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LIFE VitiCaSe

Viticulture for Soil Organic Carbon Sequestration



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Author(s)
**Vanino S., Sannino G., Nino P., De Leo S., Parisse B.,
Alilla R., De Natale F., Farina R. (CREA)**

Contributor(s)
**Beccagli C., Andrenelli M. C., Trotta S., Veloccia M.,
Pennelli B., D'Alessandro R. (CREA)**



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Coordinator contact	Simona Palermo Simona.palermo@imageline.it Mobile: +39 348 6144978		
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Contributors for soil analysis	Beccagli C., Andrenelli M. C., Trotta S., Veloccia M., Pennelli B., D'Alessandro R.		

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Executive summary

This document describes the activities and results from the beginning of the project up to the conclusion of the first season of Sustainable Soil Management (SSM) practices implementation. Pilot farms started the implementation of sustainable agricultural practices, such as cover crops and the use of mycorrhizae, in October 2024. However, some farms have encountered problems, particularly due to adverse weather conditions in their specific areas.

Simultaneously, data collection is nearing completion. The collection of economic data required an integration of the initially collected information, and the farms have almost finished integrating the missing details.

In the upcoming growing season, farms will continue implementing the practices in the best possible way, and data will be collected for monitoring the effectiveness of the practices and their impact on emissions and soil health.

Acronyms

AgERA5: Agricultural ERA5

BAU: Business As Usual

BD: Bulk Density

C/N: Ratio of Carbon and Nitrogen

C: Control

FADN: Farm Accountancy Data Network

IT: Information Technology

LCC: Life Cycle Cost

N: Nitrogen

OC: Organic Carbon

pH: Acidity

SOC: Soil Organic Carbon

SSM: Sustainable Soil Management

T: Treatment

TOC: Total Organic Carbon

WP: Work Packages

Introduction

The main objective of WP4 in LIFE VitiCaSe is to apply a business model based on C-farming in vineyards, test its sustainability (technical feasibility and economic viability), and to use the innovative C-farming IT tool developed in WP3 to quantify or estimate the improvements in SOC levels.

The Work Package 4 is structured in the following way:

T4.1 – Define the baseline management (Business as usual) for each farm

T4.2 – Soil carbon baseline management

T4.3 – Operational design of pilot actions

T4.4 – Implementation of pilot actions

This report constitutes Deliverable 4.2 of the VitiCaSe project which aims to describe the activities carried out in the first 2 years of the project, by providing an overview of activities done in the 4 pilot farms in the Veneto and Toscana regions (Fig. 1).

A detailed description of the data collected and of the first results is given in the following sections.

The activities described in this project cover the period from **September 1, 2023, to October 31, 2025**.



Figure 1 - Location of pilot areas of the "VitiCaSe" project.

1. Methods

1.1 Design of soil sampling

Soil sampling took place in a pilot area of approximately 3 hectares per farm. Within each area, 24 plants were selected, divided into 3 control rows and 3 treatment rows. Around each selected plant, following a standard grid, 3 sub-samples (0-30 cm)—one near the plant and two in the inter-row—were taken to form 1 bulk sample.

On each farm, 24 bagged soil samples (each weighing approximately 500g) were collected. From this set, 12 samples underwent texture and fractionation analyses, and 12 samples underwent chemical analyses. Additionally, 24 undisturbed soil samples were collected from adjacent areas for physical and hydrological analyses, using a core sampler. The total sample count was 192 (4 farms * 48 samples), encompassing both the bagged and core samples. The soil samples were collected in March-April 2024, as described in Table 1.

In March 2025 (Table 1), mycorrhizal sampling took place at the Tenute Ruffino and Rocca di Montemassi farms. Soil cores were collected using cylinders near several grapevines. We dug to a depth of approximately 25 cm, aiming to include as many roots as possible.

Farms	Period-Soil sampling	Mycorrhizae sampling
Castello di Albola	19/3/2024	
San Felice	5/4/2024	
Rocca di Montemassi	20/3/2024	7/3/2025
Tenute Ruffino	4/4/2024	6/3/2025

Table 1 - Period of soil samples.

In the following sections, the description of the soil characteristics at each pilot farm is provided.

1.1.1 Soil sampling in Castello di Albola

Under the supervision of agronomist Jacopo Ferrari, the “Santa Caterina-Tettoia” vineyard was sampled. We selected the control area within the same parcel to ensure an identical slope. In this vineyard the inter-rows alternate natural grassing (tilled annually at 10 cm depth without layer inversion) and cover crop (faba bean). Soil samples were collected in 4 core drills: two next to the plant and two in the middle of the strip. The undisturbed soil samples for the bulk density assessment were collected with steel cylinders in the middle of the inter-row.

The following areas have been identified:

- **Control:** From row 1 to row 17
- **Treatment:** From row 18 to the end of the plot



Figure 2 - Soil sampling in Castello di Albola experimental area.

1.1.2 Soil sampling in San Felice

In collaboration with Leonardo Bellaccini, technical head of the farm, the “San Carlo” vineyard was identified as the most suitable for the sample collection.

This vineyard was established in 2000, featuring alternating rows with natural grassing and a fava bean cover crop (used for green manure). The control area was selected within the same plot.

The following areas have been identified:

- **Control:** From row 59 to the end of the plot.
- **Treatment:** From row 1 to row 58.



Figure 3 - Soil sampling in San Felice experimental area.

1.1.3 Soil sampling in Rocca di Montemassi

Under the supervision of agronomist Stefano Galbiati, the “Dogana1” vineyard have been identified as the most suitable for the sample collection.

This vineyard presented alternating rows of natural grassing and a cover crop of faba beans and barley (used for green manure). The control area was selected within the same plot.

The following areas have been identified:

- **Control:** From row 1 to row 19
- **Treatment:** From row 20 to the end of the plot (row 31)



Figure 4 – The Rocca di Montemassi experimental area

1.1.4 Soil sampling in Tenute Ruffino

Under the supervision of agronomist Mattia Tintinaglia, the “A1-GLERA 2009 FG5MP37” vineyard was identified as the most suitable for the sample collection.

The sampled vineyard featured grass cover in all rows. Typically, the rows should alternate between natural grassing and cover crop, but due to heavy rainfall during seeding periods, it hasn't been possible to sow the cover crops for over three years. The control area was selected within the same plot.

The following areas have been identified:

- **Control:** From row 18 to row 34
- **Treatment:** From row 1 to row 17.



