LIFE Project Number

< LIFE17 ENV/ES/000439>

Final Report

Covering the project activities from 02/07/2018 to 31/12/2022

Reporting Date[1]

<31/03/2023>

LIFE PROJECT NAME or Acronym

<AGRICLOSE>

Data Project

Project location:	Italy (Lombardy, Piedmont), Spain (Catalonia)
Project start date:	<02/07/2018>
Project end date:	<01/07/2022> > **Extension date:** <31/12/2022 >
Total budget:	2,203,843 Euro €
EU contribution:	1,315,021 Euro €
(%) of eligible costs:	60%

Data Beneficiary

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[1] Include the reporting date as foreseen in part C2 of Annex II of the Grant Agreement

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KEY WORDS

Antibiotics
By-products
Circular economy
Fertilisation
Manure
Ammonia and GHG emission
Nitrates leaching
Soil carbon
Soil health

ABBREVIATIONS

ABs: Antibiotics
ARGs: Antibiotic resistant genes
CT: Conventional tillage
EC: Electric conductivity
EFSA: European Food Safety Authority
GHG: Greenhouse gases
K: Potassium
LF: Liquid fraction
N: Nitrogen
$N\text{-}NO_3$: Nitrogen in nitrate form.
NH_3: Ammonia
NT: No tillage
P: Phosphorus
PO_4: Phosphate
P_2O_5: Diphosphorus pentaoxide
PS: Pig slurry
S: Sulfur
SOC: Soil organic carbon
SF: Solid fraction

1. Executive Summary

The LIFE AGRICLOSE project responded to the existing need to solve the current disconnection between livestock farms (pigs and cattle with slurry or digested manure) and agricultural farms (high yielding irrigated fruit trees and field crops) located in the same territory. It managed the manure to close the nutrient cycle, focusing on the management of by-products coming from the treatment of manure as fertilisers. This has been carried out through efficient and sustainable strategies that have demonstrated to farmers, consumers and certification bodies their agronomic and sanitary viability.

The strategies promoted focused on the improvement of the management of liquid fraction (LF), solid fraction (SF) and digestates (DI) coming from both pig and dairy slurry. Through these, the project has contributed to close the nutrient cycle using the potential of circular economy, to increase the efficiency of nutrient use when fertilizing with by-products, to reduce the use of mineral fertilisers and to improve the quality of the soils, among others.

The project has worked to introduce the LF in the fertilisation of fruit trees beyond the application window set by certification bodies (B1.1). A demonstration plot was established with this the results have shown the feasibility of the strategy and the possibility to reduce mineral fertilisation as expected.

New strategies have been promoted to improve the fertilisation with LF of extensive crops (B1.2). The demonstrative plots established have been run as expected. The new automatic dose system has been successfully developed and installed, as well as the application of LF through sub superficial hoses, both techniques have shown great results in the improvement in the use of LF and in the fertilisation of maize, although they have not brought clear yield advantages. LF top-dressing applications have also shown great results in the fertilisation of arable crops. The relations between the electric conductivity (EC) and nutrients of LF of both pig and dairy slurry have been obtained (A1.2), resulting very helpful to improve the dosage of this effluent. Lower emissions have also been shown when the LF is incorporated into the soil.

The SF composting process (B2) has been successfully carried out at both pilot and farm scale, obtaining a compost of high quality. It has been demonstrated the technical and economic feasibility of the on-farm composting of the solid fraction of pig slurry (PS) using bulky agent that can be found nearby the farm.

The innovative system to acidify animal slurry with a powdery sulfur before mechanical separation has been successfully developed and tested (A1.1). Ammonia (NH_3) and greenhouse gases (GHG) emission during on-farm storage of acidified and non-acidified solid fraction was investigated, saving emissions after acidification.

The solid fraction spreader (B3.1) and the tank to applicate digestates (B4.1) in fruit trees have been implemented and optimised as expected. The calibration and characteristics of the solid fraction spreader are shown in the deliverable 09 and 10. SF and digestate use in apple trees have shown very good results, and there have not been differences neither on yield nor quality when compared with mineral fertilisation. In the case of SF, good experiences have been achieved when used in both pre-plantation and established trees. All these strategies will help to achieve the goal of the extension in the use of by-products in fruit trees fertilisation and in the reduction of mineral fertilisers.

The strategies to promote and improve the digestates in extensive crops (B4.2) have also good results. On one hand, there are the strategies to improve its use in maize. Top-dressing fertilisation using digestates in maize can be a feasible strategy as long as some requirements are taken into account (soil conditions, crop stage, etc.), if not, the yield losses could compromise its viability. The use of digestates in the fertilisation in maize-catch crop rotation has been carried out as expected. The results of both strategies are shown in the deliverable 18.

On the other hand, the use of DI in the fertilisation of rainfed crops has been carried out as expected. The results are available at deliverable 19.

The demonstrative fields to demonstrate the efficiency of by-products as fertilisers and soil quality improvers have been carried out as expected, showing great results and demonstrating the possibility to use them as fertilisers and offering the possibility of replace part of mineral fertilisation. The use of no tillage and minimum tillage have also showed good results, being possible to increase their use in irrigated extensive crops. Results are shown at deliverable 21.

Some strategies are already replicated and other are on the way, as the contacts have been made and some of them confirmed by signing replicability letters. The use of regression functions to estimate the composition of LF is foreseen to be replicated in another region of Spain (Comunitat Valenciana) and is also considered in national and regional legislation, as it is explained in the Transference and Replicability Plan (deliverable 24). The automatic dose system is being successfully installed in more farms beyond the project and Catalan machinery manufacturers have shown their interest in the application technology developed. Contacts with cooperatives, farmer associations and private entities have already been done in order to spread some strategies like the use of treated organic products like LF, SF or DI. There have also been an interest and a positive feedback from the sector and the policy bodies towards the strategies promoted by the project and the results obtained.

COVID-19 period affected the progress of the most actions and their monitoring. However, the extension helped to carry out the project as expected.

The environmental monitoring (C1) has included more measures than what was initially planned, which reinforces the strategies from an environmental point of view. Most of them have improved the environmental parameters if compared with traditional fertilisation strategies. The results show a better soil quality and the reduction of nitrogen (N) impact, reducing by a half the N soil content in the top-soil before sowing in some strategies. The emissions have been seen reduced, LF fertigation reduces NH_3 emissions by a third, and the acidification of PS prior separation has achieved important reduction of GHG and NH_3 in the LF and SF subsequent management.

The monitoring of antibiotics (ABs) and antibiotic resistant genes (ARGs) has been higher that was initially planned. Analytical methodologies for the determination of Abs and ARGs were stablished (A1.3) and the information about such methodologies can be seen at deliverable 1. A total of 4 families of ABs and 8 ARGs in PS, SF and LF and DI have been determined. Tetracyclines were detected in top-soils fertilised with by-products, although concentrations of ABs and ARGs of maize grain and fruits were below the limits of detection. The treatments also have shown an important role in the reduction of ABs, where SF composting reduced the load of ABs up to 90%. The European Food Safety Authority (EFSA) has been interested in the main results and conclusions obtained.

Environmental assessment (C2) was conducted following a life cycle perspective, three scenarios of fruit production and three of extensive crops were used as case studies to test the environmental performance of different by-products in comparison with mineral fertilisation. In general, SF or LF fraction of slurry as an alternative to the use of mineral fertilisers are the most environmentally interesting options.

Socio-economic assessment (C3) shows that the most of the fertilisation strategies promoted offer lower operating costs and better net profit per ton, despite presenting in some cases lower crop yields than conventional fertilisation strategies.

Key project indicators and LIFE performance indicators have been updated.

Two expert committee meetings (C5) and a field day were held sharing good experiences about the best way to improve the use of by-products in the crop fertilisation and to spread the best practices.

More than 30 dissemination events have been implemented and more than 3000 people have attended in the events organised by the project. COVID-19 impacted very severely in the dissemination of the project, since field and on-site events couldn't be carried out. These activities were postponed and partially replaced by on-line events. The production of information material (e.g. videos) was disseminated through the planned channels. A total of 10 videos were produced, which have had more than 3000 views so far.

The development of the project and the coordination among the beneficiaries worked as expected and the communication has been constant and fluent. The main ways of communication have been by mail and video-conferences.

2. Introduction

There are large European areas with high livestock density that generate a large volume of manure difficult to manage. In Spain, the regions of Catalonia and Aragon (neighboring region of one of the project's areas) are the largest producers, with more than 50% of pig heads. In Italy, the Lombardy and Piedmont regions have about 60% of pig heads. In these regions of high livestock density, it has detected a significant disconnection between livestock and farmland, increasing the difficulty in a proper manure management.

Incorrect management of livestock manure can affect the environment, such as the quality of water, soil and air. In addition, it can compromise the viability of agricultural activity, thus influencing the quality of life of the rural world with all the adverse effects that this entails.

One of the strategies that have been developed to solve the problem in the management of manure is the use of treatment systems such as solid / liquid separation or anaerobic digestion.

The by-products that come from the treatment of livestock manure, such as LF, SF or DI, have interesting characteristics to be used as fertilisers. However, their use and application is limited by technological problems (irrigation systems, application machinery), the scarce knowledge about their composition and the regulation bodies (certifications in certain agrarian products).

Therefore, it is necessary to influence a management model based on the valuation of the highest amount of manure in a nearby environment, taking advantage of all the opportunities that the surrounding crops are offering, all these through systems and practices that are easy to use by farmers.

The LIFE AGRICLOSE project have developed and promoted new strategies and technologies to solve the main problems related to the use of the LF, the SF, DI and related application technology. In addition, innovative management aspects have also been incorporated to ensure the viability and sustainability in the use of these products from a technical, economic, environmental and sanitary point of view.

The technologies and strategies developed and improved by the project have been as follows:

- Technology developed to improve the use of the LF: rapid characterization of the nutrient content by obtaining its relation with EC, installation of an automatic dosing system in sprinkler irrigation.

- New strategies to improve the use of the LF: its use as fertiliser in fruit trees through its application through drip irrigation, application in fertigation in maize, both in drip and sprinkler irrigation, promotion of its use in the topdressing fertilisation in rainfed extensive crops, use of NNA in the application of the LF to improve its efficiency.

- Technology developed to improve the use of the SF: development of an automatic slurry acidification system prior to mechanical separation with Sulfur, development of a composting methodology at the farm level using bulking agents that can be found nearby the farms, improvement of an application spreader to adapt it to the characteristics of the SF and the conditions of the orchard fruits.

- New strategies to improve the use of the SF: the use of the SF in the fertilisation of fruit trees, both in the preparation of the soil in pre-planting and annual fertiliser.

- Technology developed to improve the use of DI: improvement of an application tank to adapt it to the characteristics of the digestates and the conditions of orchard fruits.

- New strategies to improve the use of DI: its use as fertiliser in fruit trees, application in the topdressing fertilisation in maize, as well as its application in a maize-catch crop rotation, and promotion of its use in the topdressing fertilisation in rainfed extensive crops.

The results will help to set a baseline in order to extend the use of by-products in the fertilisation of fruit trees and to improve their management, what will permit that they become common fertilisers, especially in high livestock density areas, as can be mineral fertilisers or not treated manures. This would permit to reduce by 100 and 80% the use of N and potassium (K) mineral fertilisers in some fruit trees (e.g.

peach trees). The introduction of new technologies and strategies in the fertilisation of extensive crops with by-products will permit an important reduction in the consume of mineral fertilisers. The use of by-products together with innovative approaches of sustainable techniques, as the use of no tillage or minimum tillage in irrigated lands, will let to an improvement of soil quality.

The project provides information about the effects of the use of by-products in the environment. Among them, to highlight the progress that suppose in the field of ABs and ARGs when using them, determining the content of ABs in slurry and by-products derived from their treatments and establishing methodologies to determine the possible migration of ARGs from the different phases of the slurry to soils and crops.

The results of the project seek to contribute in an important way in the development of a smart, inclusive and sustainable growth (European Green Deal) by the promotion of the circular economy within the agricultural sector. The main purpose of the project is to valorize fresh manure as well as treated manure by combining and reducing with mineral fertilisers, and by applying to crops by following the good agricultural practices to minimize any negative impact to the environment and the human health.

The innovative approaches of sustainable techniques include soil protection and implementation of conservation agriculture practices, following the strategies proposed by the European Union in its Directive 2010/75/EU for the prevention and control of soil contamination derived from the industrial production, and in the European Parliament resolution on soil protection (2021/2548 (RSP)).

The Nitrates Directive (91/676/EEC) allowed to identify and monitor vulnerable areas to nitrate pollution. The Commission Implementing Decision (EU) 2017/302 establishes technical improvements available within the framework of the Directive with regard to breeding intensive use of pigs and in particular those referring to slurry and its use as fertilisers (DOUEL 43/232 of 02/21/2017). As a consequence, currently, there is more environmental awareness as a result of the effort that has been made to improve water quality.

LIFE AGRICLOSE contributes to go further in the use and management of by-products coming from treated manure, guaranteeing from their generation to final use that they do not generate risks to human health or the environment (Regulation (EC) No. 1069/2009 of the European Parliament and of the Council).

3. Administrative part

3.1. Description of the management system.

The project is structured in five activity phases according to the type of actions, as described in the table below.

Table 1. Structure of the project according the type of the actions and the beneficiaries involved.

A. PREPARATORY ACTIONS		BENEFICIARIES INVOLVED
A1. Current technologies adaptation for the best use of products resulting from the treatment of manure	A1.1. Adaptation of slurry acidification prior to mechanical separation with no strong acids	UNITO
	A1.2. Adaptation of electric conductivity use to know quickly liquid fraction nutrients	DACC
	A1.3.Adaptation of current technologies for chemical and biological analysis of antibiotics and resistance genes	CSIC
A.2. Collaboration agreements with owners and certification bodies.	A2.1. Farmers agreements	All partners
	A2.2. Agreements with certification bodies	IRTA
A3. Initial site characterization		All partners
B. IMPLEMENTATION ACTIONS		
B1. New uses and improvement of the field application of liquid fraction from slurry	B1.1. Introduction of liquid fraction from pig slurry use in orchard fruit fertigation.	IRTA
	B1.2. Improve LF management in extensive crops	DACC / IRTA /ERSAF
B2. Implantation and optimization of pig slurry solid fraction composting process in situ		IRTA
B3. Improvement of solid fraction and its compost management in orchard fruits	B3.1. Innovative application of compost in orchard trees	UNITO
	B3.2. Solid fraction and compost use in apple trees	IRTA
B4. Improvement and optimization of pig slurry digestates use in crop fertilisation	B4.1. Introduction of pig slurry digestates use in orchard trees fertilisation	UNITO
	B4.2. Improvement of digestates management in extensive crops.	DACC / IRTA
B5. Demonstration of pig slurry new by-products efficiency as fertiliser and soil quality improver		DACC / ERSAF
B6. Replicability and dissemination of the project	B6.1. Transfer plan and replicability of the project	All partners
	B6.2. Commitment letters	
C. MONITORING OF THE IMPACT OF THE PROJECT ACTIONS		
C1. Monitoring and sampling for environmental impact assessment of the project		All partners
C2. Environmental evaluation of the tested by-products management alternatives using life- cycle assessment tools		IRTA
C3. Socio-economic evaluation of the project		DACC
C4. Monitoring of the project progress and its impact through LIFE performance indicators		DACC
C5. Creation of an expert's advisory board		DACC
D. PUBLIC AWARENESS AND DISSEMINATION RESULTS		
D1. Dissemination to the public and stakeholders in general		All partners
D2. Technical communication to the stakeholders		All partners
E. PROJECT MANAGEMENT		
E1. Coordination and management of the project		All partners
E2. After-Life plan		All partners

3.2. The formal organization of the project

Coordinator and some partners had already worked together on other occasions due to collaborations in scientific projects, joint publications and communication activities, thus ensuring a productive collaboration within the framework of the project. In addition, each beneficiary is considered an expert on the subject of the action which coordinates. Communication is established between partners through on-site meetings, emails, phone calls or Skype conferences. The project team had delays in some actions due to external factors (covid-19 pandemic), not inherent in the management structure.

The administrative and financial management of the project was coordinated by the DACC and each beneficiary partner assigned a person responsible for financial monitoring who was in charge of reporting the financial development of the project's execution at each meeting of the Coordination Committee.

