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Abstract: Agriculture is not only appointed to produce food but has the potential to provide a range of ecosystem services (ES) depending on the management options adopted at field scale.

Information on the impact of management practices adopted in fruit tree crops on ES is fragmented and often not fully codified. This paper focuses on some Mediterranean fruit tree crops i.e. peach (Prunus persica), apricot (Prunus armeniaca), olive (Olea europaea) groves and vineyards (Vitis vinifera), and links mainly soil processes and functions to the provisioning, regulating and sociocultural ES.
The effects of field practices (e.g., tillage/no-tillage, cover crops, retention/burning of pruning residues, mineral/organic fertilization) on manageable soil properties (e.g., porosity, organic carbon content, composition of microbial community) and related functions (e.g., supply of nutrients, water storage, soil stability, above-ground biodiversity) were examined.
The analysis draws the attention to the pivotal role of the soil organic carbon (SOC) stocks on soil aggregates and erodibility, soil water storage, use of fresh water for irrigation, plant nutrition, biodiversity, nutrient storage and absorption of pesticides.
Sociocultural services delivered by tree crops are also discussed.

This paper highlights the dependence of ES on the sustainable field practices adopted, particularly those aimed at increasing SOC stocks (e.g., no tillage, increased carbon input, recycling of pruning residuals, cover crops).
The outcomes presented may strengthen the significance of increasing SOC management practices for fruit tree crops and be supportive of the implementation of environmentally friendly policies assisting in the conservation or the improvement of the soil natural capital.

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Ambiente, Patrimoni culturali (DiCEM)

Matera, January 5th, 2017

To:
The Editor-in Chief
Scientia Horticulturae

Dear Sir,

I'm submitting the revised version of the manuscript titled "**Orchard management, soil carbon and ecosystem services in Mediterranean fruit tree crops**" (Ms. No. **HORTI17776**) for the re-evaluation for publication as review paper in *Scientia Horticulturae.*

Thank you for considering the manuscript suitable for publication, it has been revised considering the comments raised by the reviewer and Editor using "track changes" mode as suggested. Replies to Editor are listed at the end of this cover letter, and detailed replies to reviewer's remarks are transmitted along with this cover letter as single PDF file uploaded through the dedicated web-based platform.

We hope this revised manuscript could be found appropriate for publication in *Scientia Horticulturae.*

We look forward to your next communication. Please let me know if you need any further information.

Sincerely yours,

G. Montanaro

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Answer to *Editor's comments* (positive comments are not included).

... Please note the couple of changes suggested by the reviewer.
Also, please get the English re-checked before returning the manuscript.

DONE. The changes suggested by the reviewer have been included (see L 166 and 338 of the revised manuscript) and the English checked by an English mother-language colleague.

Manuscript. No. HORTI17776

Answer to ***Reviewer #1*** *comments* (positive comments are not included).

line 166. the current botanical name for apple is Malus domestica. please check and correct
DONE.

line 338. according to the values presented, the soil erosion rate was 100 fold lower, not 10-fold lower as written. Please re-check both the values and the statement to ensure you have the correct details.
DONE. Many thanks for your remark, values of erosion rates were incorrect, in the revised version values have been cross-checked with the reference and corrected accordingly (see L 338-339).

Orchard management, soil organic carbon and ecosystem services in Mediterranean fruit tree crops

By G. Montanaro et al.

- There is limited information on the impact of management of fruit tree orchards on ecosystem services (ES)
- This paper addresses that gap focussing Mediterranean tree crops
- Sustainable management practices increase soil organic carbon (SOC) stock and concentration
- Increased SOC improves soil structure and functions and related ES

Orchard management, soil organic carbon and ecosystem services in Mediterranean fruit tree crops

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Abstract

Agriculture is not only appointed to produce food but has the potential to provide a range of ecosystem services (ES) depending on the management options adopted at field scale. Information on the impact of management practices adopted in fruit tree crops on ES is fragmented and often not fully codified. This paper focuses on some Mediterranean fruit tree crops i.e. peach (*Prunus persica*), apricot (*Prunus armeniaca*), olive (*Olea europaea*) groves and vineyards (*Vitis vinifera*), and links mainly soil processes and functions to the provisioning, regulating and sociocultural ES. The effects of field practices (e.g., tillage/no-tillage, cover crops, retention/burning of pruning residues, mineral/organic fertilization) on manageable soil properties (e.g., porosity, organic carbon content, composition of microbial community) and related functions (e.g., supply of nutrients, water storage, soil stability, above-ground biodiversity) were examined.

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1. Introduction

Soil represents a component of the natural capital containing approximately 1,500 Pg of organic carbon (C) (1 m depth) which exceeds the amount of C stored in phytomass and atmosphere (Scharlemann et al., 2014). There is an increasing categorization of the various ecosystem services (ES) provided by the natural capital which includes also vegetation, aquatic ecosystems, biodiversity and climate variables (Costanza et al., 1997). Nowadays, the generally accepted framework of ES flowing from the natural capital embraces provisioning, regulating, cultural and supporting services. All these services are beneficial to humanity through the production of goods (food, fiber, biofuel), life-supporting (e.g., pollination, water purification, climate regulation) and fulfilling processes (e.g., recreational, spiritual) (see Adhikari and Hartemink, 2016 published for review).

Soil is a potential source of a large part of ES because of the several soil-based physicochemical and biological processes resulting in a number of functions (Jónsson and Davíðsdótt, 2016). These functions (e.g., supply of nutrients, water storage, soil stability, biodiversity) and the related ES are potentially subject to change. For example, the process of soil aggregates absorbing water allows the storage of water (function) and confers the ability to supply water (service). That process→function→service causal chain could be influenced by the soil management options adopted by farmers (e.g., tillage or cover crops) (Palese et al., 2014). This view is in line with the soil ES framework proposed by Dominati et al., (2010) who discriminates between “inherent” soil properties (slope, orientation, texture, soil coarse fraction, etc.) from the “manageable” ones including C content, land cover, size and structure of aggregates, etc.

The link between the structure and function of soil and the related ES has been recently reviewed by Adhikari and Hartemink (2016). Soil organic carbon (SOC) may directly or indirectly provide a wide range of provisioning (e.g., yield, biomass production), regulating (e.g., reducing soil erosion, water regeneration, storage of atmospheric carbon dioxide (CO_2)), supporting (e.g., plant nutrients, water) and cultural ES (e.g., landscape conservation). These SOC-related ES have an increasing societal value to the extent that monetary valuations of these services are emerging (Costanza et al., 2014; Lal, 2014). Based on the evidence that soil interconnects the various C pools (i.e. atmosphere, hydrosphere, biosphere and geosphere) and that changes in SOC may significantly impact the overall global C cycle (Lal, 2016), it could be inferred that reductions in SOC stocks may negatively affect certain ES (e.g., regulation of atmospheric CO_2, supply of nutrients to plant). However, impairment of ES is often not clearly perceived as it is because masked by benefits derived from other compensating management practices. For example, soil tillage as combined with chemical fertilization may lead to the decline of SOC stocks and an increase in soil CO_2 emissions, whilst the yield may increase due to chemical inputs (e.g. fertilisers, pesticides) (West and Marland, 2002).

There is increasing attention by policymakers to protecting the natural capital and to giving a proper value to the ES promoting investments in green infrastructures and soil remediation strategies. For example, since The Soil Thematic Strategy was issued by the European Commission (EC) (EC, 2006), there is a general consensus to identify specific targets for increasing the amount of SOC by 2020 while using the soil sustainably (EC, 2011 and 2012). Therefore the assessment of ES provided by ecosystems is pivotal to recognising and boosting “the supply of” and “the demand for” ES and gaining as high priority as possible in the political agenda.

As fruit tree crops are functional systems able to sustain life that include all biological and non-biological variables, they conform to the ecosystem definition reported by Baumgärtner and Bieri (2016), whereby tree crops might be defined as fruit tree ecosystems. Within fruit tree ecosystems, soil organic carbon and tree biomass are relevant C pools that can be monitored and accounted for within annual national greenhouse gases (GHGs) reports (IPCC, 2006). International communities are aware of the evidence that perennial woody vegetation can capture atmospheric CO_2 through photosynthesis (see The Guidelines for National Greenhouse Gas Inventories

- IPCC, 2006) however this process could be affected by the management practices adopted. For example, it has recently been documented that a Mediterranean commercial peach (*Prunus persica*) orchard may have a net ecosystem C balance ranging from ~0.9 up to ~7.3 Mg C m^{-2} yr^{-1} depending on management options adopted, in addition approx. 25 Mg C ha^{-1} are stored within above and below-ground tree biomass throughout the lifespan of the orchard (Montanaro et al., 2016).