Figure 5 - Soil sampling in Tenute Ruffino experimental area

1.2 Soil parameters

Soil physico-chemical parameters were analyzed as follows:

- **Soil texture** was determined by particle size analysis via sedimentation, in accordance with Stokes' Law, using a Sedigraph to quantify the relative proportions of sand, silt, and clay.
- **Bulk density** (g cm^{-3}) was measured using the core sampling method.
- **Soil pH** was determined in distilled water using a calibrated pH meter (inoLab® Multi 9310 IDS), following the ISO 10390 standard.
- **Soil organic carbon (SOC)** content (g kg^{-1}) was analyzed using a LECO TOC Analyzer (model RC-612; LECO Corporation, 1987).
- **Total nitrogen (N_{tot})** (g kg^{-1}) was quantified with a LECO FP-528 Nitrogen Analyzer (LECO Corporation, St. Joseph, MI, USA).
- **Macro- and micronutrient concentrations** were assessed by Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES, Thermo Scientific iCAP PRO), in accordance with the EPA Method 3035A for acid digestion.



Figure 6 - Soil samples in the CREA laboratory.

1.3 Carbon stock in the soil

The estimation of the soil organic carbon stock at the field level was calculated using as input the data collected in the field in Spring 2024: the carbon content, bulk density, rock fragment content and depth of a respective soil layer (30 cm).

The formula used is the follow:

$$\text{SOC}_i \text{ stock (Mg C ha}^{-1}\text{)} = \text{OC}_i \times \text{BD}_{\text{fine}i} \times (1 - \text{vG}_i) \times t_i \times 0.1$$

Where:

SOC_i = soil organic carbon stock (in Mg C ha^{-1}) of the depth increment i

OC_i = organic carbon content (mg C g soil^{-1}) of the fine soil fraction ($< 2 \text{ mm}$) in the depth increment

$\text{BD}_{\text{fine}i}$ = the mass of the fine earth per volume of fine earth of the depth increment i

$$\text{BD}_{\text{fine}i} = \frac{\text{dry soil mass [g]} - \text{coarse mineral fragment mass [g]}}{\text{soil sample volume [cm}^3\text{]} - \text{coarse mineral fragment volume [cm}^3\text{]}}$$

vG_i = the volumetric coarse fragment content of the depth increment i

t_i = thickness (depth, in cm), of the depth increment i

0.1 = conversion factor for converting mg C cm^{-2} to Mg C ha^{-1}

1.4 Acquisition and processing of climate data

For the implementation of the IT tool (WP3 activities), it was necessary to retrieve national-level climatic data and spatialize them to achieve homogeneous ground coverage.

AgERA5 (ECMWF) is a relatively new climate dataset specifically designed for agricultural applications. Among several meteorological gridded datasets covering Italy, the AgERA5 dataset has been selected for its spatial and temporal resolution, which is suitable for agrometeorological analyses, and also because it is bias-corrected. Another important strength consists in the

availability of the monthly reference evapotranspiration, according to the FAO Penman - Monteith method (as described in Allen et al., 1998), provided by FAO and derived from the daily AgERA5 data. With reference to the Italian area, as defined by the official administrative boundaries (Istat, 2019), and to the period 1979-2022, daily series of temperature and precipitation from AgERA5 data were retrieved through a specific Copernicus Climate Data Store (CDS) API and were aggregated at a monthly time scale, while for the reference evapotranspiration, monthly data (AgERA_ET0) were directly downloaded from the FAO portal. Both the selected datasets are available in EPSG:4326, and their main characteristics are reported in Table 2.

Name	Spatial resolution	Time resolution	Spatial coverage	Time coverage	Producer	Reference
AgERA5	0.1 degrees	daily	global land areas	1979 to last complete month end	ECMWF	Agrometeorological indicators from 1979 to present derived from reanalysis
AgERA_ET₀	0.1 degrees	monthly	global land areas, excluding Antarctica	1979 to last complete month end	AQUASTAT (FAO)	Reference evapotranspiration (Global - Monthly - ~10 km) - AgERA5 derived

Table 2 - The main characteristics of the chosen datasets. AgERA_ET0 only includes reference evapotranspiration data.

The AgERA5 data is provided by the CDS as Network Common Data Form (NetCDF-4) files. Data was read and handled in R (R-Core Team, 2018) by the *ncdf4* and raster packages. Daily data for precipitation (total precipitation) and temperature (24h mean) were extracted in raster format from NetCDF files and aggregated at a monthly scale, using the sum and mean functions, respectively. Temperature data was converted from Kelvin to Celsius units.

Precipitation, temperature, and evapotranspiration monthly raster data were then converted into three separate raster time-series (covering the entire 1979-2022 period) through the *rts* package of R. Due to a slight shift between the AgERA5 and the AgERA_ET0 grids, corresponding to half a cell, the latter dataset was resampled onto the AgERA5 grid, by applying a bilinear interpolation. Long-term monthly averages for each variable were calculated from the monthly series spanning the entire analysis period (1979-2022).

1.5 Economic and environmental data collection

We collected data from each pilot farm to conduct the environmental and economic assessment of vineyard production under different Sustainable Soil Management (SSM) practices aimed at improving carbon (C) stocking. The environmental focus on the pilot farms is based on Life Cycle Assessment (LCA) analysis, which aims to quantify the potential impacts—specifically CO₂-equivalent emissions and fossil resource consumption—of various SSM practices, including Business as Usual (BAU).

The focus of economic impacts on pilot farms is based on LCC (Life Cycle Cost) and FADN (<https://agridata.ec.europa.eu/extensions/FarmEconomyFocus/FADNDatabase.html>) methodology of different SSM practices (including BAU).

The definition of the appropriate indicators and data needed to perform the assessment:

- economic data to evaluate economic impact
- emission data to evaluate environmental impact.

Economic and emission data gathered, as well as the appropriate indicators and the related procedure for their calculation, has been described in detail in deliverables D6.1: “*Framework for environmental/economic assessment in pilot farms*”.

The following table summarizes the collected information and unit size from the pilot farms for the evaluation. Business as usual data were collected at the end of 2024 (agricultural year 2023/2024).

Table 3 - Economic data collected with relative unit size.

1. Production of grapes for wine	Economic Unit size	Physical Unit size
Crop production (CP): QL/HA	Q/ha	Q/ha
prize grape(P): €/ql	€/Ql	
2. Specific costs for:	€/ha	
a) Seeds and plants	€/ha	kg/ha
b) Fertilisers	€/ha	kg/ha
b) Manure	€/ha	kg/ha
c) Crop protection	€/ha	(kg-l-n)/ha
d) Water for irrigation	€/ha	mc/ha
e) Insurance	€/ha	
f) Certification	€/ha	
g) Contracting	€/ha	
h) Diesel	€/ha	l/ha
i) Electricity	€/ha	kwh/ha
j) Human work	€/ha	
k) Machinery	€/ha	

2. Results

2.1 Soil characteristics at Castello di Albola

The **soil texture** in the experimental area is primarily loamy, as shown in Table 2. The soil texture is consistent across both the control and treated areas. Based, also, on the soil characteristics described in Deliv.4.1, the soil is classified as Aquic Haploxerepts fine mixed mesic, WRB: Stagnic Cambisols (endoskeletal, clayic).

