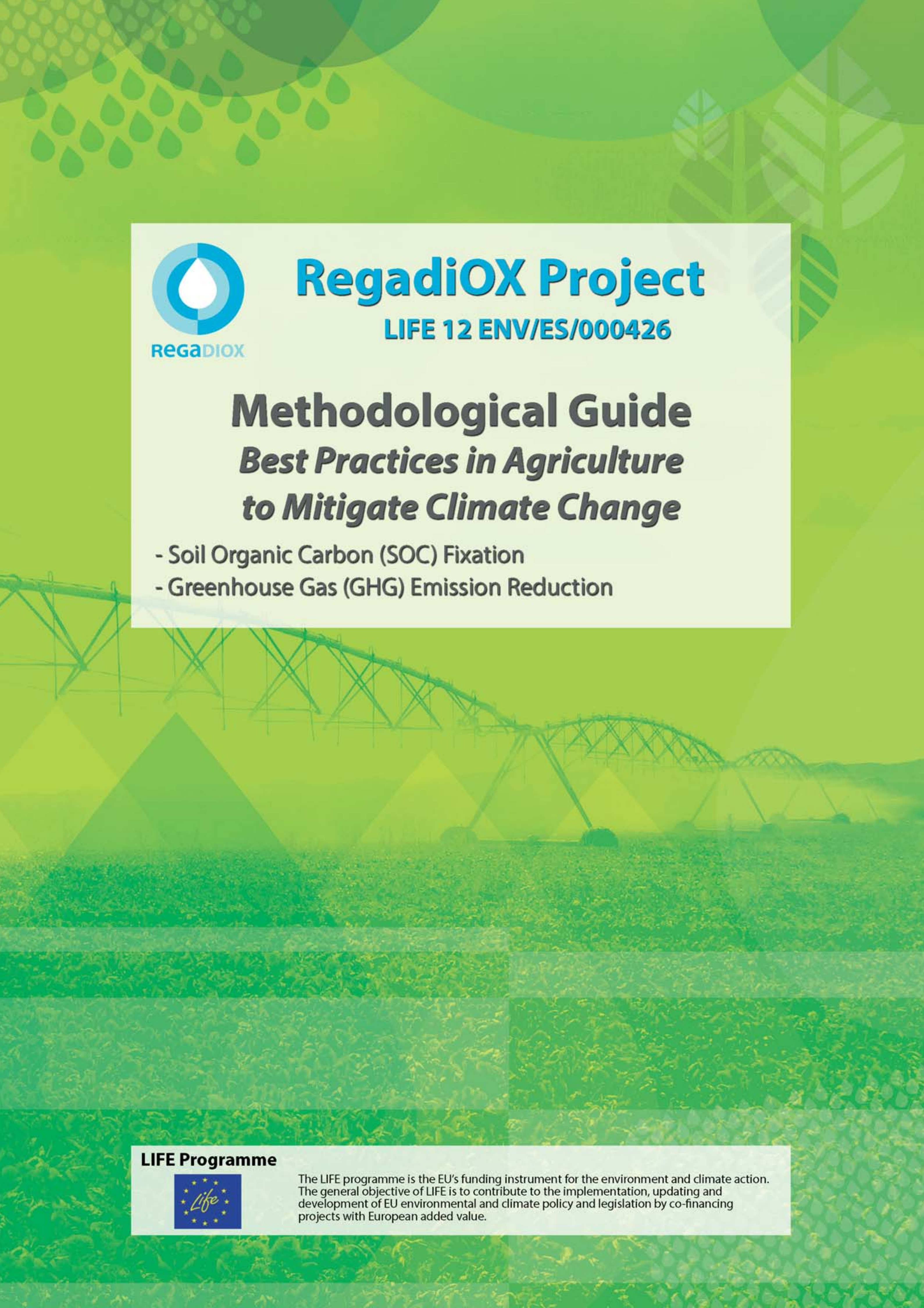


RegadiOX Project

LIFE 12 ENV/ES/000426

Methodological Guide

Best Practices in Agriculture to Mitigate Climate Change

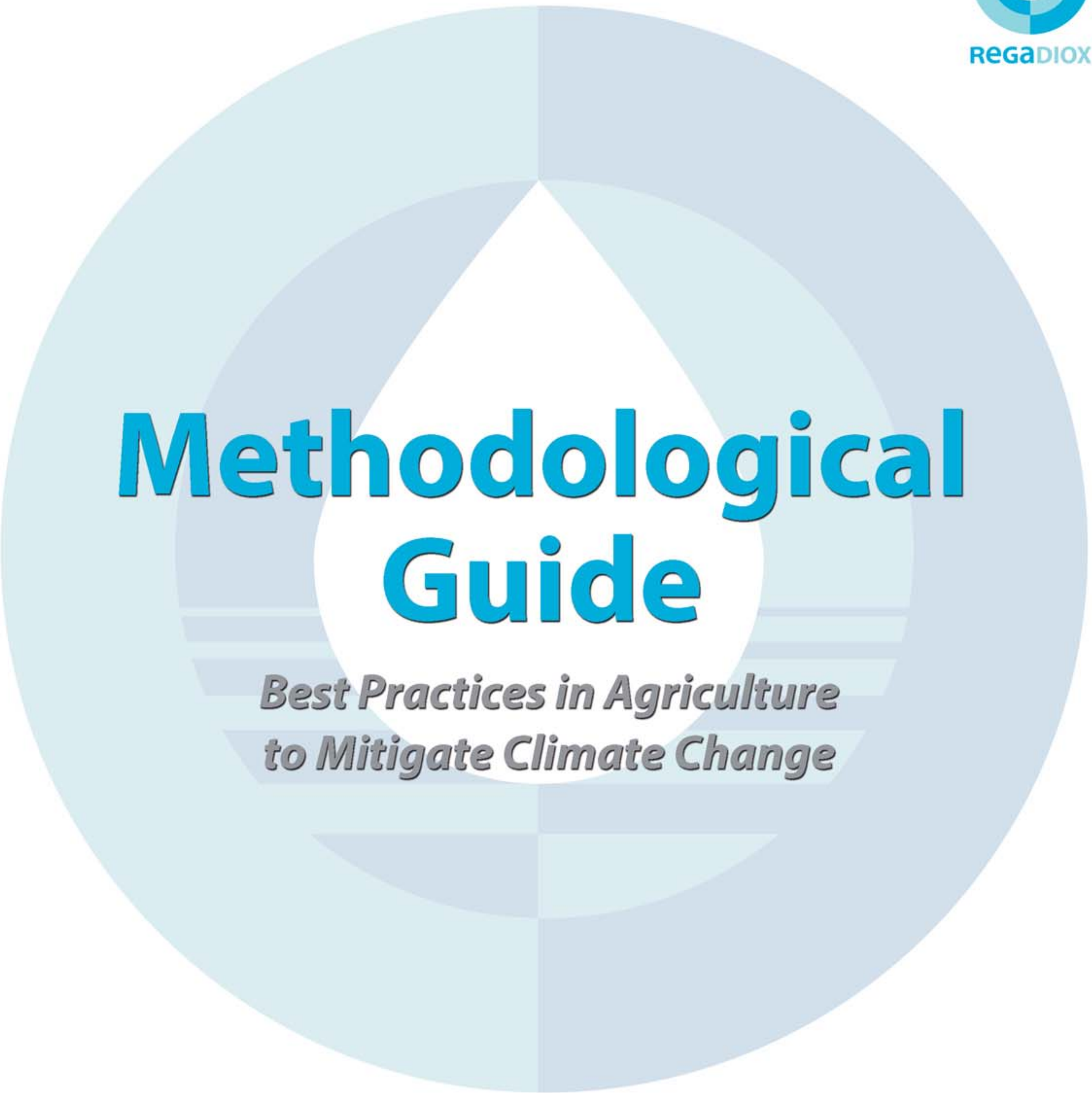
- Soil Organic Carbon (SOC) Fixation
- Greenhouse Gas (GHG) Emission Reduction

LIFE Programme

The LIFE programme is the EU's funding instrument for the environment and climate action. The general objective of LIFE is to contribute to the implementation, updating and development of EU environmental and climate policy and legislation by co-financing projects with European added value.

Methodological Guide

Best Practices in Agriculture to Mitigate Climate Change



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Objective

The **general objectivel** of the project is to **design, demonstrate, test and disseminate** the impact on climate change mitigation of an **improved model for the sustainable management of irrigated agriculture.**

The project's specific objective is to:

⇒ Design an innovative agricultural management model for irrigated farming systems to promote climate change mitigation, focusing on two strands of action:

1) Soil Organic Carbon Fixation (CO_2 balance).

2) GHG Emission Reduction (emission balance).

Actions

These objectives have been translated into a series of experimental actions enabling to quantify their effects in DIFFERENT TESTS:

1. **Transformation of dry farming into irrigated farming.**
2. **Crop intensity (no. of crops per year, type of crop).**
3. **Setting up green covers in woody crops.**
4. **Total or partial substitution of mineral fertilisers with organic fertilisers.**
5. **Irrigation layout and materials used in sprinkling irrigation.**

Finally, the results of these tests were analysed within large-scale experiences in two agricultural holdings located in different areas in Navarre.

Partners

Fundagro (project coordinator): Non-profit foundation of social interest, whose mission is contributing to dignify agricultural and livestock professions, focusing on collaborative actions that tackle with aspects regarding rural development, such as: promotion of agricultural holdings and their products, gastronomy, respect for the environment, agri-tourism, training, dissemination and awareness raising.

INTIA: The Institute of Agri-Food Technologies and Infrastructures of Navarre provides market-oriented advanced services for the development of the agri-food sector, focusing on quality, efficiency, innovation and sustainability. It includes among its objectives the dissemination of production techniques and systems, research and experimentation, certification and promotion of agri-foodstuffs and the provision of services to agricultural holdings, among which advice and training.

