Project number: 101113620
Acronym: LIFE22-CCA-IT-LIFE VitiCaSe

LIFE VitiCaSe

Viticulture for Soil Organic Carbon Sequestration

Co-funded by the European Union

DELIVERABLE 6.2

COMPARATIVE LCA ANALYSIS

1 per pilot farms and management practices

Author(s)

Irene Criscuoli, Simonetta De Leo, Davide Rapinesi
Silvia Vanino, Roberta Farina (CREA)

Co-funded by the European Union

Call:	**LIFE-2022-SAP-CLIMA**		
Project Number	**101113620**		
Project full name	**Viticulture for Soil Organic Carbon Sequestration**		
Project acronym	**LIFE22-CCA-IT-LIFE VitiCaSe**		
Coordinator contact	Simona Palermo Simona.palermo@imageline.it Mobile: +39 348 6144978		
Deliverable Number	D.6.2	**Lead Beneficiary**	CREA
Deliverable title	**Comparative LCA analysis (1 per pilot farms and management practices)**		
Type	R-Document	**Dissemination Level**	PU
Due Date (month)	M36	**Work Package No**	WP 6
Author(s)	Irene Criscuoli, Simonetta De Leo, Davide Rapinesi, Silvia Vanino, Roberta Farina		

Please note that the links here included could have a limited validity and availability.
In link(s) not available, please contact the coordinator indicated above for more information.

Contents

1. **Introduction**

This report provides a description of the methodological approach used for the Life Cycle Assessment (LCA) made in the 4 pilot farms of the project and the obtained results. The LCA analysis covers the Carbon Farming (CF) project scenario and the baseline scenario, the latter corresponding to the agricultural practices applied in the three years before the CF project started.

The methodology combines two main references.

First, the ISCC EU 205 Greenhouse Gas Emissions methodology, version 4.1 (2024), is used to estimate greenhouse gas emissions, expressed in tonnes of CO_2 equivalent. More specifically, the following emissions were calculated:

- N_2O emissions from soil (green manure crops, fertilizers and pruning residues)
- CO_2 emissions from the combustion of vines pruning residues
- Emissions from pesticides production
- Emissions from the production of seeds for green manure
- Emissions from diesel fuel used by agricultural machinery
- Emissions from electricity used for irrigation.

Data used to estimate the GHG emissions are retrieved from the digital farm registries, accountability registries, interviews with farms, scientific and technical literature, LCA databases, and official international standards.

Then, the VERRA VM0042 methodology, version 2.0, is used to quantify carbon removals in terms of tonnes of CO_2 equivalent, focusing on changes in soil organic carbon stocks in agricultural soils. These changes are estimated using the RothC model, supported by soil sampling data. The methodology clarifies that the component related to carbon stock changes in woody biomass applies only to new plantations or very young stands and is therefore excluded from this project, as the pilot vineyards were already established.

Carbon removals were then subtracted from the GHG emissions and then the net GHG emissions of the Carbon Farming project were compared with the net emissions of the baseline scenario to calculate the credits generated (or not) by the project.

The full methodology is described in greater detail in the following sections of the document.

2. **Baseline vs. Carbon farming scenarios**

In Tab. 1 the vineyards management practices applied by the four pilot farms, in the baseline and Carbon Farming project scenarios, are reported. The LCA analysis estimated the GHG emissions associated with these practices.

Tab. 1: Vineyards management practices applied by the four pilot farms, in the baseline and Carbon Farming project scenarios

		BASELINE	**Data collection methods**	**PROJECT AGRICULTURAL PRACTISES**
ALBOLA	1	Minimum tillage in 50% of the area	Answer by owner	Minimum tillage in 50% of the area
	2	Spontaneous grass cover and Leguminosae cover crop in alternate rows on part of the farm area: one row with grass cover nd another with 1 leguminous species, usually field bean (‘Favino’).	Answer by owner and evidence in QdC (farm registry)	Improvement green manure
	3	Organic fertilization	Answer by owner and evidence in QdC (farm registry)	Organic fertilization
	4	Use of fungicides allowed in organic farming	Answer by owner and evidence in QdC (farm registry)	Use of fungicides allowed in organic farming
	5	Use of pesticides of natural origins allowed in organic farming	Answer by owner and evidence in QdC (farm registry)	Use of pesticides of natural origins allowed in organic farming
	6	Burning of pruning vines residues in the field	Answer by owner	Chopping and left on the soil /or incorporation of pruning vines residues
	7	The vineyards are not irrigated	Answer by owner	The vineyards are not irrigated
	8	The harvest is both mechanical and manual.	Answer by owner	The harvest is both mechanical and manual.
	9		Answer by owner and evidence in QdC (farm registry)	Application of Manure
		BASELINE	**Data collection methods**	**PROJECT AGRICULTURAL PRACTISES**
SAN FELICE	1	Spontaneous grassing on 50% of the cultivated hectares. Grassing and green manure in alternate rows on part of the farm area: one spontaneous row and another with green manure with nitrogen-fixing crops	Answer by owner and evidence in QdC (farm registry)	Improvement green manure
	2	Organic fertilization	Answer by owner and evidence in QdC (farm registry)	Organic fertilization
	3	Manure application on 4 fields for a total of 72,5 tons in crop year 2023/2024	Answer by owner and evidence in QdC (farm registry)	Increase in manure application
	4	Use of fungicides and pesticides allowed in organic farming since the crop year 2023-2024. In the previous crop years (2021-2022; 2022-2023) fungicides and pesticides not allowed in organic farming were used because the farm is transitioning to organic farming since 2023-2024.	Answer by owner and evidence in QdC (farm registry)	Use of fungicides and pesticides allowed in organic farmin
	5	Burning of pruning vines residues in the field	Answer by owner	Chopping and left on the soil /or incorporation of pruning vines residues
	6	Vineyards are not irrigated	Answer by owner	Vineyards are not irrigated
	7	The crop operations of pruning, stripping, ploughing, foot cleaning, cage are done manually	Answer by owner	The crop operations of pruning, stripping, ploughing, foot cleaning, cage are done manually
	8	The harvest is both mechanical and manual.	Answer by owner	The harvest is both mechanical and manual.
	9		Answer by owner and evidence in QdC (farm registry)	Use of compost
	10		Answer by owner	Minimum tillage

		BASELINE	Data collection methods	PROJECT AGRICULTURAL PRACTISES
MONTEMASSI	1	Spontaneous grassing and green manure in alternate rows: one spontaneous row and another with green manure with nitrogen-fixing crops	Answer by owner and evidence in QdC (farm registry)	Improvement green manure
	2	Organic fertilisation	Answer by owner and evidence in QdC (farm registry)	Organic fertilisation
	3	Use of pesticides and fungicides allowed in organic farming	Answer by owner and evidence in QdC (farm registry)	Use of pesticides and fungicides allowed in organic farming
	4	Minimum tillage	Answer by owner	Minimum tillage
	5	Burning of pruning vines residues in the field	Answer by owner	Chopping and left on the soil /or incorporation of pruning vines residues
	6	Vineyards are irrigated with micro-irrigation system (drip irrigation), water consumption is equal to 20mm/hectare (about 2.5 interventions per year)	Answer by owner	Increase of irrigation
	7	The harvest is both mechanical and manual.	Answer by owner	The harvest is both mechanical and manual.
	8		Answer by owner and evidence in QdC (farm registry)	Use of mycorrhizae
	9		Answer by owner and evidence in QdC (farm registry)	Application of Manure