Table 2. Formal organization of the project.

Manager	Jaume Boixadera i Llobet (DACC) Carlos Ortiz Gama (DACC)	
Technical coordinator	Jordi Tugues Tarragona (DACC) Gemma Murillo Busquets (DACC)	
Executive Committee	Núria Canut Torrijos (DACC) Laura Garcia Pericon (DACC) Joan Parera Pous (DACC) Ramon Serra Roca (DACC)	Communication Financial and administrative Technical Technical
Coordination Committee	August Bonmatí Blasi (IRTA) Francesc Domingo Olivé (IRTA) Josep Mª Bayona Termens, Victor Matamoros Mercadal (CSIC) Stefano Brena, Pietro Lavazzo (ERSAF) Paolo Balsari, Elio Dinuccio (UNITO)	
Experts Group	**Instituto Vasco de Investigaciones agrarias (NEIKER)** (manure use efficiency): Ana Aizpurua **European Food Safety Agency (EFSA)** (expert food safety): Beatriz Guerra **Università degli studi di Milano** (expert in manure use efficiency): Giorgio Provolo **Universidade de Lisboa** (expert in manure treatment): David Fangueiro	

The coordination meeting with the monitoring expert were on 05-06 February 2020 and 26-27 April 2021.

Table 3. Coordination meetings.

TIMETABLE COORDINATION MEETINGS
12/11/2018
30/05/2019
05/02/2020
20/07/2020
15/12/2020
27/04/2021
16/12/2021
11/03/2022
21/06/2022

4. Technical part

4.1. Preparatory actions

4.1.1. Action A.1 – Adaptation of current technology to optimize the use of the products obtained from the zootechnical waste treatment.

A1.1. Adaptation of slurry acidification prior to mechanical separation with no strong acids (Responsible: UNITO)

	Start date		End date/deadline	
	Foreseen	Real	Foreseen	Real
Action	December 18	December 18	September 20	December 22
Milestone: acidification under laboratory conditions finished			October 18	October 18

Description:

Adjustment of slurry acidification with no strong acids: the effect of addition of sulfur (S) to raw PS before mechanical separation on NH_3 and GHG emission during storage of separated (liquid, solid) fractions was assessed in laboratory condition. Elementary S was added to fresh raw slurry in 2 doses: 0.1% (w/w) and 0.3% (w/w). Raw slurry was mechanical separated using a lab-scale screw press device. The gaseous emissions were detected through a dynamic chamber system, using an infrared photoacoustic monitor (IPD; 1412 Multi-gas Monitor, Innova® Air Tech Instruments). Elemental S addition to raw slurry without mechanical separation reduced cumulated NH_3 emissions from 9% (RS 0.1) to 28% (RS 0.3), whereas the combined (fraction sum) total NH_3 losses from both liquid and solid acidified fractions resulted on average 39% lower than those from the raw PS. The combined CO_2 eq. emissions during storage of both liquid and solid acidified fractions were reduced from 34% (0.1%S) to 72% (0.3%S).

Development of an innovative system to acidify animal slurry with a powdery sulfur before mechanical separation: a full-scale prototype for acidification of PS before mechanical separation has been designed, developed and tested at farm. It is a semi-automatic process with a working capacity of approx. 15 m^3/h. The raw slurry is conveyed in a stainless steel tank equipped with filling sensor and two mixers, where through an automatic dosing system sulfur is automatically added at the optimal dose. Then a volumetric pump pushes the acidified slurry to a screw press separator.

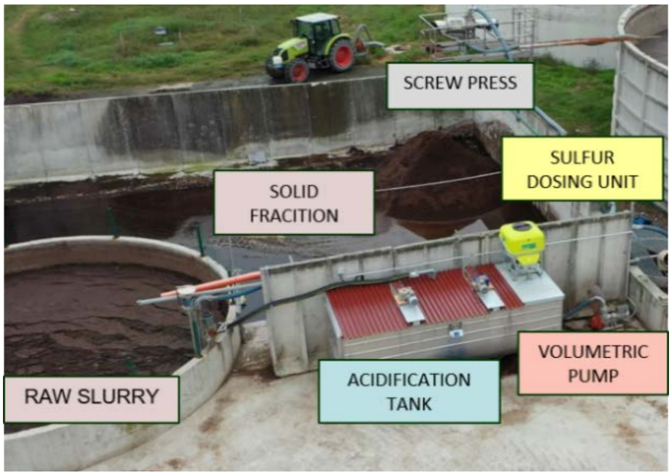


Figure 1. Automatic acidification system prototype

NH_3 and GHG emission during on-farm storage of acidified and non-acidified solid fraction over two seasons (2020 and 2021) was investigated with turned (TW) and unturned windrows (UW). In general sulfur addition did not affect total GHG emissions, but significantly reduced NH_3 emissions by 35 and 30% respectively with TW and UW.

After-life: UNITO will continue to monitor the performance of the installed system to acidify animal slurry, disseminating information to farmers, technicians and companies interested in the industrial production of the prototype to acidify the animal slurry.

A 1.2. Adaptation of electric conductivity (EC) use to know quickly liquid fraction (LF) nutrients (responsible: DACC)

	Start date		End date/deadline	
	Foreseen	Real	Foreseen	Real
Action	July 18	July 18	December 20	December 21
Milestone: *Samples collected to validate FL of PS characterization*			July 19	July 19
Deliverable 02			July 19	July 19

Description:

A) Adaptation of EC use to know quickly the nutrient content of LF of PS: 43 pig farms with separated (liquid, solid) fractions (SL-sep) were visited. A total of 80 samples have been collected to analyse the composition and obtain a relation between the EC and the nutrient content (N, Phosphorus (P) and K) of LF.

   A significant relation with the nutrient content (N, N ammonia, P and K) and EC (Sig <0.001) has been obtained. Although the relation is significant, a very good prediction is obtained with N, ammoniacal N and K (r2: 0.75, 0.79 and 0.73, respectively) nevertheless, with P the prediction is not that good (r2: 0.33). The relation obtained has been published on the project website and also on the *Oficina de fertilización* web (link).

B) Adaptation of EC use to know quickly the nutrient content of LF of dairy slurry: 25 dairy farms with SL-sep were visited. A total of 50 samples have been collected to analyse the composition and obtain a relation between the EC and the nutrient content (N, P and K) of LF.

   A significant relation with the nutrient content (N, N ammonia, P and K) and EC (Sig <0.001) has been obtained. Although the relation is significant, a very good prediction is obtained with N, ammoniacal N (r2: 0.73 and 0.80, respectively) however with P and K the prediction is less good (r2: 0,59 and 0.50, respectively). The relation obtained has been published on the project website and also on the *Oficina de fertilización* web (link).

Comparison with planned outputs and deviations: A good prediction (EC – nutrients) was obtained in both cases, in pig and dairy slurry. Also, the availability of these relationships will provide a good tool for farmers to improve crop fertilisation when applying and adjusting the LF volume according to crop nutrient requirements.

The sampling period to validate the relations was delayed due to COVID-19, but finally all the samples were taken and analysed.

A1.3 – Validation of analytical methodologies for the determination of antibiotics (ABs) and antibiotic resistant genes (ARGs) in selected matrices (responsible: CSIC)

	Start date		End date/deadline	
	Foreseen	Real	Foreseen	Real
Action	July 18	July 18	December 20	December 19
Milestone: *Completion of obtaining the project-relevant matrices for antibiotic characterization*			September 18	September 18
Deliverable 01			December 18	December 18 Revision: November 21

Description: Analytical methodologies for the determination of ABs and ARGs in organic fertilisers (PS, SF, LF and DI) were established. Non target screening techniques were applied to identify the main antibiotic classes in the selected organic fertilisers. From the results obtained, 16 ABs were selected according to abundance and prevalence. In order to quantify them in the matrices of interest (organic fertilisers, soil and fruits), specific analytical methods were implemented and validated for precision (replicate analysis) and accuracy (spiking at two concentration levels). Following recovery correction by surrogated standards, successful results were obtained in those matrices. Regarding to ARGs, 3 different DNA extraction kits were evaluated for the extraction. The ARG content in the extracted DNA was performed by real time PCR by using specific primers. A total of 8 ARGs and 16S were selected in this study. Limits of detection, limits of quantification, calibration interval and precision (5 replicates) were performed. A total of 15 samples including PS, LF, SF, DI and composted samples were analysed in duplicate. Furthermore, different stages of the production cycle were also included in the dataset.

Comparison with planned outputs and deviations: The main deviation was the delay in the availability of samples. On the other hand, due to sample heterogeneity in organic fertilisers all samples were analysed in duplicate or triplicate, in order to obtain a consistent figure. Accordingly, the number samples analysed were double than the foreseen in this action.

Modifications and major problems: As mentioned above, at least a duplicate analysis was performed for every sample to obtain a consistent figure of the AB and ARG content. Therefore, an overspending of 20% in this action was incurred. Moreover, due to the different soil properties among the different demonstration sites, the evaluation of the analytical method was performed in all soils.

Complementary actions: A National project (DAMA) (link) to investigate the uptake of ABs and ARGs in horticultural crops has been funded by the AEI (Spanish Research Agency). In this project, PS and other organic fertilisers (biosolids and organic fraction of the municipal solid waste) were evaluated under controlled (greenhouse) and experimental plots.

After-Life: A position paper will be prepared in collaboration with the other groups.

4.1.2. Action A2. Collaboration agreements with owners and certification bodies

	Start date		End date/deadline	
	Foreseen	Real	Foreseen	Real
Action	July 18	July 18	December 18	July 19
Milestone: *Agreements signed with the owners for the actions B1-B5*			December 18	December 18
Deliverable 03			December 18	December 18

Description: Eleven agreements were signed between the owners of the farms and the responsible of each action in order to guarantee the good development of the actions. Agreements include the compromises by both the project and the owners. All the agreements are included at deliverable 03.

Agreements with certification bodies couldn't be signed as GlobalG.A.P.. However, GlobalG.A.P is aware of the project and it is compromised to collaborate as planned. A meeting with the Director of Producer Solutions of GlobalG.A.P. was carried out on 21st of September of 2019. She informed us to introduce our proposal to an internal meeting celebrated in 2022.

4.1.3. Action A3. Initial site characterization

	Start date		End date/deadline	
	Foreseen	Real	Foreseen	Real
Action	July 18	July 18	December 18	April 21
Milestone: *Preparation of initial characterization reports of demonstration farms*			December 18	December 18
Milestone: *Completion of on-farm interviews*			December 18	December 18
Deliverable 05			March 19	March 19
Deliverable 06			March 19	March 19

Description: Twenty plots were characterised in order to know the soil properties and main characteristics of the farm to know their suitability to develop the actions. Most of the plots were located in Catalonia, seventeen plots, and the rest were located in Italy (3). The crops planted were rainfed cereals, maize and apple trees. In total, 68 soil samples were taken to carry out the initial characterization. The results of the sample not presented limitations and were adapted to the needs of the project for the development of the activities to be carried out (deliverable 05).

By-products of the farms linked to the actions were also analysed in order to know their composition for the proper dosing, depending on the required doses and the needs of the crop.

Comparison with planned outputs and deviations: the number of samples taken and analysis carried were less than expected in the proposal. They were adapted to the final characteristics of each plot chosen to take part in the project.

4.2. Implementation actions (B)

4.2.1. Action B1. New uses and improvement of the field application of Liquid Fraction (LF) from slurry.

	Start date		End date/deadline	
	Foreseen	Real	Foreseen	Real
Action	July 18	July 18	June 22	December 22
Milestone: *Evaluation and comparison of fertilisation strategies with FL and mineral fertilisation in extensive crops*			December 22	December 22
Milestone: *Evaluation and comparison of fertilisation strategies with FL and mineral fertilisation in fruit trees*			December 22	December 22
Deliverable 07			March 19	March 19
Deliverable 08			November 22	November 22

B1.1. Introduction of LF from pig slurry (PS) use in orchard fruit fertigation (Responsible: IRTA)

Description: The demonstration plot is a plantation of Peach cv Tardibelle, located in Soses (Lleida, Catalunya). The experimental set up is randomised completed block design. Three fertilisation strategies have been tested plus a control plot.

A new irrigation hut has been built beside the original one in order to have a better control of the demonstrative subplots, it includes a new irrigation and fertigation system. A concrete floor was prepared to put four tanks of 1.000 l that are being used to store the LF. A new drip pipe and water meters have been installed.

Although fertilisation strategies couldn't be carried out as expected in the season 2020, there have not been differences neither in yield nor fruit quality when LF has been used as fertiliser.

E. Coli, Salmonella and Listeria on soil, leaves and fruit were analysed periodically (before fertilisation, 1 month before harvest and harvest). None of these microbes were found in fruit, but E. Coli was found in some samples of leaves at harvest time.

Results were shared with GlobalG.A.P., one of the most important international certifying companies (B6), during the meeting celebrated in March 22. This company was very interested in the microbiological analysis obtained in fruits. As they are looking for zero risk to the consumers, they listened very carefully our research results.

Modifications and major problems:
Due to COVID-19 situation, fertilisation strategies couldn't be carried out on time and they had to be modified. In 2020, only a 20% of total fertilisers needed were applied with LF. LF was applied during July and August, two months before harvest. However, control parameters were followed as planned.

Comparison with planned outputs and deviations:
Demonstration plot (season 2020) was delayed due to COVID-19 situation, but it was possible to perform. Fertilisation planning was slightly modified to adapt to this circumstance. The next agricultural campaigns were planned according to the following changes settled up:

All the LF needed before burst stage was not possible to be applied, so fertilisation strategies were modified as follow: (1) Synthetic fertiliser + pig slurry LF till 2 months before fruit collection: (2) same as T1 but till 1 month before fruit collection; (3) same as T1 but till 1 day before fruit collection; and (4) fertilisation with synthetic fertiliser (control).

B1.2. Improve LF management in extensive crops

Three different strategies are carried out in order to improve the management of LF in extensive crops:

a) Surface drip irrigation with fertigation for extensive maize cultivation (responsible: ERSAF)

Description: a swine farm in Caravaggio (Lombardy) was designated for the evaluation of the effectiveness and the feasibility of digestate spreading in different irrigation systems, including surface drip irrigation with fertigation. In the farm, all the livestock slurries are driven into an anaerobic digestor, then the liquid and solid fractions are separated and redistributed on soil as fertilisers, through both injection (or immediate interment) and fertigation.

Three experimental plots were identified for irrigated maize cultivation in different crop management (Figure 2): (A) organic fertilisation (digestate) with conventional irrigation system; (B) mineral fertilisation (slow-release UREA) ("min"); (C) organic fertilisation (digestate) with surface drip irrigation with fertigation ("new").

Figure 2. Demonstrative field (Caravaggio-Lombardy)

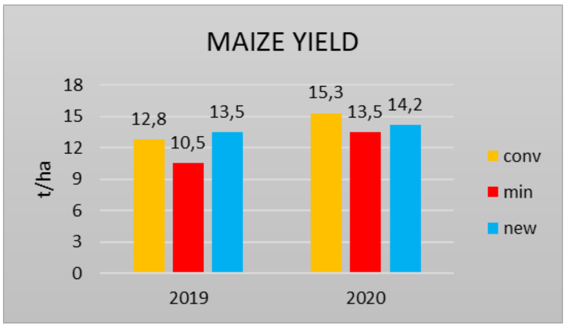


Figure 3. Maize yield (Caravaggio-Lombardy)

Data relating to the soils, soil solution and the agricultural management practices adopted were recorded. Analyses performed: soil solution (340), soil (38), digestate (1), vegetable biomass (20).

Fertigation ("new") showed not to improve significantly the crop yields compared to the conventional distribution of slurry ("conv"); the plot with only mineral fertilisation ("min") always showed lower yields (Figure 3). Therefore, its real applicability on large scale seems to be strictly connected to an economic assessment accounting, in planning phase, the expected yields and water consumption as well as the costs of installation and management of the irrigation plant.

Modifications: the sizing of the plots was modified according to the availability of the farmer. 3 plots of about 2 ha each (for a total area of about 6 ha) were used for the development of the tests.

After completing the test on fertigation, the extension of the project allowed to compare the environmental performance of different times of LF manure distribution through a monitoring of air emissions (NH_3 and GHG emissions) linked to 2 organic fertilisation activities during a full crop cycle of maize.