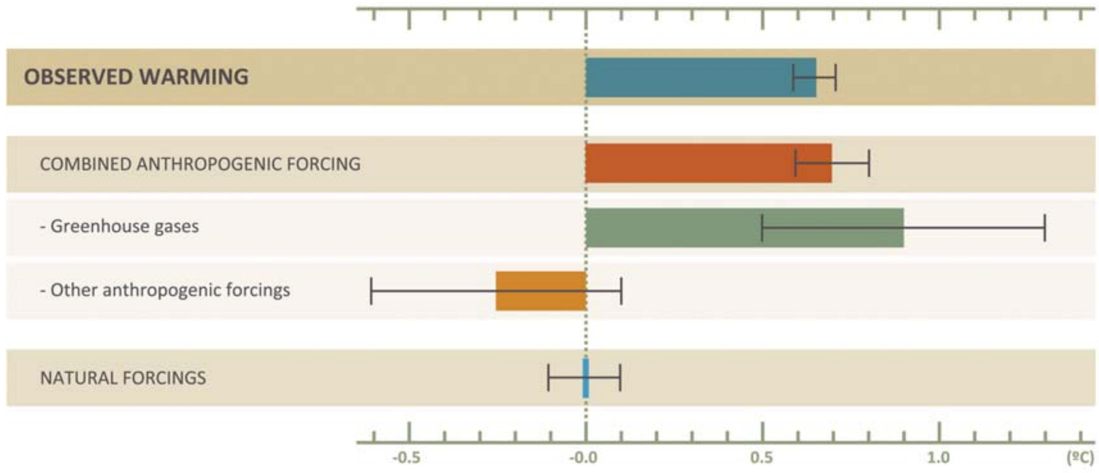
UPNA: the Public University of Navarre, via the Research Group for the Soil Sustainable Management, pursues different lines of investigation on soil handling and dynamics and their interaction with agricultural practices, and analyses and proposes practices that favour soil conservation and foster its environmental value.

Climate change, greenhouse gases (GHG) and agriculture

Greenhouse gases (GHG) are gases in the atmosphere that can warm up due to the radiation emitted by the surface of the Earth as it is warmed up by solar energy. As a consequence of this process the atmosphere warms up.

This natural phenomenon, known as greenhouse effect, is caused by gases such as carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4) and water vapour among others.

According to the latest report of the Intergovernmental Panel on Climate Change (IPCC, 2014), human influence on the climate system is clear, recent GHG anthropogenic emissions being the highest in history. Recent climate changes have had widespread impacts on human and natural systems.



Source: IPCC, 2014.

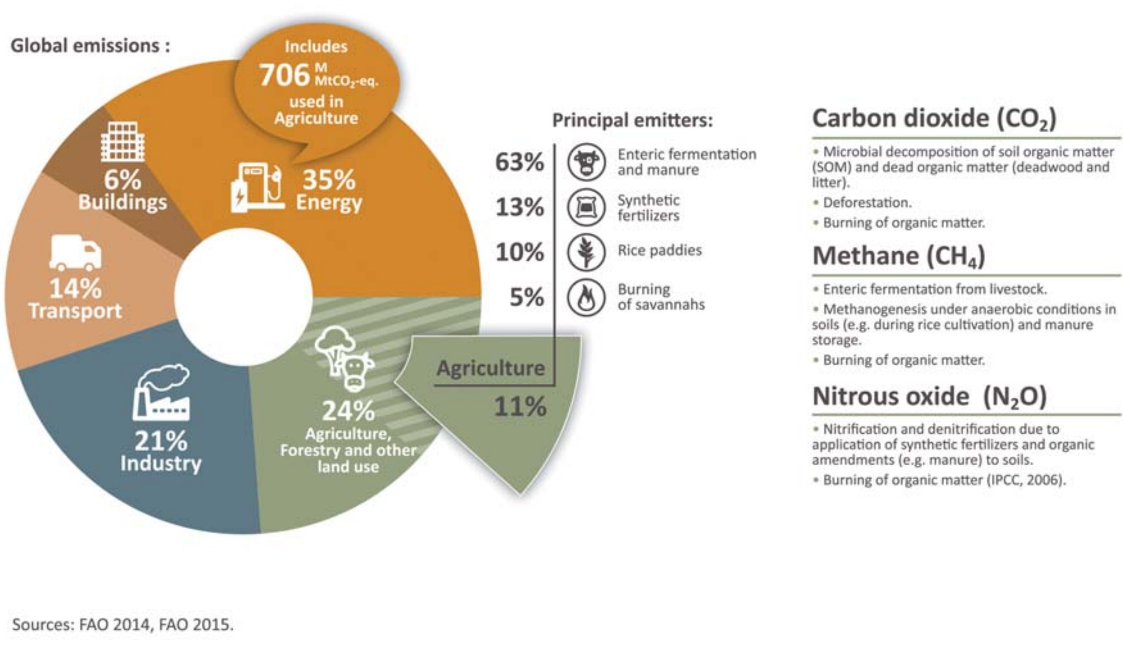
Figure 1: Contributions to observed surface temperature change from 1951 to 2010

Not all GHGs released into the atmosphere contribute in the same way to its warming. Assessing these emissions requires using units allowing to compare the emissions of different gases. CO_2 is used as reference gas and other gas emissions are converted into CO_2 equivalents (CO_2 eq) by comparing their warming potential with that of CO_2.

Global warming potential (GWP) of major greenhouse gases (GHG)

Greenhouse Gases	*Residence time in the atmosphere (years)*	*GWP*
CO_2	200	1
CH_4	12.4	28
N_2O	121	298
CFC	45-1,020	5,820-13,900
HCFC	1-12	1-1,980

Agriculture plays an essential role in the emission of major GHGs.



