FROM ANCIENT OLIVE AGROFORESTRY SYSTEMS TO MODERN CONVENTIONAL AND ORGANIC OLIVE MONOCULTURES: HISTORICAL EVOLUTION OF GREENHOUSE GAS EMISSIONS

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Introduction

The olive (*Olea europaea L.*) tree is one of the most widespread agricultural species, reaching 10.2 M ha worldwide in 2012. It is one of the most important and extensively cultivated permanent crops in the Mediterranean region, where 98% of the world's olive production is located (Kiritsakis 1998). The recent climate change emergency has brought particular attention to the mitigation potential of agriculture, including olive systems as indicates EU decision 529/2013/EU. In the Mediterranean, olive growing is a very important example of carbon sink in agriculture. The very long crop cycle, over 50 years (and up to several hundreds), ensures an effective action in CO_2 fixation and storage in soil organic matter and tree biomass, thus providing useful ecosystem services such as mitigating the effects of climate change. However, the potential of olive groves in CO_2 fixation depends on the management techniques applied (Proietti et al. 2014). In the past olive growing was part of an integrated crop system, which often included livestock and intercrops, making the olive grove an agroforestry system. Today the intensive management techniques, oriented to maximize the fruit production, accelerate the degradation of soil organic carbon, increasing CO_2 emissions and reducing the ecosystem services provided by the olive grove. Documents prove that starting from the 1500s; olive trees began to be cultivated for both olives for people and foliage for animals (Fiorino and Nizzi Griffi 1992). The tree was (and in many places still is) intercropped with cereals, grape vines or rye and oats (Boskou 1996). Later, between the XVI and XVII centuries, thanks to the influence of the Papal State, specialized olive groves with a regular planting layout appeared, while intercropping remained confined to small family olive groves (Brugnoli and Varanini, 2006). Starting from 1780 the production was destined to making oil for both human consumption and fuel (i.e. for light), while old and unproductive plants were used for firewood. At this time livestock were a component of crop production: the animals grazed the orchard and foraged on the pruning materials, reducing the cost of animals' feed, while weeding and fertilizing the olive groves. Starting from the XX century, the olive agroforestry gradually disappeared in favour of monoculture, geared to maximizing production of olive fruits. Currently, specialized and monocultural agriculture struggles to be economically viable and sustainable and a "new green agricultural vision" is getting ground, oriented towards resource preservation, including agroforestry and organic management. New polices have also raised interest in agroforestry because of its potential to increase biodiversity and deliver ecosystem services. Since agroforestry may bring benefits both economically and environmentally, producing more outputs while increasing sustainability, compared to monocultures, returning to an agroforestry approach in olive growing could be advantageous. Innovative olive agroforestry systems propose to grow economically viable intercrops and/or raise livestock grazing the grove. The evolution towards an olive agroforestry system could be a solution to: reduce soil erosion, promote water conservation, enhance biodiversity, reduce climate change impact and enhance farmers income. Understanding the changes in the environmental impact that has accompanied the change in olive growing, from ancient agroforestry system to modern conventional and organic monocultures, can provide figures for the impact of different practices. This can help better design modern agroforestry systems that combine the benefit of agroforestry with the necessary efficiency of input use, required today for profitable and sustainable agriculture. The aim of this work was to analyze the greenhouse gas emissions of olive growing throughout the latest centuries, from ancient agroforestry systems to modern conventional and organic olive monocultures.

Material and methods

The environmental impact of the different typical production models of olive growing adopted during the last two centuries in the region of Umbria in Italy was assessed in terms of carbon emissions and absorptions (i.e. carbon footprint). The timeframe of this study was 1870-2015. The inventory data required for the analysis have been obtained from technical literature, published in the different historical periods considered. Inventory data was used to calculate the carbon footprint employing emission coefficients from various sources. Emissions associated to the production of inputs and to fuel combustion were calculated taking into account the historical changes in the energy efficiency of their industrial production, estimated by Aguilera et al. (2015) based on an extensive literature review. Embodied energy values from this source were converted to greenhouse gas emissions employing the average emission intensity of world primary energy use, calculated taking into account the world primary energy mix from Aguilera et al. 2015, and carbon intensities of each energy source from Lal (2004). For the estimation of field GHG emissions such as fertilizer nitrous oxide and biomass burning N_2O and CH_4 we followed IPCC guidelines (IPCC, 2006). In the case of direct N_2O emission factors we used specific data for Mediterranean rainfed systems taken from a meta-analysis (Aguilera et al. 2013). Carbon sequestration was modelled using data from another meta-analysis of Mediterranean studies (Aguilera et al. 2013b). We applied average values of Carbon retention per Carbon input and average Carbon sequestration rates for particular tasks such as cover cropping.
From literature search we have extrapolated data about growing olive surface, olive production, tillage (like pruning and fertilization) and chemical products used, from past till today. In the ancient system, based on the literature, we considered fertilization with cattle manure, manual pruning and harvesting, and use of animal traction for tilling. The management gradually shifted towards the slow but constantly increasing introduction of machinery and fuel, as well as chemical fertilizers. Eventually, the modern systems involved permanent green cover, mowed twice a year, not grazed, soil fertilization with nitrogen (100 kg N/ha-1, 27 kg P_2O_5/ha, 85 kg k_2O/ha) and borate compounds, and periodic treatments with pesticides (copper sulphate 6 kg ha-1). For the modern organic management, instead, fertilization consisted of application of organic fertilizer (67.5 kg N/ha-1, 33.75 kg P_2O_5/ha, 56.25 kg k_2O/ha).

