Introduction of new oLIVE crop management practices focused on CLIMAte change mitigation and adaptation

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Preliminary report on CO_2 balance in olive ecosystem

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1. Summary

The present report summarise the terminology widely adopted within scientific literature for carbon (C) cycling in ecosystem and related framework to be used in the deliverables. In addition to C fluxes occurring between the atmosphere and the orchard, it has been focussed the need for accounting of “lateral” fluxes of C. That lateral transport of C refers to some (anthropogenic) aspect of orchard management such as fruit removal with harvest, C supply through organic fertilisers. All these fluxes have been combined in the Net Ecosystem Carbon Balance (NECB) which would be considered as the reference, therefore NECB >0 indicates the ability of the orchard to sequester C while NECB <0 indicates that the orchard release C. This report is preparatory for the NECB to be delivered within the oLIVE-CLIMA project.

2. Introduction

The atmospheric concentrations of the greenhouse gases carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) have all increased in past decades, in 2011 their concentrations exceeded the pre-industrial levels by about 40%, 150%, and 20%, respectively and CO_2 was indicted as the strongest driver of climate change as measured through the total radiative forcing (IPCC, 2013). Systematic measurements of atmospheric CO_2 concentration are carried out at many sites and networks all over the world (Liu et al., 2015) showing that global atmospheric CO_2 concentration has been regularly increasing at a rate of approx. 2 parts per million (ppm) per year and in places passed 400 ppm in May 2013 (Monastersky, 2013; Liu et al., 2015) (Fig. 1). Carbon dioxide concentrations have increased primarily from fossil fuel emissions and secondarily from net land use change emissions. The ocean has absorbed about 30% of the emitted anthropogenic CO_2, causing ocean acidification which will in turn reduce future ocean capability to trap CO_2 (IPCC, 2013) adding further constraints to the climate change issue.

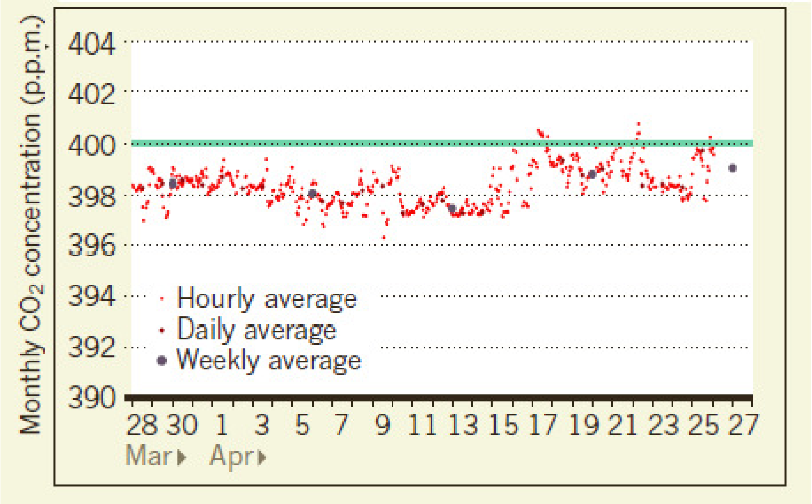


Figure 1 - Records of monthly atmospheric CO_2 concentration during some months in the 2013 at Mauna Loa, Hawaii. (Redrawn from Monastersky, 2013).

A recent review of trends in global GHG emissions reports that agriculture, forestry and other land uses (AFOLU) share approx. 22% of global GHG anthropogenic emissions and that agriculture sector (crop and livestock production) accounts for ~50% of AFOLU emissions (Toniello et al., 2015). The two main anthropogenic sources of GHG emission from agriculture are (i) the energy use (e.g. manufacture, use of external inputs and farm machinery) and (ii) the management of cultivated land. However, the agriculture sector has a great atmospheric CO_2 mitigation potential mainly because of the huge amount of carbon (C) storable in the soil which has been identified has one of the main options for GHG mitigation by the IPCC. Since the breaking of agricultural land in most regions, the soil C stocks have been depleted to such an extent, that soil now represents a potential sink for CO_2 removal from the atmosphere (Hutchinson et al., 2007). However, whether a cultivated land/ecosystem act as sink or source of CO_2 depends on the practices adopted at field scale. For example, appropriate practices promoting CO_2 capture into soil are rotations with high-biomass crops, shifting from annual to perennial crops, reducing or avoiding biomass or crop residues burning, reducing tillage, *in situ* mulching of crop residue management, optimal nutrient and water management, use of organic fertilizers, no-tillage, use of cover crops (Montanaro et al., 2010 and 2012; Petersen et al., 2013).