Carbon dioxide (CO_2)

- Microbial decomposition of soil organic matter (SOM) and dead organic matter (deadwood and litter).
- Deforestation.
- Burning of organic matter.

Methane (CH_4)

- Enteric fermentation from livestock.
- Methanogenesis under anaerobic conditions in soils (e.g. during rice cultivation) and manure storage.
- Burning of organic matter.

Nitrous oxide (N_2O)

- Nitrification and denitrification due to application of synthetic fertilizers and organic amendments (e.g. manure) to soils.
- Burning of organic matter (IPCC, 2006).

Sources: FAO 2014, FAO 2015.

Figure 2: Main sources of GHG emissions from agriculture and other land uses

The agricultural sector plays therefore a substantial role in the fight against climate change. As we have seen, on the one hand **it is a GHG-emitting activity but on the other hand, as it manages photosynthesis in a very wide surface, it has the capacity to become a carbon since, since in this biological process plants generate their own biomass by extracting CO2 from the atmosphere.**

This twofold disposition of agriculture provides an opportunity to develop strategies controlling GHG emissions from the agricultural sector, their purpose being to comply with the commitments resulting from different international agreements regarding climate change.

LIFE Regadiox places the focus on **irrigated agriculture because it is of strategic importance for the agriculture of the region** and because of its capacity for implementing measures to improve the environmental footprint of agricultural holdings.

he primary sector in Navarre accounted in 2014 for a GHG emission of 1,444 thousand tonnes of CO_2 eq. Such emissions include: enteric fermentation from livestock (CH_4) manure management (CH_4 and N_2O), soil fertilisation processes (N_2O) and rice paddies (CH_4). Not included here: soil respiration (CO_2), energy and fuel consumptions associated to agricultural activities.

Thus the primary sector represents almost 27% of emissions released in Navarre, ranking second after the industrial sector. Emissions have increased in the last year by 15% compared to 1990 levels (Government of Navarre, 2014).

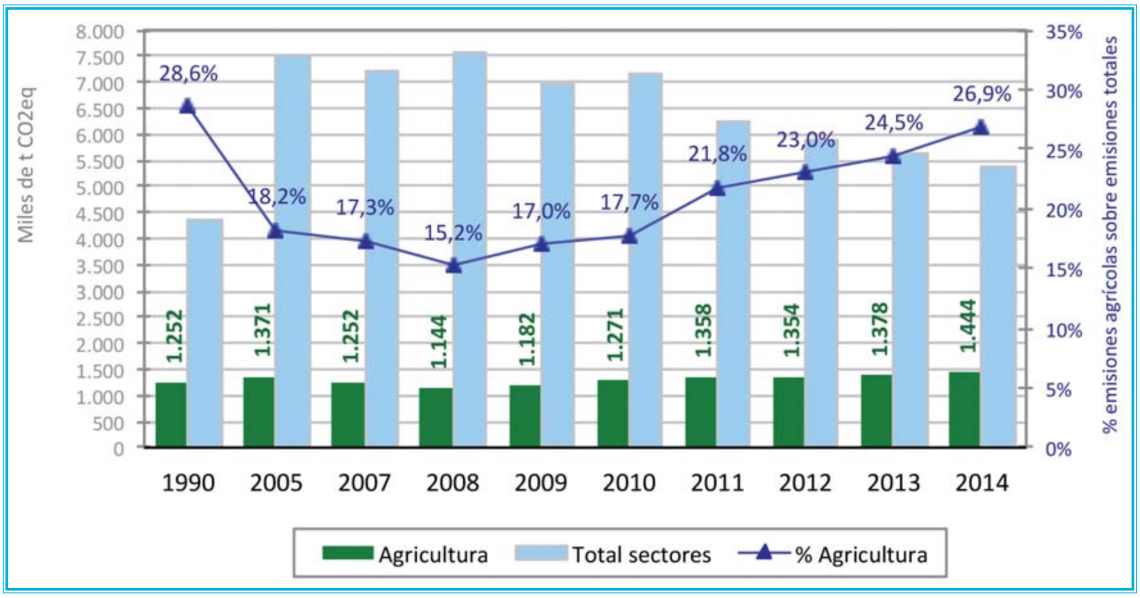


Figure 3: Evolution of direct GHG emissions in Navarre (emissions resulting from activity in Navarre

The strategy against climate change in Navarre recognizes the need to provide measures to mitigate greenhouse gas emissions through agricultural land management actions. Among other measures: improving the efficiency of irrigation and fertilisation, reducing field work operations and introducing green covers, and utilising quality organic matter as fertiliser (Government of Navarre, 2011).

Irrigation farming in Navarre

The irrigated surface in Navarre amounted in 2014 to 116,530 Ha **and accounts for 36.2% of the total area farmed and for 21.4% of the utilized agricultural area** (UAA) of Navarre. According to a study on the impact of water-pricing policies and their impact on agricultural income and employment as a result of the implementation of Framework Directive 2000/60/EC, it is estimated that the production of irrigated farmland in Navarre **would be near 0.9% of total GDP and 35% of agricultural GDP.** Gross production is 2,177 €/Ha and gross margin is 1,671 €/Ha, whereas the productivity of labour is estimated at 32,911 € of gross margin per agricultural work unit (AWU) and a Net Added Value per AWU at factor cost of 22,674 €/UTA. The study concludes that irrigation culture would concentrate 43% of agricultural employment (5,245 AWUs) and 1.8 % of total employment in Navarre. Based on the statistical information provided by the Farm Structure Survey carried out in 2013, the **irrigable area benefits 8,597 holdings**, 58.5% of total holdings in Navarre.

