# AMMONIA EMISSION REDUCTION IN MEDITERRANEAN AGRICULTURE WITH INNOVATIVE SLURRY FERTIGATION TECHNIQUES


LIFE ARIMEDA
LIFE16 ENV/ES/000400

## LAYMAN REPORT


LIFE16 ENV/ES/000400
ARIMEDA

# THE PROJECT | **PARTNERS**

## COORDINATOR

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- Management, monitoring and dissemination of the project
- Monitoring and validation of the reduction of ammonia emissions and better fertiliser use of pig slurry in the demonstration fields trials located in Aragón
- Monitoring of the emissions and evaluation of the results
- Transference of the fertigation systems

## PARTNERS

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- Connection with pig breeders and land farmers
- Demonstration and dissemination of the fertigation systems in Spain

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- Design, supply and set up of the separation prototypes

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- Technical advisory
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- Monitoring and validation of the reduction of ammonia emissions and better fertiliser use of digestate in the demonstrative fields trials located in Italy
- Development of the separation prototypes for digestate
- Transference of the fertigation system

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- Connection with pig breeders and land farmers
- Demonstration and dissemination of the fertigation systems in Italy

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- Design and testing of the separation prototypes
- Life Cycle Assessment of the fertigation systems
- Connection with biogas plant validation of the full chain sustainability

## ACQUAFERT SRL

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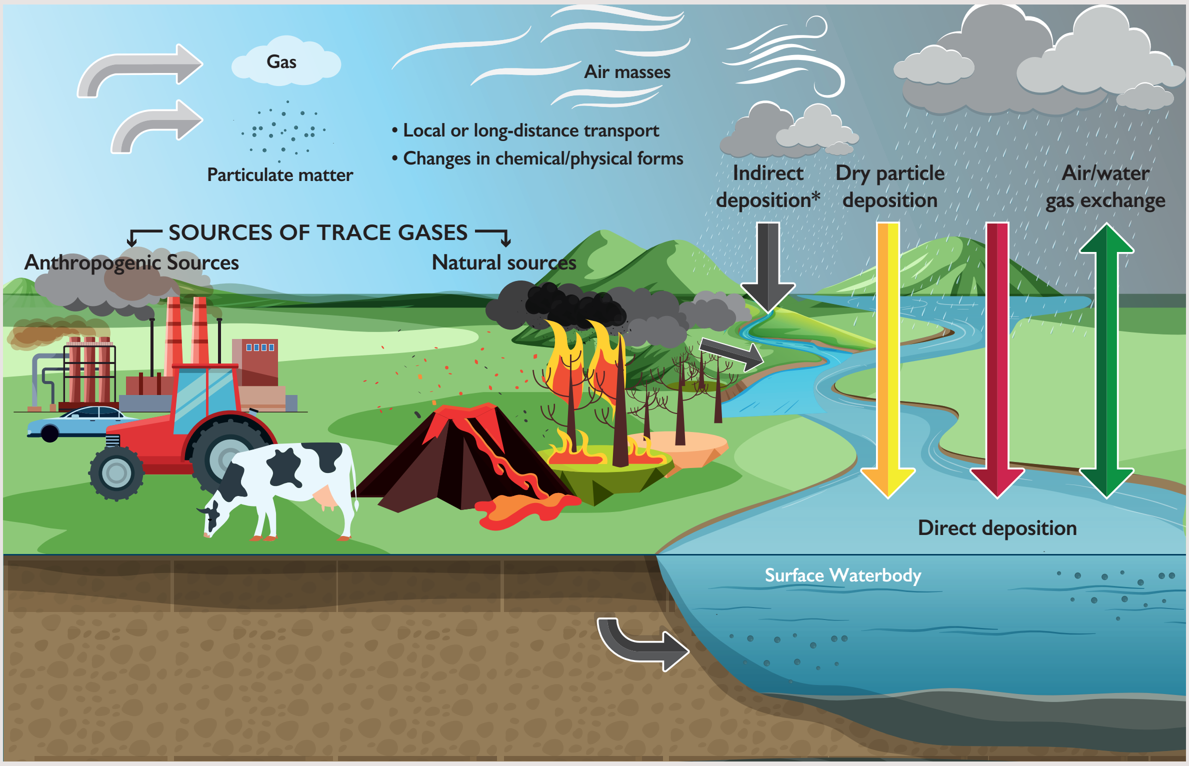
- Design, building and test of the separation prototypes for digestate in Italy
- Implementation and evaluation of fertigation demonstration trial

The LIFE ARIMEDA project has received funding from the LIFE Programme of the European Union.