	Sand (%)	Clay (%)	Silt(%)
Treatment (T)	42 ± 3	18 ± 2	40 ± 2
Control (C)	41 ± 8	15 ± 4	44 ± 7
General	42 ± 6	16 ± 3	42 ± 5

Table 4 - Soil texture values of experimental area in Castello di Albola.

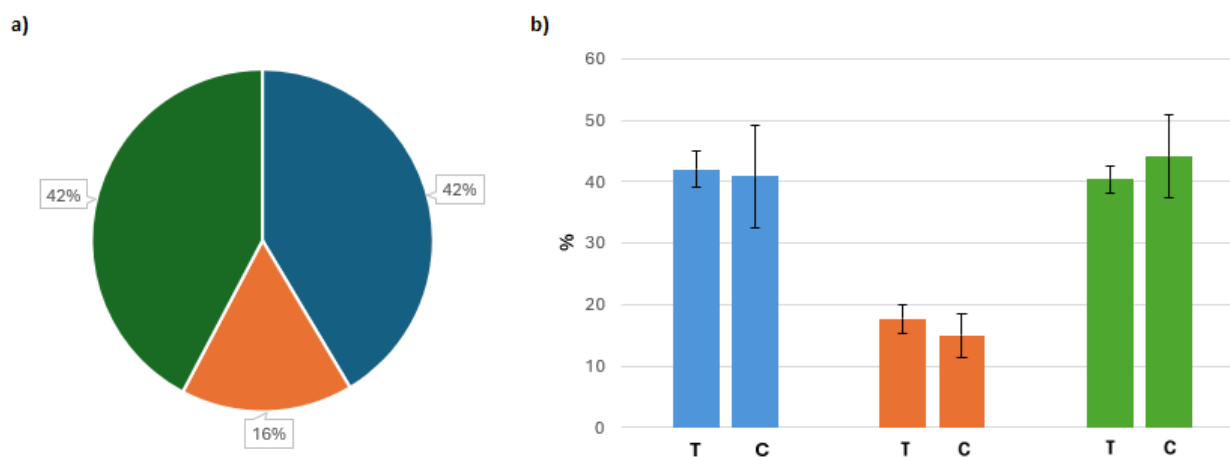


Figure 7 – a) General Soil texture of Castello di Albola soil (blue=sand, orange= clay, green = lime) b) Soil texture of Castello di Albola soil for Treatment(T) and Control(C) (blue=sand, orange= clay, green = silt)

Bulk density (BD), TOC, N, C/N ratio, and pH, are reported in Table 5:

	BD (g/cm ³)	OC	N	C/N	pH
Treatment (T)	1,2 ± 0,2	1,2 ± 0,2	0,14 ± 0,03	9,0 ± 0,9	7,65 ± 0,02
Control (C)	1,3 ± 0,2	1,4 ± 0,2	0,14 ± 0,02	9,5 ± 0,5	7,63 ± 0,07
General	1,3 ± 0,2	1,3 ± 0,2	0,14 ± 0,02	9,3 ± 0,8	7,64 ± 0,05

Table 5 - Bulk density (BD), Organic Carbon (OC), Nitrogen (N), Carbon and Nitrogen ratio (C/N), Acidity (pH) data of experimental area in Castello di Albola.

For **BD**, both the Treatment ($1.2 \pm 0.2 \text{ g/cm}^3$) and Control ($1.3 \pm 0.2 \text{ g/cm}^3$) areas exhibit relatively similar bulk densities, with the general average being $1.3 \pm 0.2 \text{ g/cm}^3$. These values suggest a moderate level of compaction.

Both Treatment (1.2 ± 0.2 for C; 0.14 ± 0.03 for N) and Control (1.4 ± 0.2 for C; 0.14 ± 0.02 for N) areas show comparable levels of **Organic Carbon and Nitrogen**. For a loamy soil, the total organic carbon value appears to be quite low.

The **Carbon Nitrogen (C/N) ratio** is consistent across both areas: 9.0 ± 0.9 for Treatment, 9.5 ± 0.5 for Control, and a general average of 9.3 ± 0.8 . A C/N ratio between 8 and 12 is generally considered healthy for microbial activity and nutrient cycling in agricultural soils. This consistency suggests a balanced decomposition process and stable microbial communities in both the treated and control plots, implying similar nutrient mineralisation dynamics.

For **pH**, both the treatment (7.65 ± 0.02) and control (7.63 ± 0.07) areas show very similar and distinctly alkaline (basic) pH values. This high pH is quite characteristic of soils derived from limestone, such as the Alberese often found in the Chianti Classico region.

The soil nutrient analysis (Table 6) suggests a mineral-rich environment, particularly high in **Calcium, Magnesium, Iron, and Potassium**. The control area shows a higher concentration of **Aluminium** ($15626 \pm 1134 \text{ ppm}$) compared to the treatment area ($11119 \pm 1344 \text{ ppm}$). These are relatively high levels; however, given the pH is around 7.6, aluminium's availability and potential toxicity are likely mitigated as it becomes less soluble at higher pH.

	Al		P		Mn		Fe		Mg		Ca		K	
Treatment (T)	11119	± 1344	1678	± 232	881	± 94	18277	± 744	16998	± 903	16515	± 924	8131	± 3103
Control (C)	15626	± 1134	2179	± 253	809	± 69	18089	± 1058	17136	± 1536	16476	± 1299	7547	± 2502
General	13373	± 2603	1929	± 349	845	± 89	18183	± 900	17067	± 1234	16495	± 1102	7839	± 2773

Table 6 - Macro-nutrients in experimental area in Castello di Albola.

The analysis of micronutrients reveals a soil composition that is generally favourable for viticulture. The essential micronutrients like **Zinc, Boron, and Copper** are present in adequate amounts, suggesting good nutritional support for the vines. Copper (Cu) levels are notably higher in the control area ($92 \pm 17 \text{ ppm}$) compared to the treatment area ($78 \pm 11 \text{ ppm}$), though both are within a healthy range.