Irrigable area between 2004 and 2014 has increased by 24.7% (see chart below), mainly due to the construction of the Navarre Canal. The construction of the Canal was planned in two stages for an irrigable area of 53,125 Ha. The first stage has transformed approximately 22,500 Ha (19% of the current irrigated farmland area), of which in 2014 87% of the area is considered as equipped with parcel irrigation systems. The second stage pending, an extension of the first stage has been projected so as to enable irrigation of further 15,275 Ha. Contracts for the extension were awarded in April 2014. The eventual deployment of Stage 2 of the Navarre Canal will reach 59,160 Ha of transformed farmland and the energy optimisation of 51.522 Ha of irrigated farmland.

Irrigated agriculture therefore means a great opportunity for Navarre in the years ahead, both in terms of social and economic significance and as a challenge to improve the environmental footprint of agricultural holdings.

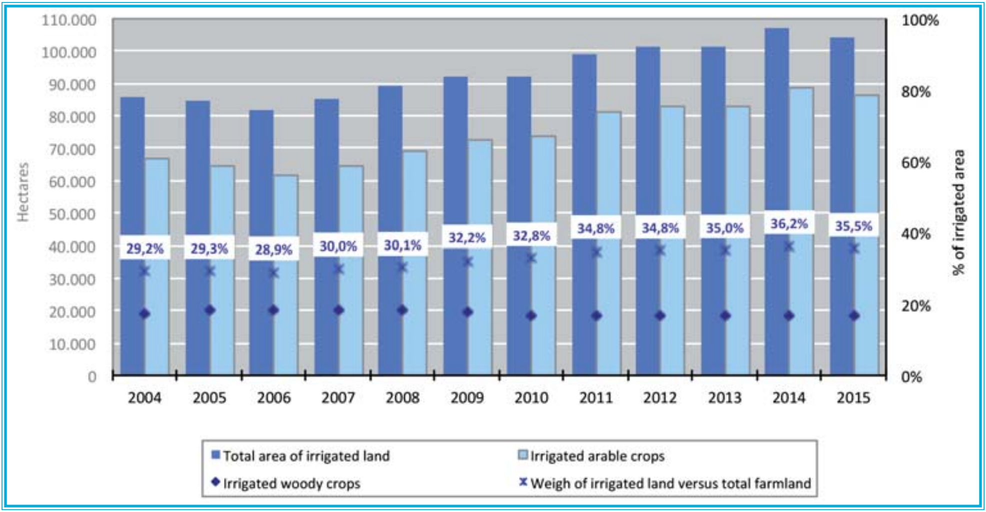


Figure 4: Evolution of irrigated farming area in Navarre

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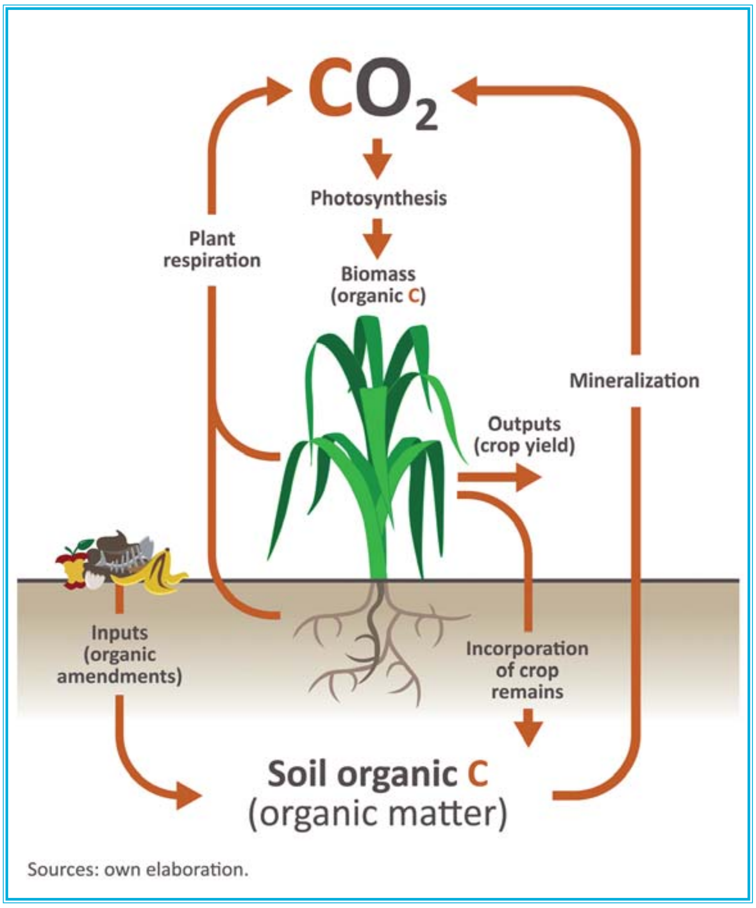
Methodology

Atmospheric carbon sequestration in agricultural soils

Soils contain large amounts of organic carbon and, in some areas of the Midlands (Zona Media) and south of Navarre, inorganic carbon as well. In addition to living components (plants, macro- and mesofauna, microorganisms), organic carbon is mostly accumulated in the different components of soil organic matter.

