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Assessment of carbon balance in intensive and extensive tree cultivation systems for oak, olive, poplar and walnut plantation

Primo Proietti [a], Paolo Sdringola [b], Antonio Brunori [a,*], Luana Ilarioni [a], Luigi Nasini [a], Luca Regni [a], Francesco Pelleri [c], Umberto Desideri [d], Stefania Proietti [e]

[a] *Department of Agricultural, Food and Environmental Sciences, University of Perugia, Via Borgo XX Giugno 74, 06121 Perugia, Italy*
[b] *Department of Engineering, University of Perugia, Via G. Duranti 93, 06125 Perugia, Italy*
[c] *Consiglio per la Ricerca in Agricoltura e l'analisi della economia agraria, Forestry Research Centre, Viale S. Margherita 80, 52100 Arezzo, Italy*
[d] *Department of Energy, Systems, Territory and Constructions Engineering, University of Pisa, Largo L. Lazzarino, 56122 Pisa, Italy*
[e] *Department of Sustainability Engineering, Guglielmo Marconi University, Via Plinio 44, 00193 Roma, Italy*

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ABSTRACT

To reduce GreenHouse Gas (GHG) emissions, the Kyoto Protocol identifies a number of activities that are closely related to land use, included in the category called Agriculture, Forestry and Land Uses (AFOLU). While forests and agricultural systems result in CO_2 absorptions (live biomass, dead biomass and soil), every process undertaken for their management requires energy and resources, which can lead to a significant reduction of the environmental benefits.

The study analyzes three tree plantations managed at different cultivation intensities in Italy, from an extensively managed plantation (a pure oak plantation) and a semi-intensively managed plantation (walnut and poplar plantation with nurse plants), to an intensively managed olive grove. Permanent and non-permanent biomass were accounted for in order to get the carbon stock of every plantation, estimated at the same age of 14 years old. The numerous processes operated for management of different cultivated species, e.g. planting, soil management, fertilization, phytosanitary treatments, pruning, harvesting, etc. were monitored and their impacts were quantified by applying the methodology known as Life Cycle Assessment (LCA). Removals (carbon sequestrations) were compared to emissions on a time scale, in order to assess the net $CO_{2\text{-eq}}$ balance. Impacting treatments and processes were identified and further analysis on the individual phases and materials were conducted.

Olive trees showed an unexpected capacity to store $CO_{2\text{-eq}}$, but this ability was evident only if annually harvested fruits and prunings were considered in the calculation. The plantation that demonstrated its ability to store most $CO_{2\text{-eq}}$ at the age of 14 was the semi-intensively managed plantation, showing a higher efficiency in the energy spent by man. The paper offers a contribution for an innovative environmental performance evaluation of different tree cultivation management systems, including the assessment of potential benefits in terms of sequestered $CO_{2\text{-eq}}$ for the studied tree plantations and possible avoided emissions thanks to sustainable agricultural practices.

1. Introduction

Emissions of carbon dioxide (CO_2), and more generally greenhouse gases are responsible in terrestrial ecosystems for climate changes on a global scale. In the global carbon budget there are emissions of about 6.6 Pg due to direct or indirect human activity (Robinson et al., 2007) compared to an annual carbon sink of 2–2.6 Pg. The forecasting models indicate that maintaining or, where possible, enhancing the capacity of Carbon accumulation in the biosphere in the next 20–30 years is an essential measure to help mitigate the increases in temperature (Smith et al., 2004), although the potential for carbon removal from the atmosphere by soil and vegetation is not able to compensate the increases in emissions.

In tree plantations, compared to herbaceous crops, the multi-annuality constitutes an advantage in terms of net Carbon (C) fixation in the system, which may be increased by some cultivation

* Corresponding author. Tel.: +39 075 5997295, +39 348 2814116 (mobile); fax: +39 075 7821437.
E-mail address: antonio.brunori@comunicambiente.net (A. Brunori).

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Glossary

AFOLU	Agriculture, Forestry and Land Uses
AGB	Above Ground Biomass
BGB	Below Ground Biomass
C	Carbon
CF	Carbon Footprint
CO_2	Carbon dioxide
$CO_{2\text{-eq}}$	Equivalent carbon dioxide
cv	Cultivar
DBH	Diameter Breast Height (1.3 m)
GHG	Greenhouse gas
GWP	Global Warming Potential
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment

strategies such as, for example, soil management by means of green cover (permanent grass coverage) instead of soil tillage, oriented to limit CO_2 emissions and/or increasing carbon sequestration in soil. Although the fruit orchards have a shorter duration of life than forest ecosystems and are not permanently covering the ground, they possess a higher potential for carbon fixation than herbaceous crops (Robertson et al., 2008), both in the plant component and in the soil, above all for species, like the olive, that can have a very long life cycle.