Complementary actions: the activities were coordinated with the working group of the University of Milan as a network with LIFE Arimeda, focused on the NH_3 emission reduction in Mediterranean agriculture with innovative slurry fertigation techniques.

b) Use of the conductimeter to improve the dose of LF (responsible: DACC)

Description: A demonstrative plot was settled up in order to test and install a system to dose automatically LF from PS according to its nutrient content. The farm, where the action was carried out, is located in Gimenells (Catalonia). The plot located beside the pig farm of the same exploitation has sprinkler irrigation, therefore the installation was prepared to apply the LF through the irrigation system, which was injected directly from the farm to the irrigation system. Three fertilisation strategies were tested in order to show, evaluate and monitor the application of LF through fertigation (Figure 4).

A conductimeter and a management equipment with a program developed especially for the use of the conductivity relation (obtained in action A1) was incorporated into the irrigation installation. Moreover, two water sensors were installed in order to adjust the irrigation and the fertigation, to control of nutrient leaching and to control soil salinization.

The equipment (Figure 5) designed and installed offers the possibility to the farmer to use and dose LF in the same way as mineral fertilisers, so the farmer only needs to introduce the N dose to the system and the volume of LF needed is applied automatically.

Figure 4. Demonstrative field (Gimenells – Catalonia)

Figure 5. Detail of the conductimeter equipment installed in Gimenells, Catalonia

In the first season (2019), the following three fertilisation strategies were compared: (1) LF dose according to the N content obtained from an analysis (usual use of the farmer); (2) LF dose using the conductimeter; (3) mineral fertilisation. All three strategies had a final target dose of 170 kg N / ha. The results showed that the use of the conductimeter significantly improved the management of the LF, however, the highest production was obtained in the mineral strategy. The equipment of the conductimeter was set during this first season.

After the first year, and after the proper functioning of the conductimeter during the first season, it was decided to improve its use (PLC programming and installation) (Figure 5) and modify the fertilisation strategies. The current fertilisation strategies were: (1) only LF (170 kg N/ha); (2) LF (170 kg N/ha) + mineral (80 kg N/ha); (3) only mineral (170 kg N/ha). The yields obtained for each campaign (2020-2021-2022), were very similar in the three strategies (12.823 kg/ha, 12.784 kg/ha and 12.653 kg/ha respectively). Therefore, it appeared that the increase of the N applied, did not lead to higher yields.

The development of maize under the different fertilisation strategies were monitored trough satellite images using the NDVI index. There were no big differences in the maize growing in the different strategies.

Microbiology (*E. Coli, Salmonella spp., Lysteria monocytogenes*) in soil, water, PS, LF and crop was analysed. E. Coli and Salmonella spp. were present in PS and LF, however, E. Coli was found in soil analysis. Also, low presence of E.Coli was found on forage but not on grain. Mycotoxins were analysed in grain. Deoxynivalenol and fumonisins were detected in some samples of all fertilisation strategies. There was not an influence when using LF in the presence of mycotoxins.

Modifications: the good functioning of the LF dosing equipment (conductimeter) was tested. So, it was decided to modify the fertilisation strategies of the demonstration plot focusing on N dosing.

After-life: Thanks to the interest in the demonstrative technologies developed within the Life Agriclose project, this action is plan to continue on time due to the interest and it contribution on the fertilisation plan and soil service (DACC).

c) Liquid Fraction (LF) use improvement as arable crop fertiliser (rainfed; Osona) (responsible: IRTA)

Description: Demonstrative fields were carried out during four campaigns in rainfed winter (mainly) crops. One demonstrative field located in Malla town (campaign 2018-19), a second demonstrative field located also in Malla town (campaigns 2019-20 until 2021-22; three crop cycles with treatments in the same place) and a third demonstrative field in Tona town (campaigns 2019-20 and 2020-21; two crop cycles with treatments in the same place). Different fertilisation strategies were applied in those fields:

the application of LF at pre-sowing, split among pre-sowing and top-dressing, or only at top-dressing moment, compared with PS application at pre-sowing.

In all sites, soil samples were taken at the beginning, for soil characterization (A3), and before top-dressing applications and after harvest, for soil nitrates determination (C1). Measurements in crop were yield and grain quality (specific weight (kg/hL), grain moisture (%), protein content (%)) in winter cereal grain, nutrient (NPK) grain content (%) on some fields and forage quality analysis for forage crops. Organic products (LF and PS) applied (pre-sowing and top-dressing) were sampled for their characterization. The relation (CE/Nutrients of LF) obtained in action A1 is used to dose LF.

The results shown that LF performs as good as PS on yield and better on grain and forage quality. Top-dressing applications improve the results in comparison with traditional pre-sowing applications.

Comparison with planned outputs and deviations: Top-dressing applications was not possible to be performed due to high rainfall episodes in Malla town (campaign 2019-2020), making impossible the access to the field with heavy machinery, as it is the one used for LF and PS applications.

After-life: this action is plan to continue during 2023.

4.2.2. Action B2. Implementation of a composting system for on-farm composting of SF of PS. (responsible: IRTA)

	Start date		End date/deadline	
	Foreseen	Real	Foreseen	Real
Action	March 19	March 19	December 20	December 22
Milestone: *Completed studies of optimal mixtures for composting*			March 19	March 19
Milestone: *Completed the test for the determination of optimal conditions for composting the FS of PS*			March 20	March 20
Milestone: *Completion of the on-farm composting test to assess its technical and economic feasibility*			December 21	December 22
Deliverable 09			March 19	March 19
Deliverable 10			May 20	May 20
Deliverable 11			December 21	December 21
Deliverable 12			December 22	December 22

Description:

B2.1. Mixture study. A selected SF of PS and two bulking agents (maize straw and peach pruning) were mixed at three rates in the lab. As a result, it was observed that the influence of the proportion on the moisture of the mixtures depends on the density of the raw materials. In this sense, materials like peach pruning were higher in density than maize straw. For this reason, the proportion of materials had more influence in parameters like pH or electrical conductivity in peach pruning rather than maize straw. This effect of the density of the bulking agent was detected for organic matter. Other properties that have been determined like bulk density or air capacity did not show a linear trend, at least for a particular bulking agent (deliverable 9).

This action was needed to plan the next action B2.2: the composting of solid fraction of pig slurry with two bulking agents (peach pruning and maize straw) and using two composting methods (static and dynamic) (Figure 6). These experiments were carried out at intermediate scale (6 m^3 each pile) According to the results, most differences between treatments, instead of the composting method used, were due to the kind of bulking agent. For instance, at the end of the process, organic matter content was higher in piles with peach pruning that the correspondent to maize straw. Nitrification in all piles was produced after three months of composting; this process was linked to the natural acidification of the materials at the end of the process; in this case, maize straw stimulated nitrification much more than the peach pruning. The pH was also lower for compost in which maize straw was used. The obtained composts were stable according to the different parameters measured (stability degree and Rottegrade test) (deliverable 10).

Figure 6.On the left: established composting piles in the experiment (B2.2). On the right: composting piles established(B2.3).

B2.3 From 1st March 2021 till December 2022 the on-farm composting was carried out in Alcarràs (Figure 6). In outdoor and harsh conditions (high temperatures/drought) in 2021 summer, particularly. The results obtained at pilot scale were confirmed during this on-farm experiment (e.g. nitrification within composting and good quality of the obtained compost); the economic feasibility was calculated and the approximate cost of producing compost was 28 €/t, at a very competitive price. Also some environmental issues were measured: impact of the composting piles in the soil fertility, gas emissions and antibiotic and antibiotic resistance genes-ARG (this last one in cooperation with CSIC) (deliverable 11).

Comparison with planned outputs and deviations: We changed the analysis of leachates (action C1.3) by different environmental measurements like ABs-ARGs, gas emissions and soil impact of leachates.

Modifications and major problems: The action B2.3 started later because of personnel availability for conducting the experiment; this was informed to the coordinator. This action lasted more than expected; the additional measurements (C.1.3) impacted upon the end of the activity since the analysis of the data had to be reviewed.

Complementary actions: Other compost projects have implemented during the project such a composting plant set up in Alcarràs or the Organic-Plus project. In addition, the compost obtained in the pilot composting (action B2.2) was used in rotation horticulture trials in Cabrils IRTA center. Training actions have also been performed in the framework of other projects: SUSTAINOLIVE (PRIMA) and TRANSGROWTH (Interreg).

After-life: As stated in the after-report LIFE AGRICLOSE project, other projects to promote the use of nitrified compost are starting: COMdeHORT-Demonstration project 2022-2024 and the Waste4Soil project (pending the grant agreement; Hz2020 2023-2027).

4.2.3. Action B3. Improvement of the management of the compost fertilisation of the SF of PS in orchard.

	Start date		End date/deadline	
	Foreseen	Real	Foreseen	Real
Action	December 18	December 18	December 21	December 22
Milestone: *Calibration of the solid fraction spreader for slurry*			December 21	December 21
Milestone: *Monitoring of completed plantations*			December 21	December 21
Deliverable 13			December 20	December 20
Deliverable 14			December 22	December 22
Deliverable 15			December 22	December 22

B3.1. SF spreader adaptation to orchard fruit conditions (responsible: UNITO)

Description: a SF spreader prototype for orchard previously developed by UNITO has been implemented and optimised (Figure 7). The main changes concerned the distribution system, which was entirely redesigned to allow the simultaneous distribution on two rows, and the control and regulation system of the distributed dose. Furthermore, the prototype has been equipped with a new electronic hardware to allow the interfacing with a prescription map.

Several spreading tests were carried out in order to evaluate transversal and longitudinal distribution uniformity following European Standard EN 1380 (2002) methodology.

All the details are indicated in the deliverable 13.

Figure 7. Solid fraction spreader prototype

The prototype spreader demonstrated to be a reliable machine for PS separated solid fraction in orchard when nutrients are applied at the proper amounts and uniformity with a well-performing automatic rate controller.

Solid Fraction distribution (acidified and not) in orchard were carried out in May 2021 and May 2022. In both experimental campaigns the use of solid fraction didn't affect the apple production compare with the fertilisation with chemical fertiliser.

Modifications and major problems: The farmer (Lagnasco town, IT) used to fertilize the orchard during spring, with 1 application per year. In 2020 the fertilisation coincided with the most restrictive lockdown period due to the COVID-19 emergency. Therefore, in 2020, the application of manure provided by the experimental plan couldn't be arranged.
The experimental layout has been modified with respect to what was initially foreseen by the project. The reason was to identify the experimental plots on a soil as uniform as possible to allow comparison between the various treatments. After the soil analysis, an area with a young apple plantation was identified, covering a total surface of 6000 m^2.

Moreover, according to the high levels of nutrients present in the soil (Action A3), it was considered appropriate to add in the experimental layout a plot without fertilisation as control.

B3.2. SF and compost on apple orchards. (responsible: IRTA)

Description: Three demonstration plots have been established.
On one hand, fertilisation was carried out in established apple trees applying composted and non-composted solid SF of PS. The two treatments were compared with a mineral fertilisation strategy. During the test, soil nitrates are monitored (action C1) and samples are taken for leaf analysis. The harvest is carried out to determine fruit yield and quality of apples. Samples of the SF of PS, soil and fruit were taken for analysis of Abs and ARGs (action C2). Data from this orchard was also used for life cycle analysis (action C1). No significant differences were showed regarding yield parameters, neither on quality parameters on harvest. No significant differences were found on leaves analysis except on P content. Similar mineral N evolution on soil between fertilisation treatments and no accumulation observed. After 3 years, a tendency was observed to increase the P soil content, % of organic matter and C/N relation on Composted SF strategy but without significant differences.

The study of the soil quality parameters was carried out in another adult plantation of Gala apple trees where 4 fertilisation strategies were compared: An organic strategy, an organo-mineral strategy, a composted SF strategy with an exclusively mineral strategy. After 5 years (4 in the case of composted SF), organic fertilisation presents an improvement in the biochemical, physicochemical, and biological properties of the soil compared to the exclusively mineral one. To summarize on established trees, it should be noted that the continuous contribution with criterion N causes an increase of P in the soil that could become excessive. In terms of fruit yield and fruit quality parameters, solid fraction is a good source of nutrients for fruit trees as an alternative to the use of mineral fertilisers.

On the other hand, an apple field trial was planted at the IRTA Mas Badia Agricultural Experimental Station in La Tallada d'Empordà (Spain) using 'JeromineCOV' apple trees, grafted onto 'G.11'. The last 30 years there were apple and pear trees on this plot. The main objective is to avoid the adverse effects caused by replanting through the incorporation of organic matter to improve the nitrification process in comparison with mineral strategy. The study analysed 3 plantation strategies in comparison to unfertilised control: a composted pig slurry SF, a composted pig slurry SF combined with organic amendment OA (pellet of *Brassica carinata*) and a standard chemical practice (composted cow manure + monoammonium phosphate + vegetable substrate + OA). The best growths represented as average shoot growth were observed in the standard strategy and in the combination of composted pig slurry SF + OA. Direct relationship between soil nitrates and vegetative growth was observed. Composted Solid Fraction of PS seemed to be a good alternative to pre-plantation amendment on apple trees but it is necessary to enrich it or adapt its rates.
More information and results on this action can be found in the deliverable 15.

<u>Complementary actions:</u> IRTA worked in FRIENDLY FRUIT PROJECT: Use of Organic manures as a form of carbon and nutrient fertilisation. Organic fertilisation with compost of pig slurry SF combined with mechanical weeding on the tree row on apple trees has been designed to suppress herbicide use as well as to improve the soil health.

<u>After-life</u>: The GALA apple tree trial that studies organic fertilisation strategies will be continued for a few years.

4.2.4. Action B4. Improvement and optimization of pig slurry digestates use in crop fertilisation.

B4.1. Introduction of pig slurry digestates use in orchard trees fertilisation (<u>responsible</u>: UNITO)

	Start date		End date/deadline	
	Foreseen	Real	Foreseen	Real
Action	December 18	December 18	December 21	December 22
Milestone: *Prototype cistern adapted for use in fruit trees*			December 19	December 19

<u>Description:</u> a slurry spreader previously developed by UNITO has been modified and optimised (Figure 8). The distribution system was redesigned to allow the distribution of digestate. The activity carried out concerned the installation of dose variable spreading equipment and the adaptation of the tank for digestate distribution. Moreover, the spreader has been equipped with a new electronic hardware to allow the interfacing with a prescription map.

Several tests were carried out in order to evaluate transversal and longitudinal distribution uniformity following European Standard EN 1380 (2002) methodology. The digestate spreader was tested through a series of field trials and its distribution accuracy and evenness was estimated. It was proven that the machinery is capable of producing a homogeneous distribution, independently from the pre-set dosage of fertiliser. Also, the spreader capability of following a prescription map was confirmed by the test.

Further details are included in the deliverable 14.

Figure 8. Digestate application tank.

Digestate distribution in orchard was carried out in May 2021 and May 2022. In both applications the apple production was recorded and no significant differences emerged between the fertilisation with digestate and with chemical fertiliser.

Modifications and major problems: idem as action B3.1.

After-life: thanks to the interest in the demonstrative technologies developed within the Life Agriclose project, through an agreement with the fruit farms association, UNITO will make the prototypes for digestate and solid fraction distribution available to several fruit farms. This will promote a sustainable management and supply chain of manure to turn the problem of exceeding nutrients of high-density livestock areas into a resource for the fruit production, by improving fertility (organic matter) of soils and reduce the use of chemical fertiliser in orchard.

B4.2. Improvement of digestates management in extensive crops.

a) Top-dressing digestate application in maize (responsible: DACC)

	Start date		End date/deadline	
	Foreseen	Real	Foreseen	Real
Action	December 18	December 18	December 21	December 22
Milestone: *Design of the new fertilisation plan with digestate in the top-dressing corn*			May 19	May 19
Deliverable 17			December 20	December 20
Deliverable 18			December 22	December 22

Four demonstrative fields were stablished in order to promote the use of DI on top-dressing applications in maize. Three fertilisation strategies were tested in each plot: (1) Digestate application at pre-sowing (150 kg N/ha) + mineral top-dressing (75 + 75 kg/ha) (conventional tillage); (2) Digestate application at top-dressing (150 kg N/ha) + mineral top-dressing (75 + 75 kg N/ha) (conventional tillage); (3) Digestate application at top-dressing (150 kg N/ha) + mineral top-dressing (75 + 75 kg N/ha) (no-tillage).

