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

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Determination of CO_2 balance in olive ecosystems

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Version	FINAL
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1. Summary

Knowledge of carbon (C) fluxes at olive groves might help to design management strategies aimed at minimize environmental impact of olive cultivation and improve its contribution to climate change mitigation. After a view on the terminology widely adopted within scientific literature for C cycling in ecosystems and related framework to be used in the deliverable, this report focuses the **Net Ecosystem Carbon Balance (NECB)** of olive groves in Italy and Greece. Through the NECB in addition to CO_2 fluxes occurring between the atmosphere and the orchard also the anthropogenic CO_2 fluxes have been accounted.

To test the effect of the various management practices on NECB the **following treatments were imposed** in various plots located in Greece: **compost, cover crops, recycling of pruning residues**, the combination of "**all**" these was also applied; untreated plots served as control. In Italy, against the locally **conventional management** (soil tillage, burning of pruning residues) a set of **sustainable practices** (no tillage, cover crops, recycling of pruning residues) were introduced. Data on annual **CO_2 soil emissions** at various plots are reported showing they ranged from 2.5 (sustainable plot, IT) to 4.1 ("prunings" plot, GR) kg CO_2 m^{-2} yr^{-1}. Emissions of CO_2 had similar patterns in IT and GR sites showing two main peaks in spring and after summer. These oscillations were in line with soil temperatures excepted during the summer time when the conceivable low soil moisture and root growth reduced the CO_2 soil emissions. In each plot, the anthropogenic C fluxes such as fruit removal with harvest, C supply through organic fertilisers or additional prunings, burning of pruning residuals were accounted for the NECB determination. In general NECB >0 indicates the ability of the orchard to sequester C while NECB <0 indicates that the orchard release C into atmosphere. Results show that grove management might influence the value of NECB which ranged from The activities developed allowed to assess that NECB ranging from negative values (approx. -245/-280 kg CO_2 m^{-2} yr^{-1} in Control/Conventional) up to 1,300 kg CO_2 m^{-2} yr^{-1} (ALL). According to the NECB definition the Control and Conventional treatments were net source of CO_2. kg C m^{-2} yr^{-1}.

Accumulation of C in soil is widely recognised as climate change mitigation tool. Based on the evidence that the management options adopted (including irrigation, C inputs) might be influential on soil C stock changes, in this report the variations of the C stock in soil (0-30 cm depth) were simulated (RothC model) over a 30 years standard period. Results show that higher is the C inputs then higher is the accumulation of C in soil.

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.

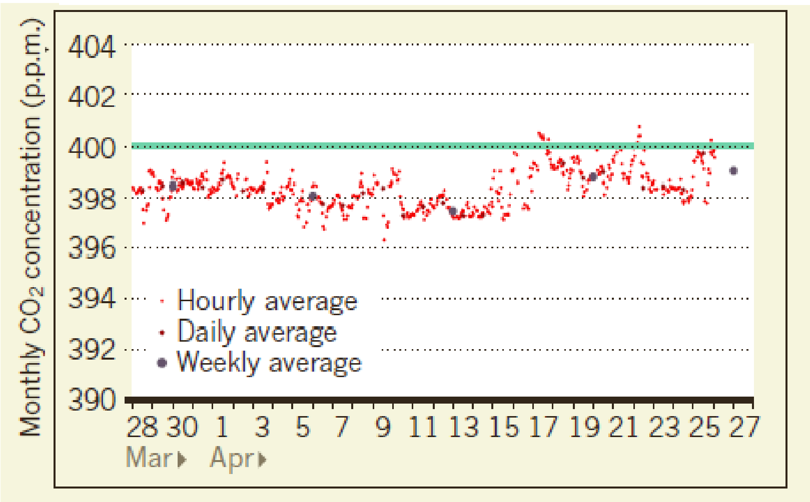


Figure 1 - Records of monthly atmospheric CO_2 concentration during some months in the 2013 at Mauna Loa, Hawaii. (Redrawn from Monastersky, 2013).

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 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.

The turnover of the soil organic matter as combined with human management/disturbance of agro-ecosystems is significant for the contribution of agriculture to greenhouse gas (GHG) emissions to the extent that the increase of 4‰ per year of the SOC may significantly help to curb GHG as debated at the last COP21 in December 2015 (Lal, 2016). In addition, there is a renewed interest in modelling the changes of soil C pool as good practice for the optimization of frameworks for national measuring and accounting of GHG (IPCC, 2014; Petersen, 2013). However, the accumulation of C into soil depends also on current level of C. Therefore, through field, management and environmental data collected within the Actions C2 and C3 of the oLIVE-CLIMA LIFE Project at Peza, Miranbello and Nileas, a Roth-C based 30-year simulations of carbon turnover in relation to environment, soil and management options and the level of soil C is also reported.

3. Ecosystem carbon balance

Assessing an ecosystem C balance might 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 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).

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

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

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 (R_h)

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.

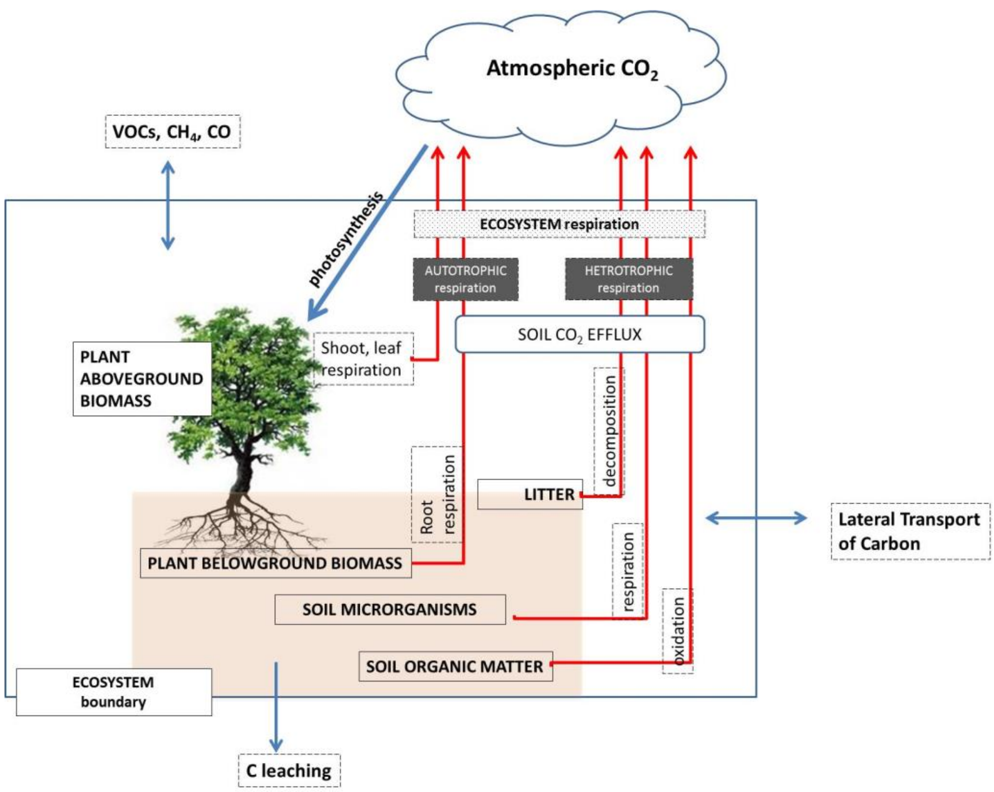


Figure 2 – Schematic representation of the main carbon fluxes in an ecosystem.

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 – R_h (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:

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

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

NECB = NPP -Rh +OF –FH (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	Carbon
					t ha^{-1} DM year^{-1}	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**

4. Experimental sites and management options

Trials were carried out at 3 olive ecosystems located in Greece and 1 site in Italy.

Greece

The study was performed from 2013 until 2017 in a 40-year old olive plantation (*Olea europaea* L., cv. Kalamata; trees planted at 7 × 7 m distances) located in Chania, Crete island, Southern Greece (35°28'34,85"N, 24°02'33,23"E). Based on the meteorological data of the station Agrokipio (35°29'37.50" N 24°02'43.80" E) located close to the experimental filed (1.5 Km distance), mean annual air temperature for the past 20 years was 18° C, mean relative humidity (RH) was 64% and mean annual rainfall was 700 mm.

Irrigation was supplied weekly from May to September according to the calculated evapotraspiration (ETc) losses, through drippers (five per tree) each with a discharge rate of 4 L h^{-1} and wetting a 1.0 m wide soil band along the tree row. Hence **a row (~ 1 m wide) and an inter-row (~ 3 m wide) soil band were identified**.

The water use for irrigation has on average a pH of 7.14, EC = 35 μs cm^{-1} , [Na] = 20.67 mg L^{-1}, [K] = 05.00 mg L^{-1}, [Ca] = 60.30 mg L^{-1}, [Mg] = 12.37 mg L^{-1}. The ETc was calculated by multiplying the reference evapotranspiration (ETo) by the empirical olive tree coefficient (Kc) (Kourgialas et al., 2014). The ET_0 was computed based on FAO Penman-Monteith method, using the appropriate meteorological data from Agrokipio station.

The following five treatments were imposed through a completely randomized design, with three replicates per treatment (n = 3, for a total of 15 plots; 4 trees per plot; covering a total of about 200 m^2 of soil.

CONTROL - Soil was tilled and herbicides were used to ensure the absence of spontaneous weeds. No external organic material was supplied. This treatment was used as reference. The average annual yield was ~2.8 t ha^{-1} (fresh weight) containing 0.78 t C ha^{-1}. The pruning material was exported and burned.

COMPOST (COMP) – Soil was not tilled and supplied with a commercial compost produced from recycled olive mill solid by-products (olive leaves, fruit pulps and stones) and liquid waste. Compost was supplied at a mean rate of 6 t ha^{-1} (fresh weight) in February 2013, 9 t ha^{-1} in March 2014, 9 t ha^{-1} in March 2015, 18 t ha^{-1} in June 2016 and 18 t ha^{-1} in April 2017. The mean value of the compost supplied during the years of soil respiration measurements (2015-2016) (18 t ha^{-1}) was considered for the NECB determination.

The compost had the following mean characteristics: C/N = 18, pH 7.8; moisture= 49.4%; 49.76% (w/w, on dry matter basis) total C, 2.77% (w/w) total N, 2.26% (w/w) total K, and 0.18% (w/w) total P. Therefore, considering the years of Rs measurements (2013-2016) the mean annual C supplied through compost application was 3.4 t C ha^{-1}. The amount of C due to leaf leaves and twigs and pruning material burned were similar to that of Control treatment. The average annual yield was 4.02 t ha^{-1} (fresh weight) containing 1.12 t C ha^{-1}. The pruning material was exported and burned.

PRUNINGS (P) – Pruning residues were mulched in loco and were distribute at a rate of 20 t ha^{-1} (fresh weight) (including ~ 17.1 t coming from neighbouring olive groves) in April 2013, May 2014, July 2015 and June 2016. Pruning residues had a moisture of about 24-30% and 51-55% (w/w; dry matter basis) total C, 0.6-1.8% (w/w) total N, 0.4-1.2% (w/w) total K, and 0.4-1.2% (w/w) total P. The average annual yield was 4.14 t ha^{-1} (fresh weight) containing 1.15 t C ha^{-1}.

COVER CROPS (CC) – 150 kg ha^{-1} of various leguminous cover crops (*Vicia sativa, Pisum sativum subsp. arvense, Trifolium alexandrinum, Vicia faba var. minor, and Medicago sativa*) were sowed mixed with 30 kg ha^{-1} of *Avena sativa* in December 2013, 2014, 2015 and 2016. In the subsequent spring, plants were mowed without being incorporated into the soil. The average annual yield was 0.96 t ha^{-1} (fresh weight) containing 0.27 t C ha^{-1}. The pruning material was exported and burned.

"ALL" - This treatment included the simultaneous application of the previous treatments compost, prunings and cover crops. The rate of compost application and recycling of pruning material and cover crop was as reported above. The average annual yield was 3.34 t ha^{-1} (fresh weight) containing 1.15 t C ha^{-1}. The pruning material was mulched in loco.

4.1 Nileas (GR)

The study area is located in south-west Peloponnese, Greece (Nileas, 37.3°N, 21,42°E) and is 280 m above sea level. The average annual rainfall is 800 mm and the mean annual maximum and minimum temperatures are 31.3 and 5.7 °C. The natural vegetation consists primarily of grass and broad-leaf weeds, a typical pattern for the Mediterranean basin. Fourty study farms were selected through one of the major olive-producing areas in Peloponnese. The plantations are consisted of irrigated and/or unirrigated adult olive trees of the "Mavrelia" and "Koroneiki" varieties, planted in a pattern of 6-8 x 6-8 m. In the majority of the experimental fields the soil texture is classified as loamy, sandy loam, with an average organic matter content of 2.3%.

4.2 Mirabello (GR)

The forty experimental sites are located in the eastern part of the island of Crete, Greece, 50 km east from the city of Heraklion (Merambellos, 35.15oN, 25.36oE) and are 270 m above sea level (average value). The average annual rainfall is 500 mm and the mean annual maximum and minimum temperatures are 28.6 and 9.3 °C. The weed flora is dominantly composed of Oxalis pes-caprae L. (Bermuda buttercup). The pilot orchards are consisted of irrigated and/or unirrigated adult olive trees (>20 years-old) of the cultivar “Koroneiki”, planted in an irregular and uneven distribution (from 5 to 15 m apart). Some of the fields are characterized by rocky soil texture. The soil, for the majority of the fields, is classified as heavy (clay and silt soils with 20-40% clay content) with an average organic matter content of 3.7%

4.3 Peza (GR)

The pilot region of Peza is located in the Prefecture of Heraklion Crete, Greece (35.21oN, 25.19oE) and is 310 m above sea level. The average annual rainfall is 600 mm and the mean annual maximum and minimum temperatures are 30.3 and 7,0 °C. Bermuda buttercup is the primary weed through the 40 experimental fields. Adult olive trees (cv. “Koroneiki”) are planted in a 7-10 x 7-10 m layout. 75% of the soils are loams with a balanced mix of sand, silt, and clay particles with an average organic matter content of 1.9%

4.4 Ferrandina (ITALY)

The trial was performed in Ferrandina (Matera Province, Basilicata Region, Southern Italy, 40° 29’N, 16° 28’E) in a 2 ha olive grove of ‘Maiatica’ which is an autochthonous cultivar of Matera Province.

Olive trees within the experimental orchard were more than 60 year old. They were vase trained and planted at a distance of about 8 m × 8 m (156 plant ha-1), as common in the studied area. The climate is classified as semi-arid with annual precipitation around 561 mm (mean 1976–2006) and mean annual temperature ranging from 15 to 17 °C. The soil of the experimental grove is a sandy loam, classified as a Haplic Calcisol (FAO, WRB, 1998), with a low organic carbon content (7.0 ± 3.8 g kg-1, mean of 0–0.60 m layer ± standard deviation) and bulk density of 1.5 (Mg m^{-3}) (Palese et al., 2013).

Starting from the year 2000, two plots were identified and managed according to **sustainable** and **conventional** practices.

The sustainable plot was irrigated with urban wastewater treated by a pilot unit according to simplified schemes (Palese et al., 2013). The reclaimed wastewater was generally distributed from May to October by drip irrigation (6 self-compensating drippers per tree, each delivering 8 L h^{-1}). The seasonal irrigation volume was on average 3500 m3 ha^{-1}. At the sustainable plot soil was not tilled but covered by spontaneous weeds and grasses mowed at least twice a year. Irrigated trees were lightly pruned each year. Pruning material was mulched in loco. The fertilization plan was drawn every year taking into account wastewater and soil chemical composition, and mineral elements balance in the orchard system (cover crops and pruning material contributions, potential yield removed from the olive grove) (Palese et al., 2013). The average amounts of N, P and K yearly distributed by the wastewater used for irrigation were 63.0, 3.0 and 58.0 kg ha^{-1}, respectively. An amount of mineral N (on average around 40 kg ha^{-1} yr^{-1}) was distributed by fertigation in order to entirely satisfy the annual N plant needs. These last correspond to the mineral element output from the orchard as yield and pruning material. Since pruning residues were cut and left on the ground, they are considered as a nitrogen output for a percentage equal to 50%. Pest and disease control was performed according to the regional service recommendations for commercial olive groves.

A view of the “sustainable” (left) and “conventional” (right) olive ecosystems in Ferrandina (IT)

The conventional grove was grown under rainfed conditions and managed according to the local horticultural practices: tillage (approx. 10 cm depth) performed 2–3 times per year, and empirical soil fertilization. Moreover, in this plot a heavy pruning was performed every two years during the winter after a productive year. Pruning residues were removed from the field and burned.

5. CO_2 soil emissions and NPP measurements

5.1 ITALY

On each soil CO_2 sampling time, emissions were measured *in situ* at 30 locations per treatment, distributed at 1/1.5 m centres along different soil bands: row, intermediate, inter-row (see Fig. 3).