Regarding heavy metals, while elements like **Nickel and Chromium** are present at relatively high total concentrations, the consistently alkaline pH of the soil is crucial in mitigating their potential bioavailability and toxicity to grapevines. The absence of **Cadmium** and very low levels of **Lead** and **Arsenic** are positive indicators for soil health (Table 7)

	Zn	Pb	Ni	B	Cr	Cu	As	Mo	Cd	Co	Na
Treatment (T)	98 ± 5	22 ± 3	131 ± 13	46 ± 3	174 ± 15	78 ± 11	1,6 ± 0,7	nd	nd	3 ± 1	nd
Control (C)	98 ± 9	23 ± 3	121 ± 10	44 ± 5	174 ± 11	92 ± 17	1,5 ± 0,9	nd	nd	2 ± 1	nd
General	98 ± 7	23 ± 3	126 ± 12	45 ± 4	172 ± 13	85 ± 16	1,5 ± 0,8	nd	nd	2 ± 1	nd

*nd= **not detected**

Table 7 - Micro-nutrients in experimental area in Castello di Albola (Zn: Zinc, Pb: lead, Ni: nickel, B: boron, Cr: chromium, Cu: copper, As: arsenic, Mo: molybdenum; Cd: cadmium, Co: cobalt, Na: sodium).

2.2 Soil characteristics at San Felice

The **soil texture** (Table 8) in the experimental area of San Felice farm is mainly sandy loamy. The treatment (T) area shows a higher sand content ($64 \pm 6\%$) compared to the control (C) area ($58 \pm 8\%$), while the control (C) area has a noticeably higher clay content compared to the treatment (T) area.

Considering also the soil characteristics described in Deliv. 4.1, the soil is classified as Typic Calcixerept fine loamy mixed mesic, WRB Haplic Calcisols (Loamic).

	Sand (%)	Clay (%)	Silt (%)
Treatment(T)	64 ± 6	6 ± 2	30 ± 4
Control C)	58 ± 8	11 ± 5	31 ± 4
General	61 ± 8	8 ± 5	31 ± 4

Table 8 - Soil texture values of the experimental area in S. Felice

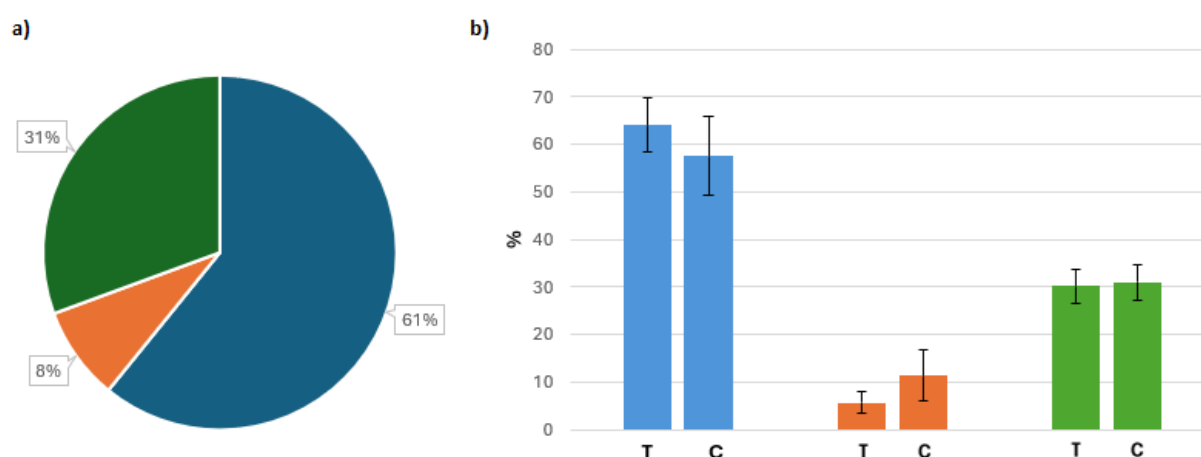


Figure 8- a) General Soil texture of San Felice soil (blue=sand, orange= clay, green = lime) b) Soil texture of San Felice soil for Treatment(T) and Control(C) (blue=sand, orange= clay, green = silt)

Bulk Density, Nitrogen content, Organic Carbon content and the **C/N ratio** (Table 9) are remarkably consistent across both groups (treatment and control); the control group's **pH** was slightly higher at 6.72 ± 0.03 , making it marginally less acidic than the treatment group, which registered 6.58 ± 0.08 .

	Bulk Density (g/cm ³)	OC	N	C/N	pH
Treatment (T)	1,2 ± 0,1	0,8± 0,2	0,07 ± 0,03	11 ± 1	6,58 ± 0,08
Control (C)	1,2 ± 0,2	0,7 ± 0,3	0,07 ± 0,03	10,0 ± 0,7	6,72 ± 0,03
General	1,2 ± 0,2	0,8± 0,3	0,07 ± 0,03	11 ± 1	6,6 ± 0,1

Table 9 - Bulk density (BD), Organic Carbon (OC), Nitrogen (N), Carbon and Nitrogen ratio (C/N), Acidity (pH) data of the experimental area in San Felice farm.

With regard to the macro- and micronutrients, as well as the heavy metals present, the data are reported in Tables 10 and 11.

	Al	P	Mn	Fe	Mg	Ca	K
Treatment (T)	39919 ± 2848	2193 ± 258	646 ± 174	15996 ± 868	18511 ± 1329	15967 ± 963	3594 ± 715
Control (C)	43711 ± 2405	1839 ± 254	622 ± 144	15309 ± 642	18285 ± 956	15280 ± 788	3149 ± 478
General	41815 ± 3225	2016 ± 309	634 ± 157	15653 ± 825	18398 ± 1138	15623 ± 929	3371 ± 637

Table 10 - Macro-nutrients in the experimental area in San Felice.

	Zn	Pb	Ni	B	Cr	Cu	As	Mo	Cd	Co	Na
Treatment (T)	59 ± 9	12 ± 4	99 ± 11	27 ± 3	146 ± 14	37 ± 15	1 ± 1	nd	nd	nd	nd
Control (C)	53 ± 4	12 ± 2	79 ± 12	26 ± 2	120 ± 12	37 ± 9	0,6 ± 0,4	nd	nd	nd	nd
General	56 ± 8	12 ± 3	89 ± 15	26 ± 3	133 ± 19	37 ± 12	0,8 ± 0,8	nd	nd	nd	nd

*nd= not detected

Table 11 - Micro-nutrients in experimental area in San Felice (Zn: Zinc, Pb: lead, Ni: nickel, B: boron, Cr: chromium, Cu: copper, As: arsenic, Mo: molybdenum; Cd: cadmium, Co: cobalt, Na: sodium).

2.3 Soil characteristics at Rocca di Montemassi

The soil texture (Table 12) of this area is mainly a clay loamy soil. The soil is classified as Typic Haploxerept fine loamy mixed thermic, WRB Eutric Cambisol (Loamic), based also on the characteristics detailed in Deliverable 4.1.

	Sand (%)	Clay (%)	Silt (%)
Treatment (T)	29 ± 12	27 ± 6	45 ± 11
Control (C)	30 ± 8	33 ± 5	36 ± 7
General	29 ± 10	30 ± 6	41 ± 10

Table 12 - Soil texture values of the experimental area in Rocca di Montemassi.