Digestate and soil (action C1) were analysed in order to know and monitor their nutrient and heavy metals content.

The development of maize under the different fertilisation strategies were monitored trough satellite images using the NDVI index. There were no big differences in the maize growing in the different strategies, only a slightly lower index was observed in no-tillage strategies in some cases.

In general treats, the application of digestate on top-dressing was feasible if it carried out at the right moment, when the maize is V4-V6 stage. Also, results shown that if a delay in the topdressing moment is done, the yield could be 10 % lower than excepted. The digestate on top-dressing offers a good opportunity to improve the efficiency on its use in maize mono-cropping (getting closer its application with the moment of maximum needs of maize), and also it permits to improve the management in double-cropping, because it permits to extend the application period when the most of times only there are few days between the harvest of the previous crop and maize sowing.

Modifications and major problems: machinery used to apply digestate was the common machinery used by the farmers. This machinery tends to be big, so it was assumed the possible danger to the crop would be bigger than using smaller machinery. But this is the available machinery for the most farmers, so it was decided to carry out the demonstration with it in order to make easier the introduction of the use of this strategy.

Due to mobility COVID restriction, fertilisation applications made not possible to done with the digestate at the right time. Moreover, because of COVID situation and associated management problems, it has been decided to redirect the demonstration plots and their strategies:

- One new plot was added, while two of the original plots (La Fuliola and Penelles) no longer were carried out.
- No-tillage was evaluated no more in the demonstration plots.
- Fertilisation strategies that were applied were: (1) Digestate application at pre-sowing (150 kg N/ha) + mineral top-dressing (75 + 75 kg/ha); (2) Digestate application at top-dressing (150 kg

N/ha) + mineral top-dressing (75 + 75 kg N/ha); (3) Digestate application at top-dressing (150 kg N/ha) + mineral top-dressing (50 + 50 kg N/ha)

b) New digestate management strategies in extensive crop fertilisation: maize - catch crop rotation. (<u>responsible:</u> IRTA)

	Start date		End date/deadline	
	Foreseen	Real	Foreseen	Real
Action	December 18	December 18	December 21	December 22
Milestone: *Design of the new fertilisation plan with digestate in the top-dressing corn*			May 19	May 19
Deliverable 17			December 20	December 20
Deliverable 18			December 22	December 22

<u>Description:</u> The tasks consist on fertilizing the annual rotation of maize and three different cover crops (ryegrass, forage rape and black oat) with digestate from the anaerobic digestion of livestock manure from a dairy cattle farm during three cycles of the agricultural rotation. The dosage of digestate is properly adapted to the fertilizing needs of the maize crop. The catch-crops (rape forage, ray grass, black oat and no crop) are not fertilised.

The average yield of the three years of corn is 10,048 t/ha, with no statistically significant differences between treatments. The quality parameters of corn production are not statistically different between the treatments either.

The production of the covered crops presents significant differences between the cereal crops: ryegrass (1,926 t/ha) and black oats (1,884 t/ha) with respect to the forage rapeseed (0,93 t/ha) and the field without cover cultivation (0,64 t/ha) of spontaneous vegetation, in the joint analysis of the three years of experience.

After evaluating the variations in soil n-nitric during the three years of the trial, the cover crops cause a reduction in the N after the maize cultivation of 20 kg/N-NO_3^-/year on average, while without cover crops and only with spontaneous vegetation, the N in nitrate form (N-NO_3^-) content of the soil increases by 17 kg/ha/year on average.

Cover crops can be an effective strategy to minimize the risk of nitrate leaching of residual nitrates from crop fertilisation.

<u>After-life:</u> this action is plan to continue during two growing seasons at least.

c) New strategies for digestate use in field crops (Digestate at top dressing in rainfed winter crops) (<u>responsible</u>: IRTA)

	Start date		End date/deadline	
	Foreseen	Real	Foreseen	Real
Action	September 19	September 19	December 21	December 21
Deliverable 16			December 20	December 20
Deliverable 19			December 22	December 22

<u>Description:</u> Demonstrative fields are carried out during two campaigns in rainfed winter crops. Campaign 2019-20: two fields at Sant Julià de Ramis and Cabanelles; campaign 2020-21: two fields at Cornellà del Terri and Cabanelles.

Different fertilisation strategies have been demonstrated in those fields: the application of DI at top-dressing and the application of DI plus the application at late top-dressing of mineral fertiliser. These treatments are compared with PS. And at the Sant Julià de Ramis site one additional treatment has been added: mineral application at top-dressing at the same N rate.

Demonstration field in Cabanelles is being carried out at the same plot (*two crop cycles*) for both campaigns.

In all sites soil samples were taken at the beginning (before top-dressing applications), for soil characterization (A3), and before top-dressing applications and after harvest, for soil nitrates determination (C1). The harvest was carried out using yield mapping machinery, to determine yield in each treatment. Grain samples were taken to analyze quality: specific weight (kg/hL), grain moisture (%), protein content (%) and nutrient (NPK) grain content (%). Organic products (DI and PS) applied (top-dressing) were sampled for their characterization.

Digestate's performance is as good as common fertilisers (PS or mineral fertilisers) in the area, when used as top-dressing fertiliser in rainfed winter crops. An exception may be fertilizing rapeseed with digestate on top-dressing, as fat content -the most important quality parameter- decreases in respect the application of other types of fertilisers.

More information and results on this action can be found in the deliverable 16.

4.2.5. Action B5. Demonstration of PS new by-products efficiency as fertiliser and soil quality improver.

	Start date		End date/deadline	
	Foreseen	Real	Foreseen	Real
Action	December 18	December 18	June 22	December 22
Milestone: *Follow-up to the evaluation of organic and mineral fertilisation strategies*			February 19	February 19
Milestone: *Demonstration field implanted in Catalonia*			March 19	March 19
Deliverable 20			February 19	February 19
Deliverable 21			December 20	December 20
Deliverable 22			December 22	December 22

a) Demonstration of the efficiency of by-products as fertilisers. (<u>responsible:</u> DACC)

<u>Description:</u> A plot has been stablished in order to promote the use of by-products as fertilisers. On one hand, the plot is divided in 36 plots in which the use of DI, LF and SF is compared with common fertilisers as PS and mineral fertilisers, as well as it includes a control (no fertilisation), all of them under conventional tillage and no-tillage. All strategies receive an amount of 300 kg N/ha (combining organic and mineral applications). On the other hand, nine subplots are fertilised only with mineral fertilisers in order to stablished the N response and improve the assessment of the use of by-products (
Figure 9).

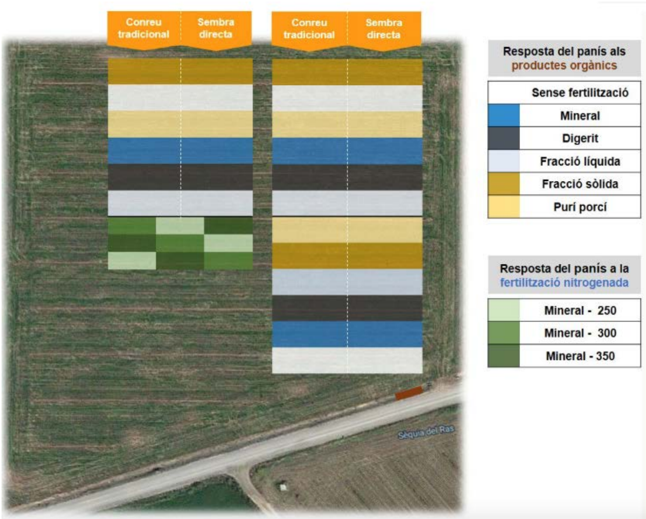


Figure 9. Demonstrative field (Castelló de Farfanya, Catalonia)

All organic products are characterised in each application. All liquid organic products were applied on top-dressing using a conventional tank, while SF was applied before sowing using a conventional spreader. Mineral fertilisation applied manually.

By-products coming from PS treatment are very good fertilisers as part of fertilisation plan for a crop with a high N demanding as maize. However, the importance of knowing the composition of each product has been proven once again to adapt its management to the fertilisation needs of the plot.

Results shown no differences between the yields obtained in the different fertilisation strategies (Figure 10). Maize had a positive react to no-tillage since the first year, due to the management strategy in these intensively irrigated areas, being able to contribute to the improvement of quality of the soil in the long term.

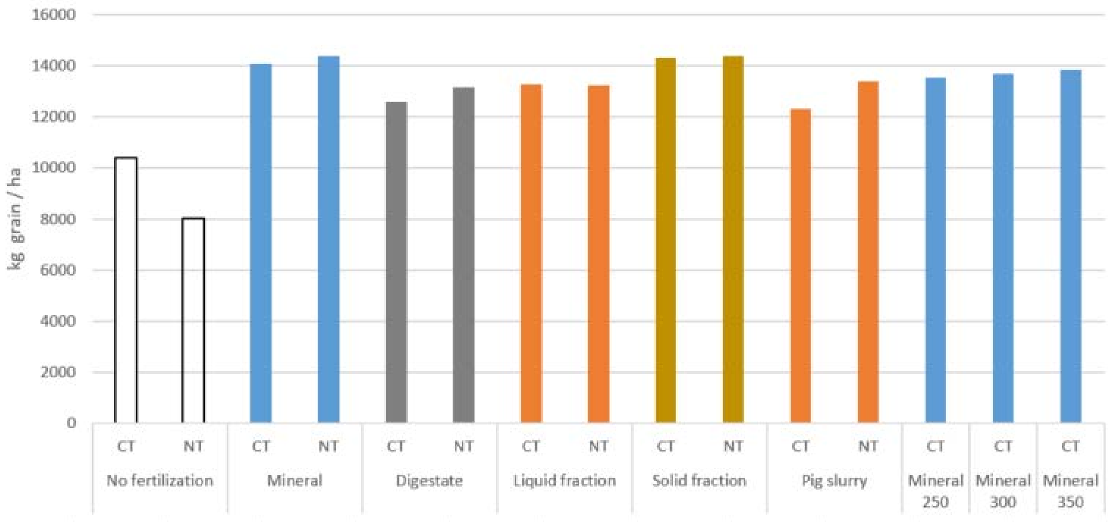


Figure 10. Average yields 2019 – 2022. (CT: Conventional tillage; NT: No tillage)

In general, the P and K soil concentration increase in all organic fertilisation strategies, this increase is higher in conventional tillage than in no-tillage. Otherwise, any organic fertilisation strategies and soil management (conventional tillage/ no tillage) showed no differences on soil organic matter.

The development of maize under the different fertilisation strategies was monitored trough satellite and drone images using the NDVI and NDRE indexes. The growing of maize was higher in mineral and SF strategies. The damage of the machinery in the application of the liquid organic products at top-dressing applications was about 9 – 17%.

More information and results on this action can be found in the deliverable 21.

After-life: Thanks to the interest in the field results obtained within the Life Agriclose project, this action is plan to continue on time due to the interest and its contribution on the fertilisation plan and soil service (DACC).

b) Use of nitro-nutritional agents (NNA) in LF application (responsible: ERSAF)

Description: A developed an integrated agronomic management model of agricultural soils was set up in a farm located in Pessina Cremonese (CR). It has led to the optimization of maize cultivation, paying particular attention to the study of tools for a sustainable use of the farm's PS as fertiliser.

NNA added to pig slurry LF were evaluated for their capacity to increase crop growth, reducing the environmental impact, in comparison with mineral fertilisation. The use of these products is part of an integrative approach which also provides for a conservative management of the soils, assuring a sustainable and stable productivity and, at the same time, preserving and strengthening both the agricultural resources and the environment.

Two experimental plots were identified within the farm (Figure 12): (A) organic fertilisation (pig slurry LF) with nitro-nutritional agents ("new"); (B) mineral fertilisation (UREA) ("min").

Data relating to the maize harvest did not emphasize important differences between the 2 experimental plots

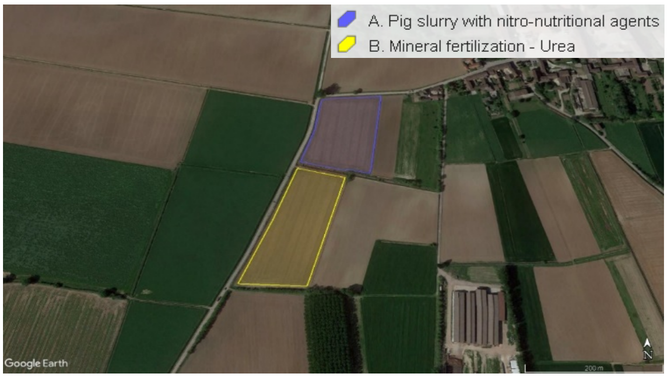


Figure 12. Demonstrative field. Pessina Cremonese (Lombardy)

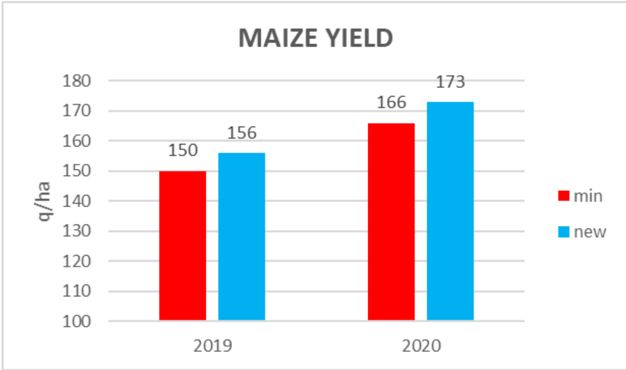


Figure 11. Maize yield, Pessina Cremonese (Lombardy)

The results showed that the integration of different sustainable practices allowed to obtain agronomic and environmental benefits, even in a short time; however, the farmer's responsibility to adapt agricultural practices according to site-specific needs becomes critical for the optimization of the process towards a "more efficient" use of these by-products with a correct application.

Data relating to the water, soils, soil solution and the agricultural management practices adopted were recorded. Analyses performed: groundwater (16), rainwater (16), soil solution (200), soil (46), PS (3), vegetable biomass (12).

Comparison with planned outputs and deviations: experimental activities were carried out in order to assess the efficiency of an integrated conservative approach including the addition of NNA to pig slurry LF compared with mineral fertilisation.

After-life: the farm will be included in the regional soil monitoring network set up by ERSAF for the verification of the long-term sustainability of the agricultural practices on the soil's quality in the Lombard plain.

4.2.6. Action B6. Replicability and dissemination of the project

	Start date		End date/deadline	
	Foreseen	Real	Foreseen	Real
Action	July 18	July 18	April 22	December 22
Deliverable 23			April 19	April 19
Deliverable 24			December 22	December 22

Description: A total of 16 activities have been full described at deliverable 24 about AGRICLOSE actions that have been replicated during the project or that are foreseen to be replicated during the After-life period. Such activities reach different scopes, which go from farm to national level. Consequently, the affected area is variable and ranges from a few hectares to the whole Spanish agricultural land.

Some replicated actions are referred to the use of LF and the conductimeter equipment: the farmer from action B.1.2 used the equipment in all the crop-land; the irrigation entity installed 4 other equipments during the project and plans other 40 more for 2023 and 2024; the trial that uses FL in maize by fertigation will be continued, and another experiment will be initiated on 2023 on almond trees; the use of the regression functions obtained by the project will be replicated in another region (Comunidad Valenciana); and the use of the conductimeter is included at national law (Spanish Royal Decree).

Some of the main regional organizations and companies working in the field of the project have shown their commitment to disseminate and promote the strategies proposed in order to improve manure management and the use of by-products as fertiliser.

There is also support from the government of Catalonia to continue/initiate new trials/collaborations (by-products, ABs and ARG) and to include the results in their agricultural assessments through the territory.

Besides, interest is also shown by all the members of the Expert Committee that ensured that will promote the obtained results in their common activities. The most interesting actions for them where the use of LF (regression functions and use in fertigation) as well as ABs and ARG (methodologies and reduction obtain by treatment of manure).