# BACKGROUND

Ammonia from anthropogenic and natural sources is a reactive form of nitrogen that may lead to adverse effects on the environment and increased public health risks. The emission and further deposition of ammonia is harmful to ecosystems because it causes acidification and disrupts plant communities damaging forests and other vegetation both directly and indirectly. Its deposition also contributes to nitrogen enrichment of waters and can therefore be a secondary cause of eutrophication. It also affects key economic sectors, such as fisheries and tourism, through inconvenient smells, spoilt landscapes, and restriction of economic and recreational (e.g., fishing) activities with high socioeconomic returns (Sarteel *et al.*, 2016).

Furthermore, $NH_3$ is a precursor for the formation of fine particulate matter ($PM_{2.5}$), which affects the respiratory and cardiovascular systems and causes premature death. According to EEA (2019), in Europe, approximately 400,000 premature deaths per year are attributable to long-term exposure to $PM_{2.5}$ concentrations (Lovarelli *et al.*, 2020). Additionally, it is also a precursor of nitrogen oxides and can be, in certain situations, a source of nitrous oxide ($N_2O$), which is a potent greenhouse gas.




Adapted from Behera *et al.*, 2013.
*Indirect deposition is direct deposition to land followed by runoff or seepage through groundwater to a surface waterbody.

The main causes of $NH_3$ emissions are livestock farming (including management of manures and slurries) responsible for over 70% of ammonia emission and the application of synthetic fertilisers contributing with 20%. Due to greater demand for meat and milk for consumption, animal production has increased considerably, resulting in a rapid rise in the number of farm animals.

Pig slurry, as well as digestate, a by-product of biogas plants wide extended in Lombardy, have a valuable nutrient content. The nitrogen in these end-products is mainly in the form of ammoniacal nitrogen, which is very prone to volatilisation. Thus, although they are an excellent fertiliser, they must be stored and applied in the field with techniques that limit emissions to the atmosphere.

The implementation of low-emission manure application is the cornerstone of an effective ammonia abatement strategy. The fertigation techniques demonstrated in the LIFE ARIMEDA project may contribute significantly to these low-emission strategies while improving nitrogen use efficiency of organic fertilizers, maximizing opportunities for substitution of synthetic fertilizer and contributing to reduction of N inputs in high-density livestock areas. However, it would be necessary to approach an integrated management bearing in mind all potential trade-offs and cascade effects of the practices implemented throughout the whole slurry chain while adopting efficient techniques at earlier stages that prevent emissions in animals'buildings and storage systems.

AEMA, 2019. The European environment - state and outlook 2020. Knowledge for transition to a sustainable Europe. European Environment Agency, Luxembourg: Publications Office of the European Union. ISBN 978-92-9480-090-9. doi: 10.2800/96749.

Lovarelli *et al.*, 2020. Describing the trend of ammonia, particulate matter and nitrogen oxides: The role of livestock activities in northern Italy during Covid-19 quarantine. Environ. Res. 191, 110048, doi:https://doi.org/10.1016/j.envres.2020.110048.

Sarteel *et al.*, 2016. Resource efficiency in practice: closing mineral cycles: final report. Luxembourg: European Commission, Directorate-General for the Environment. ISBN 9789279582387. doi:10.2779/710012.

# OVERALL GOALS AND SPECIFIC OBJECTIVES

LIFE ARIMEDA project focus on demonstrating fertigation techniques fertilizing extensive crops like maize with the liquid fraction of separated slurry and digestate in pivot and drip irrigation systems. These techniques were implemented in large productive fields with the aim of:

**1.** Reducing $NH_3$ emissions of organic fertilizing in comparison to usual practices. Ammonia emission reduction is based on:

- Reduction of ammoniacal nitrogen concentration by dilution with irrigation water
- Low air-liquid contact surface application techniques
- N dose adjusted to crop demands
- Splitting side dressing in several events, thus minimizing excess N in the soil

**2.** Replacing synthetic N by organic fertilizer in all crop cycle.

**3.** Increasing nitrogen use efficiency minimizing losses and using precision fertigation strategies scheduling nutrient doses and application times according to crop necessities.

**4.** Assessing the technical and economic feasibility of these techniques in comparison to the reference system.

**5.** Contributing to the definition of future policies and action plans in the agricultural sector by providing data and information to technicians and policy makers involved.

**6.** Increasing potential acceptance by farmers and uptake of the measures evaluated while contributing to build up stakeholder's capacity to implement these techniques in other areas.