Nowadays there is increasing attention to fruit tree ecosystems as sources of ES (Baumgartner and Bieri, 2006; Clothier et al., 2013; Fagerholm et al., 2016), however to the best of our knowledge, information on the ES provided by these ecosystems remains fragmented and not extensively codified. In addition, it does not explore in detail the impact of different management options on ES. Improving knowledge about such ES might boost the release/improvement of policies and support the wide adoption of sustainable land use and management in fruit tree ecosystems. Therefore, this paper examines relevant ES that are provided by some Mediterranean fruit tree ecosystems mainly in relation to soil management options, and discusses their potential and constraints. As there are still gaps in identifying the causal link between specific soil properties and ES (Adhikari and Hartemink, 2016), this paper aims to link mainly the increased SOC stocks to improvements in soil-related ES.

The paper focuses on fruit tree orchards, olive (*Olea europaea*) groves and vineyards (*Vitis vinifera*) and discusses the effects of field practices (e.g., tillage/no-tillage, cover crops, retention/burning of pruning residues, mineral/organic fertilization) on manageable soil properties including SOC and related functions (e.g. supply of mineral nutrients, water storage, soil stability, pesticide degradation). Then the analysis draws attention to the ES provided by tree crops under sustainable practices (*sensu* Xiloyannis et al., 2016) in terms of ability to capture atmospheric CO_2, reduction of soil erosion, improvement of soil water reservoirs and use of fresh water for irrigation, plant nutrition and biodiversity. The social context of ES and delivery of cultural services by fruit tree ecosystems are also discussed.

2. SOIL FUNCTIONS AND REGULATING SERVICES

2.1 Organic carbon sequestration

There is a general consensus on the function of soil to potentially serve as a reservoir for atmospheric CO_2 contributing to partially offsetting continuing global anthropogenic CO_2 emissions (Lal, 2016). Despite fruit tree ecosystems having the potential to remove C at a rate similar to those of forests ranging from 240 to 1250 g C m^{-2} yr^{-1} (Montanaro et al., 2016 and references therein), the C sink function of fruit tree ecosystems and the regulating ES have received relatively little attention.

There are management options which could be designed to increase C stocks in tree biomass and soil within an orchard. Such an increase in C is relevant for environmental policy to the extent that orchards have been included within the "cropland" activity to account for and report changes in C pools within GHGs national inventory reports of European Member States (EC, 2013). In the meantime, analysis on carbon atmosphere-terrestrial ecosystems exchanges mainly focuses on forest, shrublands and savannah ecosystems (see global data at http://fluxnet.ornl.gov; Corbera and Brown, 2008). In addition, based on the latest annual EU GHGs inventory (1990–2013) and inventory report (EEA, 2015) the Land Use, Land, Use Change and Forestry (LULUCF) sector is a net C sink only because of the CO_2 sink capacity of forests confirming that the potential C sequestration and regulating services of fruit tree ecosystems remain unexploited.

Soils may be both source and sink for CO_2 and others GHGs (e.g., nitrous oxide N_2O, methane CH_4). There is a general consensus about the potential role of soil in mitigating climate change, with the identification of alternative management practices (e.g., no tillage, cover crops, mulching of pruning residues, application of organic amendants) aimed at reducing emissions of CO_2 and other GHGs into the atmosphere and increasing CO_2 capture (West and Marland, 2002).

Processes involved in the terrestrial C cycle include plant net primary production (NPP), the fall of dead organic matter to the soil, heterotrophic and autotrophic respiration, and C losses including organic matter degradation, erosion and dissolved organic C leaching, harvest, fire (Baldocchi 2013; Chapin III et al., 2006). Recently, most of these components have been examined in detail in apple (~~*Prunus malus*~~*Malus domestica*) and peach orchards within the "net ecosystem carbon balance" (NECB) frame to assess whether the studied orchards acted as sink (NECB>0) or sources (NECB<0) (Zanotelli et al., 2015; Montanaro et al., 2016). However, considering that if the orchard is a sink then soil and/or biomass C accumulation occurs, monitoring SOC and C biomass could be a proxy to appraise the orchard performance on C sequestration. For example, in a Mediterranean peach orchard the application of alternative orchard management increasing the annual C input up to ~4.2 Mg C ha^{-1} (through mulching of cover crops, retention of crop residuals and compost application) significantly increased SOC stocks by approx. 30% (0.1 m depth) (Montanaro et al., 2012). However, because of the inherent spatial variability of SOC concentration (Gargouri et al., 2013) the response of SOC concentration and stock to the increased organic inputs should be cautiously appraised against space (e.g., row and inter-row) and time (e.g., number of years of application) (Montanaro et al., 2010; 2012). For example, in the case of localised supply of organic amendants (e.g., compost) the increase of organic C content at the soil band where the amendant is supplied (i.e., the row) would be faster than that of areas not receiving the amendant (i.e., inter-row) (Fig. 1) (Montanaro et al., 2010). Additionally, due to that increased organic C a concurrent increase in soil CO_2 emissions occurs (Fig. 1). Whether this increased emission could be considered as an acceptable environmental cost or not remains debatable (Montanaro et al., 2012; Mackey et al., 2013).

Throughout the 15-20 year commercial lifetime of an orchard approx. 20-25 Mg C ha^{-1} were stored in tree above- and below-ground biomass (Montanaro et al., 2016 and reference therein). Although the permanence of that C over a much longer period of time (decades) depends on the fate of that biomass, this may represent a regulating service that contributes to a renewed interest in growing fruit trees to sequester carbon.

The ability of fruit tree ecosystems to sequester atmospheric CO_2 might be defined as the net ecosystem production (NEP) which is the balance between the amount of organic C fixed by photosynthesis (gross primary production, or GPP) and the sum of autotrophic and heterotrophic respiration (Chapin III et al., 2006); NEP responds to variations in environmental variables (e.g., nutrients and water availability, weather) and to disturbing events including anthropogenic management (Chapin III et al., 2006). In fruit tree ecosystems, values of NEP vary in the range of 380 g C m^{-2} yr^{-1} measured in apple orchards to 240-330 g C m^{-2} yr^{-1} in oranges (*Citrus sinensis* L.) and 760-1,250 g C m^{-2} yr^{-1} in irrigated olive groves (Testi et al., 2008; Liguori et al., 2009; Nardino et al., 2013; Zanotelli et al., 2013).

There is emerging evidence that orchard management might significantly influence NEP and the related regulating ES. For example, in a peach field under sustainable practices (compost supply, recycling of pruning residues and adoption of cover crops) the value of NEP reached ~475 g C m^{-2} yr^{-1} while it was ~320 g C m^{-2} yr^{-1} in a conventional field (tillage, removal of pruning residuals) (Montanaro et al., 2016). Improved orchard practices increase SOC stocks and in turn the related soil functions which collectively lead to a better provisioning service (Clothier et al., 2013). Annual fruit production may increase up to 30-50% as observed in various orchards namely peach, apricot and kiwifruit under sustainable practices (e.g. no-till, compost supply, mulching of crop residues) (Baldi et al., 2010; Montanaro et al., 2010 and 2012). Findings in annual crop systems (e.g. wheat, rice, maize) further confirm the positive relationship between increased SOC stock and yield (see Lal 2006 for review).

Evidence that some orchard management practices may improve SOC stocks may support the view that ES are not a one-way flow (i.e. from ecosystems to humans) but anthropogenic maintenance or enhancement of the soil capital do occur (see the service-to-ecosystem conceptualization proposed by Comberti et al., 2015). Of course the provisioning of a service-to-ecosystem by farmers remains an option linked to the *modus operandi* of farmers since they can adopt unsustainable agriculture practices that aim at maximising provisioning ecosystem service whilst degrading other services (e.g. regulating).

There is on-going research to develop methodology and models, and provide data for the inclusion of SOC stocks change in GHGs reporting and Life Cycle Assessment environmental impact analysis (Petersen et al., 2013; Goglio et al., 2015). In addition, the regulating service (atmospheric CO_2 removal) provided by the increased SOC stocks as estimated through models, has received increased attention from IPCC in the recently issued revised supplementary methods and good practices guidance for the estimations of national GHGs emissions/removals (IPCC, 2014).

2.2 Water storage

Inadequate plant-available soil moisture at root zone can be a serious limitation to agricultural production, causing loss of yields and even crop failure. Irrigation has been introduced to avoid such risks compensating for gaps between crop requirements and soil water availability. Although groundwater use for irrigation accounts for ~40% of the total global consumptive irrigation water (Siebert et al., 2010), for rainfed crops and for the purpose of reducing irrigation water consumption, the improvement of collection/storage of rainwater remains relevant. Hence, rainwater harvesting systems for water management have been developed (Vohland and Barry, 2009; Li et al., 2009). In addition, given the increasing competition for fresh water among urban, industrial and agricultural sectors the reduction of the consumptive water footprint (WF) in irrigated crops via increasing the ratio of green (rain-sourced) to blue (irrigation-sourced) component of WF is highly desirable to minimise that competition and/or increase the surface of irrigated land.