4.3. Monitoring actions (C)

4.3.1. Action C1. Monitoring and sampling for environmental impact assessment of the project.

	Start date		End date/deadline	
	Foreseen	Real	Foreseen	Real
Action	July 18	July 18	March 22	December 22
Milestone: *Definition of the sampling programme*			December 18	December 18
Milestone: Sampling and characterization of leachate in the pilot composting plant			May 20	Deleted
Milestone: *Completion of soil, water, air and crop sampling*			December 22	December 22
Milestone: *Completion of environmental impact studies associated with antibiotics and bacterial resistance genes*			December 21	December 21
Deliverable 25			February 21	Deleted
Deliverable 26			July 22	July 22
Deliverable 27			December 22	February 23
Deliverable 28			Not required	December 22

a) C1.1. Soil quality monitoring (responsible: all partners)

Description: A total of 3100 analyses have been carried out in order to monitor soil quality. Find the determinations and distribution of all soil analysis per action in the annex 1.

The main results showed that (deliverable 27):

- Soil organic carbon (SOC): Remarkable increases of SOC were obtained in different scenarios: the use of an integrative strategy in maize and also application of SF composted in fruit trees increased the SOC in a 7%. However, plots with conservation practices reduced their contents. As a consequence, our consideration is to take into account a conservative increase (+0,4 %) in SOC because there are too many variables that may influence these results (stability of OM, soil depth, impact of catch crops, etc.).
- Soil Available P: A higher increase was detected by applying composted SF in fruit trees, in where the soil P content was doubled during the project period. In the case of maize, too high values were observed with PS treatments, no recorded with the rest of treated manure. The conservative strategies (NT) decreased in comparison with conventional ones (CT). Both results (SOC and soil P) may not be representative because they have been obtained in a short period of time and may change if they are maintained at the long term.
- Soil nitrate: Top-dressing applications and the use of catch-crops could reduce the nitrates content in a half in the top-soil of maize plots.

b) C1.2. Effects on water quality (responsible: ERSAF)

Description: Water quality was monitored in the demonstrative plots of Lombardy. Rain water (34 samples), ground water (35) and soil water (656) have been analysed. Find the determinations and distribution of all water analysis per action in the annex 1.

The results showed that irrigation could affect the circulation of nitrates in the soil solution: the nitrate content in the soil solution with the surface drip irrigation seemed to remain constant along the profile and, especially in the rhizosphere, was almost always lower than the other techniques, highlighting a potential greater nitrogen absorption efficiency by plants and a consequent lower nitrate leaching.

In the comparison between the use of urea and PS allowed to highlight that the nitrates concentration in the soil solution was significantly ($P<0.05$) higher in the first system: indeed, PS typically allows to reduce its content by an average of 30% (deliverable 27).

c) C1.3 Volume and composition of leachate generated on SF composting (responsible: IRTA)

Description: As stated in the midterm report, leachates were not analysed at pilot scale. Resources were devoted to sampling and analysis of soil under the composting piles (Alcarràs experiment), sampling for ABs and ARGs (analysis by CSIC) and measurements of gas emissions in composting piles (in cooperation with the University of Lleida). The description of the results can be checked in the deliverable 11.

d) C1.4 Antibiotics and ARGs monitoring (responsible: CSIC)

Description: Surface soils from three demonstration sites in Catalonia (i.e. Gimenells, Castelló de Farfanya and Tallada de l'Empordà) and Lombardy (Pessina Cremonesse) have been analysed for ABs and ARGs by using the methodologies validated in the A1.3. 245 samples have been analysed: manure and by-products (45), soil (89), apples (34) and maize (77).

Tetracyclines are the prevalent class of ABs in soils. Three ARGs were consistently found above quantification limits: *sul*1, *bla*TEM, *tet*M, conferring resistance to sulfonamides, penicillins, and tetracyclines, respectively (deliverable 26).

Occurrence of ABs and ARGs in the different matrices analysed:

1) Organic fertilisers: A total of 4 families of ABs and 8 ARGs in pig slurries, solid and LF and digestate has been determined. Tetracyclines, fluoroquinolones and lyncosamides exhibited the highest frequency of detection and abundance (mg/kg-μg/kg fresh weight). Sulfonamides were also detected but at lower concentrations. Among the ARGs analysed, tetracycline resistant gene (*tet*M) exhibited the highest prevalence followed by the sulfonamide (*sul1*) and integron (*intI*1). Other genes detected but at lower prevalence and abundance were β-lactamase (blaTEM) and quinolone (qnrS1) resistance genes. Solid fraction composting under termophilic conditions led to variable a reduction of AB and ARG load ranging from 85 to 99% in both ABs and ARGs.

2) Soils: Tetracyclines were detected in topsoils (0-30 cm) treated with organic fertilisers (PS, LF and SF) and DI at mg/kg (d.wt.) at the different Catalan sites (Gimenells, Castelló de Farfanya and Mas Badia. Catalonia, Spain). However, soils with high clay content (Lombardy, Italy) the antibiotic concentrations were below the limit of quantification presumably due to the strong interaction with the soil matrix. Regarding to ARGs, only three of them were consistently found above quantification limits: sul1, blaTEM, tetM (plus *intI*1); qnrS was detected only in some samples. Moreover, no or mild impact on ARG loads (>1-2 fold) of the addition of organic fertilisers for most cases, except for fields treated with pig slurries or their solid fractions.

3) Maize and fruits: maize grain and apples from 2019 and 2021 harvest collected in the different plots subjected to different treatments were analysed and the AB and ARG concentrations were below the limits of detection (low μg/kg fw) of the analytical methodologies developed for their analyses.

Comparison with planned outputs and deviations: main deviation is the delay in the project implementation due to the administrative burden and the lockdown. The first led to a 4-5 months to receive the first payment and the second we could not work in the laboratory during the lockdown for 3 months as it was not considered an essential activity. The one-year extension foreseen in the project allowed to fulfil the expected objectives.

After-life: A position paper will be prepared at the end of the project in collaboration with the other groups.

e) C1.5. Air emissions sampling in the demonstrative field (responsible: IRTA)

Description: NH_3, GHG (CH_4, N_2O, CO_2) and Aerosols emissions have been monitored in a maize filed located in Gimenells (Lleida, Catalunya), corresponding to the experimental plots of action B1. Three different plots with different fertigation strategies (synthetic fertiliser, LF of PS, and LF of PS + synthetic fertiliser) were monitored during all the growing cycle. Sampling campaign started once the crop was sown (June and lasted during 4-5 months till the harvest (October - November). Three sampling campaigns have been performed, 2020, 2021 and 2022.

In 2020, GHG were sampled using 6 static hoods and NH_3 were monitored with passive NH_3 samplers placed in 6 masts (Figure 13). Almost 200 samples for GHG and 98 samples for NH_3 has been collected and analysed. NH_3 was analysed with a colorimetric method (Spectroquant® kit), absorbance (640 nm) was read with a spectrophotometer (Hach Lange, USA). GHGs concentration were measured with gas chromatography (GC): CH4 with a THERMO TRACE 2000 (Thermo Fisher Scientific, USA) GC with a FID detector, and N_2O and CO_2 were determined with an Agilent 7820A (Agilent, USA) GC system with an electron capture detector (ECD).

The NH_3 concentration results obtained by the passive monitors analytics were used to determine the N emissions per hectare of the different fertiliser treatment suing the software Windtrax 2.0 (Thunder Beach Scientific, Halifax, Canada).

In 2021 and 2022 campaigns, instead of monitoring GHG, it was decided to follow aerosols: particular matter (PM), volatile organic compounds (VOCs) and selected pathogenic bacteria. Aerosols were measured in three different moments: i) before fertigation, ii) during fertigation and iii) after fertigation. VOCs were measured from a gas sample taken during each of the fertigation phase with a syringe and injection in Exetainer vials of 12 mL. Particulate matter, PM2.5 and PM10, were sampled using SKC UNIVERSAL 224 – PCMTX8 bombs and BGI cyclones with glass fibers filter, with an aspiration time of 1 hour. Pathogen microorganisms, were sampled with a SAS device, with an aspiration time of 5-10 minutes (100 L/min flow), using petri plaques with a specific culture medium for *E. coli, Enterococcus, Pseudomonas aeruginosa and Salmonella spp.*

Figure 13. Static hoods and passive NH_3 samplers for emission monitoring

<u>Results:</u> The average NH_3 emitted of the total N applied in the field fertilised with synthetic fertiliser was 33%, while NH_3 emissions has been reduced to 10% when applying LF of pig slurry, and to 11% when the field is fertilised with LF of pig slurry complemented with synthetic fertiliser (Figure 14). The obtained results were processed with the Windtrax 2.0 software to calculate emissions factors for each of the treatments. These results have to be contrasted with results of the next sampling campaigns and should be also take into account the effect of the nearby farm.

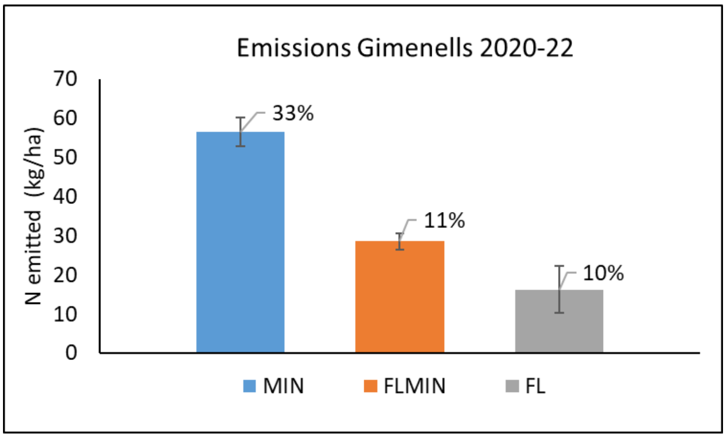


Figure 14. Average emissions of different fertiliser treatments (% emitted of the total N applied). Notes: Min (Mineral fertiliser), FLMIN (Liquid Fraction of pig slurry + Mineral Fertiliser) and FL (Liquid Fraction of Pig Slurry).

Regarding the GHG monitored carried out during 2020 campaign, no significant emissions were detected. It would be necessary to increase the sensitivity of the sampling methodology and analytical methods to quantify the low emissions of this gases.

Regarding the generation of aerosols, the samplings carried out indicate that there is no significant increase in PM2.5 or PM10 particulate matter, nor pathogenic microorganisms, neither during nor after fertilisation. The specific gas samples taken in the different phases studied also do not show a clear trend in the generation of total VOCs. It would be necessary to increase the sensitivity of the sampling and analysis method to be able to accurately quantify and identify these compounds.

Comparison with planned outputs and deviations: GHG (CH_4, N_2O, CO_2) and NH_3 emission monitoring were initially planned to do in the maize plots located in Castelló de Farfanya (Lleida) as part of action B5. Due to COVID situation and other technical issues (treatment plots were too small to monitor emissions without interferences) it was decided to perform the sample campaign in the plots located in Gimenells (Lleida, Catalunya), action B1.

The monitoring was performed two more campaign (2021 and 2022) than the initially planned in the project (deliverable 27 and 28).

Complementary actions: Gases emission monitoring in different situations (processing technologies, farms, slurry storages, different crops, etc.) to nourish the data base of emissions in the Mediterranean conditions are being performed in other running projects and future projects submitted.

After-life: Emission monitoring is a relevant issue to the environmental impact assessment, to compare new agricultural practice, etc. It is confirmed to continue (at least year 2023) with the monitoring campaigns to nourish the emission data base in Mediterranean conditions. Projects have been submitted in this direction.

4.3.2. Action C2. Environmental Assessment using Life Cycle Analysis tools of the different fertilisation alternatives based on fertilisers organic derived from slurry treatment.

	Start date		End date/deadline	
	Foreseen	Real	Foreseen	Real
Action	October 18	October 18	June 22	June 22
Milestone: *Inventory of the strategies proposed*			October 20	February 21
Deliverable 29			May 22	April 22

Responsible: IRTA

Description:

Activities have been undertaken accordingly to timetable scheduled:

a) C2.1. Objectives and definition of the system limits:

- Definition of Functional Unit: 1 ton of crop yield (apple, peach, barley and corn)
- Scope: cradle to farm gate, excluded logistics of commercialization
- Emission estimation: PEFCR guidance (EC 2017) + SALCA adapted to Mediterranean conditions based on work conducted at the Futur Agrari project (LIFE+12 ENV/ES/647) + required updates to IPCC (2019) + EAA (2019)
- Life Cycle Impact Assessment Model: Environmental Footprint EF 3.0
- Software: Simapro 9.1
- Primary data: own data
- Secondary data: Ecoinvent 3.7 (Werner et al 2016) + Agribalyse 3.1(Colomb et al 2014)

b) C2.2. Inventory data collection:
Inventory data for alternative scenarios has been conducted. Three scenarios of fruit production, apple and peach, located at Catalonia and Piedmont, and three scenarios of extensive crop production, maize and barley, all of them located at Catalonia, were used as case studies to test the environmental performance of different organic fertilisers in comparison with conventional mineral fertilisation. Different organic fertilisers were tested: i) Raw PS ii) LF from PS; iii) SF from PS; and iv); iv) compost of SF from PS, and v) different type of DI.

c) C2.3. Impact analysis
Impact Assessment for all scenarios have been conducted following the recommended models of Environmental Footprint EF 3.0 (EC 2017).

d) C2.4. Interpretation:
During this stage we have pointed out the main environmental aspects in relation with impact of organic fertilisers. These are in relation with NH_3 emissions, therefore it is advised to follow BTA as far as possible.
Regardless of the specific analysis of fertiliser substitution, environmental quantification has also shown us the importance of other processes related to agricultural production. Among them, we should highlight the importance of water in all irrigated crops, our geographical situation makes this a critical issue to consider, therefore thinking about solutions (e.g.: take advantage of slurry) that allow water saving should be a priority. Also fuel consumption has shown to be an important contributor, therefore measures to reduce its consumption should be included in the farm management.
Also during this stage is important to highlight aspects related to the methodology applied. Several issues have underlined as potential aspects for further research, these are: i) Implementation of specific datasets for organic fertilisers through local databases, which can catch the variability of products and production systems; ii) Improvement of emissions factors related to organic residue treatments (i.e. composting, anaerobic digestion, etc.) and field application; iii) Avoided impact accounting means scenario selection (being substituted) which is not always clear or enough straight forward, clear guidelines on how to proceed on this would be needed and iv) need of Circular Footprint formula definition for the specific sector of organic fertiliser application, this is clear guidelines to allocate recycled products between activity, which generates "waste" and activity that uses it.

4.3.3. Action C3. Socio-economic evaluation of the project

	Start date		End date/deadline	
	Foreseen	Real	Foreseen	Real
Action	July 20	July 20	July 22	December 22
Milestone: *First socio-economic assessment carried out*			October 20	October 20
Milestone: *Technical report of the socio-economic evaluation of the project presented*			December 22	December 22
Deliverable 30			December 22	December 22

Description: The socio-economic evaluation of the project is much more detailed at deliverable 30, which includes: i) an economic assessment of the strategies developed in the project by applying the method of Life Cycle Costing (LCC); ii) the socio-economic impacts of the project which have been evaluated through the application of the Hybrid fulfilment-importance matrix (HFIM) method; and iii) a social assessment focusing on the perception of the stakeholders through surveys (citizenship, collaborators, administration and organizations).

Regarding the economic assessment, the economic costs are calculated for each strategy considering all the life cycle components of the system. This study is in line with the LCA conducted in the project, as the inventory collected was the starting point. For each strategy, a breakdown of the costs for different alternatives is presented as well as the final balance and profit. For all the strategies the balance shows a benefit with the application of the strategies.

According to the socio-economic assessment, the HFIM allows considering performance, economic, environmental and social aspects for the evaluation of the socio-economic objectives of the project. The results show that the research conducted in AGRICLOSE has a substantial contributor to all the socio-economic objectives of the project, specially to the most technical ones (effects on the environment, hygiene and safety on agrarian production, and efficiency of manure). The most technical indicators are the ones with the highest scoring (reduction of resource consumption, area of agricultural soil under sustainable management and NH_3 emissions (application of fertilisers)).

The surveys to the citizenship reveal that it is key for the population to have reliable information regarding sustainable production processes. The collaborators of the project highlight positive aspects of the project for agriculture and farming (such as manure management or innovation) and for research (dissemination of the knowledge and synergies). Moreover, they also mention barriers and difficulties, insisting on the need to reduce bureaucracy and administrative obstacles. The administration is willing to participate proactively in the implementation of the strategies of the project, as the objectives of the project are in line with their goals for the sector (e.g. rural development or reduction of environmental impacts). Bureaucracy and lack of financing are stated as the main problems for the development of the strategies, being necessary important legislative changes to solve the problem. All the organizations consulted are in favour of adopting the strategies of the project. However, there are some barriers and difficulties that the different organisations have highlighted like the economic costs and uncertainty as the main issues.