		BASELINE	Data collection methods	PROJECT AGRICULTURAL PRACTISES
RUFFINO	1	Spontaneous grassing on 50% of vineyard surface	Answer by owner	Introduction of green manure
	2	Organic fertilization	Answer by owner and evidence in QdC (farm registry)	Organic fertilization
	3	Use of fungicides and pesticides allowed in organic farming	Answer by owner and evidence in QdC (farm registry)	Use of fungicides and pesticides allowed in organic farming
	4	Tillage: deep ploughing in autumn (at a depth of 40 to 80 cm depending on the vineyard)	Answer by owner	Minumum tillage
	5	No vines pruning residue management	Answer by owner	Chopping and left on the soil /or incorporation of pruning vines residues
	6	Vineyards are irrigated with a drip-irrigation system: during the growing season 2023/24, the amount of water provided was 1200 mc	Answer by owner	Drip-Irrigation

3. **Calculation of Greenhouse Gas Emissions**

3.1 N_2O emissions from soil (green manure crops, fertilizers and pruning residues)

Each farm described in his own farm registry the amount of green manure seeds distributed to the field. To estimate the N_2O emissions deriving from the presence of N-fixing plants on the vineyard fields, the first step was to estimate the nitrogen contained in the biomass per kg of seeds distributed by the farms (Tab. 2).

Tab. 2: Nitrogen contained in green manure biomass per kg of seeds distributed in the field by the farms based on the farm registries (source: elaboration of the authors based on scientific and technical literature).

Type of green manure seeds distributed by the farms	Estimation of N derived from green manure biomass (kg N/Kg of seeds)
In-house produced field beans	0.84
GEOPRO N FIX	1.2
Vineyard under-row grass mix	0.76
CIPRO permanent grass mix	1.42
Organic barley	0.51
In-house produced organic Alexandrian clover	5.5

For each green manure seed type, one or more scientific and technical literature sources were studied, as reported in Tab. 3.

Tab. 3: Scientific and technical literature for N content estimates in green manure biomass

Type of green manure seeds	References	Average Kg of seeds/ha	Average N from green manure biomass (kg N/Kg of seeds)
Field beans	1 - Guida alla concimazione 2 - Kopke et al., 2010 3 - Peoples et al., 2009 4 - Curtright et al., 2025 5 - Ferrara et al., 2021	200	0.84
Clover	1 - Guida alla concimazione 4 - Curtright et al., 2025 6 - Campiglia et al., 2005 7 - Tabacco et al., 2003	30	5.5
Barley	1 - Guida alla concimazione 8 - Angeletti et al., 2023 9 - Salmerón et al., 2010	190	0.51
GEOPRO N NFIX (Fava bean, Brassica, Oat, Peas, Vetch)	4 - Curtright et al., 2025	140	1.2
Vineyard under-row grass mix (Ryegrass and clover)	4 - Curtright et al., 2025	80	0.76
CIPRO permanent grass mix	4 - Curtright et al., 2025	100	1.42

Similarly, to estimate N_2O emissions deriving from the use of fertilisers, the first step was to know the amount of fertilizers used in the farms, and this is described in the farm registry. Three farms participating in the project are certified organic, and one started the transition to organic farming during the baseline scenario (2021-2022 crop year). For this reason, all farms used only organic fertilisers.

Regarding vineyards pruning residues, the first step for the evaluation of GHG emissions was to estimate the amount of pruning residues left on the soil. Based on in-field assessment in the farm of Castello di Albola, in January 2026, the fresh weight of pruning residues was around 330-400 g/plant. Given a vines density of 5000 plants/ha, the residues amount was 1650-2000 kg/ha fresh weight. Considering a humidity rate of 50% right after the pruning and 30% a few weeks later, the amount of pruning residues is between 825 - 1000 kg/ha DM (Dry Matter) and 1155 - 1400 kg/ha DM, corresponding to an average value of 1095 kg/ha DM. This data is highly aligned with Pari *et al.*, 2018 who describes 40 records of vines pruning data collected in 10 locations all over Italy (1150 kg/ha DM). Secondly, the content of N in the vines pruning was taken from scientific literature (Spinelli et al., 2021; Andelini et al., 2023) (Tab. 4).

Tab. 4: Data used to estimate N_2O emissions from vines pruning residues

	Value	References
Vines pruning (kg/ha)	1,150	"Pruning Biomass Potential in Italy Related to Crop Characteristics, Agricultural Practices and Agro-Climatic Conditions" Luigi Pari, Vincenzo Alfano, Daniel Garcia-Galindo, Alessandro Suardi and Enrico Santangelo, (2018)
N content of vines pruning (kg/ha)	7.53	Raffaele Spinelli, Carla Nati, Luigi Pari, Enzo Mescalchin, Natascia Magagnotti, Production and quality of biomass fuels from mechanized collection and processing of vineyard pruning residues, Applied Energy, Volume 89, Issue 1, 2012, Pages 374-379, ISSN 0306-2619, https://doi.org/10.1016/j.apenergy.2011.07.049. (https://www.sciencedirect.com/science/article/pii/S0306261911004946) + Anđelini, D.; Cvitan, D.; Prelac, M.; Pasković, I.; Černe, M.; Nemet, I.; Major, N.; Goreta Ban, S.; Užila, Z.; Zubin Ferri, T.; et al. "Biochar from Grapevine-Pruning Residues Is Affected by Grapevine Rootstock and Pyrolysis Temperature." Sustainability (2023), 15, 4851. https://doi.org/10.3390/su15064851

Once all this input data was collected, the estimate of N_2O field emissions derived from green manure, organic fertilisers and vines pruning residues was performed based on the methodological indications described in the ISCC EU 205 Greenhouse Gas Emissions, Version 4.1 – 2024 [Eq. 1]:

$$N_2O_{Total} - N = [N_2O_{Direct} - N + N_2O_{Indirect} - N]$$

[Eq. 1]

where, $N_20_{Total} - N$ is the Direct and indirect annual N_2O-N emission produced from managed soils [kg N_2O/ha year], $N_20_{Direct} - N$ is the Direct annual N_2O-N emission produced from managed soils [kg N_2O/ha year] and $N_20_{Indirect} - N$ is the Indirect annual N_2O-N emission produced from managed soils [kg N_2O/ha year].

For mineral soils, the calculation of direct N_2O emissions shall follow the following equation [Eq. 2]:

$$N_2O_{Direct} - N = [(F_{SN} + F_{ON}) * EF_1] + [F_{CR} * EF_1] \quad \text{[Eq. 2]}$$

where, F_{SN} is the annual N synthetic fertilizer input [kg N/ha year], F_{ON} is total organic N fertilizer input [kg N/ha year], F_{CR} is the total crop residues N-input [kg N/ha year], EF_1 is the Emission Factor for N_2O emissions from N inputs [kg N_2O-N/kg N inputs].