Recently, the positive impact of improved irrigation methods management on WF (Chukalla et al., 2015) has been demonstrated. However, improving soil aggregation and pore distribution through increased SOC stocks might improve water infiltration and in turn the soil water storage capacity (Franzluebbers, 2002; Saxton and Rawls, 2006) increasing the green component of WF. For example, at a Mediterranean rainfed olive grove an increased SOC from ~1% up to 1.4% positively affected soil structure namely the macroporosity (Fig. 2) which contributed to improving soil saturated hydraulic conductivity (Fig. 3). The better infiltration rate processes detected (Fig. 3) contributing to increasing by up 34% the amount of water stored in soil with higher SOC content compared to those with low SOC (Fig. 3). Increases in soil macroporosity and the related function of infiltration rate in top soil might also be achieved through tillage operation. However, it induces soil degradation of soil structure namely crusting and formation of plough pan at the lower boundary of cultivation (10–20 cm depth) decreasing the overall water infiltration rate and in turn triggering disservices such as surface runoff and soil erosion processes (Palese et al., 2014 and references therein).

Apart from improvement of provisioning services, improved soil water storage is significantly influential in the long-term supply of supporting and regulating ES (including hydrological services) to the extent that it is a subject focussed on by European policy makers (BIO Intelligence Service, 2014). A detailed overview of the ecosystem functions providing terrestrial hydrological services has been proposed by Brauman et al., (2007). From the improved process of infiltration of rainwater comes the function of water storage capacity and ultimately the provision of some ES. For example, hydrological ES encompass mitigation of flood damage, of sedimentation of water bodies, of saltwater intrusion into groundwater. In addition, high soil infiltration rate profoundly helps the recharge of groundwater - securing the water level in wells and the continuity of river and stream flows – and minimizes runoff and erosion processes.

The ongoing sediment deposition in reservoirs leads to progressive loss of water storage capacity posing several constraints at a social, economic and environmental scale in several countries (Bazzoffi et al., 2005; Wang and Hu, 2009; Juracek, 2015). The mean annual capacity loss of reservoirs ranges from 0.02 up to 2% of original storage capacity (Bazzoffi et al., 2005; Juracek, 2015), hence proper management of the reservoir catchment area may help to reduce the sediment deposition and improve the ability of reservoirs to provide ES (e.g., supply of drinking and irrigation water). Apart from landslide stabilizing structures (Li et al., 2014) to help to reduce watershed sediment yield, it is recommended that soil disturbance (tillage) should be avoided: this in turn will favour natural vegetation that can also improve the aesthetics of the site (see Photo 1). In order to reduce erosion, farmers could receive economic subsides in order to, for example, replace crops with trees, not-till the soil or keep farmlands particularly sensitive to erosion out of production (Brauman et al., 2007).

2.3 Soil structure maintenance

Soil structure refers mainly to the size and arrangement of soil aggregates and their stability which is mediated among other factors by SOC, in addition soil structure is important for the overall soil fertility (e.g., productivity) enhancing porosity and decreasing erodibility (Bronick and Lal, 2005). Studies on erosion and impact on agriculture intensified from the 1940s attempting also to define tolerant rates of erosion in several regions including Europe (Smith and Stamey, 1965; Richter, 1978; Verheijen et al., 2009). Evidence that erosion may impair the provision of a range of ES (Verheijen et al., 2009; Cerdan et al., 2010) drew the attention of the European Commission through the “Thematic Strategy for Soil Protection” communication (EC, 2006) recommending the definition of baseline and threshold values for monitoring soil erosion.

Cerdan et al. (2010) estimated mean rainfall erosion rates for the European cultivated soils ranging from ~20 Mg ha^{-1} in bare soil to ~3.5 Mg ha^{-1} in other lands (spring crops, orchards and winter crops), with vineyards showing the second highest soil losses (17 Mg ha^{-1}). Upon adoption of tillage operations, the rate of erosion may rise up to 38.8 Mg ha^{-1} whilst a tolerable erosion level is approx. 1.5 t ha^{-1} per year (Verheijen et al., 2009) indicating that anthropogenic activity can significantly accelerate natural soil erosion. Hence, a substantial effort is required to reduce soil erosion losses closer to tolerable levels particularly in tilled agriculture. Several definitions have been proposed for "tolerable soil erosion" (see Verheijen et al., 2009), and here we suggest that the definition should embrace the ecosystem approach, therefore a tolerable rate of erosion should not lead to any reduction in soil functions and thus in flowing ES (provisioning, regulating, cultural).

Susceptibility to soil erosion depends on soil erodibility to erosive forces determined by inherent physical, chemical and biological properties of the soil, the energy of the eroding agent (e.g., rainfall, overland flow or wind) and the land cover and management (van der Knijff et al., 2000). Vegetation or litter cover is an important factor that limits soil erosion risk to the extent that it has been included in the revised version of the widely adopted Revised Universal Soil Loss Equation (RUSLE) for soil loss calculation (Renard et al., 1997).

Litter and vegetation layers are known to protect soil from intense rain mainly by modulating surface runoff. An average 70% reduction of runoff yield as accompanied by ~ 80% lower sediment yield was recorded in soil covered with litter compared to bare soil (Li et. al., 2014). Similarly, results gained in a multi-year comparative study at an olive grove (Gómez et al., 2009) document the beneficial effect of cover crops in reducing the amount of runoff and loss of soil and mineral nutrients (Figs. 4 and 5). The beneficial effect of cover crops (or litter) in controlling water erosion in the short term is exerted mainly by intercepting rainfall and protecting the soil surface against the impact of rainfall drops, and by intercepting runoff, whilst in the long term, vegetation and litter contributing to increasing soil-aggregate stability and cohesion as well as improves water infiltration (Zuazo and Pleguezuelo, 2008).

Orchard management may significantly increase the biomass of litter layer contributing to strongly reducing soil exposure to eroding agents. For example, in a peach field the litter was increased up to 9.5 Mg ha^{-1} (dry weight) after a 7-year period of alternative practices including cover crops, while it was roughly stable at ~0.6 Mg ha^{-1} in the tilled field (Montanaro et al., 2012). Soil losses and runoff were recently analysed in Mediterranean apricot orchards (60 plots) under three land management practices (tillage/herbicide/covered with vegetation) (Keesstra et al., 2016). The highest values of soil erosion rates occurred in the herbicide treated plots (90.6 g m^{-2} h^{-1}) while it was approx. ~~10~~40-fold lower in covered soil (~~0.9~~2.2 g m^{-2} h^{-1}) and tilled plots had intermediate erosion rates (~~2.2~~51.5 g m^{-2} h^{-1}).

Soil erosion induces on-site impairments including reduction of SOC content and water-holding capacity, soil nutrients, it also declines biodiversity, and these collectively impair natural soil processes and then the provisioning ES. Once again minimizing soil erosion through adequate management may preserve most soil functions. For example, tillage induces soil loss which indirectly impoverishes the top-soil because amounts of organic C and nutrients (e.g. N, P, K) are dragged away with sediments. These amounts may be 35-fold greater than the loss in protected soil (Fig. 5). Inappropriate soil management may result in additional costs for farmers for replacing those nutrients lost with erosion and minimising the erosion-induced loss of productivity (Pimentel et al., 1995).

The regulating function of soil retention operated by litter or cover crops also allows for the provision of off-site services. For example, Pimentel et al. (1995) listed a series of erosion-induced damages of the environment surrounding the agricultural area where it occurs. Quinton et al. (2010) estimated the impact of agriculture on global soil erosion to be approx. 35 Pg yr^{-1} of sediment which corresponds to an estimate of ~0.08 Pg for C delivery to river systems by water erosion. The presence of water reservoirs within river basins reduces the flux of sediment reaching the world’s coasts because of the sediment retention within reservoirs. This might reduce the wildlife habitat function of rivers and coastal areas, increase maintenance costs of dams and shorten their lifetime (Syvitski et al., 2005)

Soil erosion occurring in cultivated lands surrounding human settlements may have a relevant impact on the urban environment and population. Wind may transport up to 56 t ha^{-1} yr^{-1} of dust which could impact humans’ health and goods (Pimentel et al., 2006). Therefore, the application of appropriate soil management at peri-urban orchards could provide regulating ES and enhance the quality of human life in the surrounding anthropized areas. The monetary subsides paid by the Andalusian Government (Spain) to farmers that adopt soil conservation measures to reduce soil erosion and its off-site impacts (e.g., eutrophication of waterways, impacts on landscape quality) is a pioneer example of the societal value of ES delivered by the maintenance of soil structure (Colombo et al. 2006).