Proper estimate of the potential for CO_2 sequestration in agricultural ecosystems would be beneficial for identification of best-practices and for a wider recognition of agriculture as key sector for atmospheric CO_2 mitigation. In addition, a consistent approach to account for agricultural emissions/sequestration would minimise disagreement as to whether an ecosystem act as sink or source. However, a more comprehensive understanding of tree growth and C partitioning and its interaction with the environment (soil, atmosphere) is needed to predict C budgets and fluxes in a scenario of future climatic change.

3. Ecosystem carbon balance

Assessing an ecosystem’s C balance may help deeper understanding of ecosystem functioning and in turn could be beneficial for the C cycle at global scale. In addition, understanding of C dynamics in olive grove using an ecosystem C balance approach may support development of new environmental friendly policy for olive industry.

Analysis of C mass exchanges between the atmosphere and an ecosystem based on micrometeorological measurements (eddy covariance, EC) has been introduced mainly for forest ecosystems (Baldocchi et al., 1988) and it is increasingly used also in fruit tree crops (e.g. apple, Zanotelli et al., 2014) including olive grove (Nardino et al., 2013). The EC based methodology for C balance has several advantages being non-destructive, providing long-term detailed records at ecosystem scale, however the EC methodology has several constraints: it operates accurately in flat and relatively large area, it provides only data on net ecosystem exchange while information on gross primary production, soil respiration and C stock variation remain to be inferred (Luyssaert et al., 2009). In addition, the financial cost of the equipment may further limit a wide use of EC particularly in hill, non-flat areas. Therefore, in order to have a more affordable C accounting methodology, this report will preliminarily focus on ecosystem C balance based on field measurements that accounts for changes in C sequestration, emissions and net C flux with time.

3.1 Definitions and framework

Gross Primary Production (GPP)

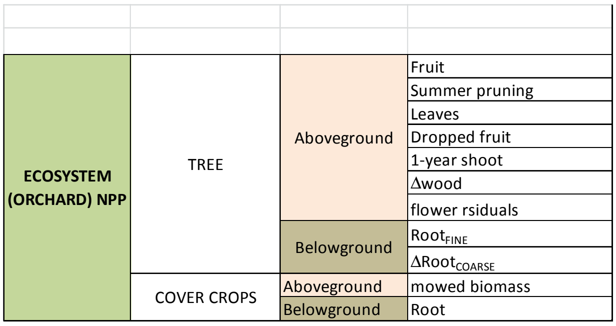
The GPP is the total amount of carbon fixed by plants (including cover crops) through photosynthesis in an ecosystem.

Net Primary Production (NPP)

The NPP is the net production of organic carbon by plants in an ecosystem occurring over a time period (usually one year or more). It is the GPP minus the amount of carbon respired by plants themselves in autotrophic respiration (Ra):

$$NPP = GPP - Ra \qquad (1)$$

The NPP accounts for new leaf (deciduous species), new shoot, fruit, new roots, flowers residuals, biomass increment of coarse roots and shoots, eventually the biomass consumed by herbivores. In addition, amounts related to the short-lived biomass (e.g. fruit drop or thinned, shoots removed through summer pruning) should be accounted, too. The same apply to cover crops if the NPP for the ecosystem is to be determined. Schematic summary for the above/below ground NPP components is reported in the Tab. 1. Importantly, only the amount of carbon produced and lost in the year for which NPP is being calculated is counted, not what was produced in an earlier year and lost in the current year (Kirschbaum et al., 2001).



ECOSYSTEM (ORCHARD) NPP	TREE	Aboveground	Fruit
			Summer pruning
			Leaves
			Dropped fruit
			1-year shoot
			Δwood
			flower rsiduals
		Belowground	$Root_{FINE}$
			$\Delta Root_{COARSE}$
	COVER CROPS	Aboveground	mowed biomass
		Belowground	Root

Table 1 – Tree and cover crops above and belowground components to be accounted for the NPP determination. Note that “dropped fruit” includes thinned fruit; Δwood and Δroot is the biomass increment in > 1-year branches, trunk and coarse root respectively.