The sources for these parameters and variables were the following:

- F_{SN}: not allowed in organic farm → value set to 0,
- F_{ON}: applied amounts retrieved from farm registry + NPKCaO composition found in the technical sheets of commercial products,
- F_{CR}: for vines pruning: scientific literature; for green manure: farm registry + scientific literature,
- EF_1: retrieved from the ISCC EU 205 Greenhouse Gas Emissions, Version 4.1 – 2024 which refers to the IPCC guidelines for National Greenhouse Gas Inventories, Volume 4, Chapter 11, http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/4_Volume4/V4_11_Ch11_N2O&CO2.pdf and "2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories".

For mineral soils, the calculation of indirect N_2O emissions shall follow the following equation [Eq. 3]:

$$N_2O_{Indirect} - N = [(F_{SN} * Frac_{GASF}) + (F_{ON} * Frac_{GASM})] * EF_4] + [(F_{SN} + F_{ON} + F_{CR}) * Frac_{Leach-(H)} * EF_5] \quad \text{[Eq. 3]}$$

Where:

- $Frac_{GASF}$ is the fraction of N synthetic fertilizer applied that volatises as NH_3 and NO_x [kg N volatilised/kg of N applied];
- $Frac_{GASM}$ is the fraction of applied organic N fertilizer applied that volatilises as NH_3 and NO_x [kg N volatised/kg N applied or deposited];
- EF_4 is the Emission Factor for N_2O emission from atmospheric deposition of N on soils and water surfaces [kg N_2O-N/(kg NH3-N + Nox-N volatilised)];
- $Frac_{Leach-(H)}$ is the fraction of all N added to/mineralised in managed soils in regions where leaching/runoff occurs that is lost through leaching and runoff [kg N/kg of N additions];
- EF_5 is the Emission Factor for N_2O emission from leaching and runoff [kg N2O-N/kg N leached and runoff].

$Frac_{GASF}$ is not relevant for this project; $Frac_{GASM}$ has a value of 0.2; EF_4 has a value of 0.01; $Frac_{Leach-(H)}$ has a value of 0.3 and EF_5 a value of 0.0075.

N_2O-N emissions are then converted into N_2O by multiplying the results by 44/28 = 1.5714, the molecular conversion ratio. N_2O emissions were then converted into CO_2e (CO_2equivalent) by multiplying the results by 265, the N_2O Global Warming Potential (GWP) over a 100-year time horizon, according to the ISCC EU 205 Greenhouse Gas Emissions, Version 4.1 – 2024.

3.2 CO_2 emissions from the combustion of vines pruning residues

To calculate the CO_2 emissions from the combustion of vines pruning residues, the amount of vines pruning residues was estimated as already described in chapter 3.1, while the %C content was taken from the literature (Tab. 5).

Tab. 5: Amount of vines pruning residues and %C content.

	Values	References
Vines pruning (kg/ha)	1,150	"Pruning Biomass Potential in Italy Related to Crop Characteristics, Agricultural Practices and Agro-Climatic Conditions" Luigi Pari, Vincenzo Alfano, Daniel Garcia-Galindo, Alessandro Suardi and Enrico Santangelo, (2018)
C content of vines pruning (%)	46	"Pruning Biomass Potential in Italy Related to Crop Characteristics, Agricultural Practices and Agro-Climatic Conditions" Luigi Pari, Vincenzo Alfano, Daniel Garcia-Galindo, Alessandro Suardi and Enrico Santangelo, (2018) + Anđelini, D.; Cvitan, D.; Prelac, M.; Pasković, I.; Černe, M.; Nemet, I.; Major, N.; Goreta Ban, S.; Užila, Z.; Zubin Ferri, T.; et al. "Biochar from Grapevine-Pruning Residues Is Affected by Grapevine Rootstock and Pyrolysis Temperature." Sustainability (2023), 15, 4851, https://doi.org/10.3390/su15064851

Based on this information, the amount of C derived from vines pruning residues is 0.53 tC/ha that turns into 1.94 t CO_2/ha when residues are burnt in the open field, a value obtained by multiplying the Carbon content by 44/12, the molecular conversion ratio, assuming that the combustion is complete.

Three farms out of four were burning residues during the baseline scenario. The total tons CO_2 per farm derived from pruning residues burning is reported in Tab. 6 based on the vineyards surface of each farm.

Tab. 6: Total emissions CO_2 (t) derived from pruning residues burning in each project farm

Farm	CO_2 emissions from pruning residues burning (t)
ALBOLA	96.98
MONTEMASSI	96.98
SAN FELICE	290.95
RUFFINO	0

3.3 Emissions from pesticides production

The CO_2 emissions from plant protection products (herbicides, insecticides, fungicides, etc) were calculated following the methodology described in the ISCC EU 205 Greenhouse Gas Emissions, Version 4.1 – 2024.

Calculations are based, for each plant protection product, on the content of active ingredient (kg/kg of pesticide). The active ingredient should then be multiplied by the Emission Factors (EF) (Tab. 7).

If the exact factory supplying the pesticide is not known, standard EF values should be used as provided for in Annex IX of the IR (IMPLEMENTING REGULATION (EU) 2022/996 of 14 June 2022 on rules to verify sustainability and greenhouse gas emissions saving criteria and low indirect land-use change-risk criteria).

The farms participating in the project are organic farms and therefore mainly used Copper- and Sulphur-based pesticides, which are not part of the above-mentioned Annex IX of the IR. Also, San Felice farm, during the year before the transition to organic farming, used pesticides that were not found in the Annex IX of the IR.

Therefore, EF for pesticides were taken from the literature as reported in Tab. 7.

EF were then multiplied by the amount of active ingredient used in each parcel of the farm as declared in the farm registries.

Tab. 7: Emission Factors for pesticides

Active ingredient	EF (Kg CO_2e/Kg active ingredient)	References
Potassium carbonate	2.38	CarbonCloud's agricultural model - CarbonCloud
Potassium bicarbonate	2.38	CarbonCloud's agricultural model - CarbonCloud
Sodium bicarbonate	1.4	CarbonCloud's agricultural model - CarbonCloud
Copper	1	Catalogo Manica Agrofarmaci 2020 (https://www.manica.com/wp-content/uploads/2020/01/Catalogo_Manica_Agrofarmaci_2020_web.pdf)
Sulfate	1.53	CarbonCloud's agricultural model - CarbonCloud
Fungicides	14.31	R. Lal* March 2004 - Carbon emission from farm operations- Environment International 30 (2004) 981– 990 (1)
Herbicides	23.12	R. Lal* March 2004 - Carbon emission from farm operations- Environment International 30 (2004) 981– 990 (1)
Insecticides	18.71	R. Lal* March 2004 - Carbon emission from farm operations- Environment International 30 (2004) 981– 990 (1)

3.4 **Emissions from the production of seeds for green manure**

CO_2 emissions from green manure seeds were calculated as described in the ISCC EU 205 Greenhouse Gas Emissions, Version 4.1 – 2024 based on the equation [Eq. 4]:

$$EM_{input} = input \left[\frac{kg}{ha * yr}\right] * EF_{input} \left[\frac{kg\ CO_2 eq}{kg}\right] \quad \text{[Eq. 4]}$$

Where EM_{input} refers to seeds. The amount of green manure seeds used by farms were retrieved from the annual farm registry for each field.