The input and storage process of organic carbon in soils is part of a cycle, represented in the figure below:



Sources: own elaboration.

Figure 5: Organic carbon cycle in agricultural soils

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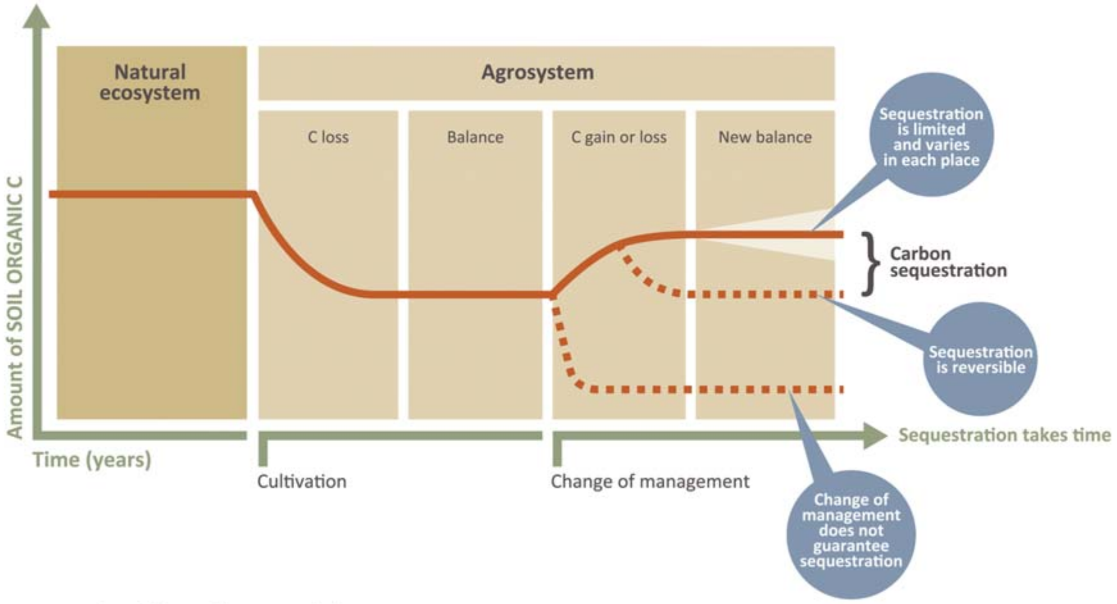
During their lifecycle plants capture CO_2 (differences between the atmospheric CO_2 that is absorbed during photosynthesis and the CO_2 released into the atmosphere during respiration), with an estimated sequestration rate of 45%-50% of the dry weight of the plant.

Once absorbed **part of the carbon input can become stabilized in the medium and long term in the organic fraction** of the soil (each tonne of stabilized organic carbon is equivalent to 3.7 tonnes of CO_2). The proportion of carbon input that is stabilized in the soil depends on the factors regulating its decomposition process (mineralization), among others: the type of organic matter, soil properties, availability of nutrients and water. The net balance between inputs and outputs determines the final amount of atmospheric carbon stabilized in the soil in a particular place.

Agriculture is a necessary participant in this cycle. In a general way, when soil is put into cultivation, a substantial par of inorganic carbon stored in the soil is lost for several reasons. The regular alteration of the soil natural structure by tillage, the supply of nutrients (and occasionally water) and further processes favour the accelerated decomposition of the organic matter accumulated in a natural manner. The lower input level due to the output of part of the biomass (crops, removal or burning of crop residue, for instance), or erosive processes can also contribute to this loss. The loss has consequences in terms of CO_2 emissions but also in terms of loss of natural fertility.

However, the implementation of agricultural practices allowing to optimize the natural cycle of carbon and to enter it in the balance on the gain side (increasing the inputs and/or reducing the losses) can contribute to fix atmospheric CO_2 in the soil as organic carbon. In this case agriculture would become an effective tool to remove atmospheric CO2. This process is known as atmospheric ***carbon sequestration.***

However, sequestration is limited (the limit is attained when a new balance is reached) **and reversible** (stored carbon can be lost if practices are discontinued over time). The evolution of organic carbon absorption rates decreases as time passes starting from the moment handling processes are changed and ending when a new balance is reached between annual inputs and outputs due to mineralization under the new conditions. For sequestration to be effective, permanence of carbon in the soil must be secured.



Source: adapted from Follet 2001 and Chenu 2015.

Figure 6: Evolution of organic carbon in soils depending on handling

The amount of organic carbon that can be accumulated varies to a great extent **depending on the climate** (and how it changes with irrigation), the type of soil and the crop that is established. It must be remembered too that an increase in soil organic matter has positive consequences on its capacity to function properly (fertility, resistance to erosion, water retaining capacity, etc.).