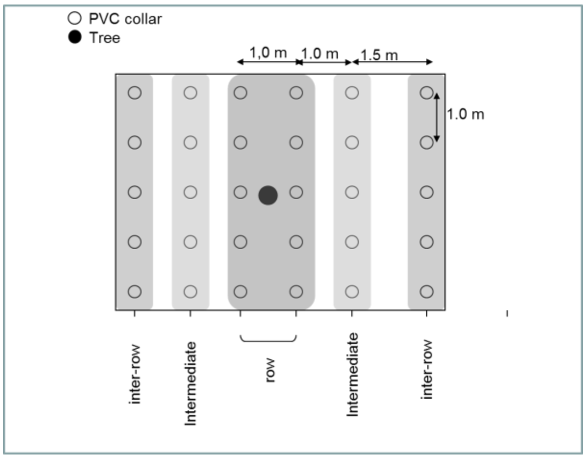


Figure 3 – Schematic of the position of the PVC collars used for CO_2 soil respiration measurements performed in Italy.

A non-dispersive infrared portable gas analyser (Li-6400, LI-COR, Lincoln, NE, USA) equipped with a soil respiration chamber (Model Li-6400-09) was used to measure CO_2 efflux by fitting the chamber to a collar (a 10 cm long section of 10 cm OD PVC pipe). In all, 60 PVC collars were pressed into the soil to a depth of 4 cm, one collar in each location. Collars were installed at the beginning of the experiment (January-February) and remained in place until the end in December. In the conventional plots, collars were necessarily removed just before tillage and were replaced in the same locations at least 24 h prior to any measurement being made. In the sustainable plots collars were placed within the understorey with any vegetation inside being clipped very short to ensure that only soil respiration was measured and to avoid errors from differences in volume within the gas chamber. Soil CO_2 efflux measurements were made every approx. 10-25 days interval from February through to December. On each occasion, measurement starting at approx. 11 am and was always completed by 1pm.

The CO_2 efflux rate was computed from the time course of CO_2 concentration increase (slope) following the fitting of the chamber to a collar – system volume of 991 cm^3 and receiving CO_2 from a known soil surface area of 79 cm^2. In preliminary experiments, it was found that multiple measurement cycles at the same location provided highly reproducible results. This allowed a CO_2 efflux measurement to be made from a single cycle of concentration increase in each sampling location. This in turn allowed completion of CO_2 efflux sampling from all 60 locations (2 plots × 30 locations per plot) in minimal time (~2 h) and so with minimal variation in soil temperature. The system operations prevent an excessive CO_2 pressure build up within the chamber by operating between maximum and minimum CO_2 concentrations which were equal to that measured on the soil surface ±10 ppm CO_2. At the same time as the CO_2 efflux measurement, soil temperature (from 0 to 15 cm depth) was measured a few centimetres away using the 6000-09TC Li-COR temperature probe. Daily estimates of the CO_2 soil emissions were derived multiplying by 24 the mean measurements made at each plot considering a 1.15 coefficient as recommended by Savage and Davidson (2003). Then integration of all daily fluxes of each treatment across the studied period was employed to calculate the annual R_s. Estimation of the per ha values of R_s was performed considering the relative abundance of each soil band considered. Values of R_s were then partitioned in their heterotrophic respiration (R_h) through the regression method assuming that at the middle of the alley root density was negligible and that emissions recorded were totally due to heterotrophic respiration (Fernandez et al., 1991; Kuzyakov, 2006). For further details on R_h see paragraph 5.3.

5.2 GREECE

On each soil CO_2 sampling time, emissions were measured *in situ* at 8 locations per treatment according to the following Figure 4. For the procedure used to calculate the annual CO_2 emissions see the paragraph 5.1.

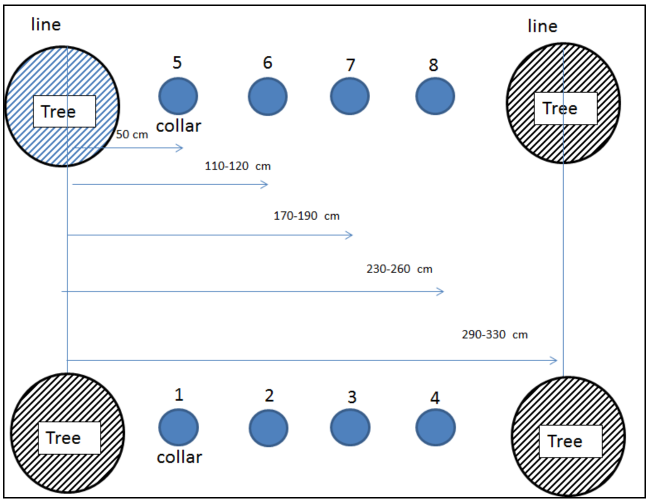


Figure 4 – Schematic of the positions (collar) where soil CO_2 emissions were measured in GR.

5.3 Heterotrophic soil respiration (R_h)

According to eq. 6 the soil respiration (R_s) must be partitioned in its heterotrophic (R_h) and autotrophic components (R_a). In this report the R_h was not directly measured but calculated from measurements of total soil respiration under the assumption that the soil respiration measured at the inter-row (or mid-alley) position was due almost entirely to the heterotrophic component while the soil respiration measured along the row position accounted for both heterotrophic and autotrophic respiration (Montanaro et al., 2017).

In Italy, adopting the regression method (see Montanaro et al., 2017 and references therein) values of R_s were linearly plotted against the distances from the inter-row so that the value of the intercept (at distance "0") would reflect the value of R_h.

5.4 Net Primary Production (NPP)

The NPP for leaf turnover and fruit was determined through the collection of samples carried out at the experimental fields. Up to 10 trees were excavated in Greece to determine the above and below standing biomass, then an annual increase of these biomasses was assumed to be 10% of the standing biomass according to annual trunk increases measured for additional 10 trees of similar age. Annual new root growth was assumed to be 10% of the total standing below ground biomass (Nuzzo et al., 1999). The pruning material was collected and partitioned in annual and permanent wood. For each component, subsamples were collected to determine the dry weight and then the C content. For fruit a dry matter concentration of 57.7% (on fresh weight basis) and a C content of 47% (on dry matter basis) was assumed (Ilarioni et al., 2013). For the IT fields values of **NPP were 3.78 (sustainable) and 1.59 kg CO_2 m^{-2} yr^{-1} (conventional)** according to Palese et al. (2013).

5.5 Long-term simulation of carbon storage into soil

The 109 experimental olive plots involved in the projects OLIVECLIMA have been divided into 12 clusters, based on their total soil carbon (TOC) content, water supply (irrigated/rainfed) and application of sustainable management practices for carbon storage in soil (treated/control). The "treated" fields are those managed according with the suggestions provided in the Project and aimed at increase the soil carbon content. The following Table 4 summarize these practices adopted at each of location considered:

Table 4 – List of practices applied or not at the 3 sites.

	Nileas	Mirabello	Peza
No tillage	YES	YES	YES
Mulching of pruning residues	YES	YES	YES
Cover crops	YES	YES	YES
Application of OMWW	NO	NO	YES
Compost	YES	YES	YES

From the combination of the various managements and TOC level, the following 12 typologies of field were analysed:

1. Treated irrigated very low TOC
2. Treated irrigated low TOC
3. Treated irrigated medium TOC
4. Treated rainfed very low TOC
5. Treated rainfed low TOC
6. Treated rainfed medium TOC
7. Control irrigated very low TOC
8. Control irrigated low TOC
9. Control irrigated medium TOC
10. Control rainfed very low TOC
11. Control rainfed low TOC
12. Control rainfed medium TOC

The thresholds to define the categories of carbon content in soil have been retrieved from the European Soil Data Center (http://esdac.jrc.ec.europa.eu/content/ptrdb-attributes): OC_TOP = Topsoil organic carbon content:

H = High (> 6 %)

M = Medium (2 - 6 %)

L = Low (1 - 2 %)
V = Very low (< 1 %)

For each defined cluster, composed of different numbers of plots, have been calculated the average data necessary to perform the simulation: soil carbon content, number of trees per hectare, soil texture, yield and amount of water irrigated (from data of 2013-2014).
The soil bulk density have been calculated from soil texture (soil calculator of century website https://www.nrel.colostate.edu/projects/century/) and a default soil scheleton of 3% has been assumed.
The ratio between Decomposable Plant Material and Resistant Plant Material (DPM/RPM) used in the Roth C simulation has been fixed equal to 0.25 for treated plots (0.2/0.8), and to 4 for control plots (0.8/0.2).
The 109 plots are located in three different areas of Greece showed in the map below: Messinia, Peza, Mirabello. The average of last 10 years climate data for each area have been used to perform the Roth C simulations:

Location	Month	Avg Temp [°C]	Avg Rainfall [mm]	Avg Eto [mm]
Merambelos - Agios Nikolaos	January	6,4	184,6	38,6
	February	6,5	173,0	35,0
	March	8,4	71,5	41,0
	April	10,9	58,0	40,5
	May	15,2	34,7	44,4
	June	18,4	5,9	48,8
	July	19,8	0,4	61,7
	August	20,1	0,7	68,3
	September	17,5	31,2	66,0
	October	14,3	130,2	57,5
	November	10,9	99,5	45,3
	December	7,8	188,5	39,7
Nileas-Kalamata	January	9,1	128,5	42,9
	February	9,9	104,0	39,8
	March	12,7	60,1	47,7
	April	15,4	44,1	46,9
	May	20,1	25,9	51,0
	June	24,1	18,0	56,4
	July	27,1	4,0	73,8
	August	27,3	9,3	81,3
	September	22,9	41,4	76,1
	October	18,1	93,0	64,3
	November	13,8	88,0	49,9
	December	10,8	112,4	44,3
Peza-Iraklio	January	12,3	78,9	48,1
	February	12,2	76,7	43,3
	March	14,2	31,9	49,9
	April	16,6	21,3	48,6
	May	20,3	12,0	51,2
	June	24,0	1,1	56,3
	July	26,4	0,0	72,6
	August	26,4	0,1	79,8
	September	23,7	14,7	77,5
	October	19,8	73,4	67,4
	November	16,7	48,7	54,5
	December	14,0	88,8	49,2

The carbon input to soil used in simulation have been retrieved from different sources:

- Pruning residues, seed mixture and weed residues, compost and olive mill waste water data have been provided from field per each of the three pilot area examined;
- Weeds and seed mixture data provided have been increased of 20% to take into account the belowground part of weeds (Celano et al., 2003).
- Leaves' turnover per tree estimated based on Ĉermák et al. (2007) e Connor e Fereres (2005), multiplied per the average tree density of the cluster.

Month of C input: November (harvesting and rainfall induce fall of senescent leaves)
Avg leaf mass: 85 mg
Leaves live for 2 to 3 years so ca.
40% of the canopy is lost (and replaced) each year.
145000 leaves average (Ĉermák et al. 2007)
58.000 senescent leaves every year => *4,93 kg senescent leaves · tree^{-1}· year^{-1}*
Specific leaf mass = 205 g m^{-2} (Connor e Fereres 2005)
Mean leaf area = 45-94 m^{2} (Cermak et al 2007) => *14,24 kg senescent leaves · tree^{-1}· year^{-1}*
Average = ***9,59 kg kg senescent leaves · tree^{-1}· year^{-1}***
It was assumed 30% moisture of leaves ad 50% carbon content of dry mass

- Fine roots' turnover estimated as 50% of aboveground trees' organs turnover (leaves turnover+pruning residues+yield) (Cannell, 1985). Months of carbon input to soil (Palese et al 2000): March for rainfed systems (winter-spring), July for irrigated systems (summer).

In the following pages are reported the results of Roth C simulations for the 26 clusters identified in the three experimental areas of OLIVECLIMA project. The simulations have been implemented for a time horizon of 30 years, assuming that before this period all plots were managed with conventional practices (as control plots), for the initialization of soil carbon pools in the Roth C model.
The version of Roth C 10_N adapted to region with semi-arid climatic conditions (Farina et al 2013) have been used, in the excel based format.

6. RESULTS

6.1 NPP

In each of the treatments, the annual C due to leaf turnover (fallen to soil) was similarly 0.419 t C ha^{-1}. Amount of pruning residues was similar and accounted for ~2.9 t ha^{-1} (fresh weight) corresponding to 2.1 t ha^{-1} dry weight and 1.2 t ha^{-1} carbon for each treatment. On average the pruning material contained 42.6% of permanent structures (branches, fresh weight) and 57.4% annual biomass (leaves and twigs, fresh weight). Here below the Table 5 reports the mean annual aboveground and belowground biomass for the olive orchards located in GR.

Table 5 – Values of the above and belowground primary productivity of the various tree components and that of fruit for the various treatments.

Tree component	NPP (t C ha^{-1} yr^{-1})	**fruit**	Fruit NPP (t C ha^{-1} yr^{-1})
Leaves	0.42	**Control**	0.78
New shoots	0.69	**Compost**	1.12
New root	1.68	**Cover crops**	0.27
Δ Trunk and Branches	2.70	**Prunings**	1.15
Δ Root	1.53	**ALL**	0.93

6.2 Annual CO_2 soil emissions ITALY

The seasonal pattern of the CO_2 soil emissions was similar at the three positions monitored showing to main peaks in spring and after summer (Fig. 5). In February as well as in December, low soil temperatures reduced CO_2 emissions to their lowest values of about 0.5 μmol m^{-2} s^{-1} irrespective of soil band and management (Fig. 5). Between February and late April emissions increased following the increase in soil temperature which risen from approx. 5 up to ~ 25 °C. Thereafter CO_2 soil emissions fell toward a minimum in beginning of July (the hottest driest period). In September, rates recovered to reach values slightly lower than the earlier peaks.

The early rapid increase in emissions occurred at the same time of season as new plant organs (e.g., shoots, roots, leaves) develop rapidly implying a rise in root metabolism and thus in soil respiration. The warming of the soil probably increased soil CO_2 efflux due also to enhanced microbial activity in that time of season (Fang and Moncrieff, 2001). Thereafter, further increases in soil temperature (to approx. 30°C) resulted in lower CO_2 emissions in all sampling positions. This apparently contrasts with correlative laboratory and field data showing that an increase in soil temperature would raise CO_2 losses (Blanke 1996; Fang and Moncrieff, 2001). However, the relationship between soil respiration and soil temperature is highly variable at high temperatures (>30°C) because soil water content can become limiting.

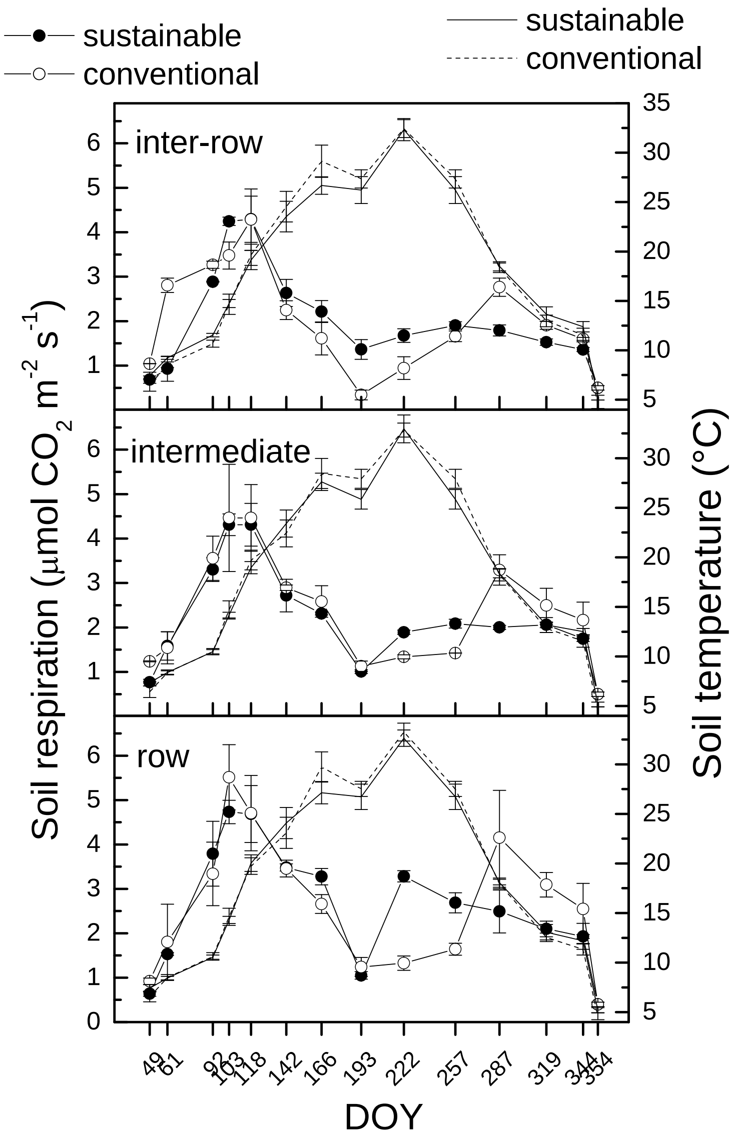


Figure 5 – Seasonal trend of CO_2 soil emission rates (line+symbol) and soil temperature (line) recorded in the Italian olive grove under sustainable (●) and conventional (○) management practices at row, intermediate and inter-row position. DOY, day of year. Bars are standard error.