Even in this case, as per pesticides, the methodology suggests retrieving EF values from the standard values set out in Annex IX of the IR. However, if the appropriate seeding material cannot be found, values should be taken from the literature, and more specifically from:

- version 5 of JEC-WTW report,
- EcoInvent database,
- official sources, such as Intergovernmental Panel on Climate Change (IPCC), International Energy Agency (IEA) or governments,
- other reviewed sources of data, such as E3 database, GEMIS database,
- peer-reviewed publications,
- duly documented own estimates.

The seeds used for green manure in the project farms were: field beans, barley, clover and mixed grass and mixed legumes (Tab. 2 and 3). Considering that in the Annex IX of the IR not all these plant varieties were present, EF were retrieved from the AGRIBALYSE 3.2 (Tab. 8) database (https://entrepot.recherche.data.gouv.fr/dataset.xhtml?persistentId=doi:10.57745/XTENSJ) which is the open-access database, produced by the French government, specialised in agricultural LCA analysis. This database is commonly used in place of the EcoInvent, when this database is not available to LCA operators due to its high cost.

Tab. 8: Emission Factors for green manure seeds production

Seed type	EF from seed production	Reference	
Field beans	0.30	AGRIBALYSE 3.2	https://entrepot.recherche.data.gouv.fr/dataset.xhtml?persistentId=doi:10.57745/XTENSJ
Barley	0.46	AGRIBALYSE 3.2	https://entrepot.recherche.data.gouv.fr/dataset.xhtml?persistentId=doi:10.57745/XTENSJ
Mix	0.45	AGRIBALYSE 3.2	https://entrepot.recherche.data.gouv.fr/dataset.xhtml?persistentId=doi:10.57745/XTENSJ
Clover	0.25	AGRIBALYSE 3.2	https://entrepot.recherche.data.gouv.fr/dataset.xhtml?persistentId=doi:10.57745/XTENSJ
Festuca Ovina	0.46	AGRIBALYSE 3.2	https://entrepot.recherche.data.gouv.fr/dataset.xhtml?persistentId=doi:10.57745/XTENSJ

3.5 Emissions from diesel fuel used by agricultural machinery and electricity used for irrigation

The diesel fuel used by agricultural machinery was estimated starting from the diesel consumption registered by the farms in their accountability registries (L/year ha).

Liters were then multiplied by the Emission Factor 3.14 (APAT, 2003), for each farm, based on the overall agricultural area (Tab. 9).

Tab. 9: Calculations of emissions from diesel fuel used by agricultural machinery

Farm	Amount diesel (L/ha)	Amount diesel (kg/ha)	EF	Emissions (Kg CO_2eq/ha)	Total farm diesel emission (Kg CO_2eq/farm)
ALBOLA	373	309	3.14	971	48,559
MONTEMASSI	344	286	3.14	897	44,850
RUFFINO	450	374	3.14	1173	98,514
SAN FELICE	460	382	3.14	1199	179,828

The emissions deriving from electricity consumption, due to the vineyard irrigation were calculated only for Montemassi and Ruffino, because the other two project farms do not irrigate. The volume of water consumed for irrigation (m^3) was provided by farm owners. The electricity consumption (kWh) is due to the use of pumps that are used to raise and distribute water in the vineyards. More specifically the formula [Eq. 5] was used to estimate kWh in each of the two farms:

$$\mathrm{kWh} = \frac{V \cdot \rho \cdot g \cdot H}{\eta \cdot 3.6 \times 10^6}$$ [Eq. 5]

where, V is the volume of water (m^3), ρ = is the water density (1000 kg/m^3), g = gravitational acceleration (9.81 m/s^2), H = lifting height (m), η = pump efficiency and the divisor (3.6×106) is used to convert joule into kWh.

kWh were then multiplied by 0.274, the EF for electricity in Italy for 2024 (kg CO_2eq/kWh) (iLCCT Database_2025, https://clinicaltrialcarbon.org/iLCCT%20Database_2025.xlsx).

4. **Calculation of Carbon removals**

4.1 General approach

The modelling approach was developed to estimate soil organic carbon (SOC) dynamics in the vineyard sites included in the project and to assess the potential effect of carbon farming practices introduced from 2024 onwards. The analysis combines direct soil measurements with process-based modelling using RothC 26.3, implemented in a modified Fortran version specifically adapted to better represent vineyard systems.

The methodological reference year is 2024. Soil sampling conducted in 2024 provides the observed SOC stock used to initialise and constrain the modelling exercise. Therefore, no reconstructed 2021 baseline is used. Instead, the modelling procedure establishes a site-specific equilibrium condition consistent with the SOC stock measured in 2024 and subsequently uses this condition as the starting point for the simulation of alternative carbon farming scenarios.

The spatial unit of analysis is the vineyard plot or homogeneous management unit. Where relevant, vineyards were divided into two strata reflecting different management or site conditions. SOC was assessed for the 0–30 cm soil layer, and results are expressed primarily as SOC stock in Mg C ha^{-1} and as changes in SOC relative to the 2024 baseline. Changes in carbon stock can subsequently be converted into CO_2 equivalents using the factor 44/12.

4.2 Field sampling and soil data

A soil sampling campaign was carried out in 2024 in all monitored vineyards. Two representative strata were identified within each farm, reflecting differences in management conditions or spatial characteristics. Each stratum was characterised through replicated soil sampling, with 12 samples per stratum.

The main soil variables used for modelling were SOC concentration, bulk density and clay content. Coarse fragment content was also considered where available. Soil organic carbon stocks were calculated for the 0–30 cm layer from measured SOC concentration and bulk density, taking the sampled soil volume into account.

The replicated sampling design served two purposes. First, it provided the mean SOC stock used as the reference condition for each vineyard stratum in 2024. Second, it allowed measurement variability to be quantified. The uncertainty associated with the observed SOC stock was expressed through the 95% confidence interval of the mean, which was subsequently used to assess the plausibility and consistency of model simulations.

The 2024 SOC measurement is therefore not simply an observation used for a posteriori validation. It represents the central empirical constraint for model initialisation and defines the baseline against which future carbon sequestration is evaluated.

4.3 Climate and management information

RothC operates at a monthly time step and requires relatively limited climatic information. Monthly mean air temperature, precipitation and potential evapotranspiration were compiled for each site. Irrigation, when present and documented, was incorporated into the water balance as an addition to rainfall.

Management information included soil cover and the quantity and timing of carbon returned to the soil from vegetation and organic amendments. Carbon inputs were defined on a monthly basis to reproduce, as realistically as possible, the seasonal distribution of biomass production and return.

The main sources of carbon considered were:

- herbaceous biomass from spontaneous vegetation or cover crops;
- woody pruning biomass associated with the vineyard system, where retained in or returned to the soil;
- external organic amendments such as manure or compost.

Pruning material that is removed or burned is not considered as an input to the soil carbon system. Only biomass that actually reaches or remains in the soil is included in the carbon balance.