2.4 Absorption of pollutants

The functions of soil in binding the molecules of pesticides used in the field potentially affect the destiny of these molecules, generating a filtering service. Because the basic processes underlying these functions involve biochemical and physical traits of the soil which are influenced by the SOC concentration, indirectly the SOC supports the filtering capacity to the extent that SOC represents a valid indicator for the filtering service (Aslam et al., 2009). There is evidence that the adoption of certain management practices may influence values of SOC concentrations and in turn the filtering capacity of soil. For example, in apple orchards it has been documented that increasing the supply of organic inputs (e.g., cover crops, compost, manure) for a 12-20 year period increased by ~30% the SOC (0.1 m depth) compared to the control field. This was beneficial for the pesticide filtering service defined through indicators for sorption and degradation of pesticide molecules (Aslam et al., 2009).

3. SOIL FUNCTIONS AND SUPPORTING ECOSYSTEM SERVICES

3.1 Supply of plant nutrients

The various management options for orchards may impact the biogeochemical processes and soil properties (e.g. pH, soil biotic activity, organic matter mineralization) dealing with the function of supplying nutrient to the plant. As a consequence, the nutrient availability and ultimately its contribution to the provisioning/regulating ES of the orchards could be affected. Industrial agriculture has resulted in environmental and social impacts because of unsustainable consumption rates of fossil fuel, topsoil and water contributing to the degradation of key biogeochemical processes including the release of plant nutrients from organic matter decomposition (Horrigan et al., 2002; DeLonge et al., 2016). For example, in degraded soil under unsustainable agriculture the natural soil plant feeding function has been impaired, hence increased inputs of chemical fertilisers are required to sustain crop yield (Singh, 2000; Liu et al., 2015).

Increasing SOC stocks through a more widespread use of existing sustainable management practices in orchards may help to reduce the application of chemical fertilisers and related environmental impact (e.g., CO_2 emissions during their production) and promote increased ES through investment in sustainable agriculture (DeLonge et al., 2016). In this regard, some relatively long-term (7-10 years) experiments involving compost supply to orchards documented the reduction or even the avoidance of chemical fertilisers. That is, in a peach field experiment due to the compost-derived availability of N, P and K, the amounts of those nutrients supplied were reduced by 60, 85 and 100%, respectively compared to that supplied to a conventional field (Montanaro et al., 2012). The application of compost at a rate of 10 Mg ha^{-1} yr^{-1} allowed a good source of macronutrients for peach trees and in turn successfully replaced the mineral fertilization. In addition, compost supply might support a linear increase in tree above-ground biomass (Baldi et al. 2010 and 2014) which favours C removal from the atmosphere.

Interaction among various orchard management practices may be beneficial for the environment creating relevant service to the ecosystem *sensu* Comberti et al. (2015). As an example, the interaction between compost supply and adoption of cover crops could be evoked. The application of compost has been shown to increase soil nutrient availability including NO_3^- after the mineralization of compost (Baldi et al., 2010; Montanaro et al., 2010). In environments with mild winter, the mineralization process may start soon after the end of winter due to favourable soil temperature at the upper layers making NO_3^- available at that time. However, at this stage trees and their roots are usually still dormant hence tree roots do not take up nutrients including NO_3^-, so this poses a significant risk of leaching. Therefore, keeping the soil untilled allow the cover crops to uptake the mineralised nitrogen serving as a natural filter and helping to minimize risks of N leaching. Conclusions by Celano et al. (1998) are in line with this idea suggesting that in the case of poor development of spontaneous cover crops they can even be sown in autumn so they can serve as catch crops for the soil mineral N available in late-winter or early-spring when trees are quiescent or poorly active.

3.2 Preservation of soil biodiversity

Generally soil organisms are associated with soil fertility to the extent that some of them participate in processes that ultimately affect certain soil features influential in productivity (e.g., nutrient availability). Soil organisms are extremely diverse and have a strong relation to soil functions which underpin ‘soil based’ ES (see Bender et al., 2016 for review). Barrios (2007) categorised soil biota in different functional groups used to illustrate the linkages of soil biota and ES or supporting processes. Briefly, these groups are: microsymbionts (e.g., N-fixing organisms, mycorrhiza) involved in nutrient and water uptake by plants; decomposers (e.g., cellulose and lignin degraders) and transformers (e.g., nitrifiers, denitrifiers) involved in nutrient cycling; soil ecosystem engineers (e.g., earthworms, termites) that contribute to modifying soil structure sequestering organic carbon, enhancing the formation of aggregates, and in turn affecting soil hydrology and GHGs fluxes, dust emission etc. A soil biotic group leading to disservice such as soil-borne pests and diseases (e.g. white grubs, plant-parasitic nematodes, root-rots) was also recognised. Later, Robinson et al. (2013) developed a framework for soil ecosystems valuation beginning to address the role of soil biota in terms of ecosystem goods and service delivery.

Soil microorganisms are sensitive to soil disturbance since the soil environment is their habitat. Agricultural fields are managed ecosystems, therefore external drivers (e.g., soil tillage, fertilization, pesticides application) could interfere with abundance of soil microorganism and related natural processes and services (Bender et al., 2016). With regard to fruit tree ecosystems, microbial biomass measured in a peach orchard subjected to compost addition linearly correlated with soil organic matter content in a range of 1.5 – 5% (Baldi et al., 2010). A survey of 72 sites indicated that a monthly tillage operated during the growing season reduced the biomass of earthworm by 20-42% in vineyards and orchards (peach, apple and kiwifruit) when compared to that of cover cropped fields (Paoletti et al., 1998). Such a suppressive effect of tillage on earthworms could be even more incisive reducing the biomass of earthworms by 90% (Lardo et al., 2012) (Fig. 7). The application of chemical weeding may have a transient suppressive effect on earthworm communities. A few years after the introduction of the chemical control of weeds the biomass of earthworms is reduced by ~98%, while later some specific earthworm ecological categories tolerant to chemicals may develop (Lardo et al., 2012 and 2015). In addition, the effect of chemical weeding on earthworm turnover may be influenced by the total soil organic matter available (Schreck et al., 2012). Ecological management of understorey may be beneficial for the environmentally friendly reduction of the primary inoculum of certain pathogens enhancing ES. For example, in vineyards the biocontrol of the *Botrytis cinerea* (an important disease of grapevines that causes worldwide crop losses and reductions in wine quality) was achieved through increasing the vines' debris decomposition using various mulch types getting a 20-fold reduction of the inoculum compared to bare soil (Jacometti et al., 2007).

Arbuscular mycorrhizas (AM) fungi are a key functional group of soil biota at the interface between soil and plant roots that have the potential to impact crop productivity and the sustainability of the ecosystem that is the conservation of the ecosystem diversity of major functional groups, soil fertility and rate of biogeochemical cycling (Brussaard et al., 2007). Gianinazzi et al., (2010) reviewed the nutritional and non-nutritional activities of AM that contribute to the ES in agroecology including improved soil stability through binding action, increasing mineral nutrient and water uptake by plants, the buffering effect against abiotic stresses, increased plant tolerance to drought, salinity, heavy metals and pollution. Once again, some orchard management options could impact the degree of root colonization by AM and in turn the beneficial effects (services) provided by the symbiosis. Recently, in organically managed orchards (nutrients supplied as compost, weed mulching) roots showed a higher colonization degree than that of apple trees under conventional management (synthetic fertilizers, herbicides) (Meyer et al., 2015). Increased AM favours the increased root uptake of certain nutrients (i.e. P, Ca and Mg) and improved soil aggregation mainly through the particle-binding effects of their underground hyphae and the higher level of glomalin and related soil binding protein associated with the higher abundance of AM (Rilling 2004; Meyer et al., 2015).

4. SOIL FUNCTIONS AND SOCIOCULTURAL SERVICES

The services provided by an ecosystem exist only because people (human capital) exists as beneficiaries of those services. The broad measuring indexes of the human capital include education, health and employment, which in turn gives significance to all infrastructures able to enhance that index (Turner et al., 2016). In this regard, in rural areas the soil becomes a key social infrastructure to the extent that it is related to the employment level of farmers and workers. This applies for all agricultural systems, however to focus on fruit tree ecosystems the case of some olive groves in Southern Italy is evoked.