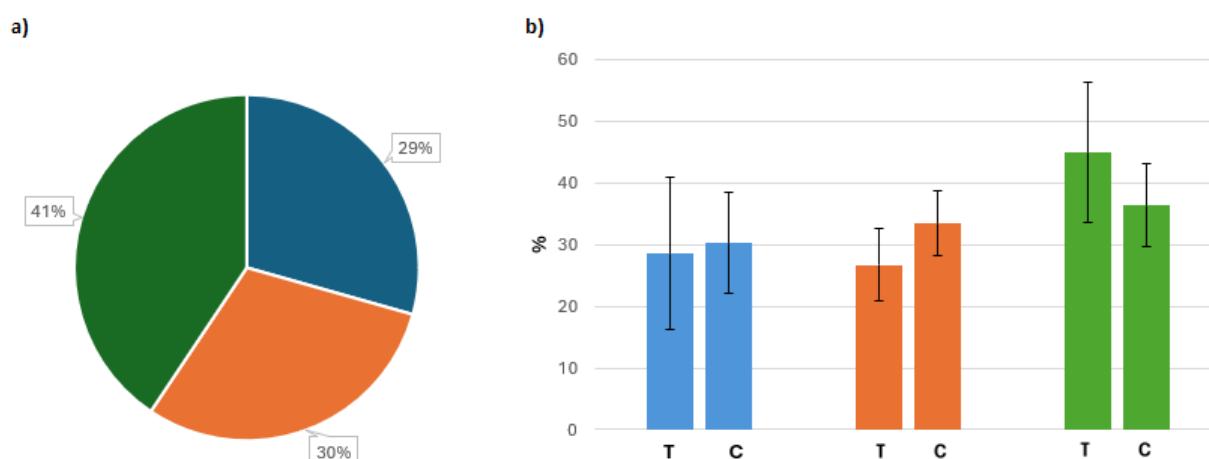


Figure 9- a) General Soil texture of Montemassi soil (blue=sand, orange= clay, green = silt) b) Soil texture of Montemassi soil for Treatment(T) and Control(C) (blue=sand, orange= clay, green = silt)

With regard to the parameters of bulk density, TOC, N, C/N ratio, and pH, results are reported in Table 13:

	BD (g/cm ³)	OC	N	C/N	pH
Treatment (T)	1,2 ± 0,1	1,1 ± 0,4	0,12 ± 0,04	9 ± 2	7,65 ± 0,04
Control (C)	1,1 ± 0,1	1,0 ± 0,2	0,09 ± 0,03	10 ± 1	7,67 ± 0,03
General	1,2 ± 0,1	1,0 ± 0,3	0,10 ± 0,03	10 ± 2	7,66 ± 0,03

Table 13 - Bulk density (BD), Organic Carbon (OC), Nitrogen (N), Carbon and Nitrogen ratio (C/N), Acidity (pH) data of experimental area in Rocca di Montemassi farm.

With regard to the macro- and micronutrients, as well as the heavy metals present, results are reported in tables 14 and 15.

	Al	P	Mn	Fe	Mg	Ca	K
Treatment (T)	19215 ± 2277	1219 ± 344	873 ± 225	17010 ± 3273	15880 ± 1499	15329 ± 1769	5287 ± 681
Control (C)	23021 ± 2523	1198 ± 352	1344 ± 355	17829 ± 2458	15172 ± 1621	15582 ± 1650	4961 ± 609
General	21118 ± 3050	1209 ± 341	1109 ± 377	17420 ± 2862	15526 ± 1569	15455 ± 1678	5124 ± 653

Table 14 - Macro-nutrients in the experimental area in Rocca di Montemassi.

	Zn	Pb	Ni	B	Cr	Cu	As	Mo	Cd	Co	Na
Treatment (T)	74 ± 5	14 ± 5	48 ± 7	43 ± 14	70 ± 16	27 ± 6	1 ± 1	nd	nd	0,6 ± 0,9	nd
Control (C)	72 ± 9	25 ± 8	57 ± 9	47 ± 10	84 ± 12	27 ± 4	3 ± 2	nd	nd	2 ± 2	nd
General	73 ± 7	19 ± 9	53 ± 9	45 ± 12	77 ± 16	27 ± 5	2 ± 2	nd	nd	1 ± 1	nd

*nd= not detected

Table 15 - Micro-nutrients in experimental area in Rocca di Montemassi (Zn: Zinc, Pb: lead, Ni: nickel, B: boron, Cr: chromium, Cu: copper, As: arsenic, Mo: molybdenum; Cd: cadmium, Co: cobalt, Na: sodium).

2.4 Soil characteristics at Tenute Ruffino

The soil texture (Table 16) of this area is mainly a silty clay soil. Based on the **Deliv. 4.1** soil characteristics, the soil is classified as Aquic Haplustept fine mesic, WRB Gleyic Cambisol (Clayic).

	Sand (%)	Clay (%)	Silt (%)
Treatment (T)	8 ± 1	43 ± 3	49 ± 2
Control (C)	8 ± 1	42 ± 2	50 ± 1
General	8 ± 1	42 ± 2	50 ± 2

Table 16 - Soil texture values of the experimental area in Tenute Ruffino.

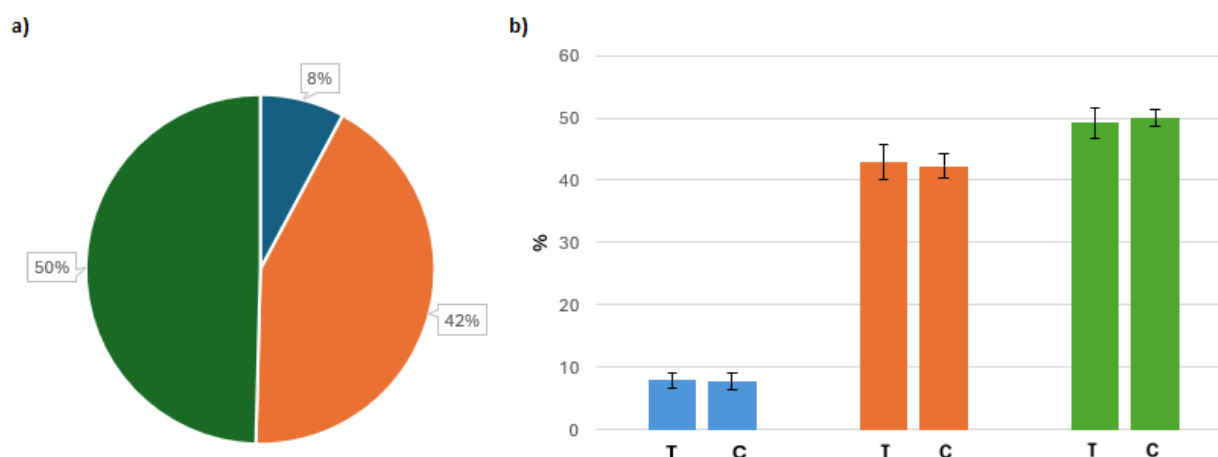


Figure 10- a) General Soil texture of Tenute Ruffino soil (blue=sand, orange= clay, green = silt) b) Soil texture of Ruffino soil for Treatment(T) and Control(C) (blue=sand, orange= clay, green = silt)

The measured parameters reported in Table 15 reveal a highly homogeneous soil, with no distinct characteristics observed between the two areas examined, called treated and control.