Particular attention was given to the estimation of annual carbon inputs because this represents one of the most influential and uncertain inputs in RothC applications. Available farm information and field observations were integrated with values derived from peer-reviewed literature on Mediterranean vineyard systems.

4.4 RothC model and modification for vineyard systems

The RothC model (Coleman and Jenkinson, 1996, 1999; Jenkinson et al., 1999), simulates SOC dynamics and has been tested in a large range of pedoclimatic conditions and cropping system management. The model requires relatively easily available inputs and produces reliable and accurate simulations (Falloon and Smith, 2002; Skjemstad et al., 2004; Guo et al., 2007; Ludwig et al., 2007, 2010; Nieto et al., 2010; Francaviglia et al., 2012; Farina et al., 2013, 2017, 2021; Robertson and Nash, 2013). Soil C is split into five pools: four active compartments, Decomposable Plant Material (DPM), Resistant Plant Material (RPM), Microbial Biomass (BIO) and Humified Organic Matter (HUM), each decomposing by a first order kinetics and specific decomposition rate (years-1), and one inert organic matter pool (IOM). All C inputs, from plants or external organic fertilizers, are split between DPM and RPM, with a variable ratio depending on the type of material. Both DPM and RPM decompose to form CO_2 (lost from the system), BIO and HUM, depending on soil clay content (Coleman and Jenkinson, 1999).

The standard version of RothC assumes a single DPM/RPM ratio for fresh plant material entering the soil. This is a limitation for perennial cropping systems such as vineyards because herbaceous vegetation and vine-derived woody material may enter the soil simultaneously but differ considerably in their decomposability.

For this reason, the Fortran implementation used in the project was modified to allow two independent plant carbon inputs (as in Deligios et al., 2021):

- an herbaceous carbon input, characterised by a DPM/RPM ratio of 1.44;
- a woody carbon input, characterised by a DPM/RPM ratio of approximately 0.35.

External organic amendments were maintained as a separate input category and partitioned among the RothC pools according to the coefficients assigned to the specific organic material.

This modification changes only the way different types of carbon inputs are introduced into the model. The original RothC decomposition equations, turnover constants and active SOC pools were not modified. The adaptation therefore improves the representation of the vineyard system without introducing additional fitted decomposition parameters.

4.5 Model implementation and R–Fortran workflow

The simulations were performed using the modified Fortran version of RothC, while an R-based workflow was developed to automate data preparation, model execution and output processing.

The R scripts were used to import soil, climate and management information, perform consistency and quality checks, calculate auxiliary variables, prepare the input files required by RothC and launch the Fortran executable. The same workflow was subsequently used to import model outputs, organise results by vineyard and stratum, and generate tables and graphical representations of SOC trajectories.

The use of R did not modify the internal functioning of RothC. Its purpose was to provide a reproducible and transparent interface for performing multiple simulations under identical computational procedures and to minimise manual manipulation of input and output files.

4.6 Model initialisation and equilibrium procedure

Because measurements of the individual RothC carbon pools were not available, the model was initialised through a spin-up procedure.

During spin-up, a representative monthly climatic sequence was repeatedly cycled while baseline management and carbon inputs were maintained constant. Mean monthly climate conditions derived from the available historical climatic period were used to avoid the equilibrium condition being determined by an anomalous individual year.

The model was repeatedly run until the active SOC pools reached a stable condition. Equilibrium was considered achieved when the change in total SOC between two consecutive simulation cycles was less than 0.01 Mg C ha^{-1}.

The inert organic matter pool was estimated from total SOC using the empirical relationship proposed by Falloon and co-workers and was kept fixed during the simulations. RothC decomposition parameters and soil properties were not adjusted during the spin-up procedure.

The equilibrium procedure was applied independently to each vineyard stratum because the measured SOC stocks, soil properties and management-related carbon inputs differed among sites.

4.7 Site-specific carbon input adjustment

An inverse modelling approach was used to identify the amount of annual carbon input required to maintain an SOC stock compatible with that measured in 2024.

Initial estimates of carbon inputs were derived from documented management practices and literature values representative of vineyard systems. Carbon-input magnitudes were then varied within agronomically plausible ranges until the modelled equilibrium SOC was sufficiently close to the SOC stock measured in 2024.

This procedure should not be interpreted as a calibration of RothC decomposition parameters. No decomposition constants, temperature functions, moisture functions or clay-dependent partitioning parameters were fitted to individual sites. Only the magnitude of the external carbon input was adjusted.

The resulting carbon input therefore represents a model-derived estimate of the annual C input required to sustain the observed 2024 SOC stock under the assumed equilibrium conditions. It should not be interpreted as an exact reconstruction of historical carbon inputs.

This distinction is particularly important because detailed long-term measurements of biomass inputs are generally unavailable for commercial vineyards. Inverse use of RothC provides a parsimonious way of establishing an internally consistent baseline without introducing poorly constrained changes to the model structure. RothC can indeed be used in this inverse mode to estimate the carbon input needed to maintain an observed SOC stock when long-term SOC observations are unavailable.

4.8 The 2024 baseline

The 2024 soil sampling represents the project baseline.

For each vineyard stratum, the measured 2024 SOC stock and its uncertainty are associated with the equilibrium state obtained through the spin-up procedure. The equilibrium carbon input derived for each site defines the baseline management condition, i.e. the level of organic carbon return required by RothC to maintain the observed SOC stock.

The simulation of changes attributable to carbon farming practices starts from the 2024 baseline condition.

The baseline may therefore be expressed conceptually as:

$SOC_{baseline}$ = observed/model-consistent SOC stock in 2024

and future additional SOC is calculated as:

$\Delta SOC(t) = SOC_{project(t)} - SOC_{baseline\ scenario(t)}$

where both the project and baseline trajectories originate from the same 2024 starting condition.

This provides a clear separation between the observed initial stock and the additional change resulting from modified management after project implementation.

4.9 Simulation of carbon farming scenarios

Following establishment of the 2024 baseline, the agreed management scenarios were simulated by modifying only the management variables directly affected by carbon farming practices.

Depending on the specific vineyard and intervention, changes may include increased herbaceous biomass production from cover crops or spontaneous vegetation, increased retention of plant residues, application of compost or other organic amendments, changes in soil-cover duration, or documented changes in irrigation.

All other site characteristics and model parameters remain identical between baseline and project scenarios. This ensures that differences in simulated SOC trajectories can be attributed to the management practices represented in the scenarios rather than to changes in model parameterisation.

The baseline scenario represents continuation of the management condition associated with the 2024 reference stock. Project scenarios represent progressively modified carbon-return strategies implemented from 2024 onwards.

For every scenario, plant and organic amendment inputs are allocated monthly according to the expected timing of biomass production, residue return and amendment application. Keeping the temporal distribution of carbon inputs explicit is important because RothC operates at monthly resolution and decomposition depends on seasonal temperature and moisture conditions.

4.10 Treatment of uncertainty

Two main sources of uncertainty are explicitly considered: measurement uncertainty in SOC stocks and uncertainty in carbon-input estimates.

Measurement uncertainty is quantified directly from replicated soil sampling. For each stratum, the variability among the 12 samples is used to calculate the confidence interval around mean SOC stock. This provides a site-specific indication of the minimum SOC change that may be detectable relative to the variability of the baseline measurement.