# MAIN PROJECT ACTIVITIES

All the project activities were undertaken in two Mediterranean areas where livestock production and irrigated crops play a key role in rural areas economy, and consequently, the impact and side effects of these activities play a major role in environment, human health and other economic sectors such as tourism: Aragón in Spain and Lombardia in Italy.

The use of techniques that reduce these emissions to the atmosphere from slurry fertilisation can provide environmental benefits and greater efficiency in the use of locally available resources to improve farm yields, minimize nutrient losses and promote nutrient circularity.

LIFE ARIMEDA assessed the performance of fertigation with slurry addressing a case/control approach and comparing the results of environmental and agronomic monitoring between fertigated and reference plots. The latter were managed by farmers using traditional fertilization practices. The fertigation techniques demonstrated in this project were implemented during three consecutive seasons, from 2018 to 2020, in large-scale extensive maize plots, and using the separated liquid fraction of pig slurry in Aragón (Spain) and of digestate in Lombardia (Italy).

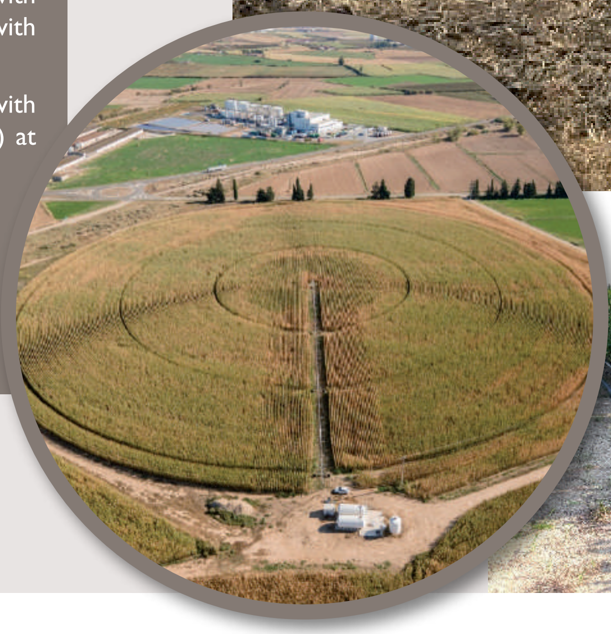
## Which fertilizing strategies did we compare?

**1. Reference (Business as usual practices):**

- **IT/Digestate:** Surface broadcasting with digestate and incorporation within 24 hours at base dressing or shallow injection. No side dressing.
- **ES/Pig slurry:** Surface broadcasting with pig slurry at base dressing and synthetic fertilizer at side dressing.

**2. Demonstration plots (Fertigation in pivot and drip irrigation systems):**

- **IT/Digestate:** 50% of N crop needs with digestate at base-dressing with direct incorporation or shallow injection and 50% with digestate liquid fraction at side-dressing with fertigation.
- **ES/Pig slurry:** 100% of N crop needs with pig slurry liquid fraction (when possible) at side-dressing with fertigation.



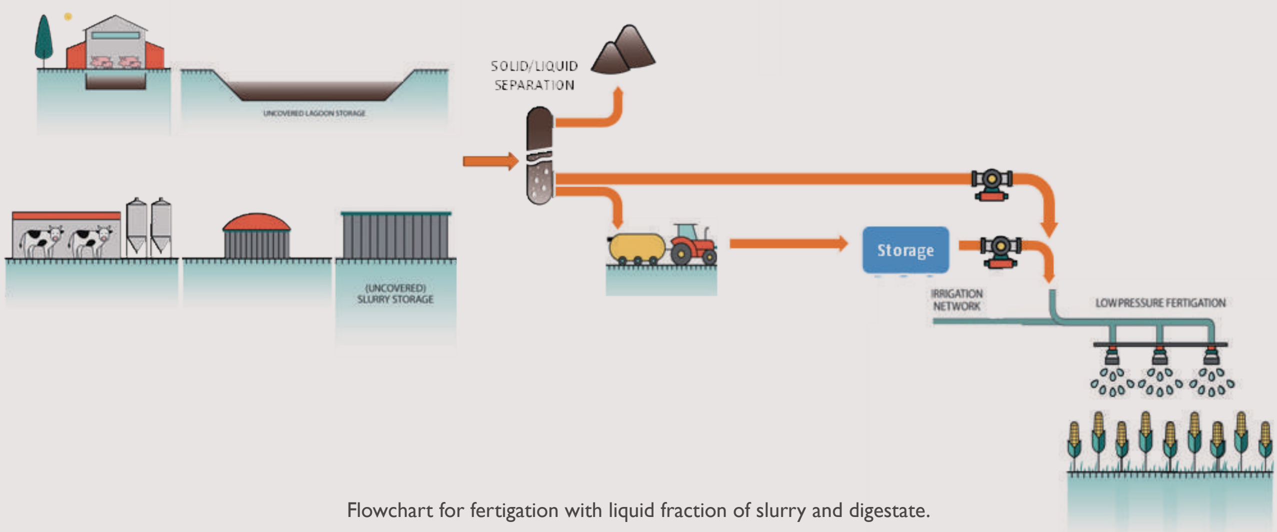
## How and where did we implement FERTIGATION with slurry?