In Italy, considering the emissions recorded at the various soil bands, the annual soil CO_2 emissions was very similar in both sustainable and conventional plots reaching approx. 2.5 kg CO_2 m^{-2} yr^{-1} (Tab. 6).

Table 6- Calculation of the annual CO_2 emissions (R_s) at the Italian olive grove

		surface per ha m2		annual emissions kg CO2 m-2 yr-1 sustainable	conventional		kg CO2 per ha per year sustainable	conventional
ROW		1250		3.523	3.52		4403.75	4395.00
INTERMEDIATE		2500		2.886	3.09		7215.00	7735.00
INTER-ROW		2500		2.594	2.63		6485.00	6567.50
MID-ALLEY		3750		1.85	1.85		6937.50	6937.50
						TOTAL	**25041.25**	**25635.00**
							kg CO2 per m2 per year	
						Rs	2.50	2.56

6.3 Annual CO_2 soil emissions GREECE

Annual CO_2 soil emissions measured at the Greek plots under different management practices revealed the influence of the measurement position row, inter-row) on emission rates at least during the early part of the year (Fig. 6). As expected also in Greece soil CO_2 fluxes had two main peaks: in spring and then after the dry summer period. Absolute values of soil CO_2 emissions tend to be higher than those measured in IT (Fig. 5 and Fig. 6) likely because of the higher soil temperature (Figs. 5 and 7). In addition, in GR at the beginning of the year soil CO_2 emissions were relatively high despite soil temperature was sitting at the minimum values (Fig. 7). On an annual average basis, the total CO_2 soil emissions were higher in treated plots compared to “control” and ranged from 3.46 (compost) to 4.1 (prunings) kg CO_2 m^{-2} yr^{-1} (Tab. 7).

Table 7 –specific values of annual CO_2 soil emissions measured at row and inter-row positions of the various treatments estimated and the average value which was used for the NEP calculation.

g CO2 m-2 yr-1									
compost		cover crops		prunings		control		all	
row	inter-row	row	inter-row	row	inter-row	row	inter-row	row	inter-row
3887	3037	4075	3636	4369	3836	3557	3190	4195	3492

kg CO2 m-2 yr-1	**Mean value**			
compost	cover crops	prunings	control	all
3.46	3.86	4.10	3.37	3.84

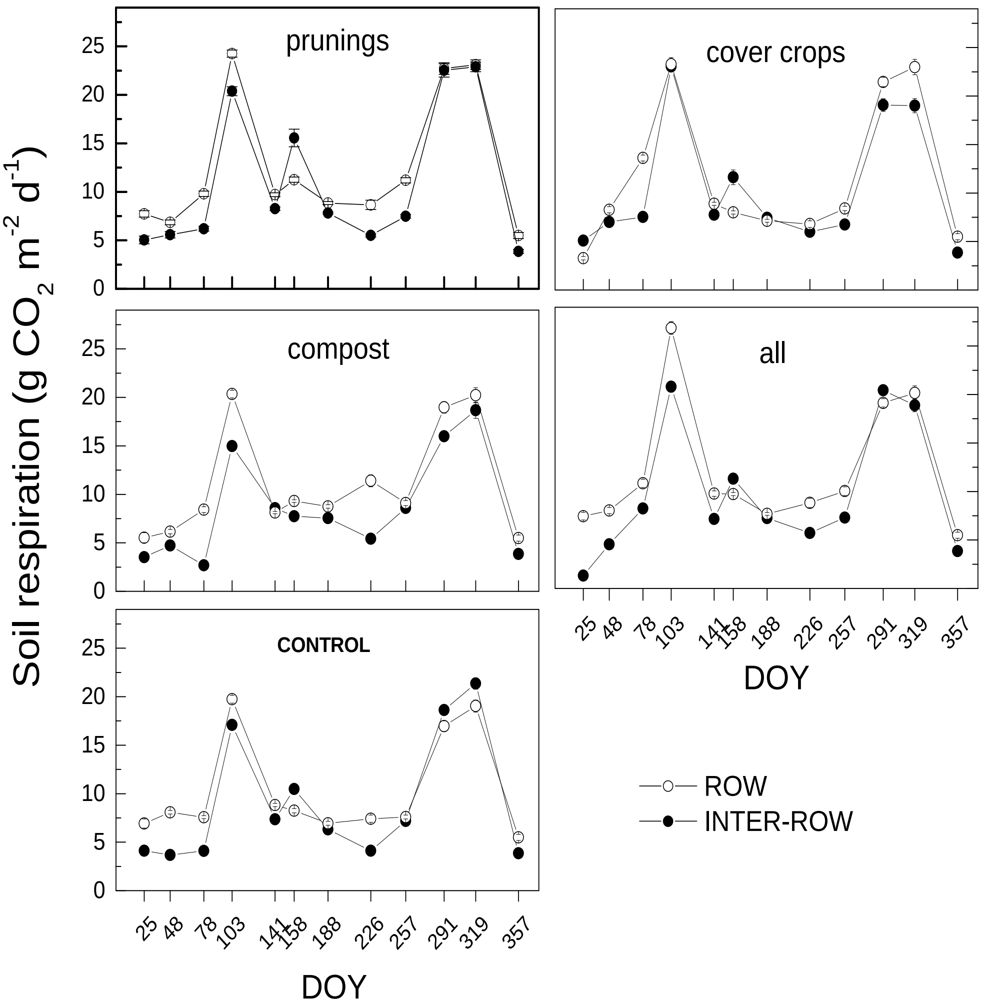


Figure 6 – Seasonal trend of CO_2 soil emission rates recorded in the Greek olive groves under various management practices at ROW (○) and INTER-ROW (●) positions. DOY, day of year. Bars are standard error.

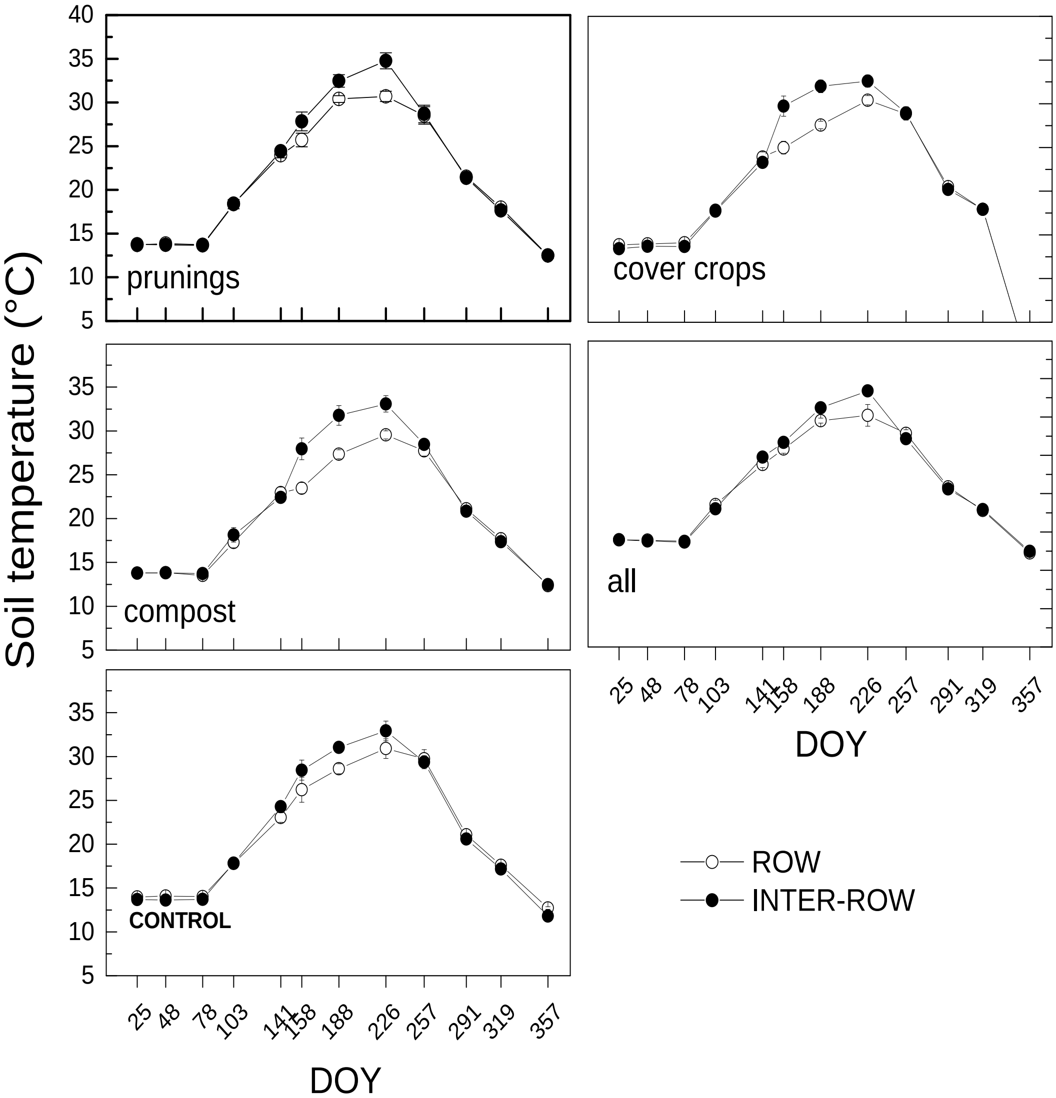


Figure 7 – Seasonal trend soil temperature (°C) recorded in the Greek olive groves under various management practices at ROW (○) and INTER-ROW (●) positions. DOY, day of year. Bars are standard error.

6.4 Heterotrophic soil respiration (R_h)

After the application of the regression method, Figure 8 highlights that the R_h value at the IT plots was 1.85 kg CO_2 m^{-2} yr^{-1} with no significant differences between the management options.

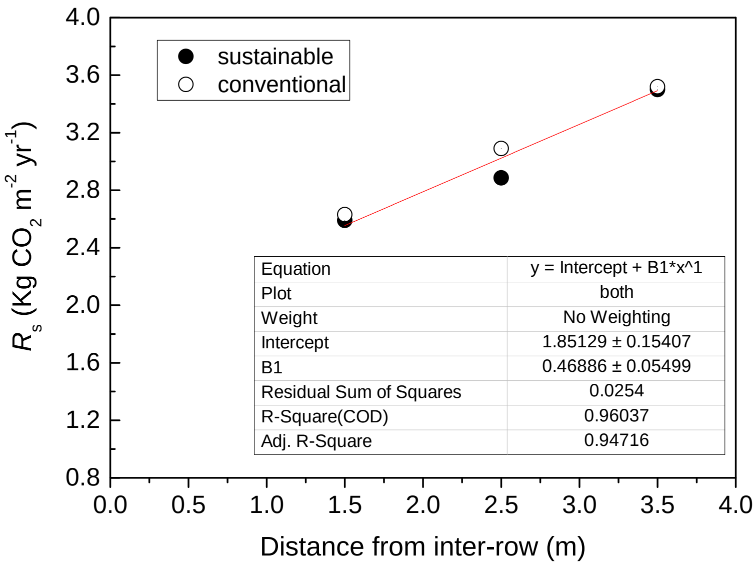


Figure 8– Linear regression of the soil CO_2 emissions (R_s) measured at various distances from inter-row.

Considering the annual values of R_s **a R_h/R_s ratio of 0.72 (conventional) and 0.74 (sustainable) were determined and used for the determination of the Net Ecosystem Productivity (see Tab. 8)**.

Table 8 – values of total (R_s) and heterotrophic (R_h) CO_2 soil emissions and their ratio at the IT plots.

	sustainable	conventional
	kg CO2 per m2 per year	
Rs	2.50	2.56
Rh	1.85	1.85
	g C per m2 per year	
Rs	682.32	698.50
Rh	504.09	504.09
Rh/Rs med	**0.74**	**0.72**

Concerning the Greek fields, considering the soil respiration measurements performed at the plots experiencing the “All” treatment during the whole 3 seasons and at the various replicates the average soil respiration measured at ROW and INTER-ROW positions ranged from 3.51 to 4.69 μmol m^{-2} s^{-1} (Table 9). Consequently the R_h/R_s ratio ranged from 0.82 (compost) to 0.92 (cover crops).

Table 9 – Three year average CO_2 soil emissions measured at row and inter-row positions in various plots under different treatments in GR.

TREATMENT	POSITION	CO_2 soil emissions g CO_2 m^{-2} yr^{-1}	R_h/R_s
control	ROW	3887	0.90
	INTER-ROW	3037	
Compost	ROW	4075	0.82
	INTER-ROW	3636	
Cover crops	ROW	4369	0.92
	INTER-ROW	3836	
Prunings	ROW	3557	0.87
	INTER-ROW	3190	
All	ROW	4195	0.84
	INTER-ROW	3492	
		Average	**0.87**

The 0.73 coefficient adopted for the IT fields is are line with the 0.75 reported by Matteucci et al. (2015) who partitioned R_h throughout a relatively long period (~ 1 year) in a Mediterranean pine forest. A similar R_h/R_s ratio equal to 0.77 has been found when accounting for space variability of soil CO_2 respiration in

apple orchards (Zanotelli et al., 2013), this further supports the R_h/R_s ratio adopted in this study which tends to be 15-20% higher than that used in other studies (Ceccon et al., 2011; Scandellari et al., 2015). Emissions of CO_2 from soil vary with space (and time) particularly in drip irrigated orchards where water is supplied only along the row differentiating soil moisture across the alley throughout the whole irrigation season (Montanaro et al., 2012; Lardo et al., 2015). Consequently, root distribution is affected by localised irrigation causing root mass density at inter-row to be very low compare to that of row (~0.2 and 15 kg DM m^{-3}, respectively) (Xylogiannis E., in preparation). The "regression approach" proposed to separate the various components of soil CO_2 efflux is based on the assumed linear relationship between root biomass and the amount of CO_2 respired by roots and rhizosphere microorganisms (Kuzyakov, 2006). Accordingly, considering the abovementioned very low root mass density at the inter-row, the R_h/R_s ratio reasonably sited at ≅1 at that position, this further supports the mean R_h/R_s value equal to 0.73 we adopted. However it was slightly higher than that reported by Almagro et al., (2009) who measured the soil respiration under the canopy (824.04 g C m^{-2} yr^{-1}) and at the inter-row position (328.86 g C m^{-2} yr^{-1}) in a approx. 100 year-old olive grove (10 × 10 m spacing).

The mean value of R_h/R_s ratio calculated for Greek plots (0.87) tends to be higher of published data likely because of an overestimation of R_s due to the relatively few points of CO_2 emission measurements per plant. More efforts are required to elucidate the space variability of R_h in Mediterranean olive groves.

6.5 Lateral transport of carbon (LTC)

The LTC was negative for the CONTROL and COMPOST treatments in GR and for both the sustainable and conventional sites in IT (Tab. 10). Results suggest that the application of compost and the recycling of pruning materials might not be sufficient to compensate the export of C due to yield and that a combination of various practices is recommended to bring the LTC in a positive area meaning that the import of C exceeds the export. A positive LTC is in favour of and increase soil and litter C stock.

Table 10- Lateral transport of carbon (kg CO_2 m^{-2} yr^{-1}) calculated for the various treatment in Greece and Italy.

	Treatment	**LTC**
GREECE	CONTROL	-0.73
	COMPOST	0.81
	COVER CROPS	3.22
	PRUNINGS	1.98
	ALL	5.08
ITALY	sustainable	-0.68
	conventional	-0.81

6.6 Net Ecosystem Carbon Balance (NECB)

Results highlight that the management practices have an huge impact on NECB (Tab. 11) which was negative when any sustainable practices are applied (see CONTROL and CONVENTIONAL) being a source of C. As expected the higher NECB was calculated for fields simultaneously receiving each of the practices (see ALL).

Table 11 – Values of net primary production (NPP), soil respiration (R_S), heterotrophic respiration (R_h), net ecosystem production (NEP), lateral transport of carbon (LTC) and net ecosystem carbon balance (NECB) for the various treatment at the Greek and Italian olive groves.