	BD (g/cm ³)	OC	N	C/N	pH
Treatment (T)	1,2 ± 0,1	2,0 ± 0,2	0,22 ± 0,04	10 ± 1	7,65 ± 0,05
Control (C)	1,18 ± 0,09	2,0 ± 0,2	0,21 ± 0,03	9,9 ± 0,7	7,5 ± 0,4
General	1,17 ± 0,09	2,0 ± 0,2	0,21 ± 0,03	10 ± 1	7,6 ± 0,3

Table 17 - Bulk density (BD), Organic Carbon (OC), Nitrogen (N), Carbon and Nitrogen ratio (C/N), Acidity (pH) data of experimental area in Tenute Ruffino farm.

With regard to the macro- and micronutrients, as well as the heavy metals present, data are reported in Table 18.

Table 18 shows a high degree of homogeneity for most elements between the "Treatment" and "Control" areas, particularly for **Fe, Mg, Ca, and K**. The concentrations of these elements are very similar in the two areas considered. However, **Aluminium (Al), Phosphorus (P), and Manganese (Mn)** show somewhat discernible differences, with the control group generally having higher concentrations of these elements compared to the treatment group.

	Al	P	Mn	Fe	Mg	Ca	K
Treatment (T)	28016 ± 2560	2670 ± 326	664 ± 153	16123 ± 859	16179 ± 1637	16599 ± 1560	7778 ± 804
Control (C)	33560 ± 3594	3035 ± 261	756 ± 138	16750 ± 1190	16888 ± 1637	17174 ± 1578	7971 ± 780
General	30788 ± 4163	2853 ± 344	710 ± 150	16436 ± 1064	16533 ± 1641	16886 ± 1562	7875 ± 781

Table 18 - Macro-nutrients in experimental area in Tenute Ruffino.

	Zn	Pb	Ni	B	Cr	Cu	As	Mo	Cd	Co	Na
Treatment (T)	101 ± 6	25 ± 1	28 ± 2	39 ± 3	52 ± 3	68 ± 10	5,8 ± 0,5	nd	nd	0,3 ± 0,6	nd
Control (C)	101 ± 6	26 ± 2	29 ± 2	37 ± 2	54 ± 4	66 ± 9	5,8 ± 0,5	nd	nd		nd
General	101 ± 6	26 ± 2	29 ± 2	38 ± 3	53 ± 4	67 ± 10	5,8 ± 0,5	nd	nd	0,1 ± 0,5	nd

*nd= **not detected**

Table 19 - Micro-nutrients in experimental area in Tenute Ruffino (Zn: Zinc, Pb: lead, Ni: nickel, B: boron, Cr: chromium, Cu: copper, As: arsenic, Mo: molybdenum; Cd: cadmium, Co: cobalt, Na: sodium).

2.5 Carbon stock results

Within experimental areas of each farm, carbon stock values are consistent between control and treatment areas and can be considered representative of the initial baseline conditions, as there are no significant differences between the two areas considered. 'Tenute Ruffino' showed, on both control and treatment conditions, the highest SOC stocks among all farms, followed by 'Castello di Albola', 'Rocca di Montemassi' and 'San Felice'.

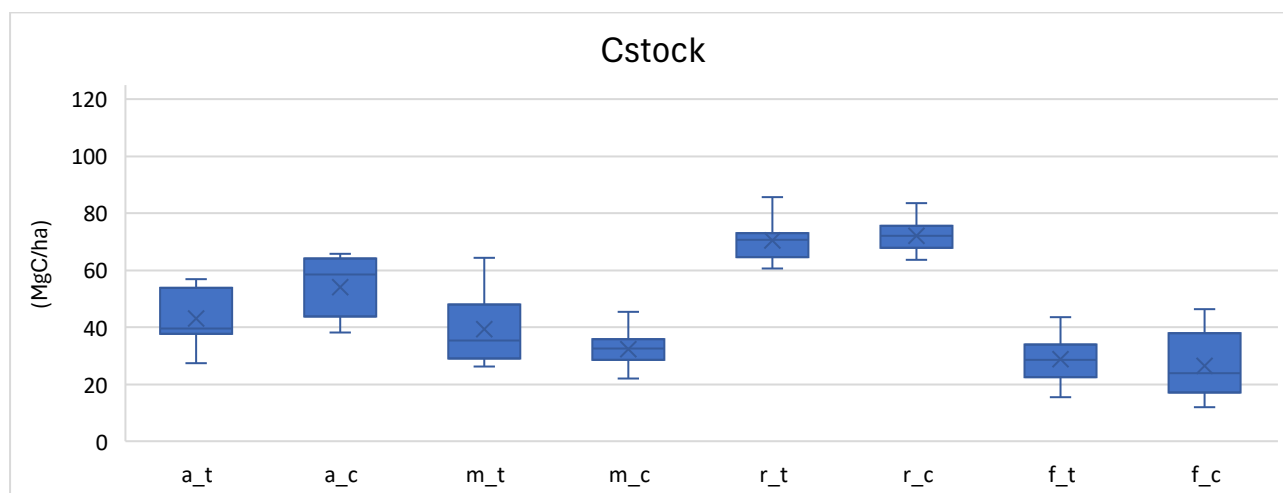


Figure 7 - Carbon stock results in the experimental areas of the VitiCaSe project, data collected in March/April 2024. (a=Castello di Albola, m=Rocca di Montemassi, r=Ruffino, f=San Felice, t=treatment, c=control).

2.6 Derived Long-Term Climate Averages

In total, 36 geographical information layers were generated, comprising 12 long-term monthly averages for each of the following variables: mean temperature, total precipitation, and reference Penman-Monteith evapotranspiration. Additionally, a layer representing the long-term annual average was produced for each variable. These layers are stored in .txt format, with each monthly or annual value linked to the latitude and longitude (EPSG:4326- WGS84) of the corresponding grid cell centre. The dataset is also being published in a Zenodo repository as open data, annotated with standard metadata (Parisse et al., 2025).