These groves encompass monumental individuals (~1000-year-old) and play a key socio-economic role through a series of ES including food, jobs for local populations, conservation of ancient culture and traditions (Mohamad et al., 2013). In addition, as this olive landscape is managed by traditional agricultural techniques, locally adapted and historic, by family it conforms to the cultural landscape definition reported in van Berkel and Verburg (2014). These productive ancient olive trees create a unique landmark to the extent that the Regional Government issued several laws in order to protect the groves against their uncontrolled transplanting from Apulia to private gardens in central Europe occurring because of their unique aesthetic (Mohamad et al., 2013). These olive groves as unique elements that characterized the history, the culture and the regional landscape also attract tourists and represent a key element of the regional green and productive infrastructure (see Ottomano Palmisano et al., 2016). The attention of policy makers to protecting that natural capital gives evidence of the ES they provide (olive oil production, ecological, hydro-geological protection) including cultural ones (e.g. landscapes, heritage) and social (employment of people).

Recently, these groves have come into the international scientific forum because local communities are fighting against their destruction imposed by a series of European Union regulations because of some quarantined bacterial diseases found in some trees (Abbott, 2015). This conceivably reflects the dependence of those communities on the complex and highly valuable ES flowing from that olive ecosystem which apply to most Mediterranean olive/oil producing countries.

The cultural services that flow from ecosystems are generally recognised as benefits people obtain such as aesthetic, recreational and spiritual experiences, ecotourism, and making use of cultural heritages (Daniel et al., 2012). Although the categorization of the *ecosystems:society* relationship has been the subject of recent increasing interest (also in terms of ecological economics), substantial gaps remain concerning the cultural services (Comberti et al., 2015). The intangible nature of most of the benefits humans derive from cultural services poses several methodological constraints dealing with the economic values of these services (Bieling and Plieninger, 2013).

Human health and well-being are positively influenced by natural daylight, fresh air and greenery (Ulrich, 1984) which are very common features of rural areas. In addition, rural areas have the potential to fulfil the needs of some people to participate in food production as well as to be in contact with plants and animals (Sznajder and Przezbórska, 2004). Hence in addition to the contemplation of farmscapes, some farms codified as agritourism offer a variety of supplementary services such as orchard tours, recreational pick-your-own, along with on-farm accommodation and food services (LaPan and Barbieri, 2014) indicating that the various categories of cultural ecosystems may easily overlap as noted by Daniel et al. (2012).

There are several worldwide examples of the service provided by the landscape aesthetic of fruit tree ecosystems. Here we would evoke the visually pleasant experience offered by vineyards and orchards in Italy and New Zealand, the multicrop fruit plantations (known as fruit gardens) in Vietnam and Sri Lanka, (Farina, 2000; Biasi et al., 2012; Daniel et al., 2012; Clothier et al., 2013). Most of them also have been recognised as cultural heritage providing further cultural services to the society (Daniel et al., 2012).

It is generally known that agro-silvo-pastoral landscapes result from a very long interaction between humans and the environment (Pinto-Correia and Vos, 2004).

Hence it would be useful to improve farmers' perceptions of ES within agricultural landscapes (Smith and Sullivan, 2014).

4 Conclusions

This paper has grouped and analysed the main ES flowing from fruit tree ecosystems including olive groves and vineyards. The examples discussed in this paper highlight the relationship between certain soil management options able to improve the provisioning of ES. Sustainable soil management appears to be central for various soil functions (mainly associated with SOC stock/concentration changes) and in turn the services provided by tree crops. Therefore, decisive action needs to be taken to limit soil C loss mainly due to erosion and emissions of carbon dioxide into the atmosphere and increase CO_2 capture by tree crops fitting with the proposal recently discussed at the Paris climate conference (UNFCCC-COP21, December 2015): to boost SOC sequestration at the rate of 4 ‰ per year to offset global anthropogenic emissions (Lal, 2016).

This paper contributes to reinterpreting the historical role of farmers as "producers of goods" as providers of more diverse services to the society (Swinton et al., 2008). In addition, the outcomes presented may strengthen the significance of increasing SOC in Mediterranean fruit tree ecosystems and can be supportive for the implementation of environmentally friendly policy within the tree crops category to help the conservation or even the improvement of the soil natural capital.

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FIGURE LEGENDS

Figure 1 – Variation of (A) soil organic carbon (%) and (B) midday soil CO_2 emissions (g CO_2 m^{-2} h^{-1}) from different positions in peach orchards locally conventional (i.e., tillage, mineral fertilisers, burning of pruning residuals) and after 4 and 7-year of changed practices to alternative (i.e., cover crops, retention of pruning residuals, application of compost). Different letters indicate statistically significant differences ($P = 0.05$ Tukey–Kramer test, $n = 60$) (Redrawn from Montanaro et al., 2012).

Figure 2 – Macroporosity measured at 0-10 cm, 10-20 cm and 20-30 cm depth of soil in two olive groves with different soil carbon concentration resulting from sustainable (High C, 1.4% SOC) and conventional (Low C, 1% SOC) management. Comparing treatments at the same soil depth * indicates statistically significant differences ($p < 0.05$ Duncan's test). Redrawn from Palese et al., (2014).

Figure 3 – Saturated soil hydraulic conductivity (mm h^{-1}) and amount of water (mm) stored at the end of winter time in the 0-200 cm soil profile in rainfed olive groves having High (1.4% SOC) and Low (1% SOC) carbon concentrations (redrawn from Palese et al., 2014).

Figure 4 - Runoff yield (mm) measured in bare soil (●) and covered with litter (○) with a 10% slope under various artificial rainfall intensities (mm h^{-1}). Lines are illustrative only. (Redrawn from Li et al., 2014).

Figure 5 – 4-year average of annual runoff (cm), soil loss (Mg ha^{-1}) and amount of sediment (kg m^{-3}) measured in a Mediterranean olive grove (steepness 11%, mean annual precipitation 576 mm). (Redrawn from Gómez et al., 2009).

Figure 6 – Annual amount of soil organic carbon (SOC) and available nutrients contained in the sediment yield in a olive grove under tillage and cover crop. Note

that N indicates the organic fraction of nitrogen. Data are the mean of 4 years, soil slope 11%, mean annual precipitation 576 mm. (Redrawn from Gómez et al., 2009).

Figure 7 – Effect of soil management (tillage and chemical weeding) on the abundance of soil earthworms (%) relative to that of cover crops (control) at various sites. Redrawn from (1) Paoletti et al., 1998; (2) Lardo et al., 2012 and (3) 2015; (4) Schreck et al., 2012.

Photo 1 – Soil management options might increase soil erodibility in a tilled field, or contribute to soil conservation and others flowing ecosystem services (e.g., soil stability, increase atmospheric CO_2 removal by cover crops) in an untilled/cover cropped field.