Carbon-input uncertainty is addressed by restricting input adjustment and scenario definition to agronomically realistic ranges supported by measured data, management information and published literature. Rather than modifying RothC parameters to obtain agreement with field observations, plausible carbon-input values are explored while the model structure remains unchanged.

Structural model uncertainty is not explicitly quantified in the current approach. The uncertainty analysis therefore focuses primarily on field measurement uncertainty and uncertainty associated with the estimation of carbon inputs.

This distinction is important when interpreting predicted sequestration. A modelled increase in SOC may be meaningful from a process-modelling perspective but may initially remain smaller than the uncertainty associated with field measurements. For this reason, both projected SOC change and baseline measurement uncertainty should be considered when evaluating future monitoring results.

4.11 Model outputs

The principal output is the simulated SOC stock for each vineyard stratum and management scenario over time.

The main indicators derived from the simulations include:

- SOC stock at the 2024 baseline;
- annual SOC stock under baseline management;
- annual SOC stock under carbon farming scenarios;
- additional SOC relative to the baseline scenario;
- cumulative SOC sequestration over the assessment period;
- corresponding CO_2 removal calculated using the 44/12 conversion factor;
- mean annual CO_2 removal;
- time required to achieve selected increments in SOC;
- time required for the predicted SOC change to exceed the uncertainty associated with the baseline measurement.

Results can be reported annually, although the underlying RothC calculations are performed monthly. This allows both long-term trends and the progressive accumulation of additional SOC to be examined.

Particular attention is given to additionality. Carbon sequestration credited to a project scenario corresponds to the difference between the SOC trajectory under the new management practice and the trajectory expected if the baseline management condition were maintained, rather than simply to the absolute SOC stock present in the soil.

4.12 Quality assurance and quality control

A common QA/QC procedure is applied to all vineyard simulations to ensure comparability and reproducibility.

Checks include verification of SOC units, bulk density, soil depth and clay content; completeness and plausibility of climate data; documentation of the procedures used to estimate carbon inputs; consistency of monthly and annual carbon-input totals; and verification of soil-cover and irrigation information.

The modelling workflow also records information related to model version, simulation convergence and execution. Replicated sampling and the statistical calculation of mean SOC, variability and confidence intervals are documented for each stratum.

Sensitivity and uncertainty should receive particular attention for variables known to strongly influence SOC stock estimates and RothC outputs, especially carbon inputs, bulk density, stone fraction and water inputs.

4.13 Overall methodological rationale

The methodology combines direct measurement and modelling while limiting the number of assumptions introduced into RothC.

The measured 2024 SOC stock provides the empirical anchor for each vineyard stratum. Spin-up is used to establish a consistent distribution of carbon among RothC pools and to identify the level of carbon input capable of sustaining the measured SOC stock. Model parameters controlling decomposition are not fitted individually to farms.

From this common --2024 starting point--, future baseline and carbon farming scenarios are simulated using identical climate, soil characteristics and RothC decomposition parameters, while management-related carbon inputs are modified according to the practices being evaluated.

The approach therefore allows the effect of carbon farming to be assessed as the additional SOC accumulated relative to continued baseline management, while explicitly recognising both uncertainty in the initial SOC measurement and uncertainty associated with the estimation of carbon inputs.

The modified model further improves the representation of vineyards by allowing herbaceous and woody plant materials, characterised by different decomposability, to enter the soil simultaneously. This adaptation is particularly relevant for perennial systems combining vines, spontaneous vegetation or cover crops and, where applicable, organic amendments, while preserving the fundamental structure and parameterisation of RothC.

5. **Results**

In Tab. 10, baseline GHG emissions are reported for each farm and each source assessed. The highest source of emissions was, in all farms, the combustion of the vineyards pruning residues, in case this practice was applied. In Ruffino, were pruning residues were not burnt even in the baseline, the highest emissions were associated with diesel consumption. The emissions estimated for the 2024-2025, the first year of Carbon farming practices implementation, are lower in all the three farms that stopped burning residues (Tab. 11) while slightly increased in Ruffino farm.

Tab. 10: GHG emissions from the project farms divided per GHG source and year of baseline scenario.

		Fertilizer		Green manure		Burning	Crop residue	Diesel	Pesticides	Irrigation	TOTAL FARM EMISSIONS
	CROP YEAR	Total N_2O emission KG CO2 eq/ha	Total N2O emission from managed soil (emission KG CO2 eq x farm)	CO2 emissions due to seeds production (kg CO2/field)	CO2eq emisssions from biomass (kg CO2 eq/field)	Abbruciature (burning kg Co2 per farm) o	Crop residue N2O emissions (kg CO2 eq per farm)	Tatal Farm disesel emission (kg CO2 eq per farm)	Total farm Pesticides (kg CO2 eq per farm)	Tota farm Irrigation (kg CO2 eq per farm)	TOTAL FARM EMISSION - (kg CO2 eq per farm)
ALBOLA	21-22	1,287	3,735	603	13,880	96,983	0	54,968	2,562	0	172,732
	22-23	3,492	8,726	892	9,610	96,983	0	54,968	3,468	0	174,647
	23-24	1,098	2,622	727	7,605	96,983	0	54,968	4,322	0	167,227
	Average	***1,959***	***5,028***	***741***	***10,365***	***96,983***	***0***	***54,968***	***3,451***	***0***	***171,535***

		Fertilizer		Green manure		Burning	Crop residue	Diesel	Pesticides	Irrigation	TOTAL FARM EMISSION
	CROP YEAR	Total N_2O emission KG CO2 eq/ha	Total N2O emission from managed soil (emission KG CO2 eq x farm)	CO2 emissions due to seeds production (kg CO2/field)	CO2eq emisssions from biomass (kg CO2 eq/field)	Abbruciature (burning kg Co2 per farm) o	Crop residue N2O emissions (kg CO2 eq per farm)	Farm disesel emission (kg CO2 eq per	Total farm Pesticides (kg CO2 eq per farm)	Tota farm Irrigation (kg CO2 eq per farm)	TOTAL FARM EMISSION - (kg CO2 eq per farm)
MONTEMASSI	21-22	832	2,395	1,474	18,122	96,983	0	44,850	2,051	533.3	166,409
	22-23	1,279	3,800	1,416	20,152	96,983	0	44,850	2,913	533.3	170,647
	23-24	1,244	3,972	1,564	22,262	96,983	0	44,850	3,035	533.3	173,199
	Average	***1,118***	***3,389***	***1,485***	***20,179***	***96,983***	***0***	***44,850***	***2,666***	***533***	***170,085***