The **selection of demonstration fields** and the monitoring layout were thoroughly planned at every site. The technicians, hand in hand with farmers, sought to for representative fields of every project region, far from animal farms, to avoid or reduce interference in environmental monitoring activities.

Fertigation techniques convert slurry and digestate available from farms or biogas plant storages into high-value fertiliser at the moment they arrive at field-cropped soils. The fertigation process requires several steps that should be considered and analysed in detail to design a fine-tuned system adapted to the requirements of each specific case:

1. Solid-liquid separation of the pig slurry/digestate
2. Storage of the obtained liquid fraction at the farm or biogas plant facilities
3. Transport of the liquid fraction to the field by pipelines, lorry or tractor coupled with a tank
4. Liquid fraction storage in the field (if necessary)
5. Design of the liquid fraction injection system in the irrigation network
6. Monitoring of the nutrient content in the liquid fraction
7. Development of an accurate fertilizing plan: splitting and schedule of the nutrient doses supplied to the crops
8. Management of the pivot and drip irrigation system (dilution rates: slurry liquid fraction / irrigation water, water doses, etc.)

Additionally, it is essential to develop correct management practices for each of the steps to avoid problems or malfunctioning that may adversely affect the quality of fertigation.




Flowchart for fertigation with liquid fraction of slurry and digestate.

# Fertigation in Spain with pig slurry

The demonstration plots were located at two sites characterized by different types of soil, Cinco Villas (ES-S1-P and ES-S1-D) with shallow (ca. 45 cm) and stony soils and La Litera (ES-S2-P and ES-S2-D) with deep (ca. 100 cm) and heavy soils. Two demonstration fields, 1 equipped with a centre pivot and 1 with a subsurface drip irrigated system, and a reference field were installed at each site and cultivated with grain maize during three years.

In Spain, two portable prototypes were designed and built for mechanically separating the solid fraction of the pig slurry. The first prototype provided a liquid fraction suitable for injection into pivot irrigation systems, and the second prototype was designed to separate in a second step the liquid fraction obtained with the first prototype and provide a liquid fraction suitable for injection into drip irrigation systems.


The use of pivot systems facilitates fertigation with pig slurry liquid fraction because of the greater nozzle hole diameter (>2 mm), which admits larger solid particles (<500 μm). Drip irrigation requires removing particles larger than 100 μm and thus a second separation stage. The pivot prototype consisted of a filtering ramp followed by a screw press where the nonfiltered slurry was pressed to improve separation performance (reducing the water content in the final solid fraction). The mesh size of the prototype sieve was progressively diminished from 600 μm up to 250 μm in the last monitored year. The drip irrigation prototype was a vibrating screen with a 100 μm separation mesh in the first year that was reduced to 80 μm in the last campaign.

## Fertigation in Italy with digestate

Livestock production in Lombardia, with a strong presence in the southeast of the region, is amongst the most intensive systems in Europe. As a result, large amounts of livestock effluents are generated. In close connection with livestock activity but also with the main energy crops (mainly maize and autumn-winter cereals), numerous plants for the production of electricity from biogas have been built in the last 20 years. Digestate is the by-product of this activity and has a valuable nutrient content.