Figure 1

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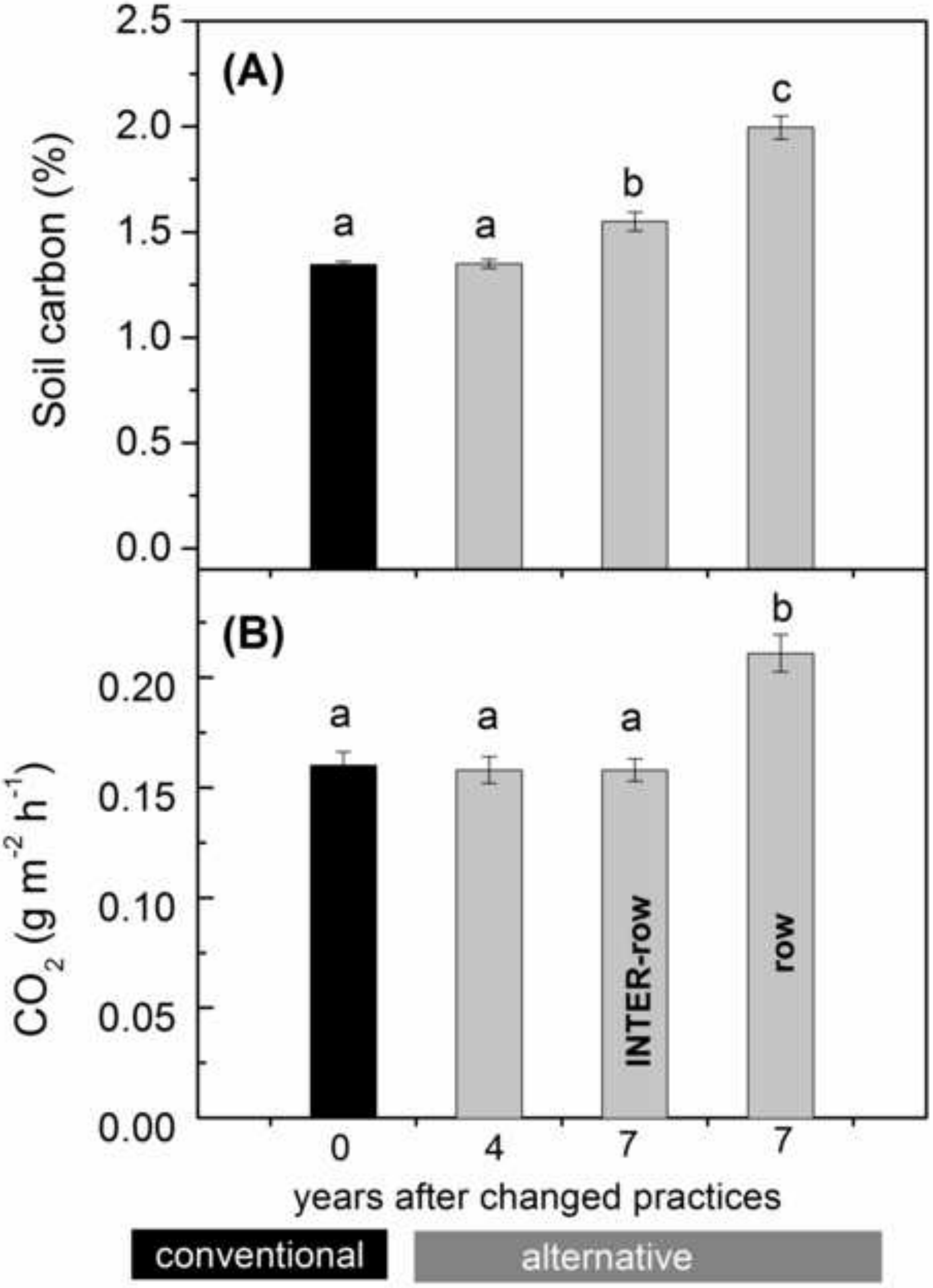
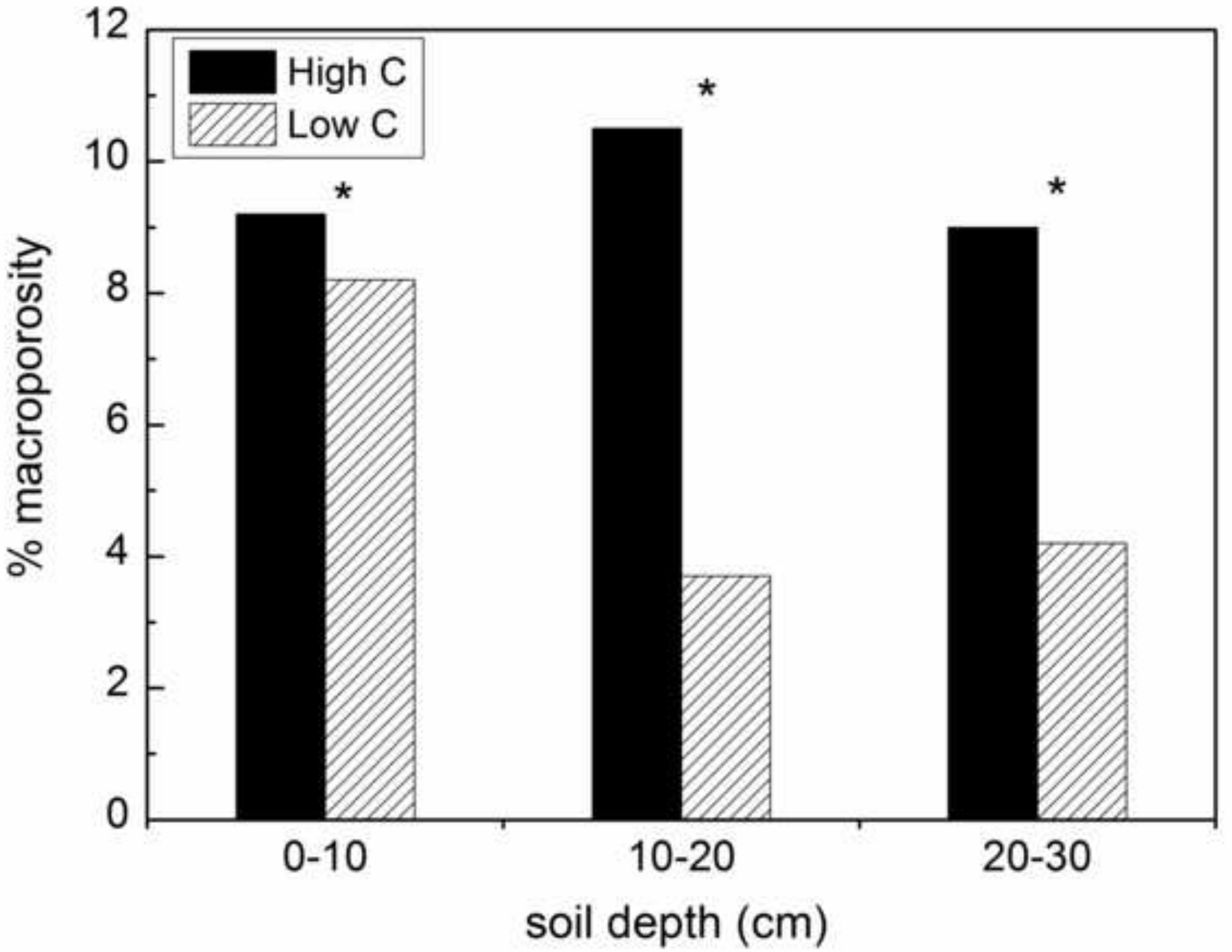


Figure 2



12
10
8
6
4
2
0
% macroporosity
High C
Low C
*
*
*
0-10
10-20
20-30
soil depth (cm)

Figure 3

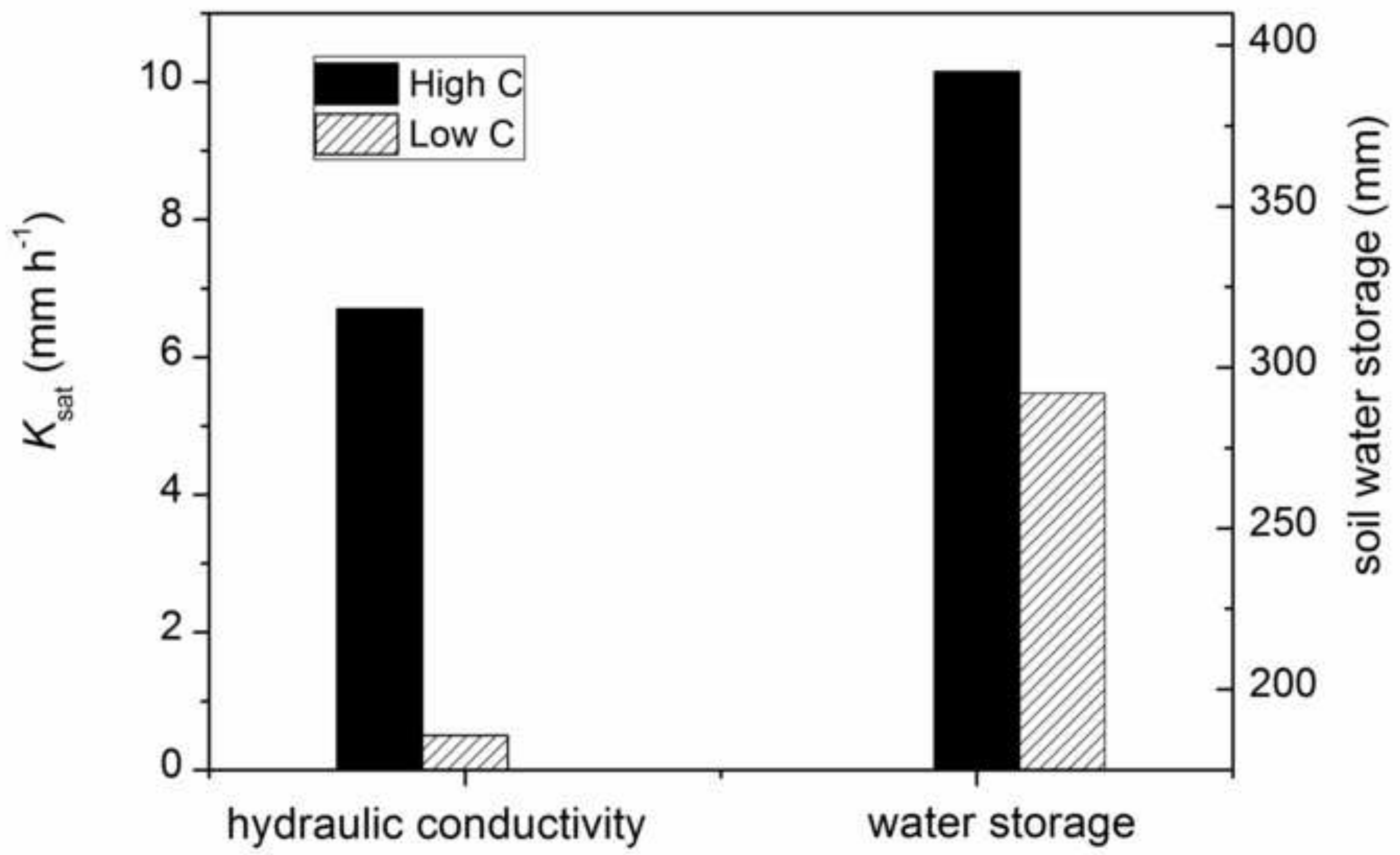

High C
Low C
K_{sat} (mm h^{-1})
0
2
4
6
8
10
soil water storage (mm)
200
250
300
350
400
hydraulic conductivity
water storage