Results

Starting form 1870, the impact (i.e. emissions) of olive growing increased over time, due to the use of chemical fertilizers and the burning of olive pruning in the field. The increase in production (per hectare) that came with the introduction of monoculture, accompanied by the use of chemical fertilizer, pesticide and machinery, led to increased impact. In particular, after 1930 the introduction of machinery substituting animal work and chemical fertilizers start increasing emissions and the trend continues in the 50s and up to the 80s.when the intensification of agricultural management (bigger tractors, soil fertilization with nitrogen phosphorus potassium and periodic treatments with pesticides) and the burning of pruning residues increased CO_2 emission to the highest levels without increasing productivity or economic convenience. After this period the new attention to sustainability and ecosystem services led to a reduction of practices with the highest impact such as tilling and burning of pruning materials. Regarding the two modern most widespread managements (i.e. conventional and organic) the results show that the organic management greatly reduces (66%) CO_2 emission and increases (110%) soil carbon sequestration, thanks to the use of organic fertilizer in place of chemical fertilizers and the use of permanent green cover in place of tilling.

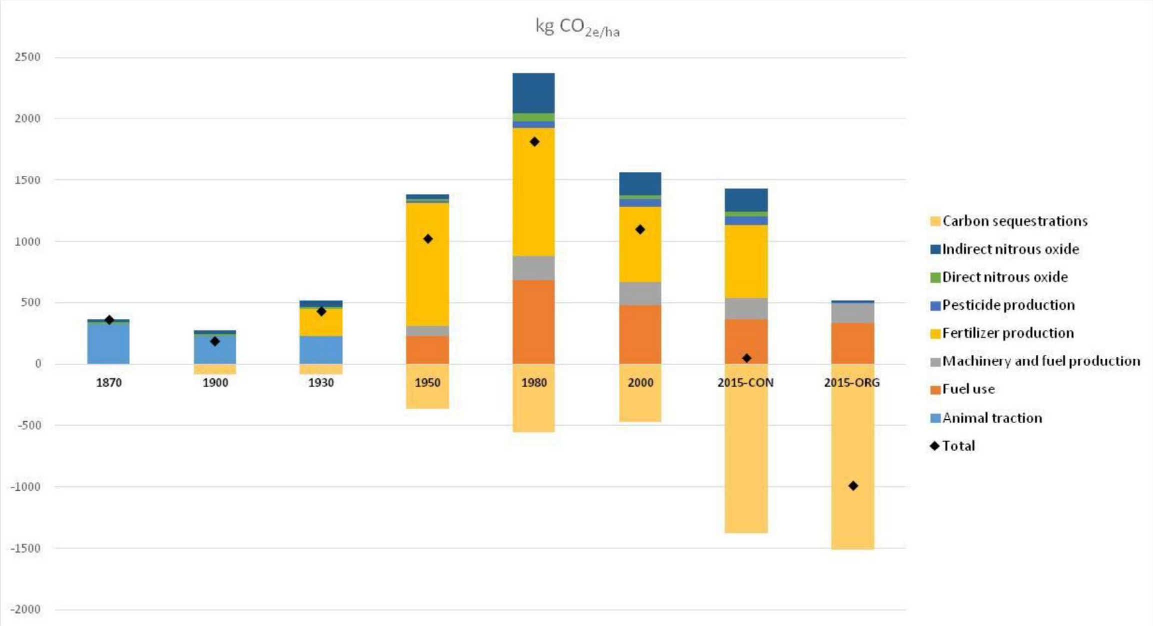

Figure 1: Carbon emissions (positive values) and Carbon sequestrations (negative values) of typical olive groves in the region of Umbria, Italy, throughout the centuries, from 1870 to 2015 (2015 is differentiated in conventional and organic olive monoculture). Carbon emissions and Carbon sequestration are expressed in kg of CO_2 equivalents.

Discussion

Ancient olive agroforestry systems were more sustainable in terms of emissions, mostly due to the absence of fossil fuels and chemical fertilizers. Modern systems have greater emissions, but also greater productivity, due to increased plant density, but also greater emissions. However, the impact of modern monocultures was reduced, from the 80s to nowadays, thanks to the replacement of tilling with green mulch (fuel saving), while productivity was not affected. With the organic system, replacing chemical fertilizers with manure and reducing pesticides, the impact is further reduced, again without loss of productivity, based on the literature consulted. However, managing weeds and pruning still represent a cost (economically and environmentally) since they need to be mowed and chopped, respectively. Re-introducing some of the ancient agroforestry practices, like grazing and feeding pruning materials to animals, which could then fertilize the crop, albeit with innovative designs that are more suited to modern agriculture, would further reduce the emissions, both directly (reducing the emission related to mowing, chopping of pruning materials, and fertilization) and indirectly (turning weeds and pruning material into feed, thus saving the impact related to feed production elsewhere). Current studies are evaluating the environmental benefits of such practices under modern agroforestry designs.

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