		NPP	Rs	Rh/Rs	Rh	NEP	LTC	**NECB**	**NECB**
		Kg CO2 m-2 yr-1							g C m-2 yr-1
CONTROL		2.86	3.37	0.9	3.03	-0.17	-0.73	-0.90	**-244.97**
COMPOST		2.98	3.46	0.817	2.83	0.16	0.81	0.97	**264.42**
COVER CROPS		2.67	3.86	0.92	3.55	-0.88	3.22	2.34	**638.63**
PRUNINGS		3.00	4.10	0.87	3.57	-0.57	1.98	1.41	**383.52**
ALL		2.91	3.84	0.84	3.23	-0.31	5.08	4.77	**1300.56**
sustainable		3.78	2.5	0.74	1.85	1.93	-0.68	1.25	**340.60**
conventional		1.59	2.56	0.72	1.84	-0.25	-0.81	-1.06	**-289.70**

6.7 Long-term soil organic carbon dynamics

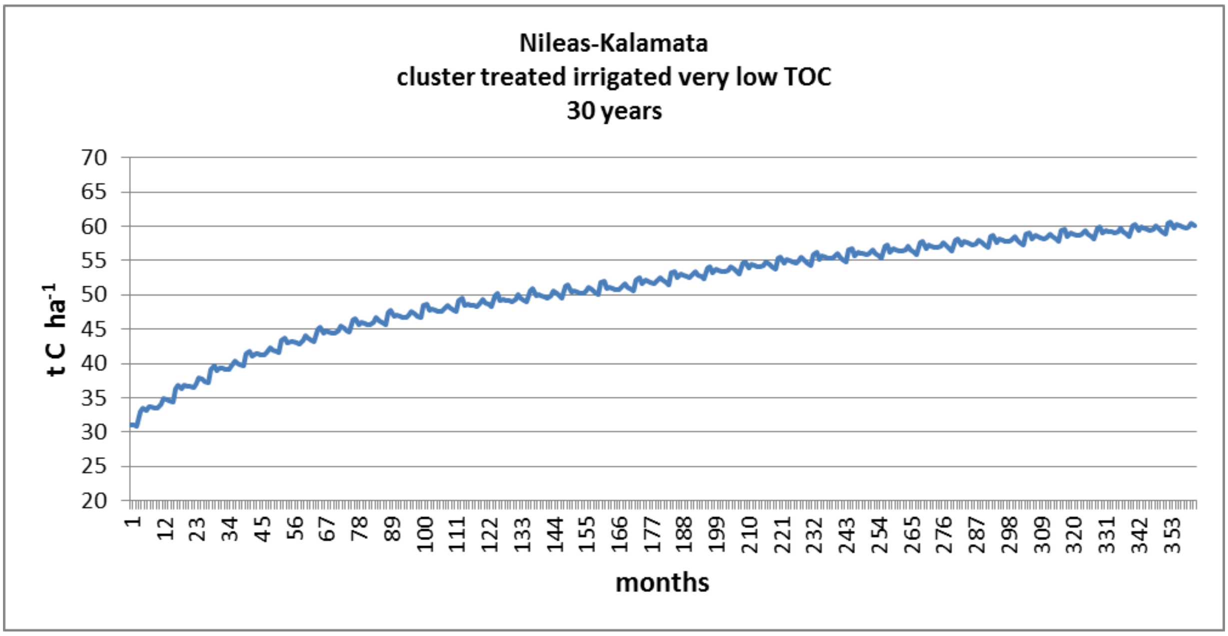
NILEAS (10 simulations)

1. Treated irrigated very low TOC

4 plots: 12.01 55.03 59.01 8.03

Sand= 42,1% Silt= 31,0% Clay= 26,9%
Avg n. trees ha^{-1}= 194

Soil Organic C from 0,85% to 1,64% in 30 years → storage of 0,97 t C ha^{-1} $year^{-1}$ in soil = 3,6 t CO_2 ha^{-1} $year^{-1}$ removed from atmosphere



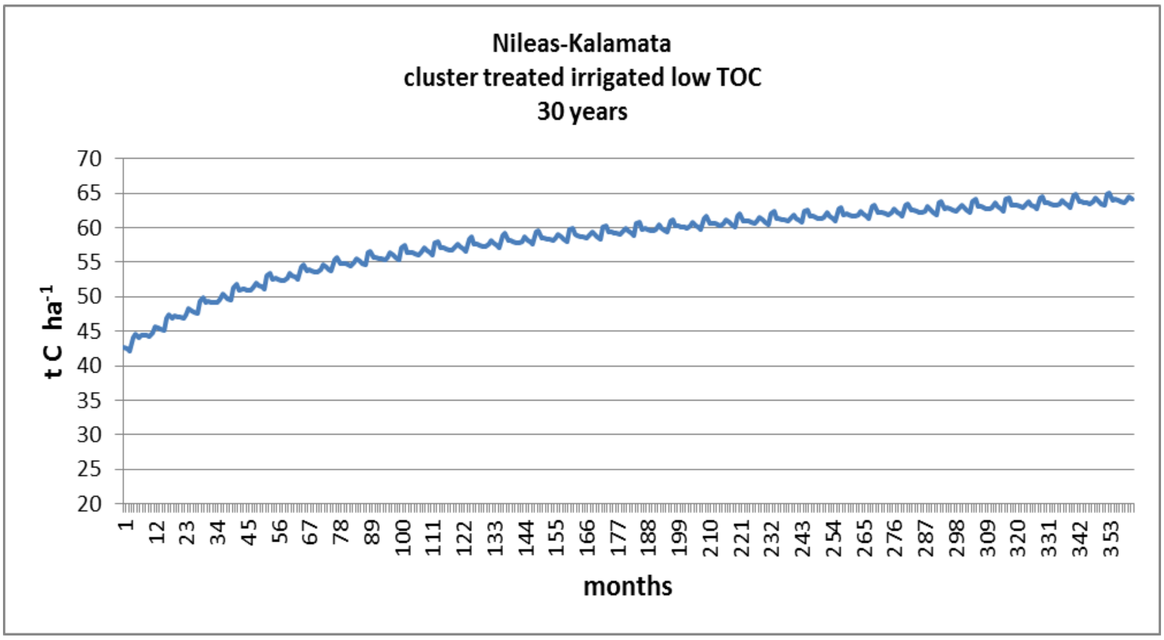
2. Treated irrigated low TOC

4 plots: 10.03 17.04 27.04 180.08

Sand =34,1% Silt=35,9% Clay=30,1%

Avg n. trees ha^{-1}= 167

Soil Organic C from 1,2% to 1,79% in 30 years → storage of 0,7 t C ha^{-1} $year^{-1}$ in soil = 2,6 t CO_2 ha^{-1} $year^{-1}$ removed from atmosphere



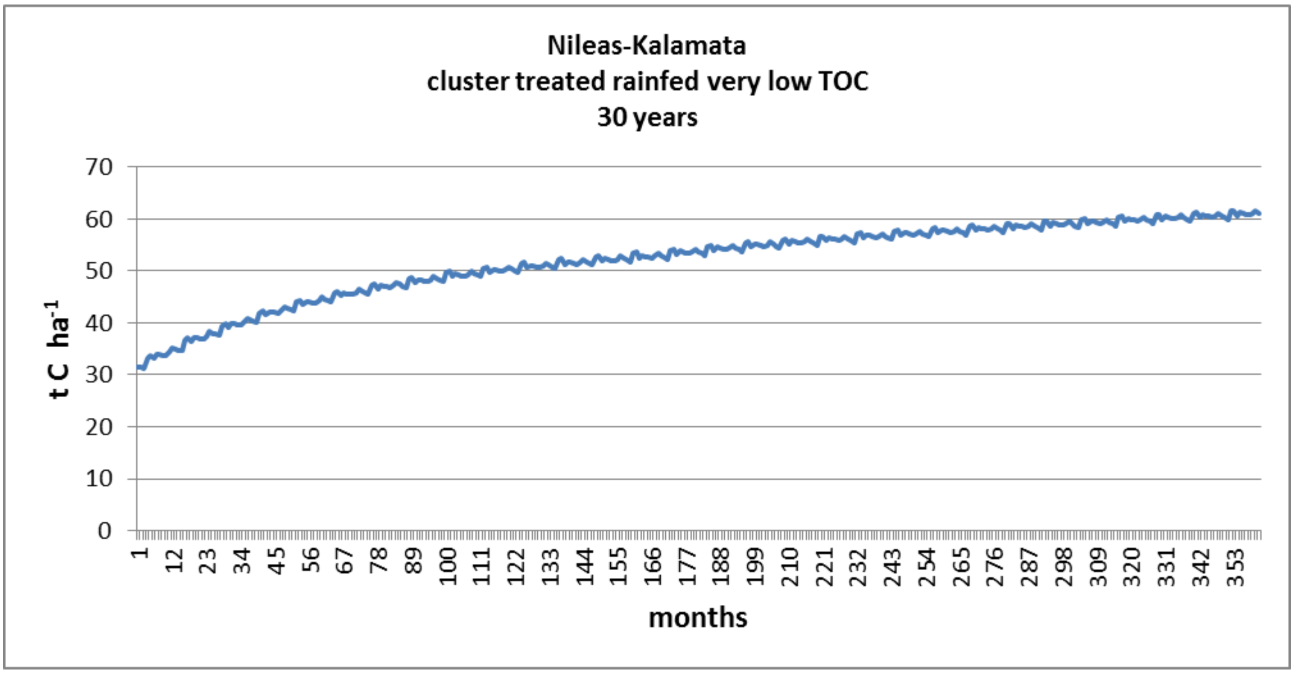
3. Treated rainfed very low TOC

2 plots: 30.04 73.02

Sand= 36,0% Silt=37,5% Clay=26,5%

Avg n. trees ha^{-1}= 195

Soil Organic C from 0,87% to 1,68% in 30 years → storage of 0,98 t C ha^{-1} $year^{-1}$ in soil= 3,6 t CO_2 ha^{-1} $year^{-1}$ removed from atmosphere



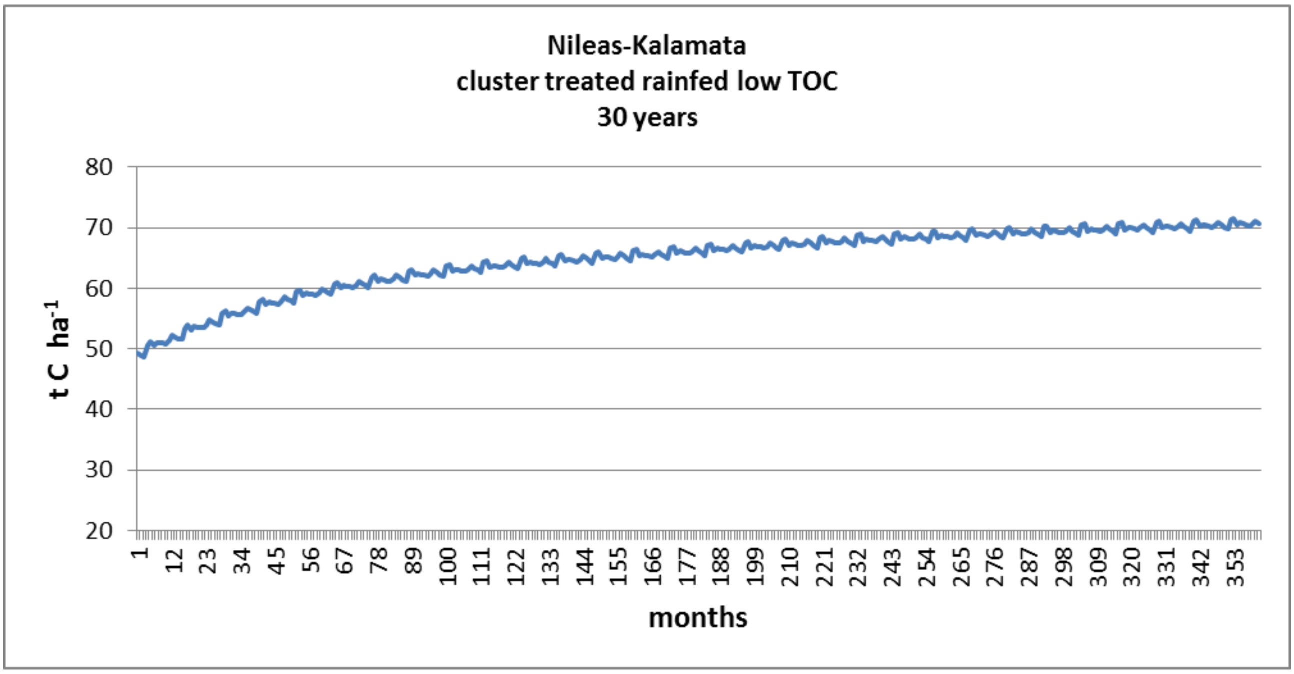
4. Treated rainfed low TOC

8 plots: 10.04 200.01 21.01 40.04 41.03 44.01 58.01 8.01

Sand= 34,7% Silt=39,7% Clay= 25,7%

Avg n. trees ha^{-1}= 187

Soil Organic C from 1,35% to 1,94% in 30 years → storage of 0,71 t C ha^{-1} $year^{-1}$ in soil = 2,6 t CO_2 ha^{-1} $year^{-1}$ removed from atmosphere



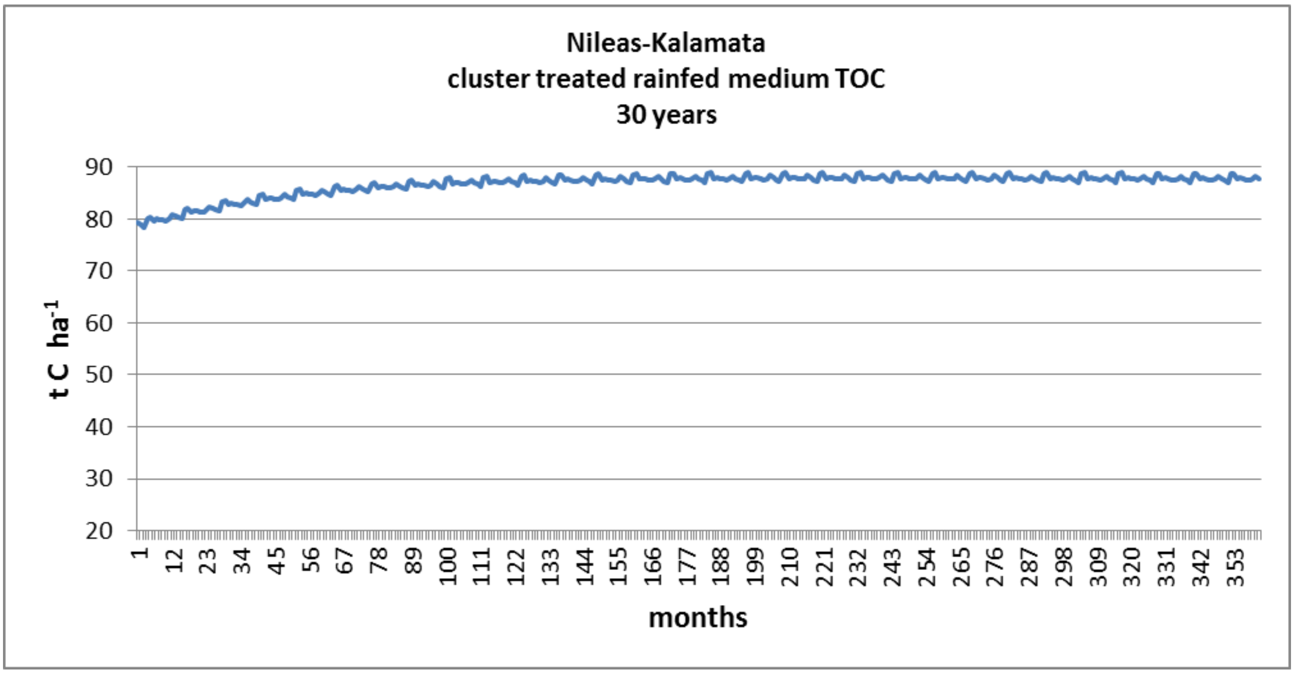
5. Treated rainfed medium TOC

1 plot: 180.10

Sand= 55,2%   Clay= 20,8%   Silt=24,0%

Avg n. trees ha^{-1}= 288

Soil Organic C from 2,11% to 2,32% in 30 years → storage of 0,28 t C ha^{-1} $year^{-1}$ in soil = 1,03 t CO_2 ha^{-1} $year^{-1}$ removed from atmosphere