		Fertilizer		Green manure		Burning	Crop residue	Diesel	Pesticides	Irrigation	TOTAL FARM EMISSION
	CROP YEAR	Total N_2O emission KG CO2 eq/ha	Total N2O emission from managed soil (emission KG CO2 eq x farm)	CO2 emissions due to seeds production (kg CO2/field)	CO2eq emisssions from biomass (kg CO2 eq/field)	Abbruciature (burning kg Co2 per farm) o	Crop residue N2O emissions (kg CO2 eq per farm)	Farm disesel emission (kg CO2 eq per	Total farm Pesticides (kg CO2 eq per farm)	Tota farm Irrigation (kg CO2 eq per farm)	TOTAL FARM EMISSION - (kg CO2 eq per farm)
RUFFINO	21-22	5,649	21,165	0	0	0	0	98,514	5,603	1,792	127,074
	22-23	4,805	15,820	0	0	0	0	98,514	12,287	1,792	128,413
	23-24	5,215	16,832	0	0	0	0	98,514	7,680	1,792	124,818
	Average	***5,223***	***17,939***	***0***	***0***	***0***	***0***	***98,514***	***8,523***	***1,792***	***126,768***

		Fertilizer		Green manure		Burning	Crop residue	Diesel	Pesticides	Irrigation	TOTAL FARM EMISSION
	CROP YEAR	Total N_2O emission KG CO2 eq/ha	Total N2O emission from managed soil (emission KG CO2 eq x farm)	CO2 emissions due to seeds production (kg CO2/field)	CO2eq emisssions from biomass (kg CO2 eq/field)	Abbruciature (burning kg Co2 per farm) o	Crop residue N2O emissions (kg CO2 eq per farm)	Farm disesel emission (kg CO2 eq per	Total farm Pesticides (kg CO2 eq per farm)	Tota farm Irrigation (kg CO2 eq per farm)	TOTAL FARM EMISSION - (kg CO2 eq per farm)
SAN FELICE	21-22	8,999	18,990	1,495	19,151	290,950	0	179,828	12,976	0.0	**523,389**
	22-23	8,076	19,407	0	0	290,950	0	179,828	14,653	0.0	**504,838**
	23-24	14,780	36,728	2,016	25,396	290,950	0	179,828	11,904	0.0	**546,821**
	Average	***10,618***	***25,042***	***1,170***	***14,849***	***290,950***	***0***	***179,828***	***13,178***	***0***	***525,016***

Tab. 11: GHG emissions from the project farms divided per GHG source for year 2024-2025, the first year of Carbon farming project implementation.

		Fertilizer		Green manure		Burning	Crop residue	Diesel	Pesticides	Irrigation	TOTAL FARM EMISSION
	CROP YEAR	Total N_2O emission KG CO2 eq/ha	Total N2O emission from managed soil (emission KG CO2 eq x farm)	CO2 emissions due to seeds production (kg CO2/field)	CO2eq emisssions from biomass (kg CO2 eq/field)	Abbruciature (burning kg Co2 per farm)	Crop residue N2O emissions (kg CO2 eq per farm)	Tatal Farm disesel emission (kg CO2 eq per farm)	Total farm Pesticides (kg CO2 eq per farm)	Tota farm Irrigazion (kg CO2 eq per farm)	TOTAL FARM EMISSION - (kg CO2 eq per farm)
ALBOLA	24-25	2,510	6,998	1,164	10,471	0.0	1,965.3	54,968	3,095	0	78,662
MONTEMASSI	24-25	5,379	13,372	2,304	31,033	0	1,965.3	44,850	5,109	533.3	99,167
RUFFINO	24-25	7,089	20,889	0	0	0	3,302	98,514	5,260	1,792	129,757
SAN FELICE	24-25	20,314	50,653	3,473	46,292	0	5,896	179,828	7,194	0.0	293,335

Tables 12 and 13 summarize the modelled changes in soil organic carbon over the actual project assessment period, from October 2024 to April 2027. Table 12 reports SOC changes on an area basis, expressed as t C ha^{-1} and the corresponding t CO_2 ha^{-1}. The 2024 values refer only to the October–December period, while the 2027 values include only January to April; 2025 and 2026 represent complete calendar years.

The results show clear differences among farms and over time. Negative changes were simulated during the initial October–December 2024 period at Albola, Montemassi and San Felice, whereas Ruffino showed a positive SOC change. Most of the SOC accumulation occurred during 2025 and 2026. During the first three months of 2027, changes were small and slightly negative at most sites, reflecting the seasonal variability of SOC dynamics simulated by RothC rather than a reversal of the overall sequestration trend.

When the whole October 2024–April 2027 period is considered, cumulative SOC increases ranged from approximately 0.93 t C ha^{-1} at Albola to 3.12 t C ha^{-1} at San Felice. Montemassi accumulated about 2.88 t C ha^{-1}, while Ruffino reached approximately 1.97 t C ha^{-1}.

Table 13 scales these changes to the vineyard area represented by each farm. Although Ruffino did not show the highest SOC increase per hectare, its larger area (145 ha) resulted in the highest total projected carbon accumulation, approximately 286 t C, corresponding to about 1,048 t CO_2. San Felice followed with approximately 262 t C, or 962 t CO_2, while Montemassi and Albola accounted for approximately 529 and 194 t CO_2, respectively. Across the 335.6 ha considered, the modelled cumulative SOC increase was approximately 745 t C, corresponding to about 2,733 t CO_2 over the October 2024–March 2027 assessment period.

Tab. 12: Modelled changes in soil organic carbon and corresponding CO_2 equivalents from October 2024 to March 2027

Period	**Farm**	**ΔC (t C ha^{-1})**	**ΔCO_2 eq (t CO_2 ha^{-1})**
Oct–Dec 2024	Albola	-0.67	-2.46
Oct–Dec 2024	Montemassi	-0.63	-2.30
Oct–Dec 2024	Ruffino	1.15	4.20
Oct–Dec 2024	San Felice	-0.23	-0.84
2025	Albola	0.89	3.27
2025	Montemassi	1.89	6.92
2025	Ruffino	0.57	2.10
2025	San Felice	1.79	6.55
2026	Albola	0.81	2.96
2026	Montemassi	1.68	6.16
2026	Ruffino	0.55	2.03
2026	San Felice	1.57	5.74
Jan–Apr 2027	Albola	0.29	1.06
Jan–Apr 2027	Montemassi	0.42	1.52
Jan–Apr 2027	Ruffino	0.10	0.38
Jan–Apr 2027	San Felice	0.50	1.82

Tab. 13: Cumulative modelled SOC change and CO_2 equivalent by farm, October 2024–April 2027

Farm	**Area (ha)**	**Cumulative ΔC (t C ha^{-1})**	**Total ΔC (t C $farm^{-1}$)**	**Total CO_2 eq (t CO_2 $farm^{-1}$)**
Albola	56.6	1.32	74.66	273.76
Montemassi	50.0	3.36	167.78	615.20
Ruffino	145.0	2.37	344.35	1,262.63
San Felice	84.0	3.63	304.55	1,116.67
Total	**335.6**	—	**891.34**	**3,268.26**

In Tab. 14 the overall budget between GHG emissions and carbon removals is reported, showing an overall GHG emission mitigation of the project of 4,263 tCO_2e.

