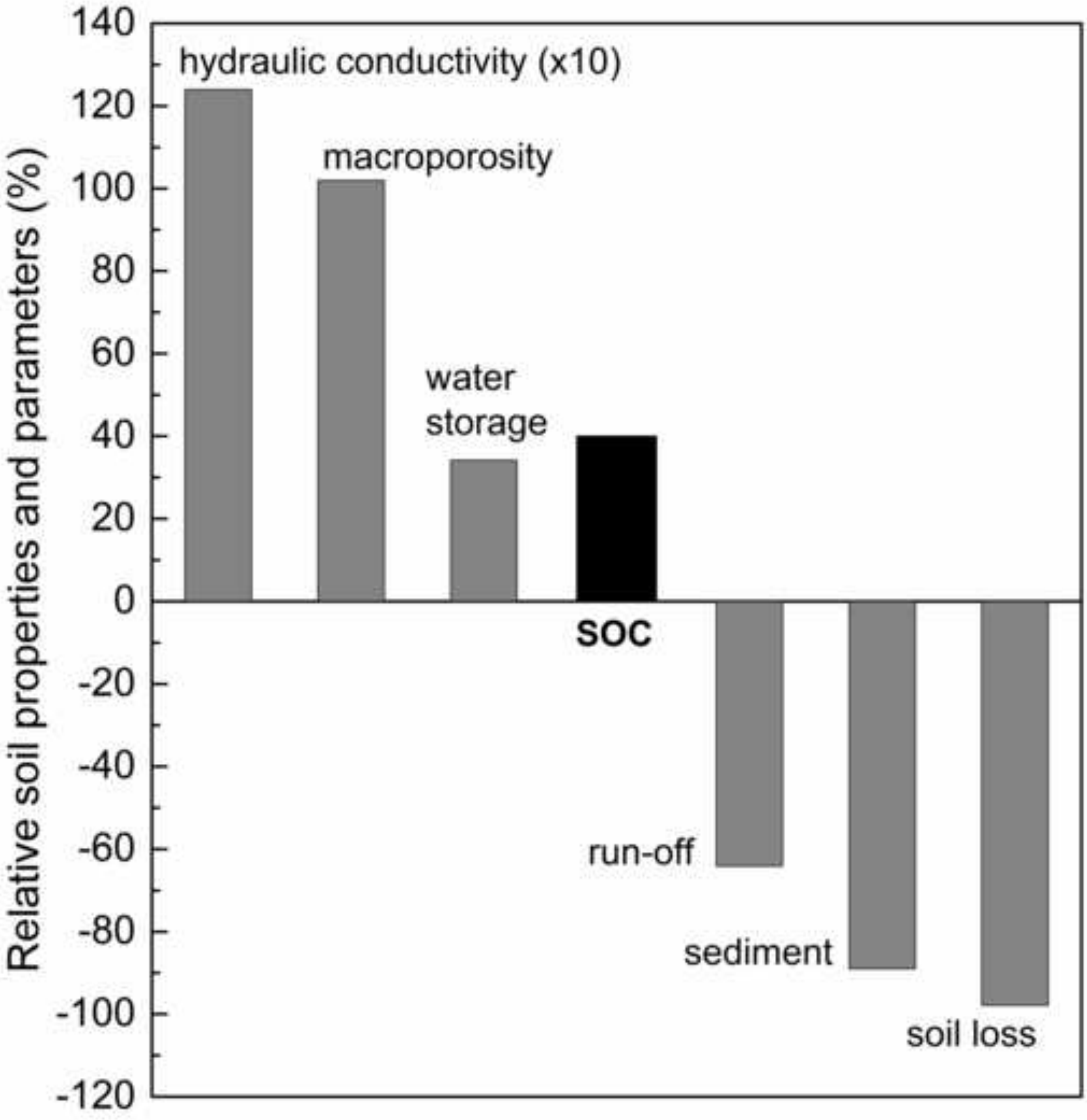

80
70
60
50
40
30
Soil organic carbon (t C ha^{-1})
2000
2007
2010
2013
2015
Year

Figure 3


Relative soil properties and parameters (%)
140
120
100
80
60
40
20
0
-20
-40
-60
-80
-100
-120
hydraulic conductivity (x10)
macroporosity
water storage
SOC
run-off
sediment
soil loss