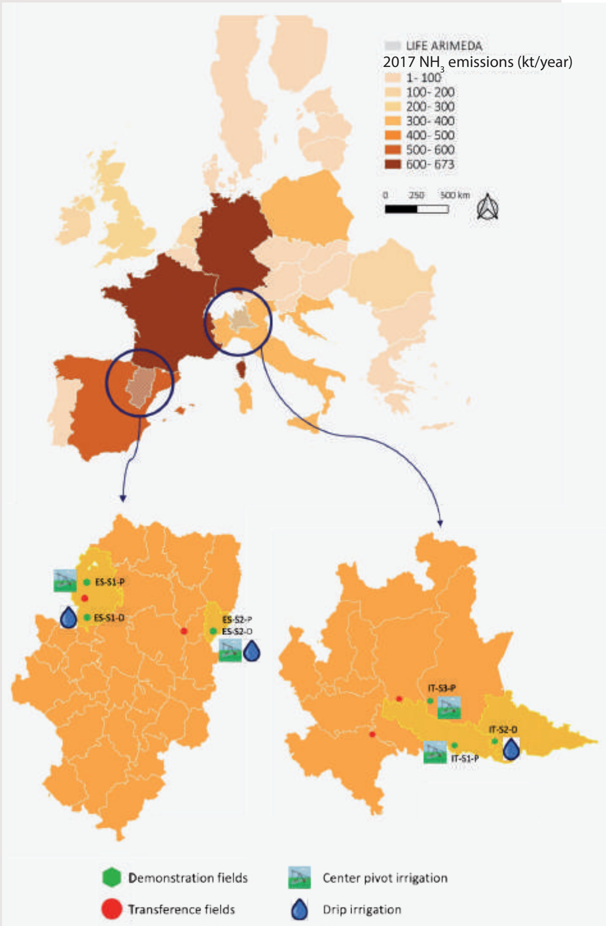
The demonstration plots were equipped with drip irrigation (IT-S2-D) and with centre pivot irrigation (IT-S1-P and IT-S3-P) cropped to fodder maize during 3 years for each system.

The digestate solid-liquid separation prototypes followed a similar process on all the farms. The raw digestate was sent to a first separation step, consisting of a screw press, and the obtained liquid fraction was pumped to a second separator. The second separator consisted of a vibrating screen or a microfilter, and the liquid fraction obtained was injected into the fertigation pipeline.

The screw press separators operated with different screen sizes ranging from 500 to 900 µm. The vibrating screen was coupled to a system that cleaned the screen at regular intervals using a solution of sulfuric acid (50% v/v) in farms with pivot fertigation. The microfilter was used in the farm where fertigation was performed in drip irrigation systems.

LIFE ARIMEDA separation prototypes

| Location | | Ref. | Surface | Irrigation system | Monitored campaigns |
|---|---|---|---|---|---|
| Country | Region | | ha | | |
| Spain | Aragón, Cinco Villas | ES-S1-P | 10.4 | Pivot | 2018-2019-2020 |
| | | ES-S1-D | 2.1 | Drip | 2018-2019-2020 |
| | | ES-S1-R | 0.7-4.3 | Sprinklers | 2018-2019-2020 |
| | Aragón, La Litera | ES-S2-P | 6.4 | Pivot | 2018-2019-2020 |
| | | ES-S2-D | 2.0 | Drip | 2018-2019-2020 |
| | | ES-S2-R | 1.1-1.5 | Sprinklers | 2018-2019-2020 |
| Italy | Lombardia, Cremona | IT-S1-P | 10.6 | Pivot | 2018 and 2019 |
| | | IT-S1-R | 7.0-9.0 | Pivot | 2018 and 2019 |
| | Lombardia, Mantua | IT-S2-D | 10.2-19.1 | Drip | 2018, 2019 and 2020 |
| | | IT-S2-R | 3.0-7.0 | Drip | 2018, 2019 and 2020 |
| | Lombardía, Brescia | IT-S3-P | 27.0 | Pivot | 2020 |
| | | IT-S3-P | 10.0 | Pivot | 2020 |




Location of LIFE ARIMEDA demonstration and replication fields

## What have we monitored and assessed?

The environmental and agronomic benefits of fertigation relative to traditional fertilizing practices was assessed qualitatively and quantitatively in large productive plots and on the basis of sound and scientifically proven methodologies.

The technicians from the Agrifood Research Center of Aragon (CITA) and from the Department of Agricultural and Environmental Sciences, University of Milan, in close collaboration with the Research Centre for the Management of Environmental and Agricultural Risks (CEIGRAM-Universidad Politécnica de Madrid), developed detailed monitoring protocols and measurement methods to compare fertigation technique with the usual fertilization practices in north-eastern Spain (Aragón, in the regions of Cinco Villas and La Litera) and in northern Italy (Lombardia, provinces of Brescia, Cremona and Mantua). The use of the same monitoring and estimation procedures in all sites enabled the obtaining of comparable data and reliable information.