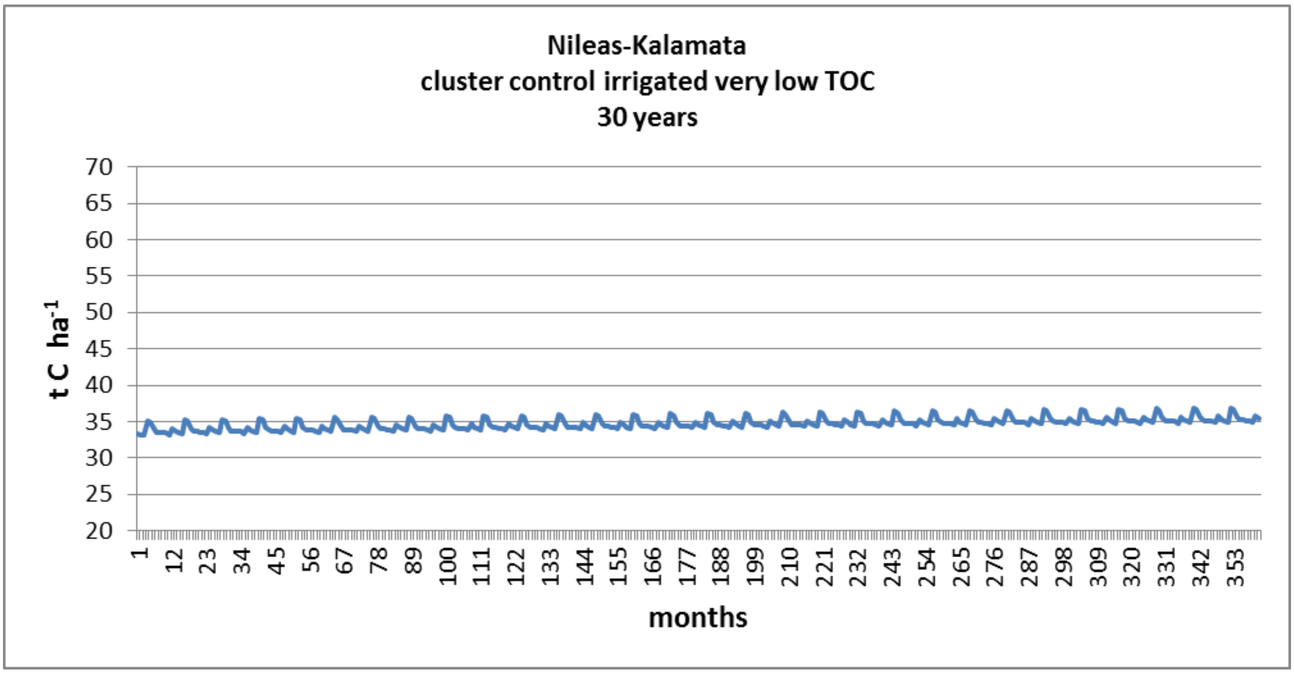
6. Control irrigated very low TOC

2 plots: 17.10 27.03

Sand= 55,2% Silt= 28,2% Clay=16,6%

Avg n. trees ha^{-1}= 219

Soil Organic C from 0,85% to 0,9% in 30 years → storage of 0,07 t C ha^{-1} year^{-1} in soil= 0,26 t CO_2 ha^{-1} year^{-1} removed from atmosphere



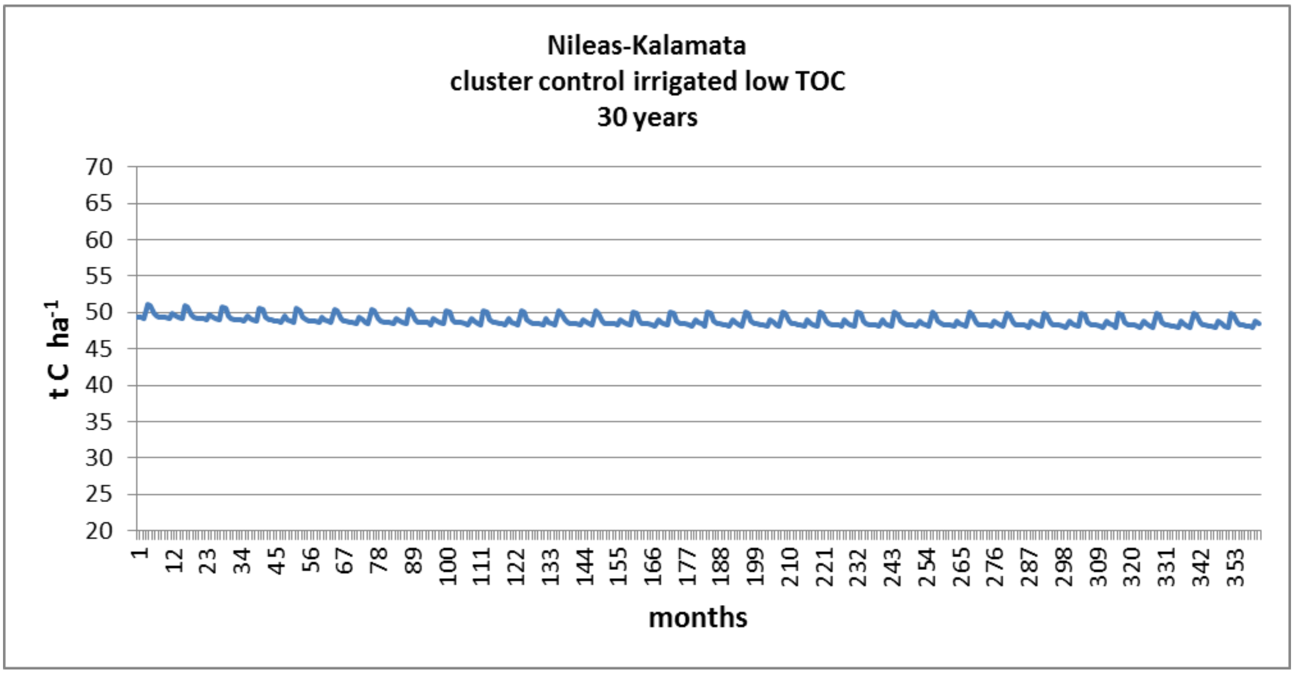
7. Control irrigated low TOC

6 plots: 8.04 10.02 10.05 17.07 59.05 98.02

Sand=31,0% Silt=39,2% Clay=29,7%

Avg n. trees ha^{-1}= 217

Soil Organic C from 1,37% to 1,35% in 30 years → decrease of 0,035 t C ha^{-1} $year^{-1}$ in soil = 0,13 t CO_2 ha^{-1} $year^{-1}$ emitted in atmosphere



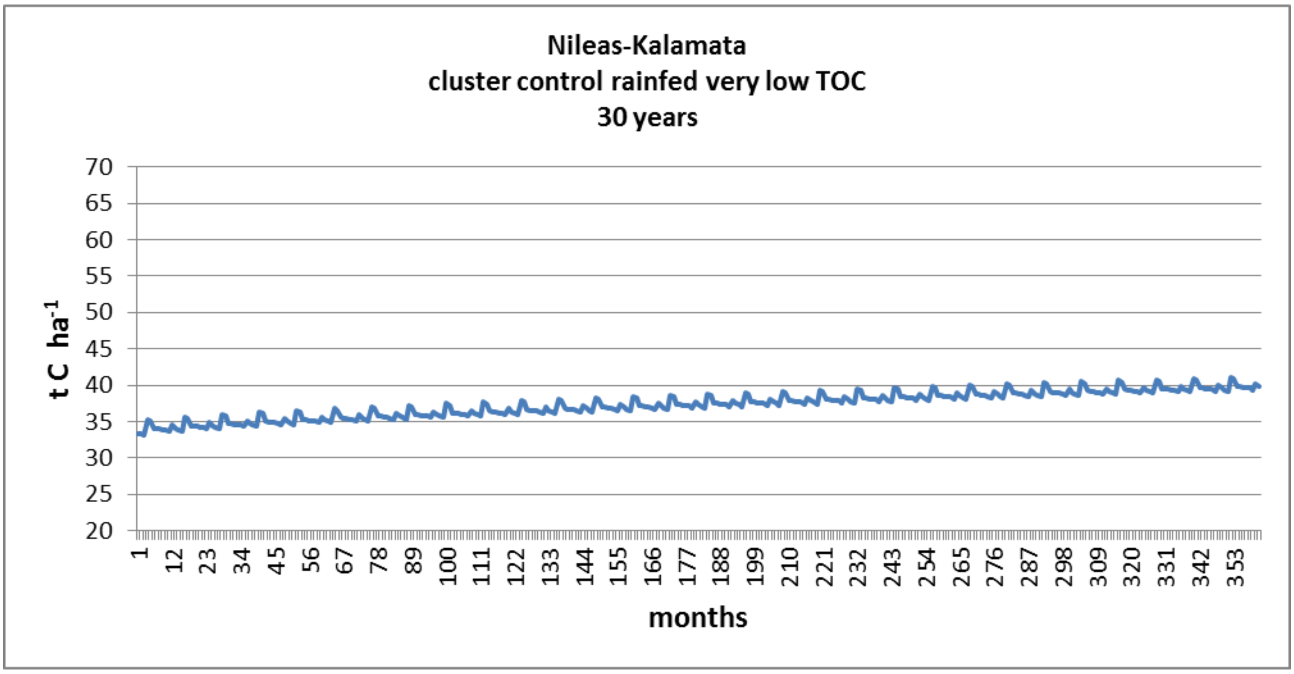
8. Control rainfed very low TOC

1 plot: 17.03

Sand= 23,6%   Silt=47,6%   Clay=28,8%

Avg n. trees ha^{-1}= 172

Soil Organic C from 0,91% to 1,12% in 30 years → storage of 0,21 t C ha^{-1} $year^{-1}$ in soil = 0,78 t CO_2 ha^{-1} $year^{-1}$ removed from atmosphere



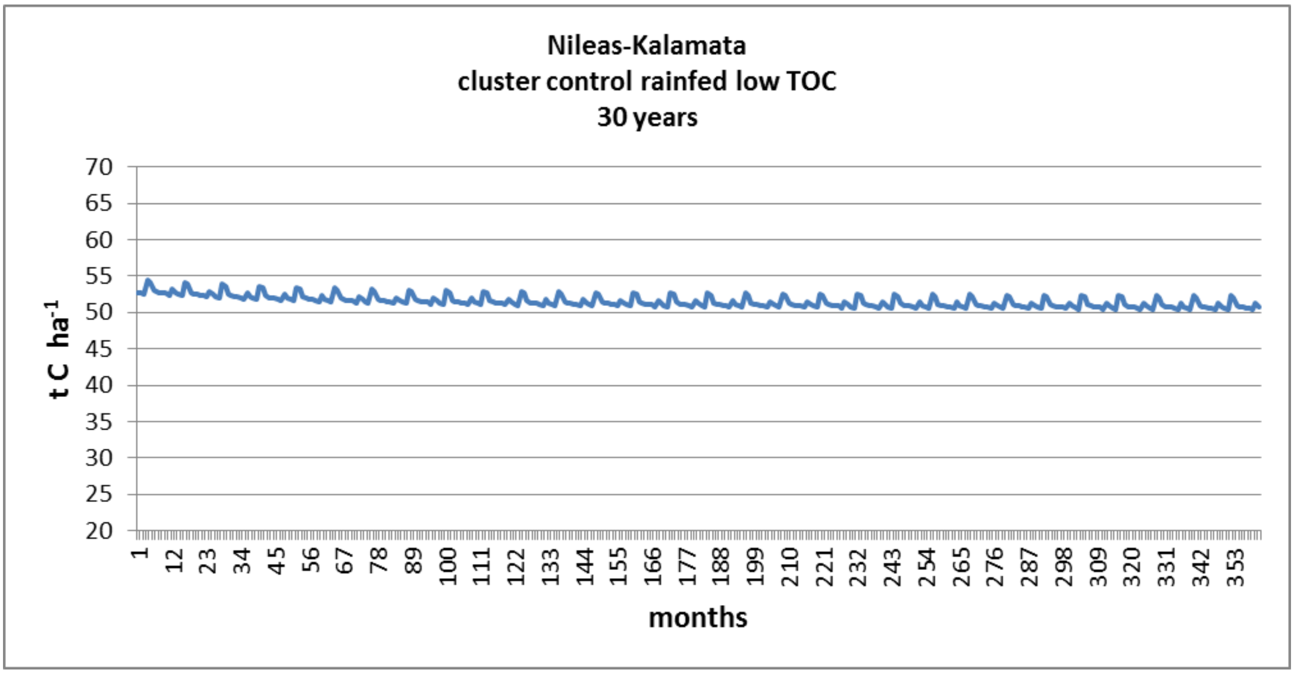
9. Control rainfed low TOC

9 plots: 180.06 20.02 23.01 23.02 41.04 43.02 48.01 55.05 8.02

Sand=41,7% Silt=34,6% Clay=23,6%

Avg n. trees ha^{-1}= 180

Soil Organic C from 1,41% to 1,36% in 30 years → decrease of 0,065 t C ha^{-1} $year^{-1}$ in soil = 0,24 t CO_2 ha^{-1} $year^{-1}$ emitted in atmosphere



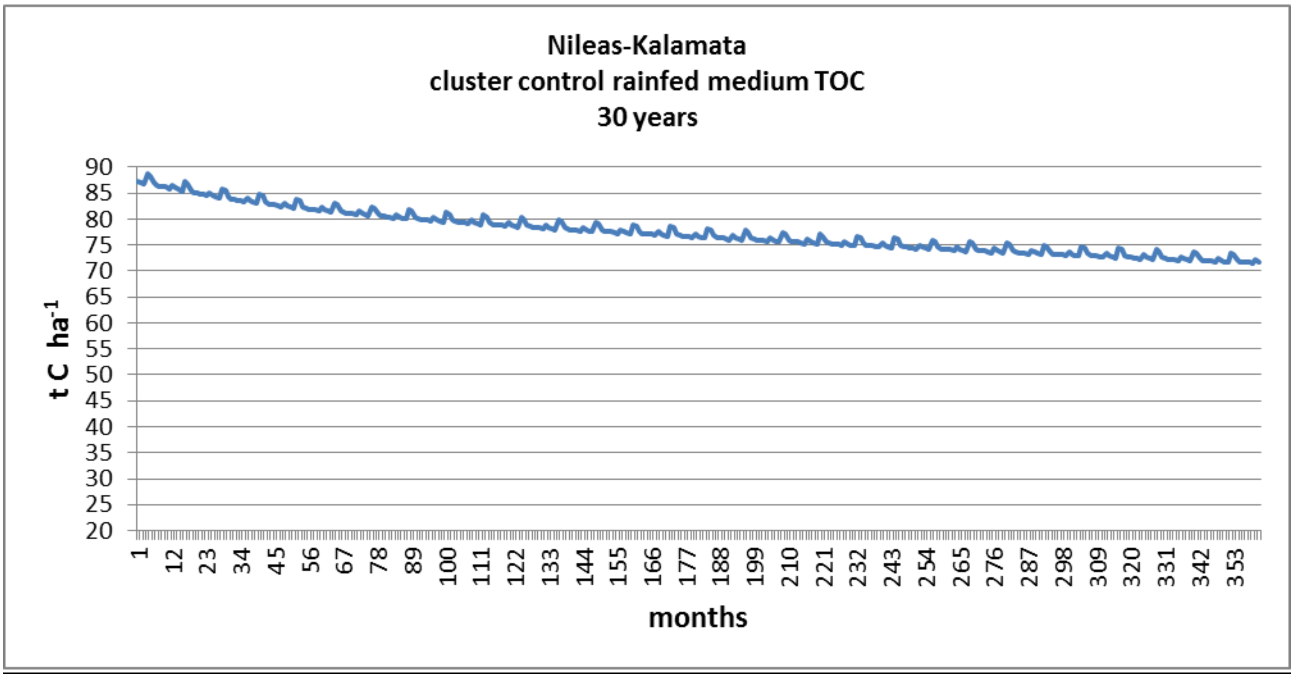
10. Control rainfed medium TOC

1 plot: 180.11

Sand=56,4%   Silt=19,6%   Clay= 24,0%

Avg n. trees ha^{-1}= 140

Soil Organic C from 2,3% to 1,9% in 30 years → decrease of 0,5 t C ha^{-1} $year^{-1}$ in soil = 1,89 t CO_2 ha^{-1} $year^{-1}$ emitted in atmosphere



MIRABELLO (8 simulations)