Autotrophic respiration (Ra)

Because of internal plant metabolisms, part of the carbon fixed through photosynthesis is lost again in atmosphere by autotrophic respiration (Ra). Usually amount of Ra reaches ~ 50% of GPP and it refers the carbon lost by both the above and belowground plant biomass.

Heterotrophic respiration (Rh)

Apart from Ra, soil is a source of carbon (and other gases) because of heterotrophic respiration from soil organisms, and eventually from litter decomposition and from organic matter oxidation. Hence “soil CO_2 efflux” includes Ra and Rh as schematized in Fig. 2.

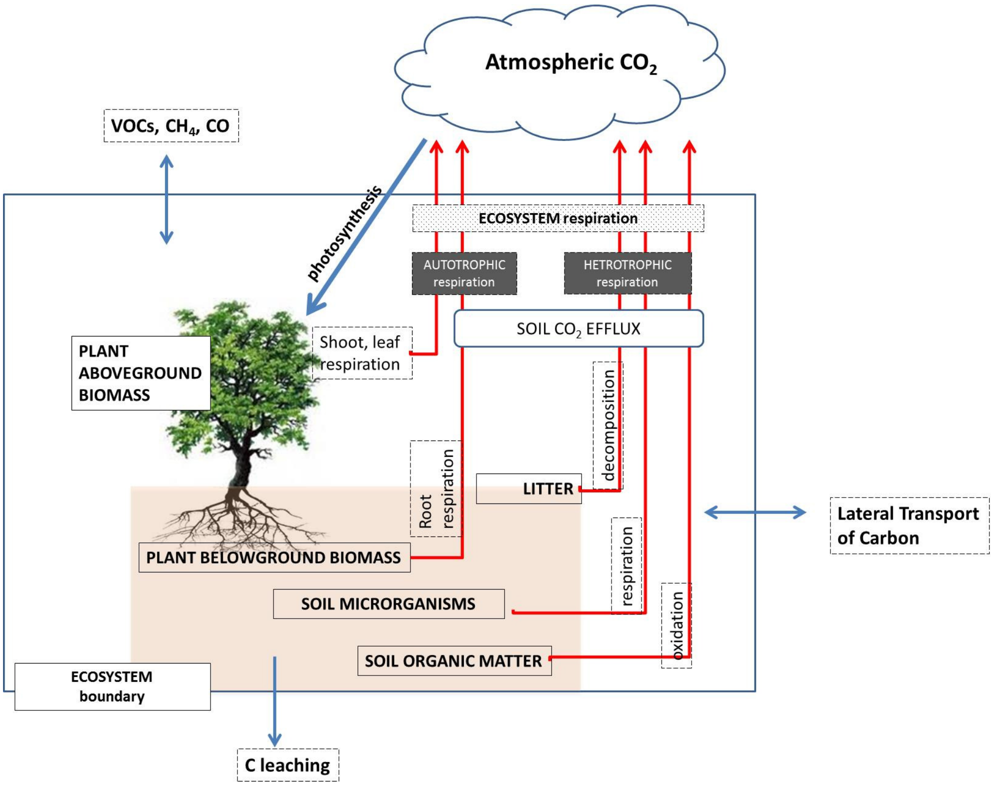


Figure 2 – Schematic representation of the main carbon fluxes in an ecosystem.

Net Ecosystem Production (NEP)

The NEP has been defined as the difference between the ecosystem photosynthetic gain of C (i.e. the gross primary production, GPP) and the ecosystem (plant, microbial, animal) respiratory loss of C (i.e. the ecosystem respiration, Re) (Chapin III et al., 2006) (Fig. 2)

NEP = GPP - Re (2)

Considering that Re is the sum of Ra and Rh, and that NPP = GPP-Ra the eq. 2 becomes:

NEP = NPP – Rh (3)

hence NEP refers to the net primary production (NPP) minus carbon loss due to heterotrophic respiration. Note that the term NEP equals the NEE (net ecosystem exchange) when fluxes are determined using atmospheric-based measurements (eddy covariance) over time scales of hours. The NEP is more used when C fluxes measurements are based on ecosystem-carbon stock changes.