# ENVIRONMENTAL MONITORING

**Ammonia emission** were calculated using WindTrax free simulation software (Thunder Beach Scientific, Halifax, Nova Scotia, Canada) that uses a backward Lagrangian stochastic inverse dispersion model (bLS IDM). This model infers emission rates from a known emitting surface using air ammonia concentration, that were monitored in LIFE ARIMEDA project with ALPHA® (Adapted Low-cost Passive High Absorption) samplers, and weather records (wind velocity and direction). ALPHA® were exposed by triplicate, placed 1.2-1.5 m above crop canopy and evenly distributed over the fields[1] surface for at least ten days after every fertilizing event and sampled at intervals between 24 hours and 3 days and outside fertilizer periods with lower frequency.


**Risk for nitrate leaching**: The nitrate concentration in soil solution below the root zone was monitored using ceramic suction cups weekly.

# AGRONOMIC MONITORING

**Crop yields** were monitored recording the harvesting of the whole plots and with manual controls, sampling different areas of each plot to estimate harvest index and N extraction.

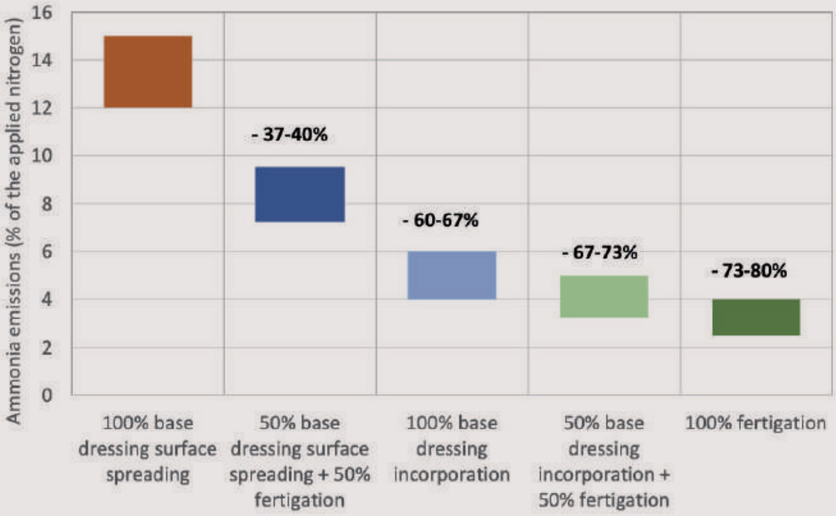
**Nitrogen use efficiency** was calculated as the ratio N crop uptake/N applied. N crop uptake was calculated from crop yields and total N analysed by combustion (above ground biomass and grain yield in Spain) and doses applied were monitored thought the volumes of liquid fraction supplied in each plot and its content in nitrogen.

Additionally, project data was used to implement a **life cycle assessment** (LCA) and evaluate the environmental impact of maize cultivation considering different irrigation and fertigation techniques in representative scenarios in Northern Italy (Lombardia) and in north-eastern Spain (Aragón). This environmental assessment was completed with a detail economic feasibility study that took into account the key features that constrain the use of fertigation.

Finally, a social study surveyed the perception of farmers about the main burdens and benefits they identify that affect the incorporation of these new practices into their agricultural activity attending 24 economic, environmental, legal, social and technological indicators.

# LIFE ARIMEDA project RESULTS

The application of digestate and pig slurry liquid fractions through fertigation significantly **reduced ammonia emission** in comparison to reference practices. The application of 50% of crop nitrogen needs with digestate before sowing with direct incorporation to the soil and the remaining 50% in fertigation reduced ammonia emissions in more than 60% when using pivot irrigation systems and 90% with subsurface drip irrigation.




Range of ammonia emissions expected with different application techniques and sharing of the application between base-dressing and side-dressing in Lombardia.

In the case of pig slurry all crops N need were covered using fertigation. For pivot irrigation systems, ammonia emission were reduced in the average by 76% and with subsurface drip irrigation was achieved almost total reduction of ammonia emissions with 90% reduction.

Dilution rates of digestate and pig slurry with irrigation water and meteorological conditions (temperature and wind velocity) were important factors driving emissions amount. The splitting of digestate and pig slurry liquid fractions with irrigation allowed a reduction in the amount of N applied that also affected positively to reduction of ammonia emissions.