Overall, it must be considered that the potential for mitigation of this mechanism is small compared to global emissions. Yet it can account for a relatively significant proportion of emissions from agriculture (e.g. Chenu et al., 2014).

Soil C sequestration under RegadiOX has been assessed based on a "space-time" approach to the quantified stock existing in dry and irrigated farming parcels and considering that the baseline for irrigated parcels is that of dry parcels under the same conditions (soil units, agro-climatic zone). For this purpose the project has utilized the sampling protocol proposed by the European Commission, known as "Area-frame randomized soil sampling protocol". The protocol has been applied to equivalent series of soils in each irrigated area.

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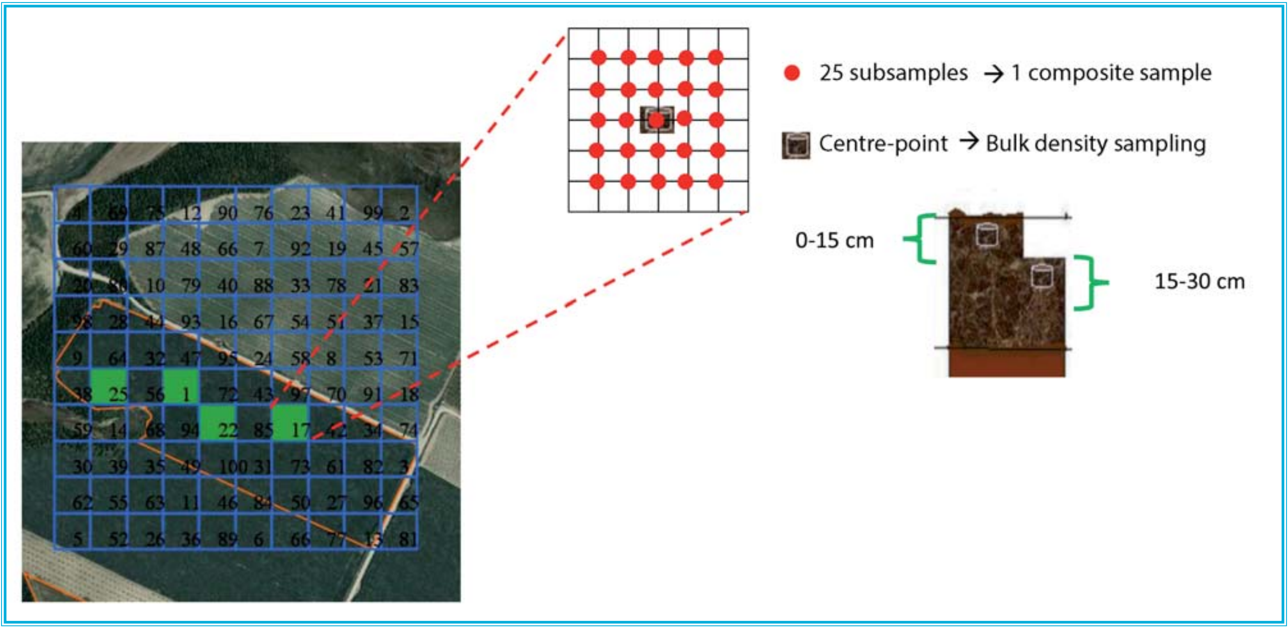

Figure 7: Sampling protocol used to quantify soil organic carbon stock

Greenhouse Gas (GHG) emission estimates

Greenhouse gas (GHG) emission estimates have been made using the tool developed under the EURENERS 3 project for calculating the Carbon Footprint (CF) of agri-food products by measuring the amount of GHG released into the atmosphere during their Lifecycle. The tool's calculation methodology complies with the requirements of PAS 2050 based on the lifecycle analysis of agri-food products.

Picture of the signing of the collaboration agreement between Fundagro and Teder

This tool takes into consideration both direct and indirect emissions. Calculations were made at parcel level, counting the emissions related to the agricultural soil, the production of inputs such as seeds, phytosanitary products and fertilisers, electricity used for pumping (where applicable), fuels used for tillage and motor oils for tractors, treatment of plastic waste from phytosanitary product containers and authorised burning of agricultural residues.

For each of the activities carried out in agricultural parcels, emissions are calculated multiplying the data collected from each activity by their respective emission factor. The tool relies on a broad database of emission factors associated to different inputs and activities to calculate the total value of GHG emissions expressed in kilograms of de CO_2 equivalent.

Emission balance: Greenhouse gas emissions and CO_2 sequestration are analytically studied to yield comparable quantitative data.

Demonstration land parcels

RegadiOX has been developed in a series of agricultural parcels in Navarre.

A preliminary study on the pedological and climatic characterisation of Navarre was conducted to enable the selection of this network of parcels, by describing the soils and validating the areas selected for test purposes.

Parcels were selected for demonstration purposes all around the irrigated geography of Navarre on the basis of the homogeneity of parcels and the coherence of soils, so as to enable a sufficiently objective analysis of the resulting data from each of the actions.