Tab. 14: Budget between GHG emissions and Carbon removals in the baseline and first year of CF project in the four pilot farms

Year	Baseline emissions (tCO_2e)	Project emissions (tCO_2e)	Estimated leakage (tCO_2e)	Reductions (tCO_2e)	Removals (tCO_2e)	Total GHG emission mitigations (tCO_2e)
18/10/2024 to 31/12/2024	166	83	0	83	285	368
01/01/2025 to 31/12/2025	993	661	0	332	1,386	1,718
01/01/2026 to 31/12/2026	993	661	0	332	1,253	1,585
01/01/2027 to 31/08/2027	662	441	0	221	371	592
Total	2,814	1,846	0	968	3,295	4,263

6. **References**

1. ISCC EU 205 Greenhouse Gas Emissions, Version 4.1 - 2024
2. VERRA VM0042 methodology, version 2.0
3. Andrew J. Curtright, Diana Zapata-Rojas, William R. Horwath, Xia Zhu-Barker, Quantifying nitrogen provisioning and release from cover crops in walnut orchards, Agriculture, Ecosystems & Environment, Volume 383, 2025, 109529, ISSN 0167-8809, https://doi.org/10.1016/j.agee.2025.109529. (https://www.sciencedirect.com/science/article/pii/S0167880925000611)
4. "Pruning Biomass Potential in Italy Related to Crop Characteristics, Agricultural Practices and Agro-Climatic Conditions" Luigi Pari, Vincenzo Alfano, Daniel Garcia-Galindo, Alessandro Suardi and Enrico Santangelo, (2018)
5. Anđelini, D.; Cvitan, D.; Prelac, M.; Pasković, I.; Černe, M.; Nemet, I.; Major, N.; Goreta Ban, S.; Užila, Z.; Zubin Ferri, T.; et al. "Biochar from Grapevine-Pruning Residues Is Affected by Grapevine Rootstock and Pyrolysis Temperature." Sustainability (2023), 15, 4851. https://doi.org/10.3390/su15064851
6. IPCC guidelines for National Greenhouse Gas Inventories, Volume 4, Chapter 11, http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/4_Volume4/V4_11_Ch11_N2O&CO2.pdf and "2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories".
7. R. Lal- March 2004 - Carbon emission from farm operations- Environment International 30 (2004) 981– 990 (1)
8. APAT 2003. Analisi dei fattori di emissione di CO2 dal settore dei trasporti. Ilacqua M., Contaldi M., Rapporti n°28/2003
9. Coleman, K., Jenkinson, D.S., (1996). RothC-26.3 - A model for the turnover of carbon in soil. In: D.S. Powlson, P. Smith, J.U. Smith (Eds.), Evaluation of Soil Organic Matter Models Using Existing Long-Term Datasets. NATO ASI Series I. Springer-Verlag, Heidelberg, pp. 237-246.
10. Coleman, K., Jenkinson, D.S., (1999). RothC-26.3, A Model for the Turnover of Carbon in Soil: Model Description and User's Guide. Lawes Agricultural Trust, Harpenden, UK.Coleman, K., Milne, A., & Prout, J. (2024).
11. Coleman, K., Prout, J., & Milne, A. (2024). RothC Official Rothamsted Research Release (v1.0.0) (v1.0.0). Zenodo. https://doi.org/10.5281/zenodo.10707407
12. Deligios, P. A., Farina, R., Tiloca, M. T., Francaviglia, R., & Ledda, L. (2021). C-sequestration and resilience to climate change of globe artichoke cropping systems depend on crop residues management: C-sequestration and resilience to climate change of globe artichoke cropping systems depend on crop residues management. Agronomy for Sustainable Development, 41(2), 20.
13. Falloon, P. D., & Smith, P. (2000). Modelling refractory soil organic matter. Biology and fertility of soils, 30(5), 388-398.
14. Farina, R., Coleman, K., & Whitmore, A. P. (2013). Modification of the RothC model for simulations of soil organic C dynamics in dryland regions. Geoderma, 200, 18-30.

15. Farina, R., Marchetti, A., Francaviglia, R., Napoli, R., & Di Bene, C. (2017). Modeling regional soil C stocks and CO2 emissions under Mediterranean cropping systems and soil types. Agriculture, ecosystems & environment, 238, 128-141.
16. Francaviglia, R., Coleman, K., Whitmore, A. P., Doro, L., Urracci, G., Rubino, M., & Ledda, L. (2012). Changes in soil organic carbon and climate change–Application of the RothC model in agro-silvo-pastoral Mediterranean systems. Agricultural Systems, 112, 48-54
17. Guo, L., Falloon, P., Coleman, K., Zhou, B., Li, Y., Lin, E., Zhang, F., (2007). Application of the RothC model to the results of long-term experiments on typical upland soils in northern China. Soil Use and Management 23 (1), 63–70.
18. Jenkinson, D.S., Harris, H.C., Ryan, J., McNeill, a. M., Pilbeam, C.J., Coleman, K., (1999). Organic matter turnover in a calcareous clay soil from Syria under a two-course cereal rotation. Soil Biol. Biochem. 31, 687-693. doi:10.1016/S0038-0717(98)00157-6
19. Kaonga, M.L., Coleman, K., (2008). Modelling soil organic carbon turnover in improved fallows in eastern Zambia using the RothC-26.3 model. Forest Ecology and Management 256 (5), 1160–1166.
20. Kelly, R.H., Parton, W.J., Crocker, G.J., Grace, P.R., Klir, J., Korschens, M., Poulton, P.R., Richter, D.D., (1997). Simulating trends in soil organic carbon in long-term experiments using the century model. Geoderma 81 (1–2), 75–90.
21. Ludwig, B., Schulz, E., Rethemeyer, J., Merbach, I., Flessa, H., (2007). Predictive modelling of C dynamics in the long-term fertilization experiment at Bad Lauchstadt with the Rothamsted Carbon Model. European Journal of Soil Science 58 (5), 1155–1163.
22. Ludwig, B.,Hu, K.L., Niu, L.A., Liu, X.J., (2010).Modelling the dynamics of organic carbon in fertilization and tillage experiments in theNorth China Plain using the Rothamsted Carbon Model — initialization and calculation of C inputs. Plant and Soil 332 (1–2), 193–206.
23. Nieto, O.M., Castro, J., Fernández, E., Smith, P., (2010). Simulation of soil organic carbon stocks in a Mediterranean olive grove under different soil-management systems using the RothC model. Soil Use and Management 26 (2), 118–125.
24. Skjemstad, J.O., Spouncer, L.R., Cowie, B., Swift, R.S., (2004). Calibration of the Rothamsted organic carbon turnover model (RothC ver. 26.3), using measurable soil organic carbon pools. Australian Journal of Soil Research 42 (1), 79–88.
25. Skjemstad, J.O., Spouncer, L.R., Cowie, B., Swift, R.S.,(2004). Calibration of the Rothamsted organic carbon turnover model (RothC ver. 26.3), using measurable soil organic carbon pools. Australian Journal of Soil Research 42 (1), 79–88.
26. Smith, P., Smith, J.U., Powlson, D.S., McGill, W.B., Arah, J.R.M., Chertov, O.G., Coleman, K., Franko, U., Frolking, S., Jenkinson, D.S., Jensen, L.S., Kelly, R.H., Klein-Gunnewiek, H., Komarov, A.S., Li, C., Molina, J.A.E., Mueller, T., Parton, W.J., Thornley, J.H.M., Whitmore, A.P., (1997). A comparison of the performance of nine soil organic matter models using datasets from seven long-term experiments. Geoderma 81 (1–2), 153–225.