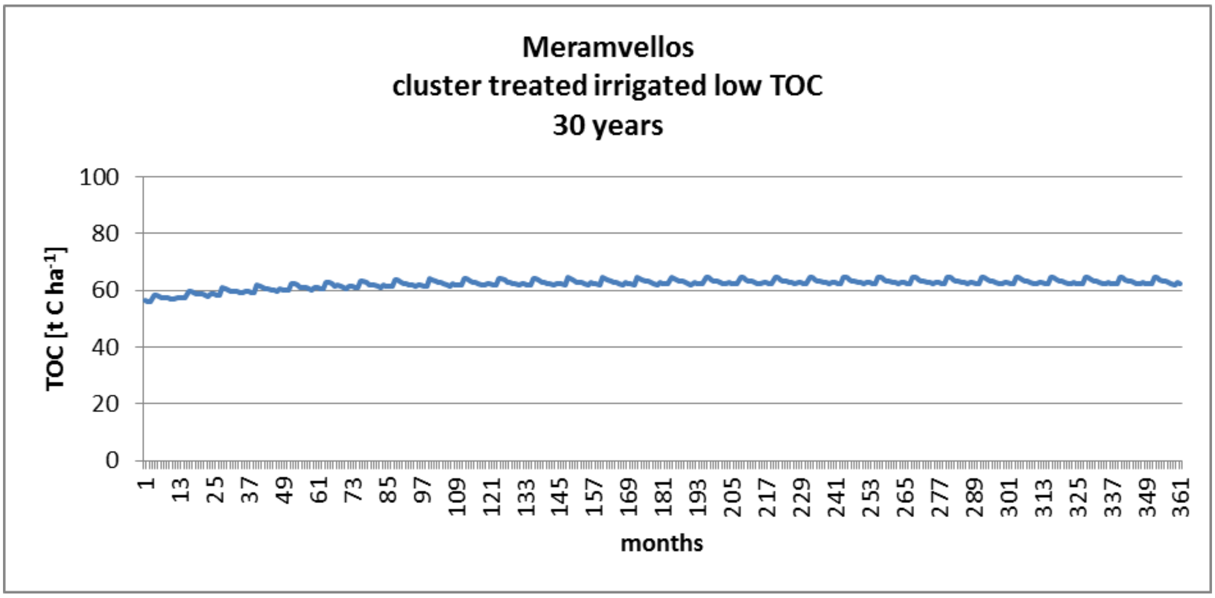
1. Treated irrigated low TOC

4 plots: MΣME0041 MΣME0043 MΣME0863 MΣME0870

Sand= 44% Silt=26,8% Clay=29,2%

Avg n. trees ha^{-1}= 258

Soil Organic C from 1,55% to 1,72% in 30 years → storage of 0,2 t C ha^{-1} $year^{-1}$ in soil = 0,73 t CO_2 ha^{-1} $year^{-1}$ removed from atmosphere



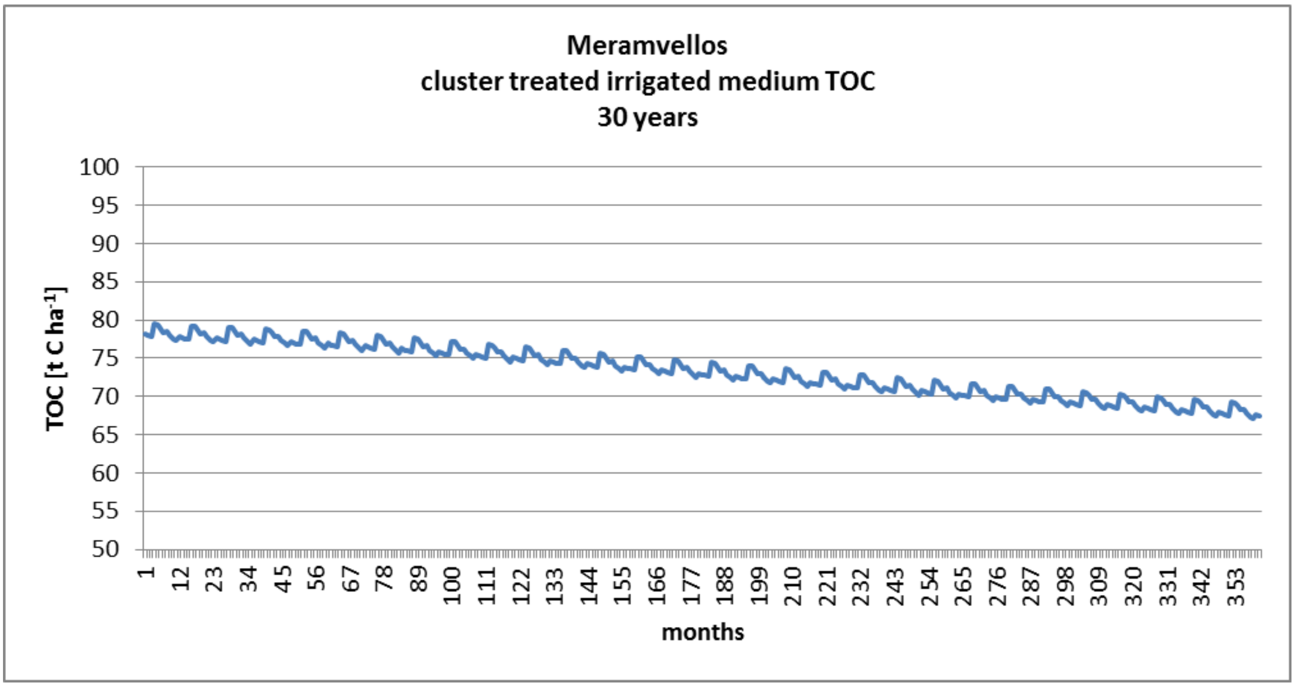
2. Treated irrigated medium TOC

4 plots: AAME1065 MΣME0042 MΣME0044 MΣME0452

Sand= 28,6% Silt= 22,8% Clay=48,6%

Avg n. trees ha^{-1}= 217

Soil Organic C from 2,34% to 2,01% in 30 years → decrease of 0,36 t C ha^{-1} year^{-1} in soil = 1,32 t CO_2 ha^{-1} year^{-1} emitted to atmosphere



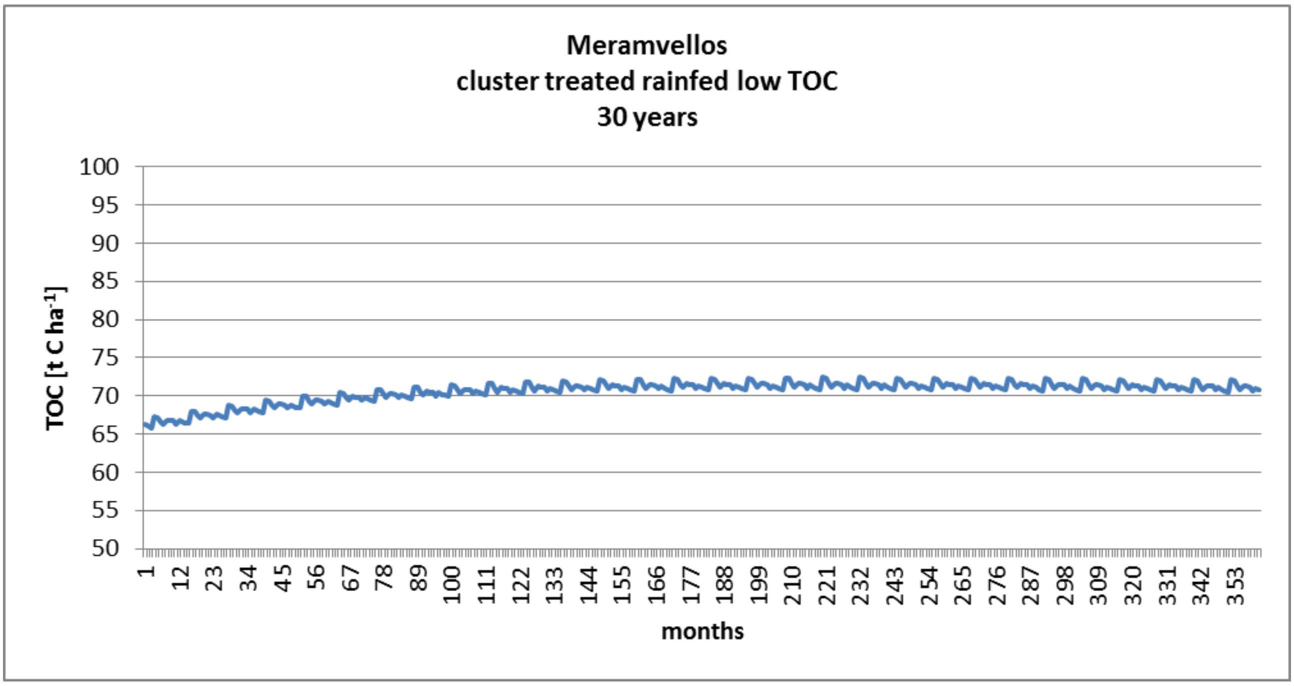
3. Treated rainfed low TOC

4 plots: AAME0435   MΣME0225   MΣME0475 MΣME0864

Sand=39,1%   Silt=36,4%   Clay=24,5%

Avg n. trees ha^{-1}= 195

Soil Organic C from 1,80% to 1,92% in 30 years → storage of 0,15 t C ha^{-1} $year^{-1}$ in soil = 0,55 t CO_2 ha^{-1} $year^{-1}$ removed from atmosphere



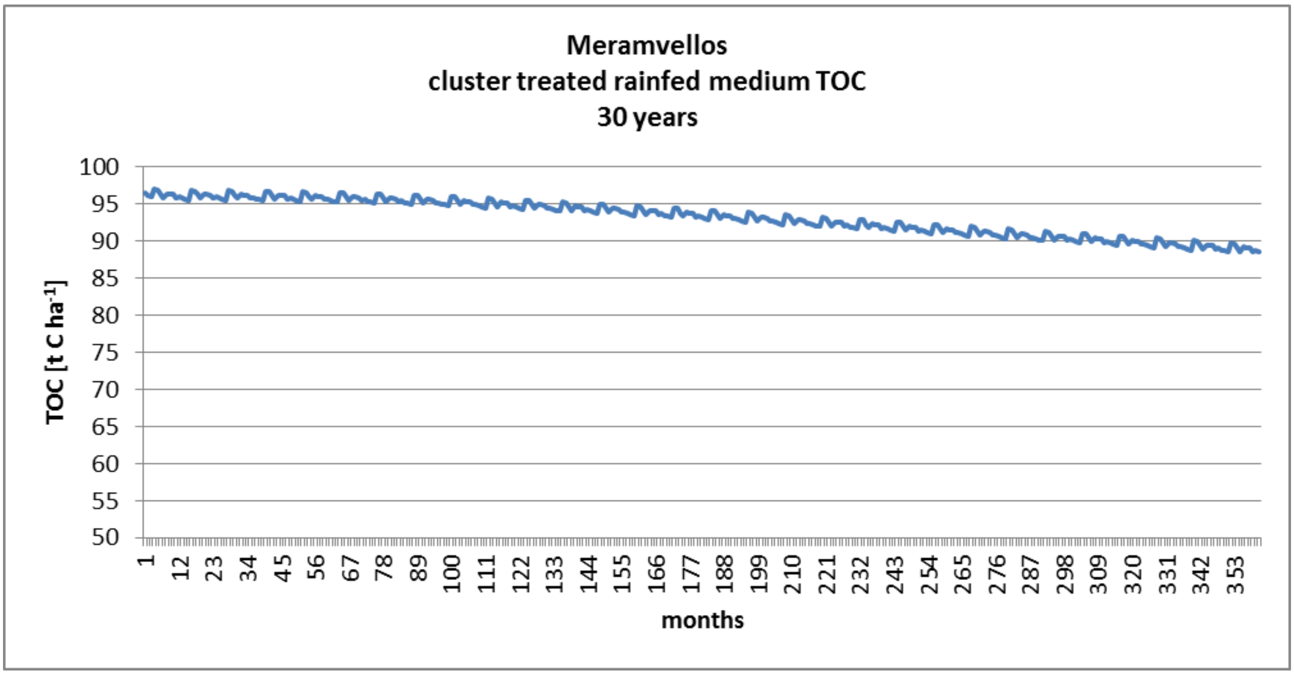
4. Treated rainfed medium TOC

6 plots: AAME0865 MΣME0282 MΣME0464 MΣME0467 MΣME0469 MΣME0546

Sand =25,87% Silt= 33,73% Clay=40,4%

Avg n. trees ha^{-1}= 107

Soil Organic C from 2,84% to 2,60% in 30 years → decrease of 0,27 t C ha^{-1} $year^{-1}$ in soil = 0,99 t CO_2 ha^{-1} $year^{-1}$ emitted to atmosphere



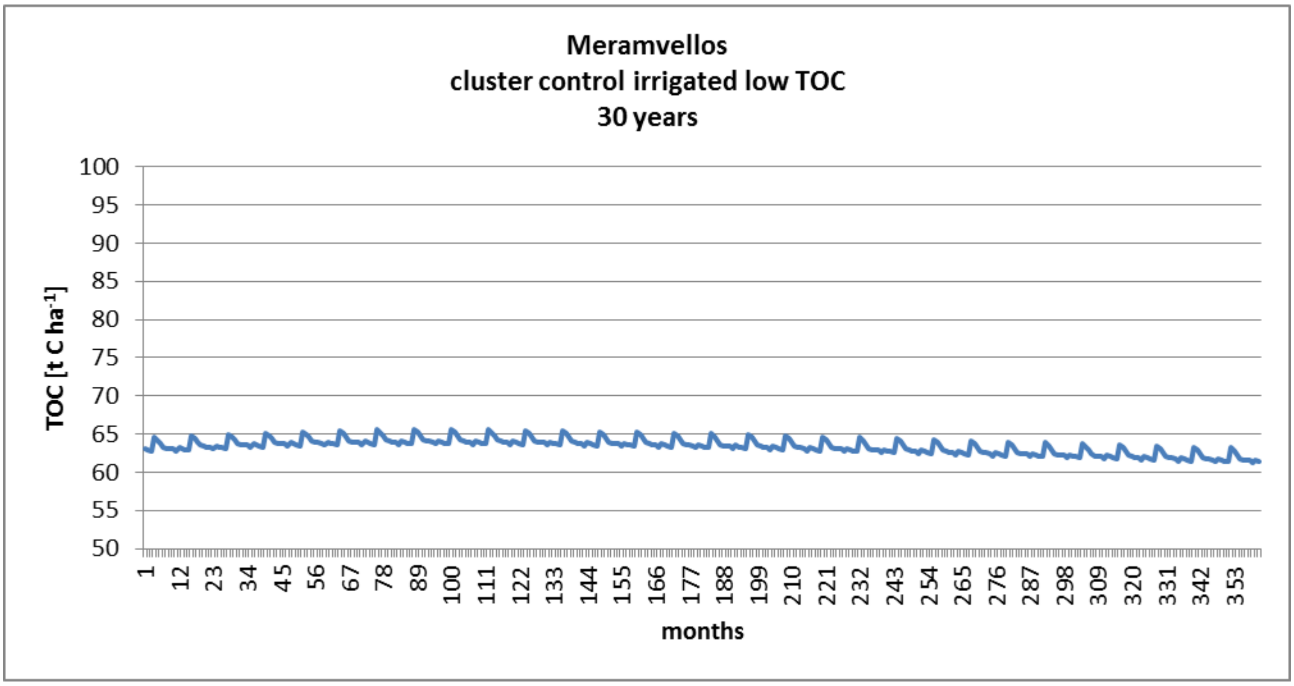
5. Control irrigated low TOC

4 plots: MΣME0037 MΣME0845 MΣME0423 MΣME0860

Sand=34,6% Silt=35% Clay=30,4%

Avg n. trees ha^{-1}= 193

Soil Organic C from 1,76% to 1,72% in 30 years → decrease of 0,05 t C ha^{-1} $year^{-1}$ in soil = + 0,18 t CO_2 ha^{-1} $year^{-1}$ emitted to atmosphere



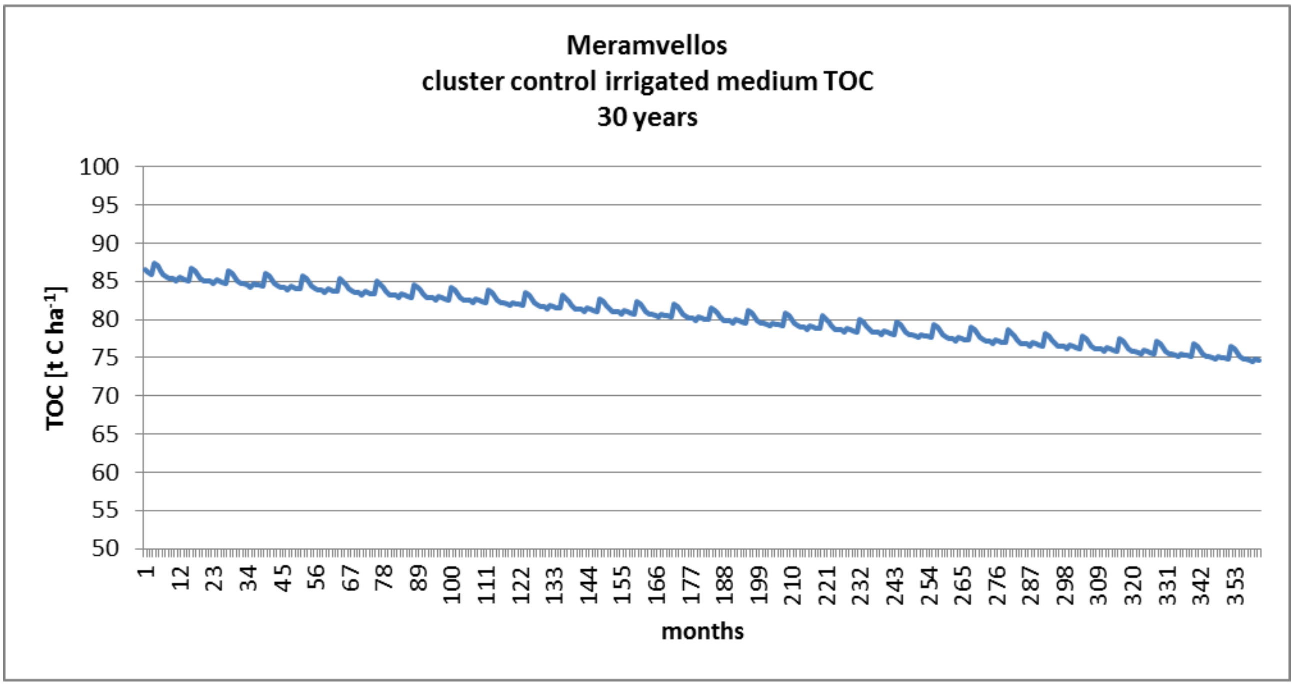
6. Control irrigated medium TOC

5 plots: AAME0027 MΣME0038 MΣME0429 MΣME0451 MΣME0453

Sand=32,88% Silt=27,28% Clay=39,84%

Avg n. trees ha^{-1}= 207

Soil Organic C from 2,52% to 2,18% in 30 years → decrease of 0,39 t C ha^{-1} $year^{-1}$ in soil = 1,43 t CO_2 ha^{-1} $year^{-1}$ emitted in atmosphere