Overall, the results of the deliverable are promising for the strategies developed in Agriclose. Firstly, the case studies assessed show a net benefit, so there are economic incentives for their implementation. Secondly, the project has a substantial socio-economic impact in line with the objectives of the project. Finally, the different stakeholders considered through the surveys have positive perception of the strategies defined and are willing to proactively contribute to their implementation.

4.3.4. Action C4. Monitoring of the project progress and its impact through LIFE performance indicators

	Start date		End date/deadline	
	Foreseen	Real	Foreseen	Real
Action	July 18	July 18	July 22	March 23
Milestone: *Update LIFE KPI Webtool Progress report*			November 19	November 19
Milestone: *Update LIFE KPI Webtool Final report*			December 22	March 23
Deliverable 31			December 22	March 23

Key project indicators: all the information related with KPI can be found in the point 5 “Key Project-level Indicators”.

LIFE Performance Indicators: Some performance indicators are based on the potential of use of the strategies promoted according the current situation and forecast in the presence of by-products in the agrarian sector. Some of them have been achieved from the life cycle analysis carried out. In general, the impact of the project has been achieved as expected. However, during the project, there has been an important increase of the treatment of slurries, so the availability of by-products coming from these treatments has increased and therefore the potential impact of the project in the improvement of their management also has been increased in the same way. This is the main reason of the variation of the indicators in comparison with the values set in the proposal. Find the details and bibliographic references at deliverable 31. Some clarifications about the indicators bellow:

- It is considered an extension of 350,000 ha of cereals and 45,000 ha of fruit trees currently existing in Catalonia.

- At the end of the project, more than 2 Mt of manure is treated in Catalonia, close to 1 Mt through a separator and 680,000 t by composting and close to 0.5 Mt by anaerobic digestion in biogas plants. It is expected to treat around 3 Mt in the coming years.
- It is assumed that 30% of these products could be reused as fertilisers in the cereal and fruit fields based on the actions designed in this project, thanks to both the higher efficiency and the reduction of the emissions achieved in the project, thus counting as avoided waste.
- This 30% of by-product could replace the use of mineral fertilisers.
- IT is assumed an average nutrient content of 3.85 kg N, 2.67 kg diphosphorus pentaoxide (P_2O_5), and 2.55 kg K2O per t of slurry and an application rate of 30 t/ha.
- The acidification of slurry previous to the separation permits to reduce 100% the use of dangerous substances (sulphuric acid) and it have achieved a reduction of emissions until 35% of NH_3 and 49% of GHG.
- Avoided GHG emissions have been calculated, by replacing synthetic fertilisers with organic fertiliser, based on information from the ecoinvent v3 database, (Wermet *et al*., 2017).
- The avoided NH_3 emissions have been calculated based on the improvement in application techniques (Bitmann *et al*., 2014) and that has been confirmed by the results obtained in the project.
- The hectares of cereal and fruit trees where these applications can be carried out are counted as optimal management, also taking into account the aspects of application and the contribution the soil quality.
- The increase of soil organic matter and therefore C stored on it is accounted for based on the work of Yagüe *et al*. (2016).
- For the calculation 3 years from the end of the project, it is assumed that the production of treated slurry will increase up to 3 Mt only in Catalonia.

Progress indicators: In general, progress indicators have been followed as accorded and the progress of the project has been as expected. The COVID emergency influenced the project progress, leading to some delays. In particular, there was some delays / modifications in the following actions: A1, B1, B2, B3, B4, C5 and all those related with the dissemination and the management of the project. Some of them were compensated with the extra season added through the extension of the project. However, these delays didn't compromise to achieve the goals of the actions.

4.3.5. Action C5. Creation of an expert's advisory board

	Start date		End date/deadline	
	Foreseen	Real	Foreseen	Real
Action	July 18	July 18	July 22	December 22
Milestone: Creation of the expert committee			December 18	December 18
Deliverable 32			December 22	December 22

Description: Expert committee was composed by experts of the main disciplines of the project fields as: manure treatment, manure use efficiency as fertilisers and food safety. The composition of the expert panel is:

- David Fangueiro (Universidade de Lisboa)
- Giorgio Provolo (Università degli studi di Milano)
- Ana Aizpurua (Instituto Vasco de Investigaciones Agrarias)
- Beatriz Guerra (Autoridad Europea de Seguridad Alimentaria)

The meetings were held in the deliverable 42, and the final report of the Expert Committee in the deliverable 41.

Comparison with planned outputs and deviations: Expert Committee was created later than expected as well as the celebration of the first meeting. However, the delay does not compromise the objectives of its creation.

4.4. Public awareness and dissemination of results (D)

	Start date		End date/deadline	
	Foreseen	Real	Foreseen	Real
Action	July 18	July 18	July 22	December 22
Milestone: Programmed Web			December 18	December 18
Milestone: Press conferences at the beginning of the project			March 19	March 19
Milestone: Press conferences at the end of the project			December 22	December 22
Milestone: LAYMAN Report available to the public			December 22	January 22
Milestone: Guides in pdf format published on the web			December 22	December 22
Milestone: Final meeting of the project			December 22	May 22
Milestone: Networking conclusions integrated in After-LIFE plan			December 22	December 22
Deliverable 33			June 20	June 20
Deliverable 34			December 22	January 22
Deliverable 35			December 22	December 22
Deliverable 36			December 22	January 22
Deliverable 37			December 22	December 22
Deliverable 38			December 22	December 22
Deliverable 39			December 22	December 22

a) D1. Dissemination to the public and stakeholders in general

Description:

- Logo design, image of the project and communication plan:

The logo and the image were defined at the beginning of the project. See the leaflet of the project in the annex 5 as an example.

The communication plan was ready at the beginning of the project. It has been carried out as expected. However, some events have been adapted to the needs detected during the development of the project.

A roll-up, a flag and merchandising were acquired in order to make visible the project (annex 2 and 3).

- Communicative tools

Web (https://agriclose.eu/) was ready during the first semester as expected. There have been 20,928 visits. Five newsletters were sent to more than 500 people, which are available in English, Italian, Catalan and Spanish.

All notice boards (9 field panels and 1 interior panel) were installed (deliverable 33).

- News and social media

Press conference were carried out and more than 75 news about it were published (newspaper, TV, digital newspapers, etc.). Five news about the project were published in regional and local TV, as well as, three radio interviews (deliverable 35).

Twitter account (@lifeagriclose) has 159 followers and more than 201 tweets were posted. Publications about the project have also been posted in the social media of the organizations (see the Facebook of ERSAF).

Comparison with planned outputs and deviations: Although the number of newsletters foreseen was 8, the COVID restrictions made it difficult to execute and deliver to the stakeholders. In the Mid-term report we informed that we expected to send 6 newsletters instead of 8. It was expected to send the 5th newsletter around June – July 2022, to inform about the PROFEM conferences celebrated in May 2022. The recorded videos were edited in Autumn 2022, so we decided to join newsletters 5 and 6.

After-life: dissemination actions will continue after the end of the project through the AGRICLOSE website and social media, as well as the social channels of the organizations.

b) D2. Technical communication to the stakeholders

It has been an active participation in different communication events:

- Two technical guides have been published:
    - Composting guide (deliverable 12). It's a tool to transmit the composting system to technical staff, farm owners and other interested parties.
    - Use guide. It introduces the main types of treated livestock manure available on the market, whose technology of treatment come from, an indicative composition of the nutrients and other elements they contain, the regulations that apply to them on Catalonia as well as examples of its possibilities of application to agriculture.
- Two scientific publications have been published in the journal Environmental Research as open access:
    - "*Antibiotic and antibiotic-resistant gene loads in swine slurries and their digestates: Implications for their use as fertilisers in agriculture*". Environmental Research 194 (2021) 110513.
    - "*Impact of organic soil amendments in antibiotic levels, antibiotic resistance gene loads, and microbiome composition in corn fields and crops*". Environmental Research 214 (2022) 113760
- Five international conferences: European Sustainable Nutrient Initiative (ESNI), ManuResource, Conference and Esposizione Internazionale di Macchine per l'Agricoltura e il Giardinaggio (EIMA International) and IEEE International workshop on metrology for agriculture and forestry.
- Nine national conferences: XVIII Jornadas sobre producción animal (Asociación Interprofesional para el Desarrollo Agrario), Conference of the Italian Society of Agricultural Engieneering (AIIA), Worshop Festival del suolo, Workshop Redazione del programa d'azione nitrati 2024-2027, Congress AIDA, XVI European Society for Agronomy Congress, IX Remedia workshop, BIT2022 and Seminar in the framework of International Week of Compost.
- More than 32 local / regional events. The technical documentation of the conference is available on the web.
- Twenty networking meetings / participation events with LIFE ARIMEDA, LIFE AGROgestor AND LIFE SPOT, among others (deliverable 38).

More than 3.000 attendees took part in the events organised by the project, although a higher number should be considered if we also consider the collaboration in external conferences or field days. Audience have showed interest about the progress of the project and the development of the promoted strategies from different points of view: technical, agronomical, economical and sanitary. There is a special interest on the feasibility of the techniques, compost (technology and commercialization), legal frame in the use of by-products, environmental and sanitary effects and more.

Multimedia: 31 videos including the same version in different languages, with more than 3000 views. All has been published in Agriclose website and in RuralCat (agrarian network with more than 30.000 users).

Datasheet: more than 10 publications with technical and specific content of the project actions that include the results. All has been published in Agriclose website.

Modifications and major problems: The years 2020-21 made it difficult to hold field events due to COVID-19. This was a big issue, because of the importance to promote the tested strategies/technologies and to stimulate direct discussion with local farmers and stakeholders. These activities were postponed and partially replaced by online events and the production of informative material (e.g. videos) to be disseminated through the intended channels. The extension of the project helped to compensate the delays and meet expectations regarding this aspect.

After-life: All partners will continue to disseminate information to farmers, technicians and companies interested in the management strategies proposed by the project. In particular: best fertilisation practices when using by-products, composting process, application machinery, new technology and devices, environmental issues and more.

Another scientific publication will be published with the title “*Fate of veterinary antimicrobials in decentralised swine slurry composting under thermophilic conditions: A field-scale study*” at Waste Management Journal.

4.5. Project Management (E)

	Start date		End date/deadline	
	Foreseen	Real	Foreseen	Real
Action	July 18	July 18	July 22	December 22
Milestone: *KOM meeting*			October 18	November 18
Milestone: *Creation of the organisation committee*			October 18	October 18
Milestone: *Creation of the expert committee*			October 18	December 20
Milestone: *Final meeting*			December 22	May 22
Milestone: *After-LIFE plan published on the web*			December 22	March 23
Deliverable 40			November 18	November 18
Deliverable 41			December 22	December 22
Deliverable 42			December 22	December 22
Deliverable 43			December 22	March 23

<u>Description:</u> the communication among beneficiaries has been constant and fluently, main ways of communication have been by mail and video-conferences. At least, one meeting with all beneficiaries was hold every 6 months. The main meetings hold have been:

- Kick off meeting (Barcelona, 12-13th November 2018)
- Follow up meeting (Barcelona, 30th May 2019)
- Meeting with the advisor and all partners (Lleida, 5th February 2020).
- Coordination meeting (on-line, 20th July 2020)
- Coordination meeting (on-line, 15th December 2020)
- Meeting with the advisor and all partners (online, 27th April 2021)
- Coordination meeting (on-line, 16th December 2021)
- Follow up meeting (Caravaggio, 7th March 2022)
- Expert Committee meeting (Lleida, 20th May 2022)
- Final workshop (Vic, 30th November 2022)

<u>Comparison with planned outputs and deviations</u>: It was expected to celebrate at least one on-site coordination meeting in each region of the project. However, because of COVID-19 situation only one meeting could be celebrated in Italy.

4.6. Main deviations, problems and corrective actions implemented

There had not been important difficulties that impacted the correct development during the project. Of course, the COVID emergency influenced the project progress, leading to some delays, mainly in action B3, B4 and dissemination activities (action D), which were really strongly impacted, limiting the possibility of creating events that would facilitate the dissemination of the project, involving more stakeholders on the issue of sustainable management of zootechnical effluents. Also actions A1, B1, B2, B5, C1, C5 and E suffered some affectation. Dissemination difficulties were compensated with the celebration of on-line conferences and the elaboration of extra material (short videos, factsheets, etc.). All the actions carried out in order to compensate the deviations worked well and they helped to meet the expectations to achieve the final goals of the project.

4.7. Evaluation of Project Implementation

4.7.1. Methodology applied

The applied methodology has been effective in assessing alternative sustainable manure management techniques, the development of new technologies and environmental monitoring, as the obtained results are the ones expected.

This methodological approach has allowed to optimize the use of by-products from the treatment of livestock manure as organic fertilisers, expand the range of management possibilities, reduce the use of mineral fertilisers and improve the soil quality without negative impacts on yields or quality.

Technology developments have been very successful. Automatic dosage system of LF, slurry automatic acidifier and application machinery (spreader and tank) have shown great results, achieving the proposed goals.

Concerning to the environmental monitoring, GHG emissions (action B1.2.) were so low that they were close to the detection level of the methodology used (static hoods). Contrary, the passive samplers for NH_3 has shown a good performance.

The methodologies implemented to analyze ABs and ARGs involving LC-MS/MS and q-PCR are successful since they provide precise and accurate results in a variety of pig slurries and derived products, soil and crops.

4.7.2. Results

The techniques tested in the demonstrative plots proved the effectiveness of the proposed strategies in terms of improving their use as organic fertiliser and reducing the environmental impact. Furthermore, these techniques are not showing negative effects on either the yields or the quality of the final products.

See the objectives, foreseen and achieved results as well as their evaluation in annex 4.

The application of the innovative technologies mainly involves environmental benefits becoming apparent in longer time and moderated economic benefits in terms of yields and lower consumptions. Most of the fertilisation strategies promoted offer lower operating costs and better net profit per ton, despite presenting in some cases lower crop yields than conventional fertilisation strategies. For example, in the composting strategy, the cost for the compost of 28 €/t has been calculated. If the same nutrients were provided with mineral fertiliser, this would be 70 €/t, without taking into account the improvements in organic matter, microelements, increased microbiological activity of the soil and the improvement of its structure.

The dissemination of the project has been successful since the feedback from stakeholders and farmers have shown their interest to know about the strategies proposed by the project and their implementation.

Also the replicability is being successful, the automatic dose system of LF is already a reality in the market and is being used beyond the framework of the project.

The information and knowledge generated through the project will allow to improve regional, national and EU legislation. It could contribute to improve the legislation regarding to manure management and fertilisation, antibiotic management in farms or food safety. In particular, the project will have a direct impact on the regional fertilisation regulations of Catalonia and Lombardy. This impact is more detailed at “Policy implications” chapter.

4.7.3. Analysis of benefits

a) Environmental benefits (quantitative and qualitative)

The results of the monitoring activity carried out on all the environmental matrices showed that the “innovative strategies” offer better parameters of environmental quality in terms of:

Fertility – Soil organic carbon (SOC):
- *Soil organic carbon (SOC):* Remarkable increases of SOC were obtained in different scenarios: the use of an integrative strategy in maize and also application of SF composted in fruit trees increased the SOC in a 7%. However, plots with conservation practices reduced their contents. As a consequence, our consideration is to take into account a conservative increase (+0,4 %) in SOC because there are too many variables that may influence these results (stability of OM, soil depth, impact of catch crops, etc.).

- *Soil available P*: A higher increase was detected by applying composted SF in fruit trees, in where the soil P content was doubled during the project period. In the case of maize, too high values were observed with PS treatments, no recorded with the rest of treated manure. The conservative strategies (NT) decreased in comparison with conventional ones (CT). Both results (SOC and soil P) may not be representative because they have been obtained in a short period of time and may change if they are maintained at the long term. The application of SF composted in fruit trees has increased the soil organic matter in a 13% and it has doubled the soil P content. The use of DI in an integrative strategy has led to an increase of the SOC in a 14%.