3.2 Carbon accumulation in ecosystems

Based on eq. (3), it appears that an ecosystem accumulates C when GPP is greater than Re (i.e. GPP/Re >1) whilst an ecosystem lose C when ecosystem respiration exceeds GPP (i.e. GPP/Re <1) thus they can be defined as autotrophic and heterotrophic ecosystems, respectively (Lovett et al., 2006).

Farming can play a major role in climate regulation, both by limiting emissions of GHGs and by sequestering carbon in plants and soil, depending on their management, therefore farms should be considered as “managed ecosystem” (Swinton, 2008). In this context, the total C imports and exports including the anthropogenic sources (or removal) of C should be accounted when determining the ecosystem C balance at orchard scale. According to Chapin III et al., (2006) it is suggested to use the Net Ecosystem Carbon Balance (NECB) in order to include that anthropogenic components and others C sources and sinks identifying “lateral” C fluxes and non-CO_2 fluxes with a positive (absorption) or negative (emission, consumption) sign.

Among the components of the lateral C fluxes are the inorganic/organic dissolved C in soil solution (DIC, DOC), volatile organic compounds (VOC), organic fertilisers (OF), fruit harvest (FH), pruning material (PM) when burned, monoxide C (CO), methane (CH_4), soil exudate, C exported to mycorrhizas, C leaching below the root zone (see Tab. 2 and Fig. 2).

Table 2 – lists the main lateral transport C (LTC) components to be accounted for the NECB determination (adapted from Lovett et al., 2006 and Chapin III et al., 2006), note that pruning material is accounted only when burned.

"Lateral" transport of C (LTC)	MANAGEMENT, SOIL FEATURES and INTERACTIONS	*negative sign*	Yield
		positive sign	compost/manure
		negative sign	pruning material
		negative sign	Erosion
		negative/positive sign	VOC, CH_4, CO,
		positive sign	C export to mycorrhizas
		positive sign	Exudates
		negative sign	C leaching

Considering that most of these LTC components are relatively small and very difficult to assess, the NECB could be simplified as:

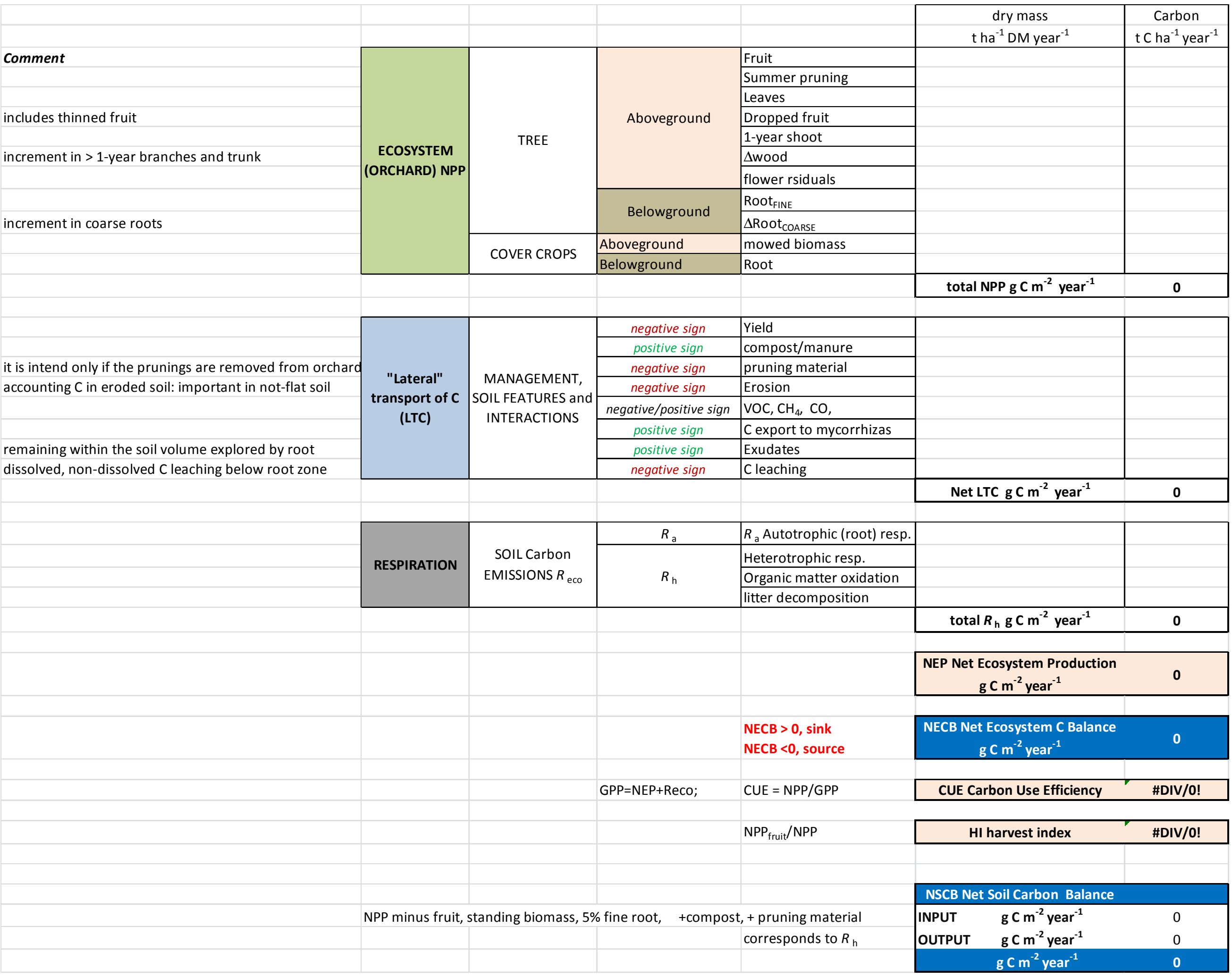
$$NECB = GPP - Re + OF - FH \qquad (5)$$