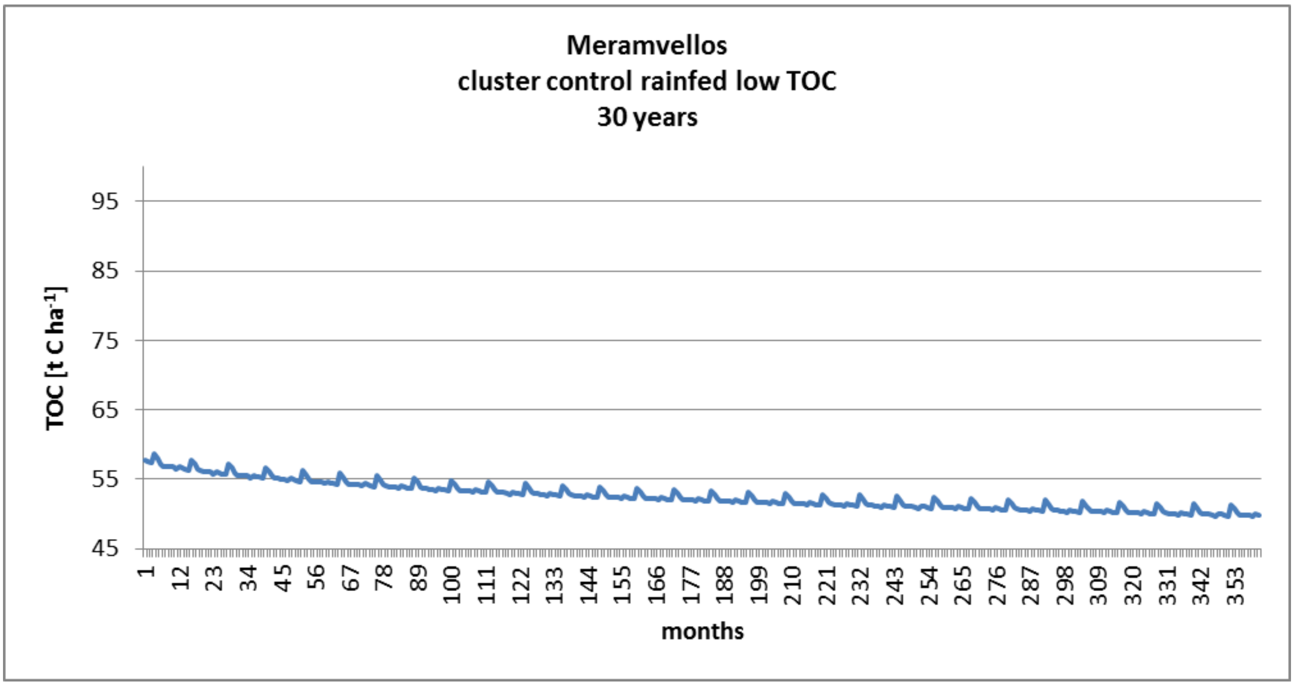
7. Control rainfed low TOC

7 plots: AAME0436 AAME0341 AAME0343 AAME0347 MΣME0279 MΣME0283 MΣME0479

Sand=34,74% Silt=38,23% Clay=27,03%

Avg n. trees ha^{-1}= 145

Soil Organic C from 1,7% to 1,46% in 30 years → decrease of 0,27 t C ha^{-1} $year^{-1}$ in soil = 0,99 t CO_2 ha^{-1} $year^{-1}$ emitted to atmosphere

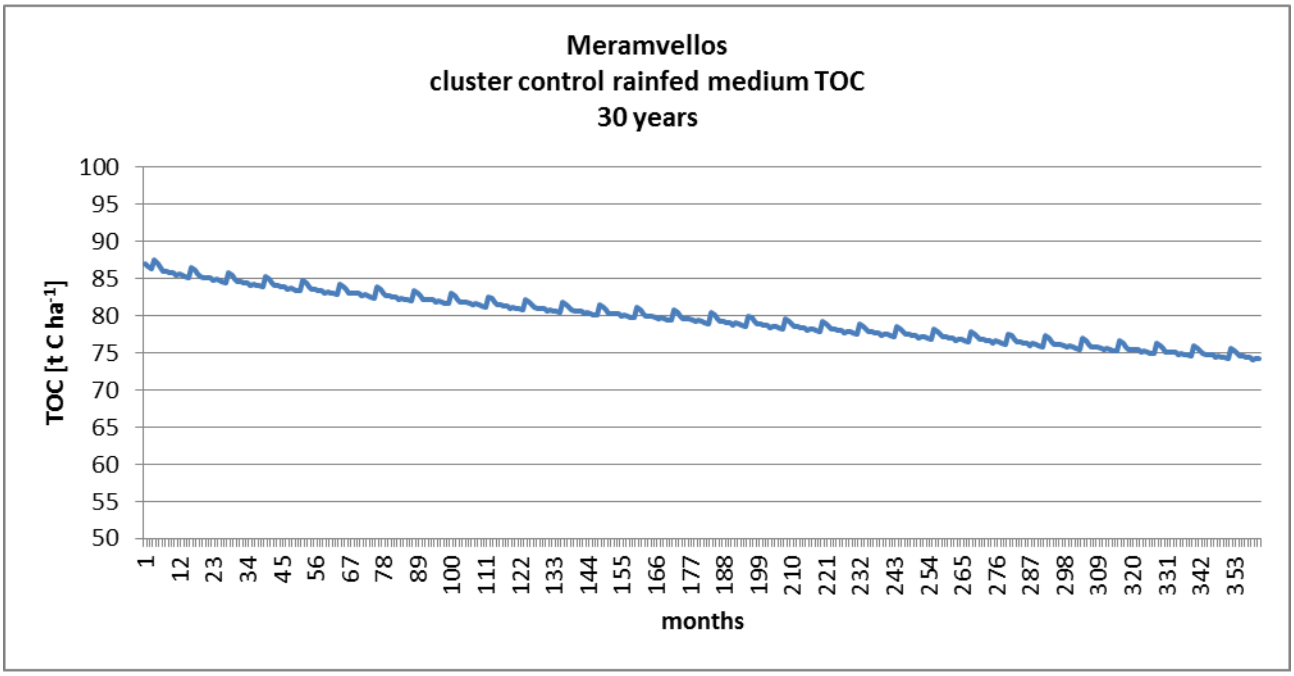


8. Control rainfed medium TOC

4 plots: MΣME0226 MΣME0457 MΣME0483 MΣME0542
Sand=37,4% Silt=27,7% Clay=34,9%

Avg n. trees ha^{-1}= 116

Soil Organic C from 2,47% to 2,11% in 30 years → decrease of 0,43 t C ha^{-1} $year^{-1}$ in soil = 1,57 t CO_2 ha^{-1} $year^{-1}$ emitted to atmosphere



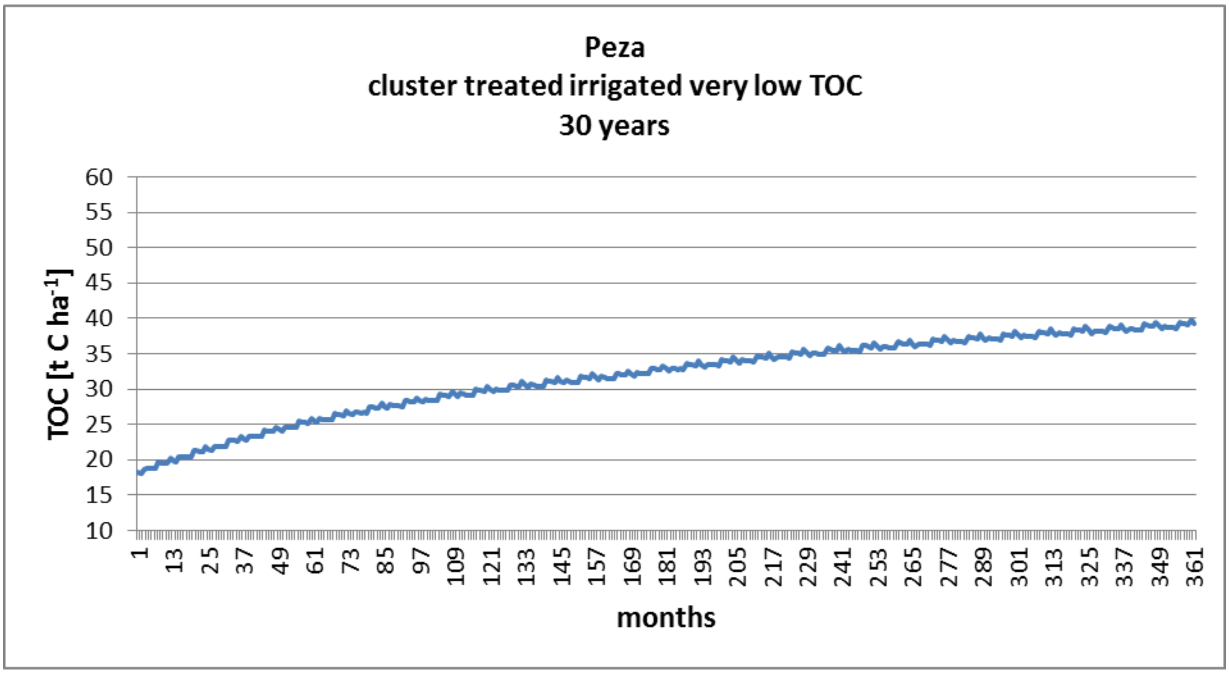
PEZA (8 simulations)

1. Treated irrigated very low TOC

3 plots: 103004 17302 17303 (old code)
Sand= 47,5% Silt= 25,3% Clay= 27,2%

Avg n. trees ha^{-1}= 213

Soil Organic C from 0,5% to 1,06% in 30 years → storage of 0,7 t C ha^{-1} year^{-1} in soil = 2,57 t CO_2 ha^{-1} year^{-1} removed from atmosphere

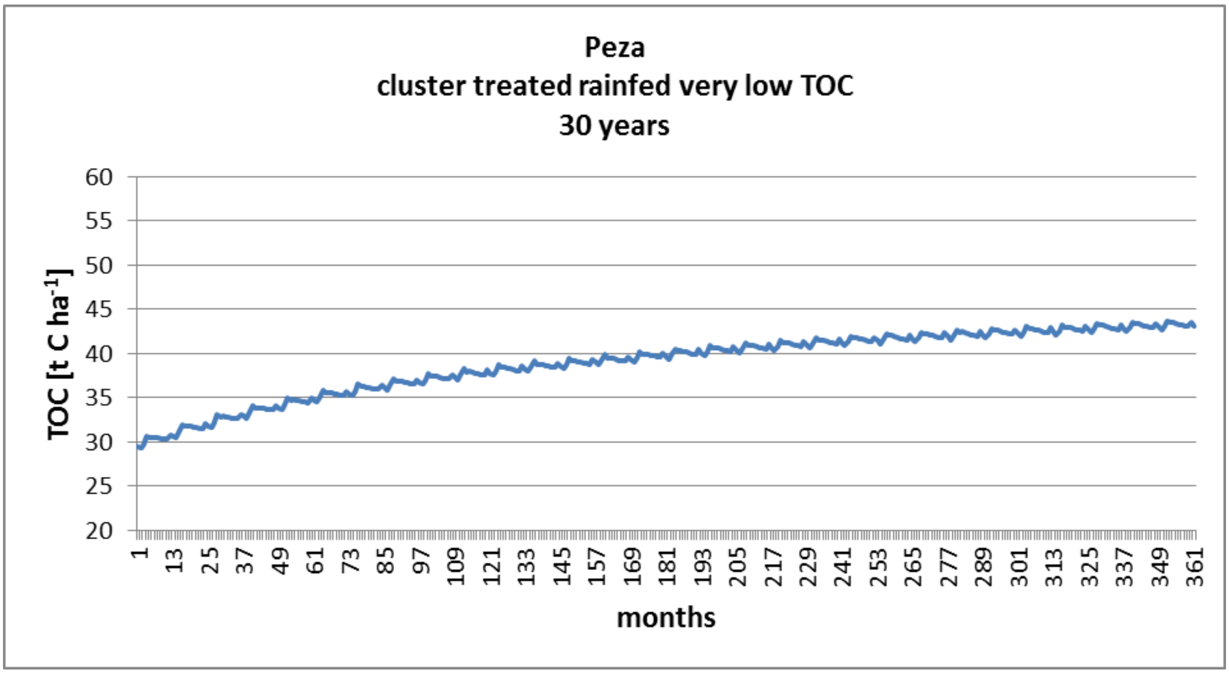


2. Treated rainfed very low TOC

3 plots: 53504 79801 79807 (old code)
Sand= 30,9% Silt= 41,1% Clay= 28%

Avg n. trees ha^{-1}= 167

Soil Organic C from 0,83% to 1,21% in 30 years → storage of 0,45 t C ha^{-1} $year^{-1}$ in soil = 1,65 t CO_2 ha^{-1} $year^{-1}$ removed from atmosphere

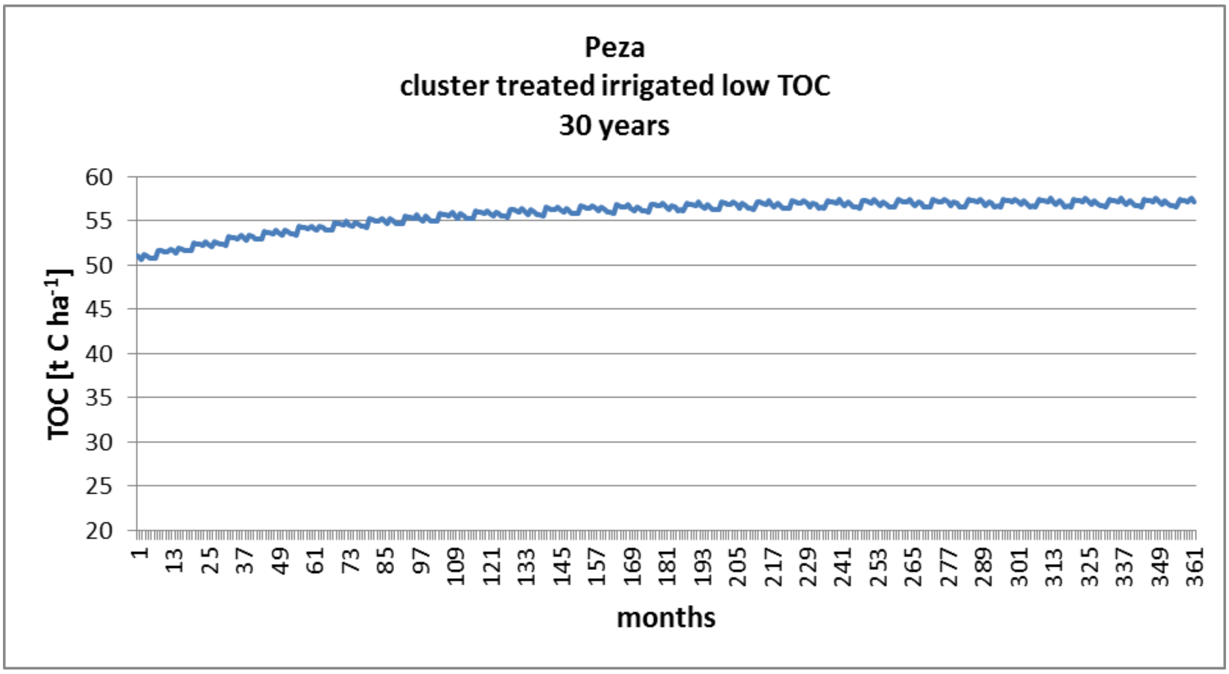


3. Treated irrigated low TOC

1 plot: 1508 (old code)
Sand= 43,2% Silt= 30% Clay= 26,8%

Avg n. trees ha^{-1}= 117

Soil Organic C from 1,4% to 1,56% in 30 years → storage of 0,2 t C ha^{-1} $year^{-1}$ in soil = 0,75 t CO_2 ha^{-1} $year^{-1}$ removed from atmosphere