Agricultural tree crops have a relative importance in central and northern Europe, while they have great economic importance for Italy and in general for northern Mediterranean countries (Olesen and Bindi, 2002), where they represent 16% of agricultural land (FAO, 2012). In Italy, according to the latest National Forest Inventory of 2005, wood plantation sector is present in 122,252 ha (Gasparini and Tabacchi, 2011). Of this area, 20,479 ha of tree plantations were subject to natural restrictions (they are designed to protect the soil and do not have a productive destination) and therefore have low anthropogenic input, while 101,773 ha have productive goals, with defined crop cycles and cultivation operations (plant, pruning, cutting) and related anthropogenic input of medium and high intensity. The sector of fruit plantations in Italy invests 3,114,765 ha (Marchetti et al., 2012), of which 1,140,685 ha are olive groves.

Among the activities identified by the Kyoto Protocol as effective to reduce GreenHouse Gas (GHG) emissions, a number of actions closely related to land use are included into the category called Agriculture, FOrestry and Land Uses (AFOLU). Mechanisms affecting absorptions and emissions can be both natural and anthropogenic, and are characterized by a series of complex biological, physical and chemical processes that are widespread and highly variable over time. On the one hand, through photosynthesis, plants absorb CO_2 from the atmosphere and release O_2; a portion of the absorbed CO_2 returns to the atmosphere through plant respiration, while a part is stored in various organic compounds, creating a so-called *carbon sink*. It increases its value up to a limit beyond which the biological losses – due to respiration and the death of the trees – balance the carbon increment for photosynthesis. On the other hand, an important aspect to be considered for a correct carbon balance evaluation in the agricultural sector is the impact due to the numerous processes used to manage different cultivated species (Van der Werf et al., 2009), e.g. cultural practices such as planting, soil management, fertilization, phytosanitary treatments, pruning, tree felling and logging, etc.

These actions are responsible for not-negligible equivalent carbon dioxide ($CO_{2\text{-eq}}$) emissions, which should be quantified by monitoring the related material and energy flows and by applying the methodology known as *Life Cycle Assessment (LCA)*. It proposes a system vision of productive processes and their derived products, including the calculation of Carbon Footprint (CF).

While the quantification of the amount of carbon sequestrated by forests has been the object of extensive studies (Brown, 2002; Fonseca et al., 2011; Kauppi et al., 2010; Peichl and Arain, 2007), information about agricultural systems is extremely limited. Considering the lack of knowledge on these topics, three plantations managed at different cultivation intensities were studied and compared in their first 14 years. They included a less intensively managed plantation (with oak), a semi-intensively managed plantation (with walnut and poplar) and an intensively managed olive grove. Fresh and dry weight measurements were conducted to estimate their biomass and the respective carbon stock of the above-ground parts of the plantations, as well as the quantification of the non-permanent components (pruning and fruits) of the olive grove which were annually harvested. Impacting treatments and processes were identified and further analysis on the individual phases and materials were conducted to propose possible actions for reducing emissions throughout the entire plantation life cycle. Removals (carbon sequestration) and emissions were compared on a time scale, in order to assess the net $CO_{2\text{-eq}}$ balance. The same approach was applied during a previous study on an olive grove, as intensive agricultural system (Proietti et al., 2014).

These plantations were located in their typical growing area and any human induced management input (fertilizers, thinning, pruning, cultivation techniques, etc.) was planned to increase their health and structural stability, their annual wood increment (walnut and poplar plantation) or annual fruit production (olive grove).

1.1. Life Cycle Assessment and carbon footprint in tree cultivation

The "*LCA is a method of evaluation of the environmental burdens associated with a product, process, or activity by identifying and quantifying energy and materials used and wastes released into the environment; and to identify and evaluate opportunities to affect environmental improvements*". Life Cycle Assessment is currently the best technique to quantify environmental impacts during the entire lifespan of products or processes, through the inventory of inputs and outputs in a selected system, the assessment of potential impacts and the interpretation of results. It evaluates the entire life cycle of the process or activity, including extraction and processing of raw materials, manufacture, transport, distribution, use, reuse, recycling and final disposal (SETAC, 1993).

LCA is an internationally standardized method through UNI EN ISO 14040: 2006 and UNI EN ISO 14044: 2006, included into the International Standards Organization ISO 14000, related to environmental management systems and instruments for their implementation. This approach moves from a separate study of individual elements of production processes to an overall view, where all the processes of transformation ("cradle to grave" up to "cradle to cradle" perspective) are considered. The application of the LCA methodology does not guarantee the improvement of environmental performance, but it can identify possible sustainable actions to be implemented in terms of technology and management. An LCA is a scientific model, a simplification of a physical system, therefore a complete representation of any effect on the environment cannot be reached; the accuracy of an LCA depends on availability, accessibility and quality of relevant information (Hertwich, 2005; JRC-IES, 2010).

Carbon footprint is defined *as the sum of GHG emissions and removals, expressed as net impact on global warming in terms of* CO_2