Figure 9 provides an overview of all the results of processing over the Italian area. As expected, temperature values peak in summer, and the highest values are generally recorded in coastal areas, as well as in the Po Valley. Cooler conditions are closely linked to mountainous terrains. Reference evapotranspiration values shows a spatial distribution pattern very similar to that of temperature values, while largest precipitation amount characterizes the alpine areas from March to November and the autumn period, mainly on the Tyrrhenian areas.

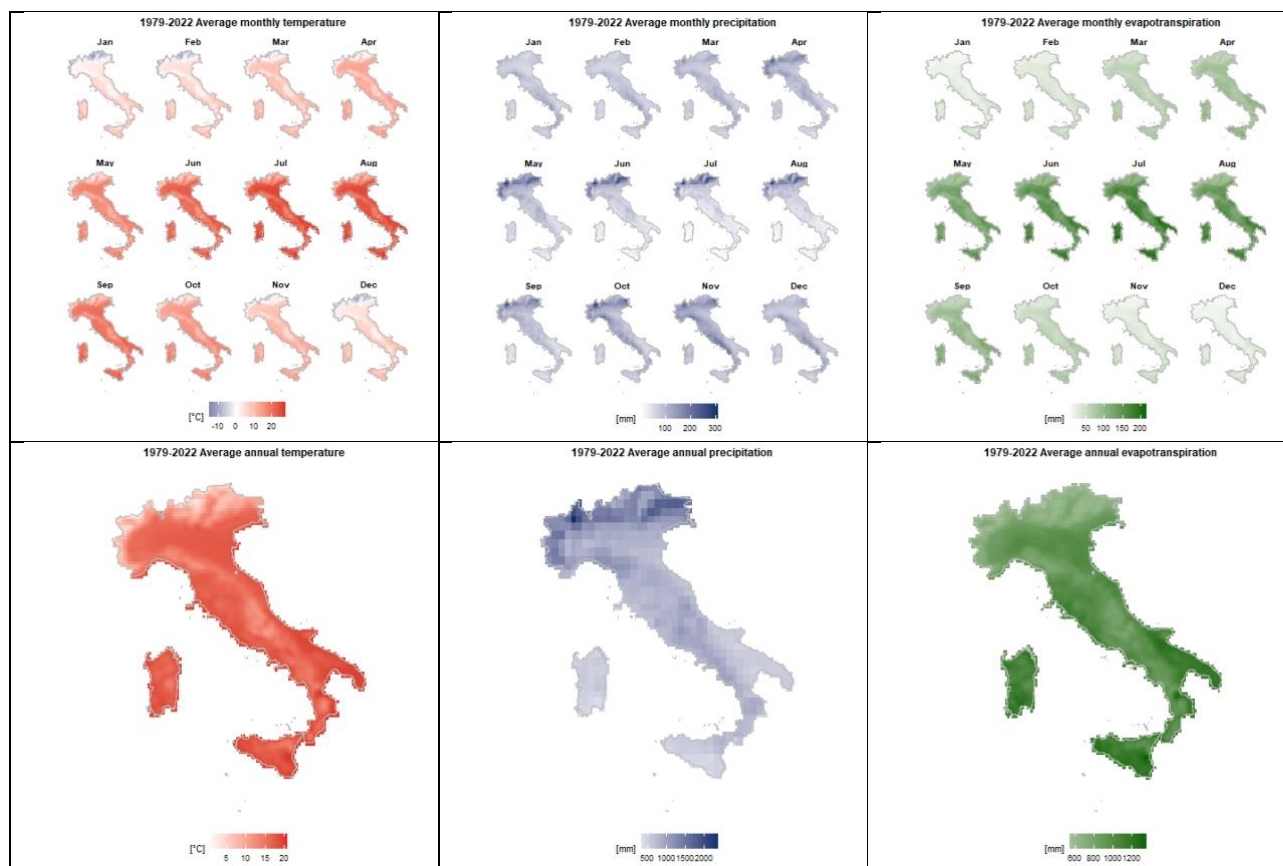


Figure 8- Monthly (1st row) and annual (2nd row) long-term averages of the three agrometeorological variables used to calibrate the model over Italy.

2.7 Baseline emissions results

The following table and graphs show the GHG emissions of the pilot farms due to different emission sources.

The main Emission Drivers are diesel, nitrogen, and manure. Diesel is the most significant source of emissions for all four farms, highlighting the heavy reliance on machinery and fossil fuels for operations. Nitrogen (direct and indirect) is the second-largest contributor across all farms, reflecting the environmental impact of fertilizer use. Manure and Pesticides contribute significantly for San Felice and Montemassi, but are either zero or low for Castello di Albola and Tenute Ruffino.

Table 20 - Baseline emissions for the pilot farms.

	Farm surface area	Nitrogen (direct and indirect)	Fertilizers for technical production	Manure	Pesticides	Diesel	Energy for irrigation	Total emission	Total emission	Emission per hectare
	Ha	kg Co ₂ eq.						kg Co ₂ eq.	t co2eq.	t co2eq./ha
Castello di Albola	56.6	20028	5202		849	54,969	-	81,048	81.05	1.43
Montemassi	50	36413	16114	8930	696	44,850	562	107,565	107.57	2.15
Tenute Ruffino	84	24622	11188		537	98,514	1,890	136,751	136.75	1.64
San Felice	150	33749	20716	21592	10181	179,828	-	266,066	266.07	1.77
Total emissions from farms									591.43	1.74