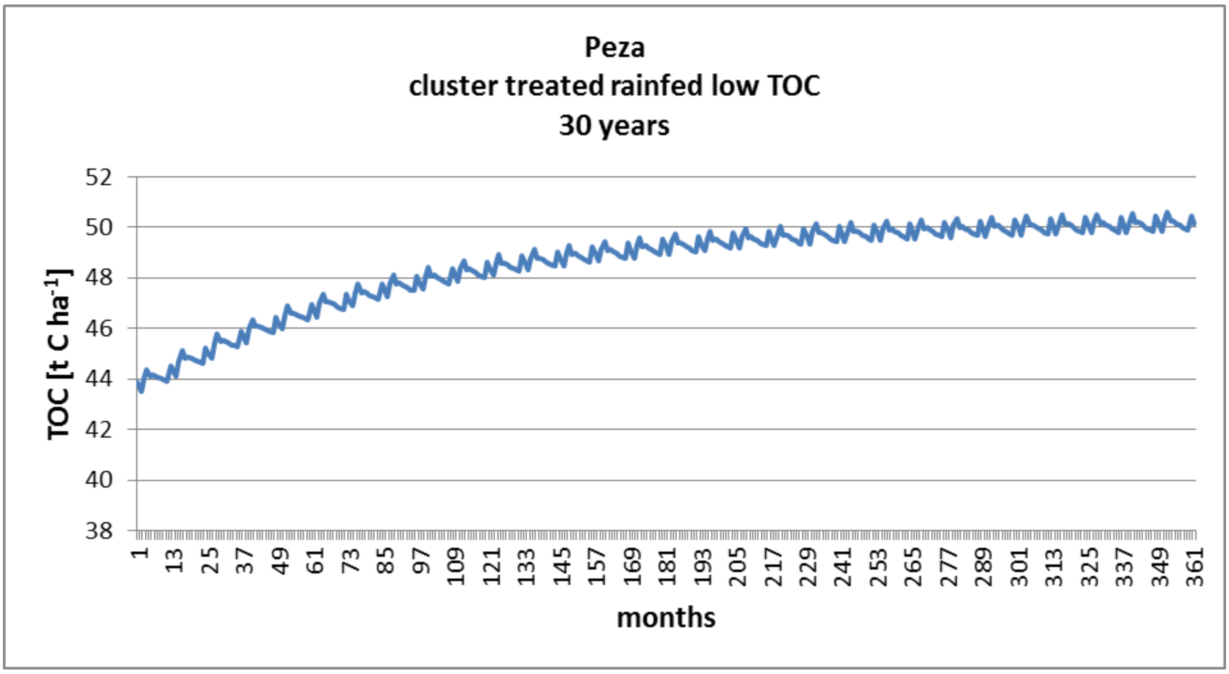


4. Treated rainfed low TOC

Plots: 105106 24101 59001 79803 79804 87204 95203 (old code)
Sand= 28,6% Silt= 37,4% Clay= 34%

Avg n. trees ha^{-1}= 191

Soil Organic C from 1,26% to 1,44% in 30 years → storage of 0,21 t C ha^{-1} $year^{-1}$ in soil = -0,77 t CO_2 ha^{-1} $year^{-1}$ removed from atmosphere



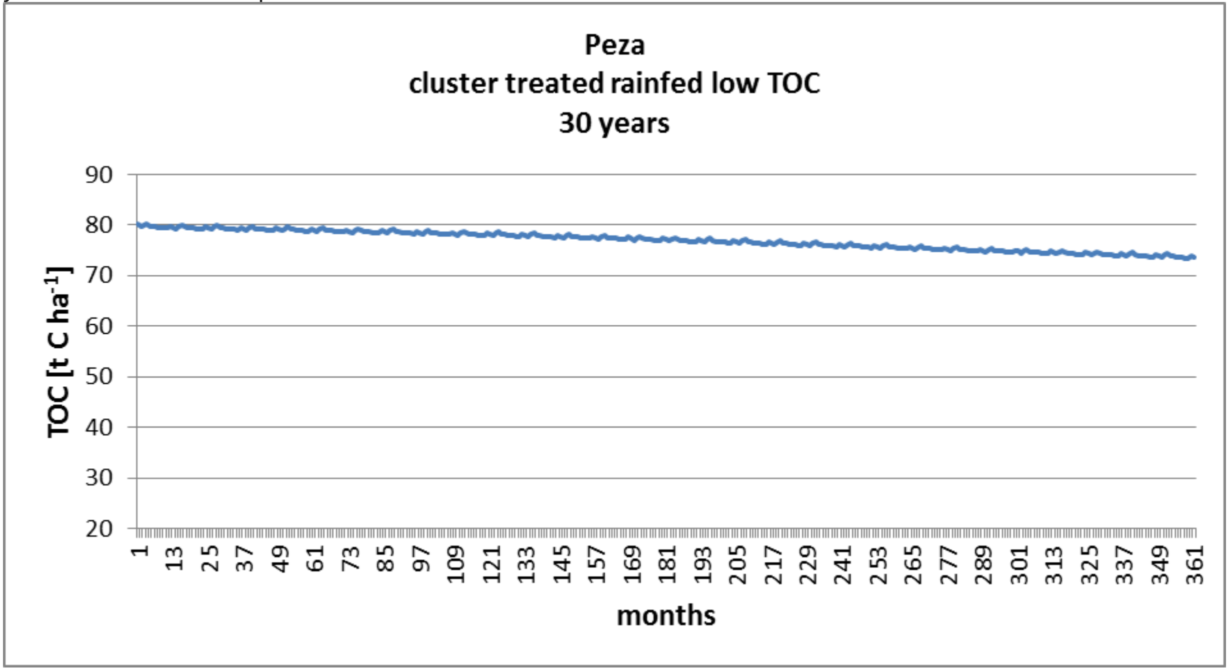
5. Treated rainfed medium TOC

2 plots: 105107 87206 (old code)

Sand= 25,8% Silt= 28,8% Clay= 45,4%

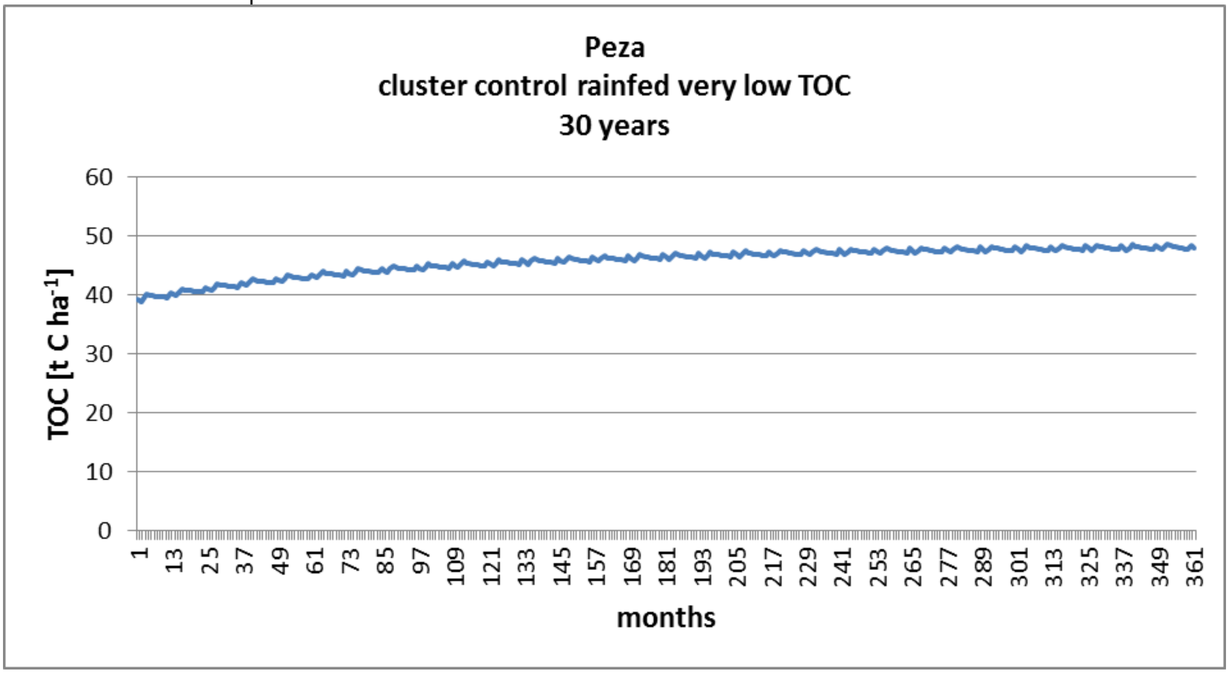
Avg n. trees ha^{-1}= 142

Soil Organic C from 2.38% to 2,18% in 30 years → decrease of 0,22 t C ha^{-1} year^{-1} in soil = 0,81 t CO_2 ha^{-1} year^{-1} emitted to atmosphere



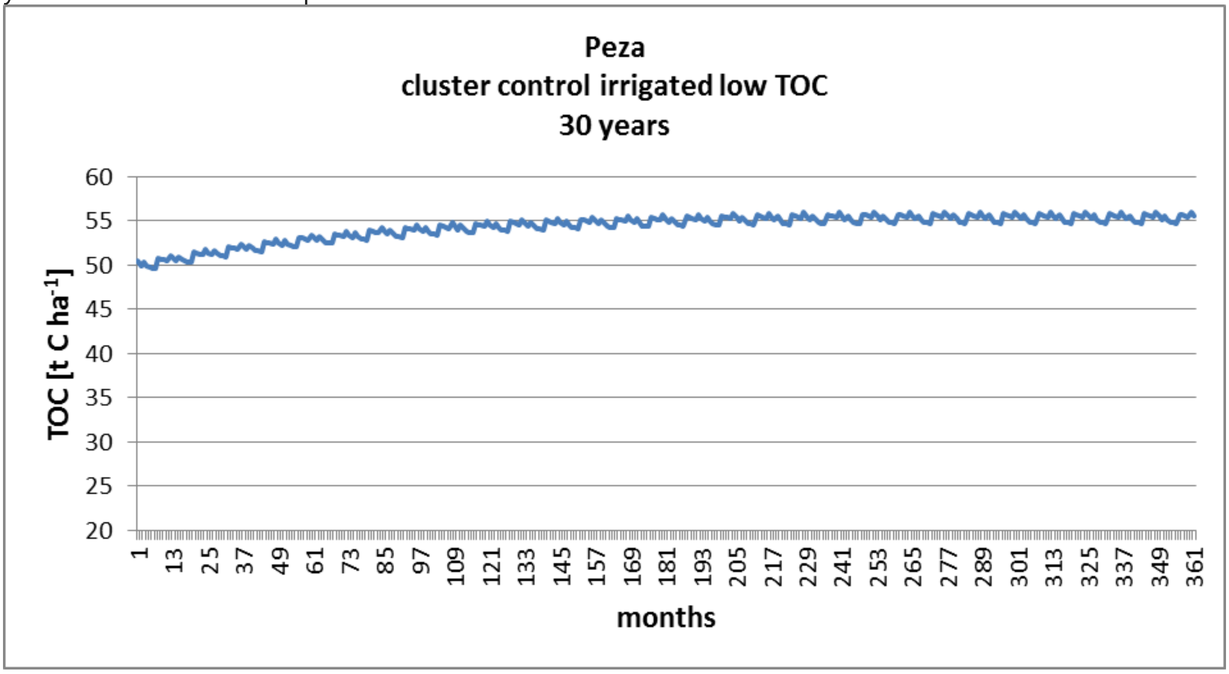
6. Control rainfed very low TOC

1 plot: 103006 (old code)
Sand= 62% Silt= 21,6% Clay= 16,4%
Avg n. trees ha^{-1}= 235
Soil Organic C from 0,99% to 1,21% in 30 years → storage of 0,29 t C ha^{-1} $year^{-1}$ in soil = 1,08 t CO_2 ha^{-1} $year^{-1}$ removed from atmosphere



7. Control irrigated low TOC

3 plots: 3501 3502 25917 (old code)
Sand= 56,5%   Silt= 26,8%   Clay= 16,7%
Avg n. trees ha^{-1}= 191
Soil Organic C from 1,29% to 1,41% in 30 years → storage of 0,17 t C ha^{-1} year^{-1} in soil = -0,62 t CO_2 ha^{-1} year^{-1} removed from atmosphere



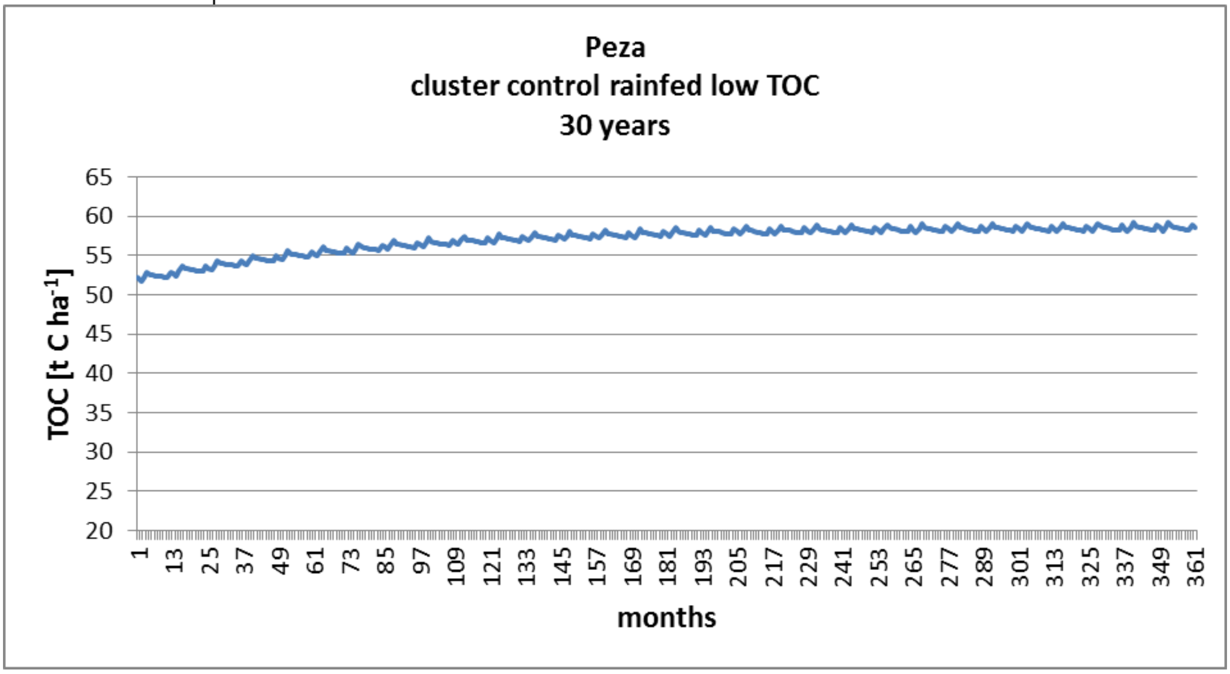
8. Control rainfed low TOC

14 plots: 105102 105104 105105 1501 22917 2407 24109 25910 5105 5201 53501 59005 64006 87207 (old code)

Sand= 28,3% Silt= 38,6% Clay= 33,2%

Avg n. trees ha^{-1}= 207

Soil Organic C from 1,49% to 1,67% in 30 years → storage of 0,21 t C ha^{-1} $year^{-1}$ in soil = 0,78 t CO_2 ha^{-1} $year^{-1}$ removed from atmosphere



7. Conclusions

This deliverable focussed the suitable framework for the determination of the C balance in a olive ecosystem providing information on the impact of various management practices on the soil CO_2 emissions and on the NECB. The NECB method highlights the significant impact of growers' management choices on the overall C budget and in turn on the potential mitigation of the atmospheric CO_2 provided by olive ecosystems.

The activities developed allowed to assess that NECB ranging from negative values (approx. -245/-280 kg CO_2 m^{-2} yr^{-1} in Control/Conventional) up to 1,300 kg CO_2 m^{-2} yr^{-1} (ALL treatment). According to the NECB definition the Control and Conventional treatments were net source of CO_2.

The simulations for the soil carbon changes as affected by management and water supply highlight the beneficial effect of the introduction of sustainable practices. The increased soil C (0-30 cm depth) in treated plots after a 30-year period ranged from 6 up to 20 (Peza), from 20 to 30 (Nileas) and from 5 to 20 (Mirambello) t C ha^{-1}. By contrast, in control plots soil C content remained roughly stable or even reduced by 5-10 t C ha^{-1}. In addition, simulations showed that in some cases despite the adoption of the sustainable practices a decline in SOC might be expected (see case 5 at Peza) suggesting that the import of organic raw material should be increased.

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