Figure 4

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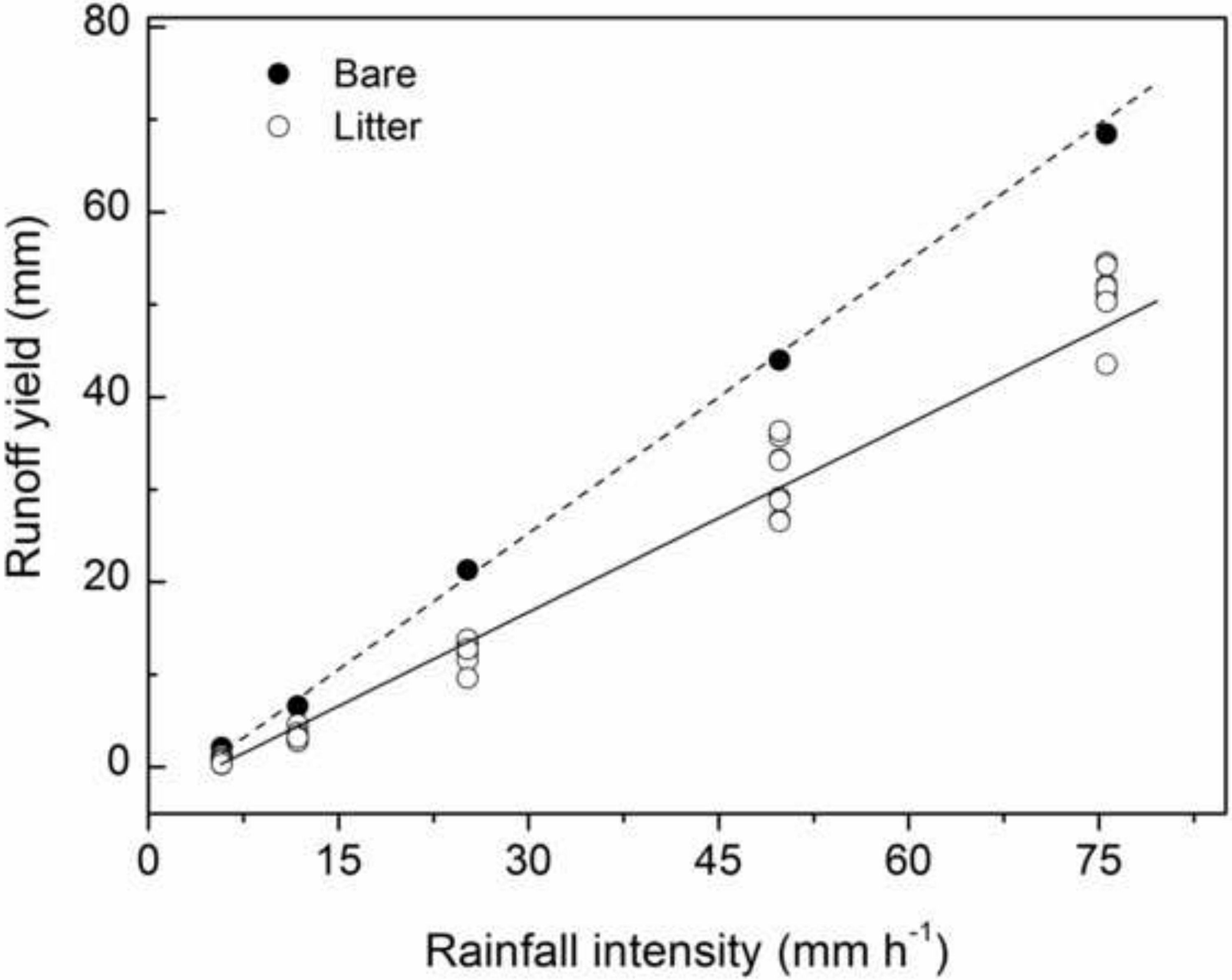