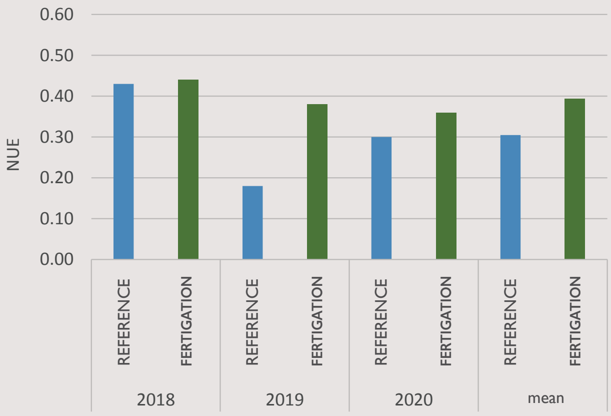
| | **Ammonia emissions** (±SE) | **Reduction in Ammonia emissions** (±SE) | **N applied** (±SE) | **Reduction in N applied** (±SE) |
|---|---|---|---|---|
| | *kg N/ha* | *%* | *kg N/ha* | *%* |
| **Reference** | 83.6 (±16.0) | | 357.4 (±16.7) | |
| **Pivot** | 18.4 (±3.8) | 76.0% (±4.2) | 277.4 (±13.4) | 29% (±4.5) |
| **Drip** | 5.9 (±1.4) | 90.0% (±3.5) | 261.5 (±26.6) | 25% (±9.2) |

Average ammonia emissions in fields monitored in Aragón (Spain), with the reductions in ammonia emissions and the amounts of N applied to fertigated fields with respect to the reference fields. (SE: standard error).

Pig slurry and digestate solid-liquid separation is necessary for producing a liquid fraction suitable for injection into the irrigation system. During the process of separation also ammonia emissions are produced. In the project we made a first approach to estimate these emissions, than in the case of the digestate, were estimated in a 0.3% of the total nitrogen contained in the digestate. These emissions are much lower than those produced during field application.

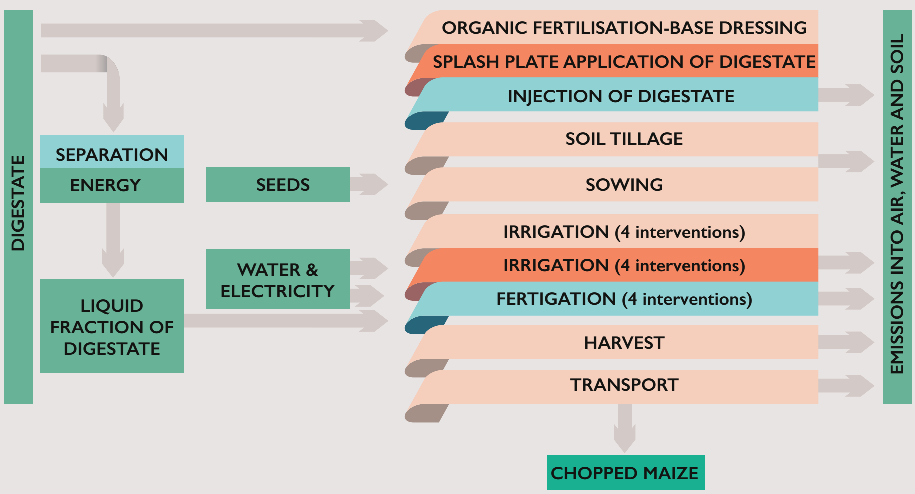
The control of nitrate concentration below the root zone periodically during the crop cycle showed that **the risk for nitrate leaching was not higher in fertigated fields** than in reference fields. In pivot fertigated fields nitrate concentrations were systematically lower than in reference fields, mainly driven by the lower amounts of N applied. In subsurface drip fields nitrate concentration maintained the same level than in reference fields.

**Yield (grain and fodder) and crop N uptake** presented a high variability depending on the year, but were similar in digestate and pig slurry fertigated fields than in reference fields. NUE in reference fields was low in Italy, but consistent with the experience in the same area (0.2-0.4). NUE was increased with fertigation only If the amount of N applied was reduced with fertigation, that was not always possible. NUE in Spain in reference fields was highly variable (0.3-0.7) depending on soil and management of the field. Fertigation increased NUE in demonstration fields due to splitting of the nitrogen applied that also permitted a reduction of the total N rate, avoiding excess N during the crop cycle and that reducing the risk for losses.




Nitrogen use efficiency (NUE) calculated as the ratio of the nitrogen uptake to the nitrogen applied in the three years of monitoring in the reference (in blue) and fertigated (in green) fields in IT-S2-D farm in Lombardia.