- *Soil nitrate*: Top-dressing applications and the use of catch-crops can reduce the nitrates content in a half in the top-soil of maize plots.

<u>Water quality</u>: Fertigation with LF highlights the potential of greater N absorption efficiency by maize and a consequent lower nitrate leaching. The nitrate content in the soil solution with the surface drip irrigation seemed to remain constant along the profile and, especially in the rhizosphere, was almost always lower than the other techniques, highlighting a potential greater nitrogen absorption efficiency by plants and a consequent lower nitrate leaching. In the comparison between the use of urea and PS allowed to highlight that the nitrates concentration in the soil solution was significantly higher in the first system: indeed, PS typically allows to reduce its content by an average of 30%.

<u>Emissions</u>: Regarding to the results obtained in Italy, LF fertigation permits to reduce NH_3 emissions by up to a third compared to mineral fertigation in maize. It also has seen that its injection into the soil can reduce NH_3 emissions by half if compared with surface application, obtaining values of around 5%. The acidification of the slurry with S before separation has reduced NH_3 and GHG emissions by between 20 and 25% in the subsequent management of LF and SF. And the applications of SF and digestate in fruit trees show that N_2O emissions after their spreading was significantly lower compared to the chemical fertiliser, and NH_3 emissions after digestate application resulted relevant.

According to maize trials in Catalonia, the average NH_3 emitted of the total N applied in the field fertilised with synthetic fertiliser was 33%, while NH_3 emissions has been reduced to 10% when applying LF of PS, and to 11% when the field is fertilised with LF of PS complemented with synthetic fertiliser. Regarding the GHG, no significant emissions were detected. Regarding the generation of aerosols, the samplings carried out indicate that there is no significant increase in PM2.5 or PM10 particulate matter, nor pathogenic microorganisms, neither during nor after fertilisation. No clear trend was attributed to the generation of total VOCs.

<u>ABs and ARGs</u>:
- *Organic fertilisers:* A total of 4 families of ABs and 8 ARGs in pig slurries, solid and LF and digestate has been determined. Tetracyclines, fluoroquinolones and lyncosamides exhibited the highest frequency of detection and abundance. Among the ARGs analysed, tetracycline resistant gene (*tet*M) exhibited the highest prevalence. Solid fraction composting under termophilic conditions led to variable a reduction of AB and ARG load ranging from 85 to 99% in both ABs and ARGs.

- *Soils:* Tetracyclines were detected in topsoils (0-30 cm) treated with organic fertilisers (PS, LF and SF) and DI at mg/kg (d.wt.) at the different Catalan sites (Gimenells, Castelló de Farfanya and Mas Badia. Catalonia, Spain). However, soils with high clay content (Lombardy, Italy) the antibiotic concentrations were below the limit of quantification presumably due to the strong interaction with the soil matrix

- *Maize and fruits*: maize grain and apples from 2019 and 2021 harvest collected in the different plots subjected to different treatments were analysed and the AB and ARG concentrations were below the limits of detection (low μg/kg fw) of the analytical methodologies developed for their analyses.

Sustainable management of livestock manure in agricultural areas with high intensity of livestock farms leads to environmental benefits that materialize in the long term in soil fertility, water and air quality. All strategies promoted by the project will contribute to have a more sustainable, safer and cleaner manure management.

b) Economic benefits

The adaptation of farms to sustainable agronomic management practices of livestock manure involves an economic investment whose sustainability is a function of the real benefits obtained. Most of the fertilisation strategies promoted offer lower operating costs (e.g. soil management or mineral fertilisers consumption) and better net profit per ton, despite presenting in some cases lower crop yields than conventional fertilisation strategies. In any case, the quality of final products has been positively affected.

The possible economic benefits from the implementation of the project strategies ranged from 562,000 € to 3,7 M€, depending if we are more or less conservative. The estimations have been calculated on the basis of a 100% substitution of mineral fertilisers, by using N or P doses (according to the action), by not accounting the installation treatment costs and by considering that the by-product is free-cost (situation that can be considered in some surplus areas). A total of 4 situations have been calculated and the benefits extended to a part of the potential area of Catalonia, Lombardy and Piedmont.

- 100% substitution of N mineral fertilisers by LF on irrigated orchards (apple, pear, peach, nectarine and almond trees). **Action B1.1.**
  References considered: doses of 100 kg N/ha; price of fertiliser at September 2022 of 2.9 €/kg N; range of farmers who implement this action from 1 to 5% of the whole considered area.
  Economic benefit range: 146,748 **-** 733,740 €

- 100% substitution of N mineral fertilisers by LF on irrigated maize crops. **Action B1.2.**
  References considered: doses of 170 kg N/ha; price of fertiliser at September 2022 of 2.9 €/kg N; range of farmers who implement this action from 1 to 5% of the whole considered area.
  Economic benefit range: 237,747 – 1,188,735 €

- 100% substitution of N mineral fertilisers by LF/DI on rainfed cereal crops (wheat and barley). **Actions B1.3/B4**
  References considered: doses of 100 kg N/ha; price of fertiliser at September 2022 of 2.9 €/kg N; range of farmers who implement this action from 0,1 to 1% of the whole considered area.
  Economic benefit range: 237,747 – 1,215,516 €

- 100% substitution of P mineral fertilisers by SF/Compost on rainfed vineyard, olive and almond trees. **Action B3**
  References considered: doses of 100 kg N/ha; price of fertiliser at September 2022 of 1.7 €/kg P_2O_5; range of farmers who implement this action from 1 to 10% of the whole considered area.
  Economic benefit range: 36,208 – 362,081 €

c) Social benefits

The sustainable management of agronomic practices in an area with a high density of livestock farms meets a great social interest from both farmers and stakeholders, leading to the continuous research for innovative solutions that allow to optimize benefits and minimize negative impacts.

The new by-products management practices contribute to the sustainable use of integrated fertiliser, plant health, protection of water against the contamination produced by nitrates as it has seen in the environmental benefits. This has an indirect impact on the processing costs and the value of by-products for the various stages of pig and crop production.

On the other hand, these strategies reveal some socio-territorial implications in the rural areas, influencing the socio-economic status of farmers, providing them a set of solutions in order to be able to carry out their activity. This fact will encourage the farmers to remain producing in the rural areas instead of shifting to other economic activities.

The main impact of the project at a socio-economic level comes from the technical improvements of the strategies promoted. In this sense, the more technical indicators (reduction in resource consumption, area of agricultural land with sustainable management and NH_3 emissions) show a greater impact.

ANNEXES

ANNEX 1. Soil and water samples

1. Soil samples taken and analysis carried out in the initial characterization (A3)

Action	Plot	Location	Nº of soil samples
B1	1	Soses (Catalonia)	1
	2	Gimenells (Catalonia)	3
	3	Caravaggió (Lombardy)	3
	4	Malla (Catalonia)	2
	5	Malla (Catalonia)	3
	6	Tona (Catalonia)	3
B3	7	Lagnasco (Piedmont)	12
	8	La Tallada d'Empordà (Catalonia)	3
	9	La Tallada d'Empordà (Catalonia)	3
B4	10	Lagnasco (Piedmont)	12
	11	Torregrossa (Catalonia)	1
	12	La Fuliola (Catalonia)	1
	13	Penelles (Catalonia)	1
	14	Térmens (Catalonia)	1
	15	Baix Empordà (Catalonia)	4
	16	Cabanelles (Catalonia)	3
	17	Sant Julià de Ramis (Catalonia)	3
	18	Cornellà del Terri (Catalonia)	3
B5	19	Castelló de Farfanya (Catalonia)	4
	20	Pessina Cremonese (Lombardy)	2

2. Environmental monitoring samples (C1)

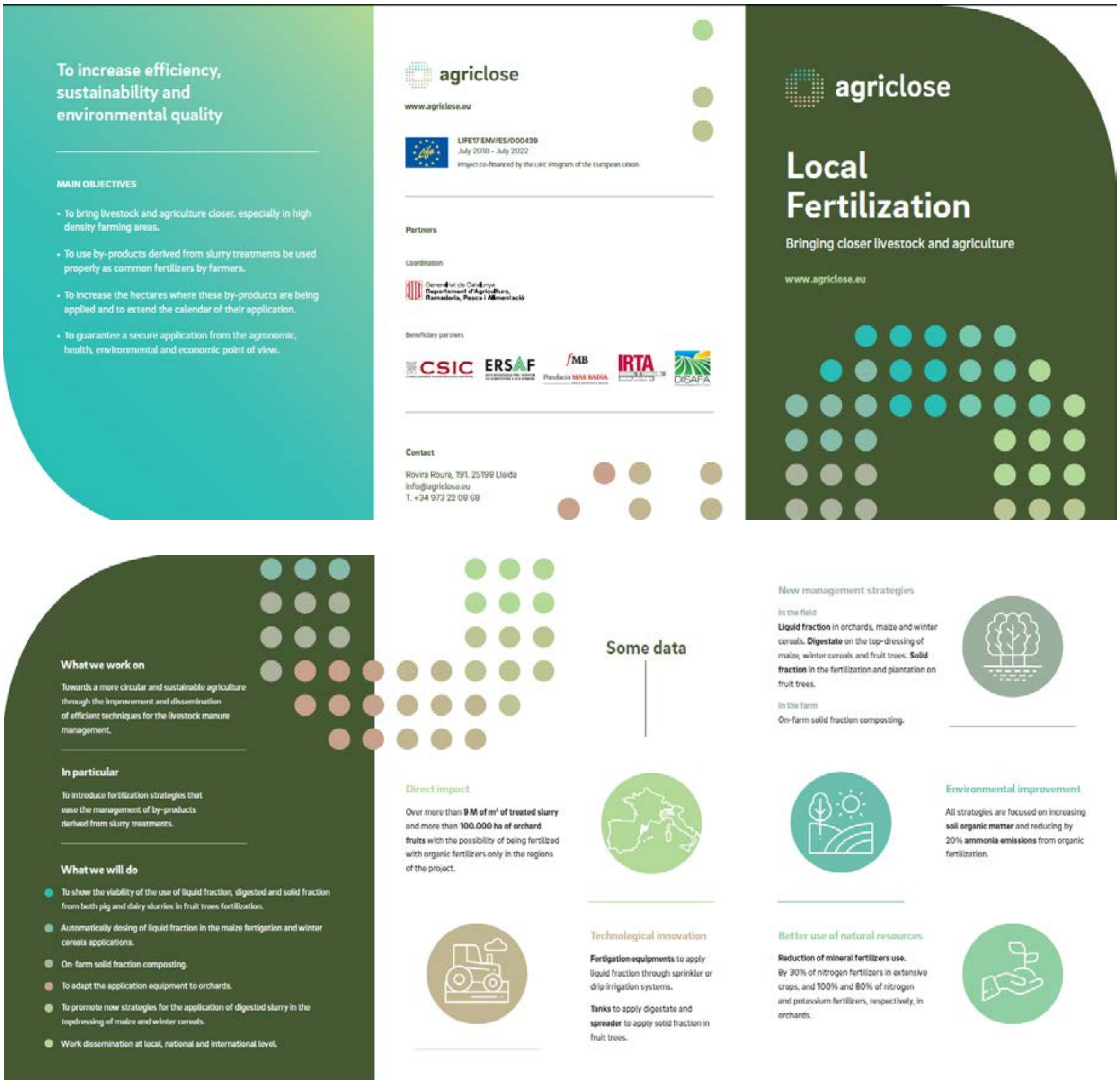
2.1. Soil samples (C1.1.)

ACTION	ACTION	Nº OF SAMPLES	DETERMINATION
B1	B1.2. (DARP)	27	Nitrates
		€€	organic matter
		27	phosphorus and potassium
	B1.2. (ERSAF)	35	pH, nitrates, phosphorus, potassium...
	B1.2. (IRTA)	52	nitrates
B3	B3.2 (IRTA)	240	NITRATES
B4	B4.2. (DARP)	143	NITRATES
		5	HEAVY METALS
	B4.2. (IRTA)	144	NITRATES
		288	Final soil analysis
B5	B5 (DARP)	1612	NITRATES
		45	HEAVY METALS
		45	organic matter
	B5 (ERSAF)	44	pH, nitrates, phosphorus, potassium...

2.2. Soil water samples (C1.2.)

ACTION	RAIN WATER	GROUND WATER	SOIL WATER	DETERMINATION
B1.2.			310	EC, $N\text{-}NO_3$, $N\text{-}NH_4$.
			310	PO_4
B5	20			PO_4, $N\text{-}NO_3$, N-NH4
	20			EC
		20		PO_4, $N\text{-}NO_3$, $N\text{-}NH_4$
		20		EC
			244	$N\text{-}NO_3$, $N\text{-}NH_4$
			184	EC
			244	PO_4

ANNEX 2. Leaflet of the project.



Link to english version: https://agriclose.eu/en/divulgacio/

ANNEX 3. Merchandising, flag and roll-up.

FLAG

ROLL-UP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ANNEX 4. Results

Action	Sub-action	Foreseen in the revised proposal	Achieved	Evaluation
A.1	A1.1.	Objectives: To optimize the use of the products obtained from the zootechnical waste treatment. Expected results: To reduce by 60, 50 and 30% the emissions of NH_3, CH4 and N2O, respectively, during storage of the acidified SF (45, 134 and 0.5 t/year, respectively).	1) Lab and field scale trials to assess the effect of addition of elementary sulfur to raw pig slurry before mechanical separation on pH, and emission of NH3 and GHG during storage of separated (liquid, solid) fractions. 2) Design, development and testing at farm (Racconigi, province of Cuneo, Piedmont Region, northwestern Italy) of a full-scale prototype for automatically addition of powdery S to pig slurry before mechanical separation.	Lab scale experiments revealed that the addition of elemental S to pig slurry before mechanical separation is an effective method to acidify the manure and to decrease up to 50% NH_3 and GHG emissions during storage of the separated solid and liquid fraction. NH_3 and GHG emission during on-farm storage of acidified and not acidified solid fraction over two seasons was also investigated with turned (TW) and unturned windrows (UW). In general sulphur addition significantly reduced NH3 emissions by 35 and 30% respectively with TW and UW, without affecting total GHG emissions.
	A1.2.	Objectives: improve the use of LF of pig slurry as fertiliser. Expected results: To obtain the relation between EC and nutrient content of LF.	The relation has been achieved as expected. Moreover, the relation between EC and nutrient content of dairy slurry has been obtained (not expected in the proposal).	LF of pig slurry: A very good prediction has been obtained with N, ammoniacal N and K (r2: 0.75, 0.79 and 0.73, respectively). LF of dairy cow: A very good prediction has been obtained with N, ammoniacal N (r2: 0.73 and 0.80, respectively) but with P and K the prediction is less good (r2: 0,59 and 0.50, respectively). Both relations will continue be validated with more samples (after-life).
	A 1.3.	Objectives: to validate analytical procedures for the determination of ABs and ARGs in by-products, soil and crops (maize, peach and apple) Expected results: to obtain precise and accurate qualitative and quantitative results in samples of different characteristics.	Detection limit at the low ppb level. The RSD below 20% for most of the ABs. Relative recoveries higher than 60%. Versatility of the methodology to the matrices of interest.	Sensitivity is satisfactory for most of the analyses. The achieved precision is successful since the analyses are in the ppb-ppm range. Recoveries are successful since the methodology is not analytic specific. The analytical methodologies have been evaluated in all the matrices of the project interest.
A2.1		Objectives: Identification a maximum of 34 farms and definition of the experimental plan Expected results: signing of agreements with farmers	Definition of the experimental plan in accordance with the availability of farmers:	The identified farms had the suitable requisites for the implementation of the experimental activities foreseen by the project. Twelve agreements were signed in order to develop the actions in the eighteen plots.
A3		Objectives: initial characterization of farm soils. Expected results: identification of the starting environmental conditions of the project in the partner farms	The analysis and field interviews performed allowed to have a complete overview of the initial conditions of the designed experimental tests. All the farms and plots were adequate to develop the strategies proposed by the project.	78 soil samples for laboratory analysis defined the initial soil qualitative state. 18 analysis of organic products, 2 analysis of crops and 30 of soil solution helped to know better the starter point. Field interviews to collect information about: the history of the farm's management, the fertilisation techniques, the usual agricultural practices.