Figure 5

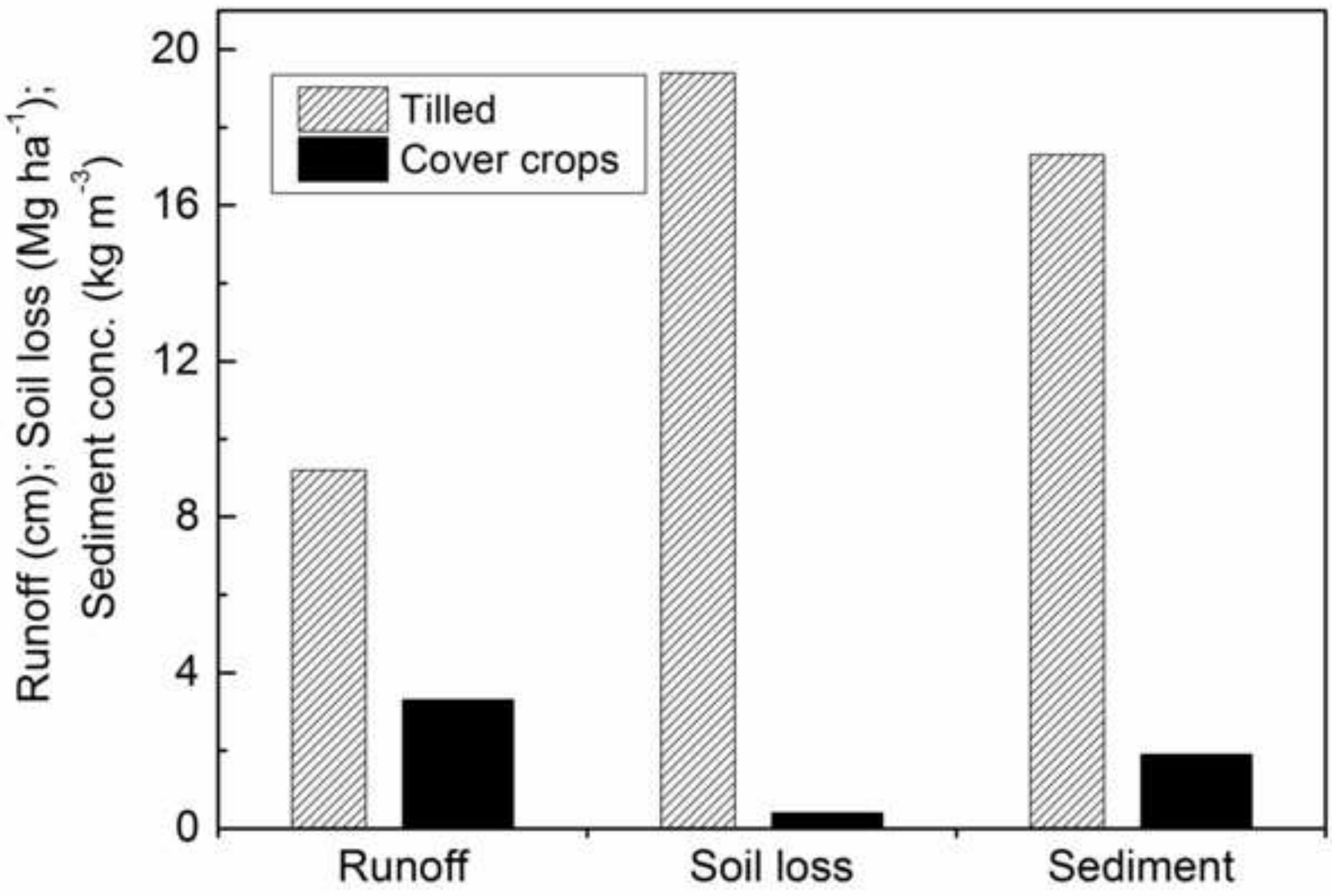
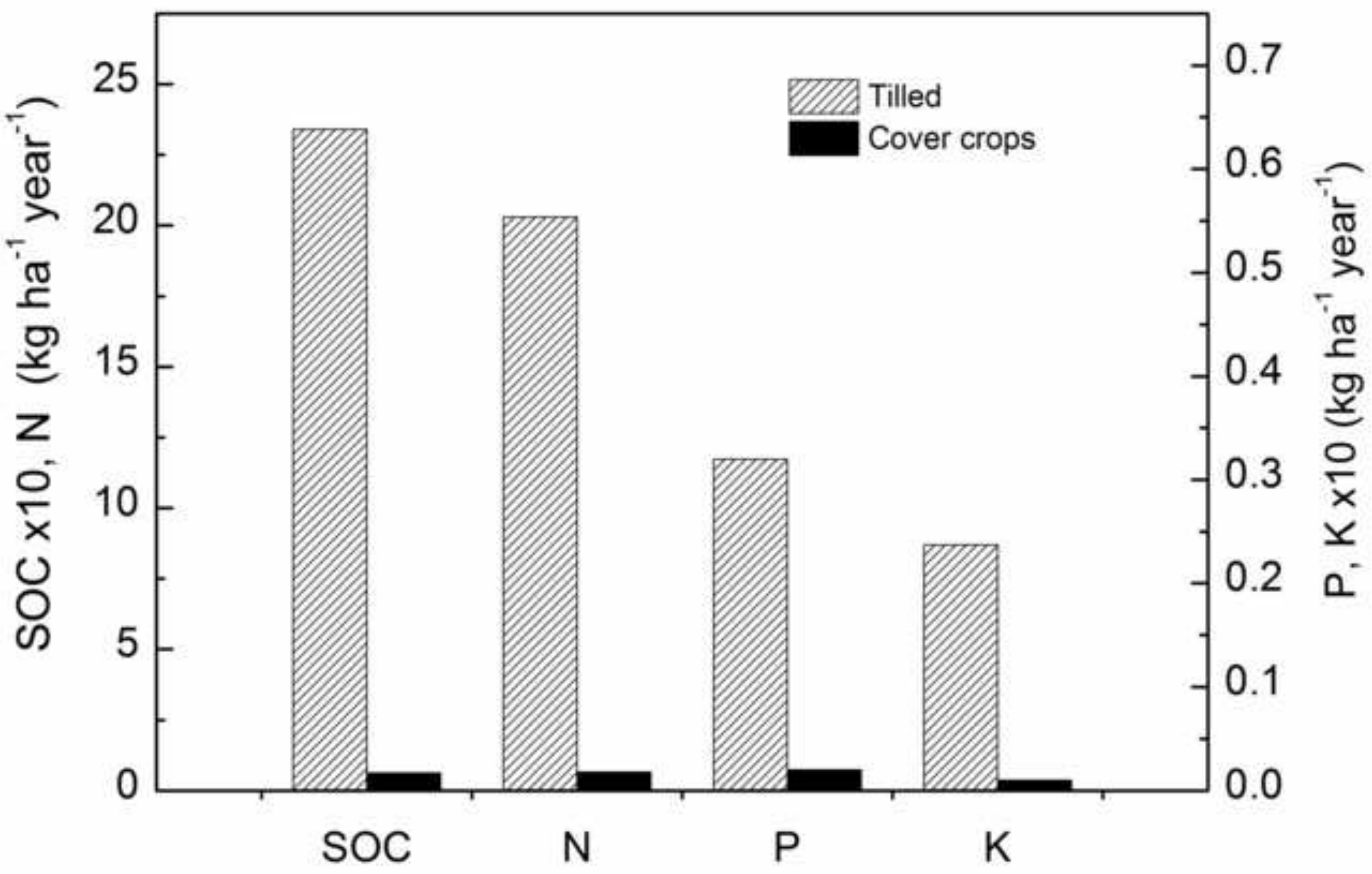

Runoff (cm); Soil loss (Mg ha^{-1});
Sediment conc. (kg m^{-3})
20
16
12
8
4
0
Tilled
Cover crops
Runoff
Soil loss
Sediment

Figure 6



SOC x10, N (kg ha^{-1} year^{-1})
25
20
15
10
5
0
P, K x10 (kg ha^{-1} year^{-1})
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
▨ Tilled
■ Cover crops
SOC
N
P
K

Figure 7

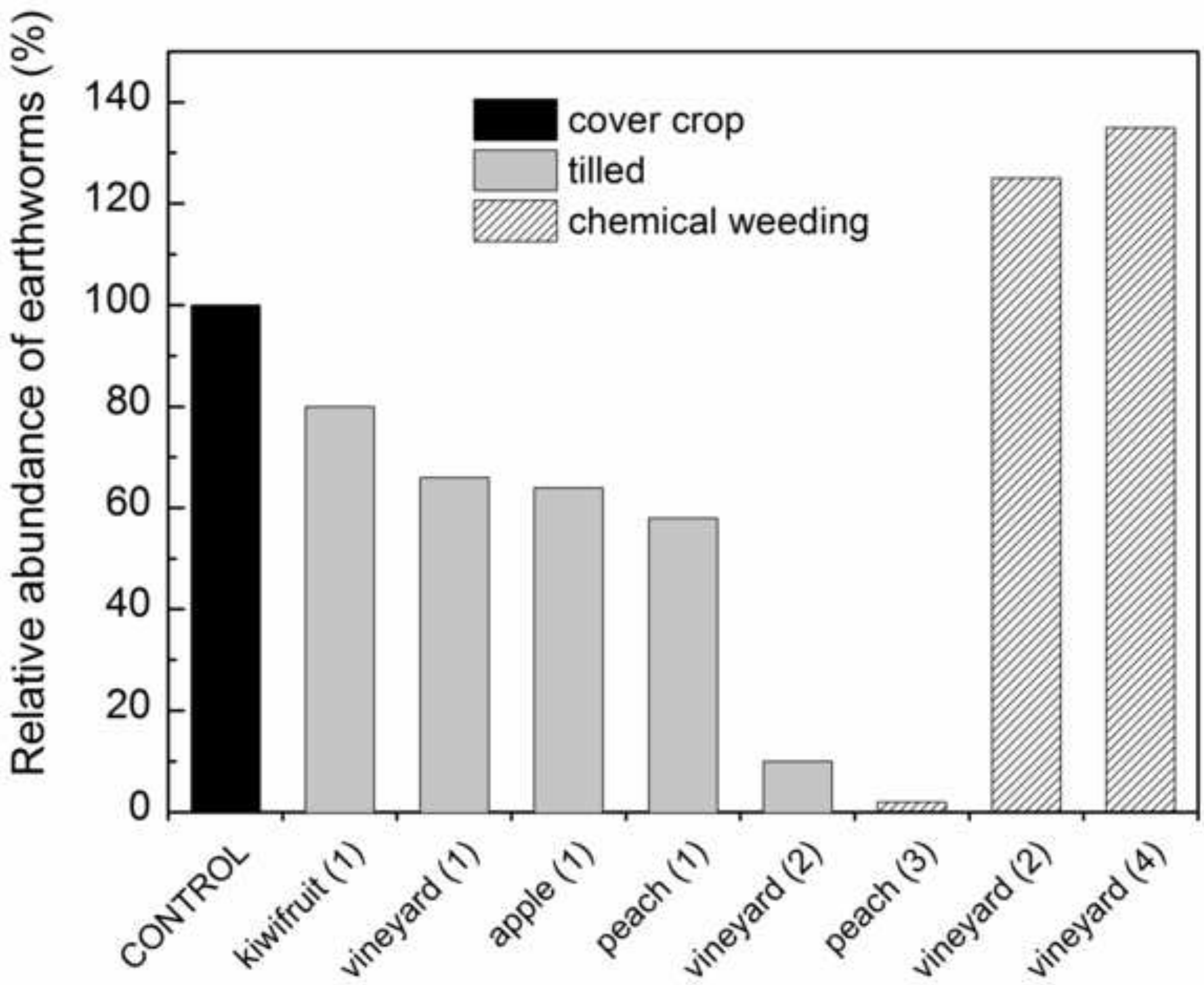

Relative abundance of earthworms (%)
140
120
100
80
60
40
20
0
cover crop
tilled
chemical weeding
CONTROL
kiwifruit (1)
vineyard (1)
apple (1)
peach (1)
vineyard (2)
peach (3)
vineyard (2)
vineyard (4)

Photo 1