The LCA results were not unequivocal when comparing usual practices (reference fields) and fertigated fields: there is not a best scenario that outperforms the others in all the evaluated impact categories. The reduction in ammonia losses in fertigation scenarios entails a significant reduction in the environmental impacts associated with this pollutant. Thus, climate change, particulate formation, soil acidification and some of the different types of eutrophication are noteworthy for a context such as that of the Po Valley in Lombardia (Italy) and Ebro Valley in Aragón (Spain). However higher impact occur in fertigation scenarios than in reference for those impacts where the role of the solid-liquid separation and electricity for fertigation is most relevant as human toxicity with carcinogenic effects and mineral and fossil resource depletion. The outcomes of the LCA can be useful for policy-makers and regional officials for the identification of the most effective solutions to drive the application of organic fertilizers towards more sustainable manure management.




Activities considered in the life cycle analysys for digestate fertigation with drip irrigation in Italy.

Additionally, the survey undertaken among farmers in Aragón and Lombardia evidence that they recognize fertigation as an opportunity for improvement of livestock manure management in their regions. The economic advantages of the mixed livestock-agricultural is perceived as the main incentive for the implementation of these techniques, including the ease of handling and distribution of the products, the replacement of synthetic fertilizers by organic products, and the recycling of the available resources within the productive chain. Respondents consider that the main barriers are in the investments that are necessary for solid/liquid separators and injection systems, the operation and maintenance costs of the sytems, the lack of professionalization of the sector and the needs of technical personnel for planning and proper execution of fertigation.

However, it was repeatedly insisted that the lack of a clear regulation in the use of these practices, the restrictions on the use of organic fertilizers that prevent taking advantage of all the benefits of this technique and the absence of regulatory measures that favor and promote the use of organic fertilizers versus synthetic ones are the main bottle necks for the introduction of this innovative techniques.

# DISSEMINATION

The adoption of new practices and techniques that help to mitigate ammonia emissions derived from the use of organic fertilizers (as livestock manures) in the agricultural sector, such as fertigation, can generate important benefits in the value chain of the food produced and, consequently, promote the use of good practices in the management of slurry and digestate from anaerobic digestion facilities. However, this goal can only be successfully achieved if farmers are fully aware of the benefits to be derived from the application of these technologies and fully join this global effort, otherwise it will fail. The environmental sustainability of production systems is not a sufficient incentive on its own and the profit margins of livestock and agricultural production systems must be taken into account when proposing alternative management techniques to the usual ones.

For that reason, a key aspect of the project activities was the dissemination and direct transference of the know-how to the sector, technicians, administrations at all scales, scientific community and social agents, gathering and always bearing in mind the feedback received. The main communication tools and dissemination activities addressed in the project were:

- Website, newsletters and the presence of the project in social media (Twitter, YouTube, etc.).
- Noticeboards and technical publications.
- Dissemination and educational videos involving all the project partners.
- Scientific publications and attendance to national and international congresses.
- Participation in agricultural fairs.
- Organization and participation in technical workshops and field visits.
- LIFE ARIMEDA Final publication.

# TRANSFERENCE and FUTURE

The analysis of the potential for transfer of these innovative techniques to other Mediterranean areas was conducted using a result-based approach and based on the benefits and limitations identified throughout the LIFE ARIMEDA project. The technique was transferred into five other agricultural sites during the project, two in Aragón and three in Lombardia.

Two key supporting tools of the LIFE ARIMEDA project are freely available in the project website (www.lifearimeda.eu) in order to catalyse the dissemination of the lessons learnt in the project:

- Guide of good fertigation practices that gathers the key issues and main know how acquired throughout the project in the implementation of fertigation techniques.
- ARIMEDA app that supports and guides the user in the design and appropriate fertigation strategy in your fields.

In addition, the ARIMEDA Transference platform made up by all the project partners and other entities interested, including research centres, irrigation communities, administration, etc. go on supporting the transference of the know-how acquired throughout the project through field visits, technical assistance collaborations and acting as a communication channel to connect technology suppliers and interested farmers in the implementation of these techniques.

The results of this project provide data and information that will serve for setting discussion to local, regional and national administration when updating or defining new policies and strategies that can contribute to a better management of livestock effluents improving the agronomic conditions of European agriculture.

**LIFE ARIMEDA PROJECT**

Ammonia emission reduction in Mediterranean agriculture with innovative slurry fertigation techniques

**LIFE Programme Environment and Resource Efficiency**

**DURATION:** 01/09/2017 – 30/09/2021

**PROJECT BUDGET:** 2.608.324 €

**EU CONTRIBUTION:** 1.522.293 € (59.11%)

More information at:

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