B1	B1.1.	Objectives: To introduce the LF as a common fertiliser in fruit trees. Expected results: To replace mineral fertiliser with organic fertiliser while maintaining yield, quality and safety	No microbiology was detected in fruit samples. Only E.Coli was detected in some leaves samples, but the detection was not linked to the use of LF. It has been demonstrated that the use of LF can be used beyond the current limitations of the certification bodies. No differences between the use of mineral fertilisers or LF in yield and fruit quality.	Yield and quality parameters analysed: yield (kg/ha), size and quality (firmness, sugar, dry matter and color). Crop nutrition parameters analysed: nutrient leaves content. Microbiology analysis: E. Coli, Salmonella and Listeria. This monitoring confirmed the viability of the strategy proposed by the project, which has confirmed that permits to reduce by 100% the use of nitrogenous fertilisers in peach orchards by applying the LF of pig slurry. The use of phosphoric and potassium fertilisers also can be reduced depending on the soil and its content in the LF.
	B1.2.	Objectives: to establish the use of LF as a common fertiliser in the top-dressing fertilisation of extensive crops. Expected results: To develop an automatic dosage system to apply the LF through fertigation. To prove the best irrigation and fertilisation efficiency in new drip-irrigation systems. LF performs as good as PS when used as fertiliser for rainfed crops.	The automatic dosage system of LF has been developed successfully. The tested drip-irrigation system highlighted the potential to reduce the use of mineral fertilisers, decreasing both the environmental impact and losses in the environment. LF fertigation shows the improvement of the nitrogen use in both amount and in time, reducing losses. In the case of drip-irrigation, its real applicability on large scale seems to be strictly connected to an economic assessment accounting, in planning phase, the expected yields and water consumption as well as the costs of installation and management of the irrigation plant In rainfed areas, the objective and the expected results have been achieved. LF performs as good as PS as fertiliser, in both yield and quality. Top-dressing applications improve the results in comparison with traditional pre-sowing applications.	The automatic dosage system has shown the best use of LF as fertiliser, offering a best adjustment of the amount applied to crop requirements. The real feasibility of fertilizing extensive irrigated crops with the liquid fraction through fertigation was assessed by demonstrative actions in two experimental plots (5 ha). Yield and grain quality have been measured in all strategies.

B2		Objectives: To demonstrate the feasibility of the on farm composting of the solid fraction of pig slurry. Expected results: To check the technical and economic feasibility of the on-farm composting.	High quality compost has been obtained at both pilot scale and farm scale.	The results obtained in the on-farm composting are quite similar to the ones obtained in pilot conditions. The analysis carried out during the monitoring confirm the feasibility of the process and the final product obtained.
B3	B3.1.	Objectives: To use the SF as a common fertiliser in fruit trees, helping to close the nutrient cycle using the potential of circular economy. At the same time, this will improve the quality of the soil by increasing the organic matter content through fertilisation with solid fraction. To introduce precision farming techniques when applying SF in fruit trees. Expected results: to have fully machinery adapted to the efficient fertilisation of fruit trees with SF	Good yield and quality have been observed when fertilizing with SF. The spreader has been successfully adapted to the application of SF. It is capable of producing a homogeneous distribution, it reaches a good longitudinal distribution evenness (CV<15%), both longitudinally and transversely to the working direction. The transversal distribution was also tested and it was confirmed that the spreader applies the product in the correct portion of the inter-row, where root adsorption is higher. The machinery is able to follow a prescription georeferenced map, which allows the spreader to autonomously control its distribution rate, according to its position.	Monitoring of yield and quality of apples. Distribution measures according to the standard EN13080-2002).
	B3.2.	Objectives: idem B3.1. Expected results: to achieve good results in apple trees when applying SF, both as an amendment and as a fertiliser.	Good development of apples trees has been observed when applying SF prior plantation. Good yield and quality have been observed when fertilizing with SF.	Apple trees formation, yield and fruit quality have been measured, The results verified the feasibility to achieve a good tree development, yield and fruit quality in apple orchards when the fertilisation is based with the use of SF.
B4	B4.1.	Objectives: To use the digestate as a common fertiliser in fruit trees, helping to close the nutrient cycle using the potential of circular economy. To introduce precision farming techniques when applying digestate in fruit trees. Expected results: to have fully machinery adapted to the efficient fertilisation of fruit trees with digestate.	The spreader reached a good longitudinal distribution evenness (CV<15%). The transversal distribution was also tested and it was confirmed that the spreader applies the product in the correct portion of the inter-row, where root adsorption is higher. The spreader has been implemented with a software that permits to upload a distribution rate prescription georeferenced map, which allows the spreader to control autonomously its distribution rate, according to its position. Good yield and quality have been observed when fertilizing with digestate.	Monitoring of yield and quality of apples. Distribution measures according to the standard EN13406-2002).

	B4.2.	Objectives: To improve and make easier the management of digestates. To quantify the efficiency of different catch crops in the reduction of the N surpluses on maize fertilisation. To demonstrate the effectiveness of digestates in a maize cropping system and winter rainfed crops. Expected results: To introduce digestate application on maize top-dressing fertilisation. Most suitable catch crop to minimize the risk of nitrate leaching during winter in a maize cropping system. Digestate will perform as good as pig slurry when used as top-dressing fertiliser for winter rainfed crops.	Most of the objective and the expected results are achieved. Digestate top-dressing applications in maize have been carried out on the demonstrative plots. Yields have been affected by the top-dressing application, so it is considered that more work have to be done in order to adapt the management and reduce the possible losses. However, top-dressing applications in maize can be feasible if the application is at the right time. Including catch crops in a maize rotation retain nitrate-N during the fallow period and reduce the soil N content before sowing. So, it reduces the risk of N leaching. The catch-crop that has fitted better to the criteria has been black oat, though other species has also well performed in some years. Digestate's performance is as good as common fertilisers (pig slurry or mineral fertilisers) in the area, when used as top-dressing fertiliser in rainfed winter crops. An exception may be fertilizing rapeseed with digestate on top-dressing, as fat content -the most important quality parameter- decreases in respect the application of other types of fertilisers.	The development of the crop and the yield of maize and catch crops have been monitored in order to measure the efficiency of the strategies. Yield and protein content have been measured in winter crops demonstrative fields. For rapeseed fat grain content has also been measured.
B5		Objectives: to assess and promote the use of by-products that optimize the effectiveness of organic fertilisers distribution and the application of soil conservation management practices for crops with a high demand for nutrients. Expected results: to maintain or increase crop growth, reducing the NH4 losses in atmosphere (when conservation agriculture is applied), and maintain or improve the yield of the crops.	By-products could replace common fertilisers, as there is no difference in the maize yield. It has been seen that is the farmer's responsibility to adapt agricultural practices according to site-specific needs becomes critical for process optimization towards a "more efficient" use of these by-products with a correct application. The integration of different sustainable practices has allowed to obtain agronomic and environmental benefits, even in a short time; however,	The results basically confirmed the general indications on environmental balances and on the technical evaluation of the tested techniques; they also highlighted some operational aspects that may be appropriate to consider for the introduction of these techniques into farm management. Maize yield and environmental parameters have been monitored in the demonstrative plots in order to assess the different approaches.

B6		Objectives: To replicate and spread the innovations developed and promoted by the project. Expected results: To replicate some strategies beyond the framework of the project. To sign an agreement of collaboration with GlobalG.A.P.	Some strategies are already replicated and other are on the way, as the contacts have already carried out: - The automatic dose system is being installed successfully in more farms beyond the farms linked to the project. - Catalan machinery manufacturers have shown their interest in the application machinery developed. Contacts have already done. - Contacts with other projects and entities have already be done in order to spread other strategies: use of organic products in fruit trees, the use of the conductimeter in the dose of LF, etc. GlobalG.A.P and LIFE AGRICLOSE are in touch in order to analyse the results and to discuss about the possibility to introduce some of the strategies proposed in their certification schemes. There is an interest and a positive feedback from the sector towards the strategies promoted by the project, as could be seen in all the workshops organised, in particular, at the PRO-FEM workshop organised in May of 2022.	Most of the collaborators have signed agreements to apply the strategies beyond the project. Installation of the automatic dose system in farms not linked with the project. PRO-FEM was held successfully during two days, with the attendance of more than 250 people and the participation of more than 30 experts from different countries.
C1	C1.1.	Objectives: Monitoring of soil quality. Expected results: To improve those parameters related to soil fertility and to reduce the impact of N.	The results are showing a better soil quality and the reduction of N impact. In particular: - LF fertigation, moving the by-products fertilisation to top-dressing applications, to sowing catch-crops and no-tillage reduce the risk of N leaching. - LF fertigation doesn't show an accumulation of salts.	Moving the digestate application to top-dressing in maize and the sowing of catch-crops in a maize rotation reduce nitrates content by a 50% before sowing. Some practices have shown an increase of SOC higher than expected. The use of composted SF in apple orchards have supposed and increase of organic matter by 13% and the

			- The integration of different sustainable practices contributes the increase of SOC. - The use of SF has increased both P and SOC. No-tillage have not shown the expected results in the increase of the soil organic matter. More time may be needed in order to see the impact of the strategy on the soil quality, although the strategy have shown more environmental benefits beyond the SOC sequestration.	sowing of catch crops have shown an increase of the SOC by 7%. The application of composted SF has doubled the soil phosphorus content.
	C1.2.	Objectives: To monitor water quality. Expected results: To improve water quality.	The nitrate content in the soil solution with the surface drip irrigation seemed to remain constant along the profile and, especially in the rhizosphere, highlighting a potential greater nitrogen absorption efficiency by plants and a consequent lower nitrate leaching. The use of LF reduces the nitrates concentration in the soil solution compared with mineral fertiliser (urea).	160 soil solution samples were collected and analysed for nitrogen and phosphates content: - 594 analysis of nitrates (NO_3-N) in water have been done: rain water (20), ground water (20) and soil solution (554). - 594 analysis of ammonia (NH_4-N) in water have been done: rain water (20), ground water (20) and soil solution (554). - 594 analysis of phosphorus (PO_3^{-4})in water have been done: rain water (20), ground water (20) and soil solution (554).
	C1.3.	Objectives: To monitor compost leachates	No leachates were generated during the composting process; Other actions have been developed instead of the foreseen action: a) the sampling for antibiotic and antibiotic resistance genes. In the stated conditions, the on-farm composting has been successful for the removal of such substances. b) impact on soil composition of the composting piles has been described c) an approach to gas emissions has been done.	
	C1.4.	Objectives: To evaluate the impact of the occurrence of ABs and ARGs in soils and crops Expected results: Abs and ARGs presence in soil, crops and by-products.	A total of 4 families of ABs and 8 ARGs in pig slurries, solid and liquid fractions and digestate has been determined. Tetracyclines were detected in topsoils (0-30 cm) treated with organic fertilisers (pig slurries, liquid and solid fraction) and digested products. Concentrations of Abs and ARGs of maize grain and fruits were below the limits of detection.	245 samples have been analysed: manure and by-products (45), soil (89), apples (34) and maize (77).

			Solid fraction composting reduced the load of ABs up to 90%.	
	C1.5.	Objectives: To sample, analyse and calculate emission in crops fertilised with different strategies Expected results: Emission factors for each gas and situation. To reduce the emissions compared with traditional strategies.	LF fertigation has made it possible to reduce NH_3 emissions by up to a third compared to mineral fertigation in maize. When LF is applied with a tank, its injection into the ground can reduce NH_3 emissions by half if compared with surface application, and obtain values of around 5%. The acidification of the slurry with S before separation has reduced NH_3 and GHG emissions by between 20 and 25% in the subsequent management of LF and SF. When applying SF and digestate in fruit trees: N_2O emissions after their spreading was significantly lower compared to the chemical fertiliser. NH_3 emissions after digestate application resulted relevant, accounting around 23% of applied nitrogen.	Emissions were monitored in different demonstrative plots: B1.2., B3.1. and B4.1.) GHG emissions were sampled through static hoods, while NH_3 was sampled with passive samplers.
C2		Objectives: To provide a holistic environmental vision of the innovative strategies. Expected results: To analyse the life cycle of the innovative strategies.	Very useful study, for both detecting potential hotspots of alternative fertilisation and underlining potential methodological issues when LCA tools are applied. Results provided in corresponding deliverable 29.	LCA has been applied in accordance with ISO standards 14040 and 14044 and consequent amendments. The methodological guideline established in the frame of EF (Eutrophication, freshwater) initiative was applied.
C3		Objectives: To assess the strategies proposed from a social and economic point of view. Expected results: the determination of the direct and indirect social and economic impacts of the innovative strategies.	Most of the fertilisation strategies promoted offer lower operating costs and better net profit per ton, despite presenting in some cases lower crop yields than conventional fertilisation strategies. The main impact of the project at a socio-economic level comes from the technical improvements of the strategies promoted. In this sense, the more technical indicators (reduction in resource consumption, area of agricultural land with sustainable management and NH_3 emissions) show a greater impact.	The methodology used in the cost analysis has been the cycle cost analysis. Socio-economic effects have been assessed with the Hybrid-fulfilment importance matrix. It allows to evaluate these impacts from a holistic perspective, taking into account the environmental, social, economic and technical dimensions. 280 surveys carried out to know the perceptions of different groups of stakeholders (4): collaborators, citizenship, agrarian sector and public entities.

C4		Objectives: To carry out the project as expected. Expected results: To achieve the goals of the project as expected. To monitor environmental, social and economic impacts.	KPI updated. In spite of the changes of interpretation during the project, their value has evolved as expected. The performance indicators related to environment, climate, better use of natural resources, sustainable use and dissemination of the project have been as expected. Some progress indicators were modified because the COVID situation. However, most of them were followed as accorded.	Indicators values come from the execution of the actions.
C5		Objectives: To improve the feasibility and replicability of the strategies proposed. Expected results: Conclusions about the best options to apply and replicate the solutions proposed by the project.	The experts conclude that the most of the strategies promoted are feasible to be implemented and have real possibility of establishment. The improvement of the environment exists but there is the need of a strong driving force to obtain a diffusion of the practices, and also the main issue could be the cost of some actions to be implemented. Results obtained regarding to ABs are very relevant and they will be very valuable for the scientific community and for further risk assessments, however, future research line could be to look into the Agriclose samples for the antimicrobial resistant bacteria and genes of highest priority.	Expert committee created. Two expert committee meetings and a field day were held. Final report of the Expert Committee delivered.
D1		Objectives: To promote the project and the solutions proposed. Expected results: To spread greater attention by farmers and stakeholders to environmental sustainability and the feasibility of the strategies applied.	The communication plan and the merchandising were ready as expected. 5 newsletters were sent to more than 500 people. 10 notice boards (9 field panels and 1 interior panel) were installed. More than 75 news published in the press (newspaper, TV, digital newspapers, etc.). Two press conferences were hold.	In spite of COVID-19, the dissemination tools were successful and they were adapted to the needs of the project and mostly they followed the communication plan expected. Some activities didn't reach the initial objectives (newsletters, press conferences), however, it is considered that have not affected the effectiveness of the project dissemination. Moreover, a lot of dissemination activities and material not planned in the proposal were carried out.

D2		Objectives: To transfer practices and methods to stakeholders and farmers in order to integrate them into their regular management. Expected results: To reach all the potential users of the solutions promoted.	The project has been widely disseminated, contributing to the promotion of the strategies. Some information: - More than 18,000 visits to the website. - 10 videos with more than 3,000 views. - More than 30 conferences held with more than 3,000 attendees. - Attendance at 10 congresses. - More than 10 factsheets published in the webpage. - The guideline of the use of by-products published. - 20 networking activities.	In spite of COVID-19, the dissemination activities were successful and they were adapted to the needs of the project and mostly they followed the communication plan expected. There has been a good response to the events organised and the feedback has been very positive. The workshops carried out and the attendance in congresses have been higher than planned in the proposal.
E1		Objectives: To carry out the project as expected.	The project has been carried out as expected. There have been 10 meetings with all partners.	Communication tools used and meetings program have permitted to have a fluently communication among partners and to develop the project as expected.
E2		Objectives: To plan the activities that will be carried out beyond the end of the project.	Plan after-life developed. More than 10 activities have been stablished in order to continue developing the strategies promoted by the project. More publications are expected to spread the outputs of the project. Contacts have been done in order to guarantee the replicability of some strategies of the project.	All the activities carried out will guarantee to continue the work started with the project and spread the news beyond the framework of the project.