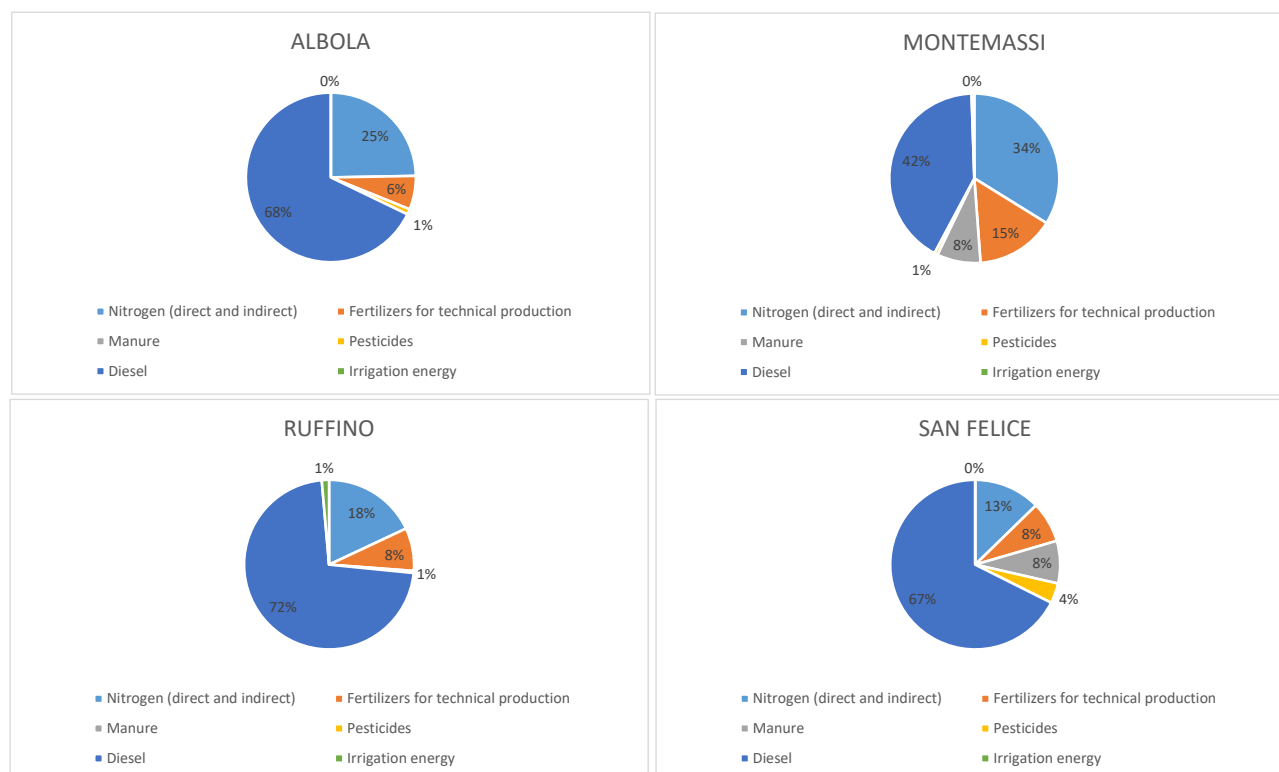


Figure 9 - Baseline emissions data aggregated by different categories in the different pilot farms.

2.7.1 Monte Carlo Analysis of Uncertainties in the Estimation of Emissions on Farms

This section presents a quantitative analysis of the uncertainty in the estimates of CO₂-equivalent emissions for the four farms in the project. Using Monte Carlo simulation, 10,000 simulations were generated (each simulation produces a random value based on the defined distribution: mean = estimated value, standard deviation = variability) for each farm, assuming a $\pm 10\%$ variability around the estimated value. The results include the probabilistic distributions, 95% confidence intervals (the range within which the actual emissions are expected to fall with 95% probability), and an interpretation of the findings.

The estimation of greenhouse gas emissions in agriculture is subject to uncertainty due to variability in input data and emission factors.

Uncertainty due to agricultural activity input data

The data related to the main emission sources in viticulture—fuel, organic fertilizers, and crop protection products—were collected directly from the farms and incorporated into the Life Cycle Inventory (LCI), which forms the basis for emission calculations, and whose quality we are fairly confident in. The greatest element of uncertainty in the activity data concerns the quantification of nitrogen supplied by pruning residues, which is used in the calculation of N₂O emissions (both

direct and indirect – N₂O leaching and runoff), for which we were unable to obtain data. Therefore, following a literature review, a single study was identified that provides values for this parameter, specific to the Emilia-Romagna region (Fasolo et al, 1983).

Emission factors (EFs to convert agricultural inputs and outputs into greenhouse gas emissions)

Emission factors can vary depending on geographic and climatic variability (rainfall, temperature, soil types), local agricultural practices, the type and management of agricultural activities, etc. In estimating emissions, efforts were made to use national-level data where available, or standard calculation values at the European level. The EF values used in the emission estimates are reported in Annex 1 of Deliverable 6.1.

For each farm, a normal distribution of total emissions was assumed, with a standard deviation equal to 10% of the estimated value. A total of 10,000 simulations were performed. From these simulations, 95% confidence intervals were calculated for each farm.

Table 21 - Results of the Monte Carlo analysis for the farms.

Farms	Estimated value in the project (t CO ₂ eq)	Interval of confidence (95%) t CO ₂ eq	Expected variability around the estimated value.
Castello di Albola	81.00	64.83 - 96.95	yes
Montemassi	107.00	85.98 - 127.89	yes
S. Felice	265.00	213.56 - 317.01	yes
Tenute Ruffino	136.00	109.67 - 162.27	yes

The Monte Carlo analysis made it possible to quantify the uncertainty in the emission estimates of the project's farms. The results show that, despite some variability, the estimated values fall within consistent confidence intervals.

3. Monitoring

During the first agricultural season, we conducted farm visits from June 24 to July 4, 2025. The aim was to monitor the season's progress, verify the effective application of the adopted sustainable management practices, identify any issues that arose and assess whether to continue with the initially defined practices or implement changes.

In the first crop season of the project, in Tenute Ruffino, only vine pruning shredding was carried out. Cover cropping and other soil preparations weren't possible due to widespread rain until May 2025, which precluded soil preparation (Table 18).

	Sept '24	Oct '24	Nov '24	Dec '24	Jan '25	Feb '25	Mar 25	Apr'25	May '25	Tot of period
Sum (mm) Prec	162	191.8	11.6	36.4	46	72	109	91.8	106.6	827.2
Rain days (n.)	10	11	3	4	10	6	12	8	11	75

Table 22 - Precipitation in mm and number of days in the cropping season 2024/25, Meteorological station in Noventa di Piave - Grassaga (data elaborated from Arpa.veneto.it) located near "Tenute Ruffino".

At the Rocca di Montemassi farm, the recommended best agronomic practices were fully implemented. Specifically, manure was applied as fertilizer in two fields. Across all fields, cover cropping with faba bean and barley, along with vine pruning shredding, was carried out. Within the experimental area, a designated sub-area was utilized for the application and testing of mycorrhizae.

At the San Felice farm, a seed mix was sown across nearly the entire surface. The cover crop shredding has been performed using two different techniques: a fine shredding, and a chain-shredder method that provides a mulching effect.

At the Castello di Albola pilot farm, pelletized fertilizer and manure were applied where possible (due to high application costs). Fava bean and barley cover crops were shredded and buried in alternate rows, while in other fields they were rolled with a roller-crimper but not buried. On the alternate rows natural grass cover was mulched between 2 and 3 times per season.

4. Conclusions

In conclusion, during this first agricultural year, data were collected from the farms to assess the chemical and physical characteristics of the soils, as well as the economic and agronomic information needed to establish the baseline for the future calculation of soil carbon stock as planned in the project.

Farms have begun the implementation of the agronomic practices selected, some following the suggested guidelines, others encountering problems, especially due to the weather conditions in the specific areas.

The collection of economic data required an integration of the initially collected data, and the farms have almost finished integrating the missing information.

In the next year, farms will continue to implement the practices as effectively as possible, and data will be collected for monitoring.

5. References

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