which equals the following eq. assuming that pruning material is mulched in loco:

$$NECB = NPP - Rh + OF - FH \qquad (6)$$

Considering that the ecosystem (orchard) is the reference, NECB >0 indicates the ability of the orchard to sequester C while NECB <0 indicates that the orchard release C. An Excel spreadsheet as been assembled to collectively report all components of C ecosystem balance (Tab. 3).

Table 3 – List of components for NECB and other indexes determination



					dry mass t ha^{-1} DM year^{-1}	Carbon t C ha^{-1} year^{-1}
Comment	**ECOSYSTEM (ORCHARD) NPP**	TREE	Aboveground	Fruit		
				Summer pruning		
				Leaves		
includes thinned fruit				Dropped fruit		
				1-year shoot		
increment in > 1-year branches and trunk				Δwood		
				flower rsiduals		
			Belowground	Root$_{FINE}$		
increment in coarse roots				ΔRoot$_{COARSE}$		
		COVER CROPS	Aboveground	mowed biomass		
			Belowground	Root		
					total NPP g C m^{-2} year^{-1}	**0**
	"Lateral" transport of C (LTC)	MANAGEMENT, SOIL FEATURES and INTERACTIONS	*negative sign*	Yield		
			positive sign	compost/manure		
it is intend only if the prunings are removed from orchard			*negative sign*	pruning material		
accounting C in eroded soil: important in not-flat soil			*negative sign*	Erosion		
			negative/positive sign	VOC, CH$_4$, CO,		
			positive sign	C export to mycorrhizas		
remaining within the soil volume explored by root			*positive sign*	Exudates		
dissolved, non-dissolved C leaching below root zone			*negative sign*	C leaching		
					Net LTC g C m^{-2} year^{-1}	**0**
	RESPIRATION	SOIL Carbon EMISSIONS R_{eco}	R_a	R_a Autotrophic (root) resp.		
			R_h	Heterotrophic resp.		
				Organic matter oxidation		
				litter decomposition		
					total R_h g C m^{-2} year^{-1}	**0**
					NEP Net Ecosystem Production g C m^{-2} year^{-1}	**0**
				NECB > 0, sink **NECB <0, source**	**NECB Net Ecosystem C Balance g C m^{-2} year^{-1}**	**0**
			GPP=NEP+Reco;	CUE = NPP/GPP	**CUE Carbon Use Efficiency**	**#DIV/0!**
				NPP$_{fruit}$/NPP	**HI harvest index**	**#DIV/0!**
					NSCB Net Soil Carbon Balance	
	NPP minus fruit, standing biomass, 5% fine root,			+compost, + pruning material	**INPUT** g C m^{-2} year^{-1}	0
				corresponds to R_h	**OUTPUT** g C m^{-2} year^{-1}	0
					g C m^{-2} year^{-1}	**0**

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