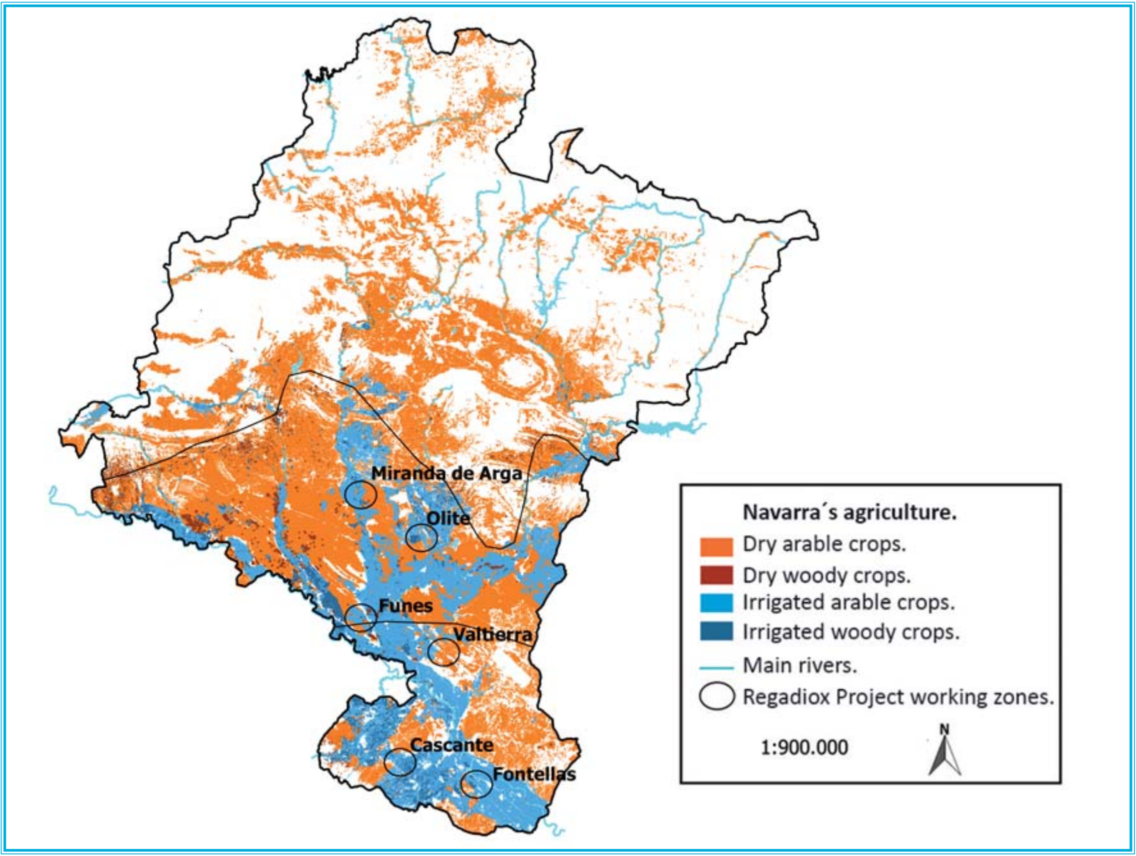

Figure 8: Location of RegadiOX areas

This has allowed to estimate greenhouse emissions and atmospheric CO_2 sequestration in each of the actions of the project.

The network of parcels consisted of parcels in **6 irrigated areas**, with **woody crops (vine, olive) and arable crops,** in different frequent situations, as well as **equivalent dry parcels** (same soil type, known history) in certain areas.

Climate zone (Papadakis)	*Geographical area*	*Handling*	*Crop*	*Soil type (Soil Taxonomy)*
Mediterranean climate	Miranda de Arga	Dry	Barley	Typic Calcixerept
		Irrigated	Grain maize	
		Irrigated	Grain maize	
		Irrigated	Lucerne	
		Irrigated	Horticulture	
		Irrigated	Olive with cover	
	Olite	Irrigated	Vine with cover	Petrocalcic Calcixerept
		Irrigated	Vine with cover	
Clima estepario frío	Funes	Dry	Barley	Xeric Haplocalcid
		Irrigated	Fodder maize	
		Irrigated	Grain maize	
		Irrigated	Horticulture	
	Valtierra	Dry	Barley	Xeric Haplocalcid
		Dry "org fert"	Barley	
		Irrigated	Grain maize	
		Irrigated	Horticulture	
	Fontellas / Ribaforada	Irrigated	Olive with cover	Typic Calcixerept
		Irrigated	Olive w/o cover	
	Cascante	Irrigated	Vine with cover	Xeric Calcigypsid
		Irrigated	Vine w/o cover	

Experimental actions

The estimated emissions and stored organic carbon of these parcels have been verified.

1. Arable crops (land-use change from dry to irrigated farming and different irrigated crops)

1.1. ORGANIC C STORAGE

Irrigated farming, in general, involves a higher organic C sequestration rate in soils compared to traditional dry farming, as it increases the amount of biomass produced per unit area.

Irrigated crops can be put into groups depending on how they modify the inputs and outputs of the carbon cycle:

- Fodder crops – no or occasional tillage.
- Annual crops – one crop per crop year.
- Intensive tillage – crop rotation, several crops per year (e.g. cereal + horticultural).

The values of stored organic C varied differed between areas and between cultivation systems. Differences amounting to almost 40% were observed in certain areas, depending on the characteristics of the crop, the soil, the agro-climatic zone and the duration of irrigation.

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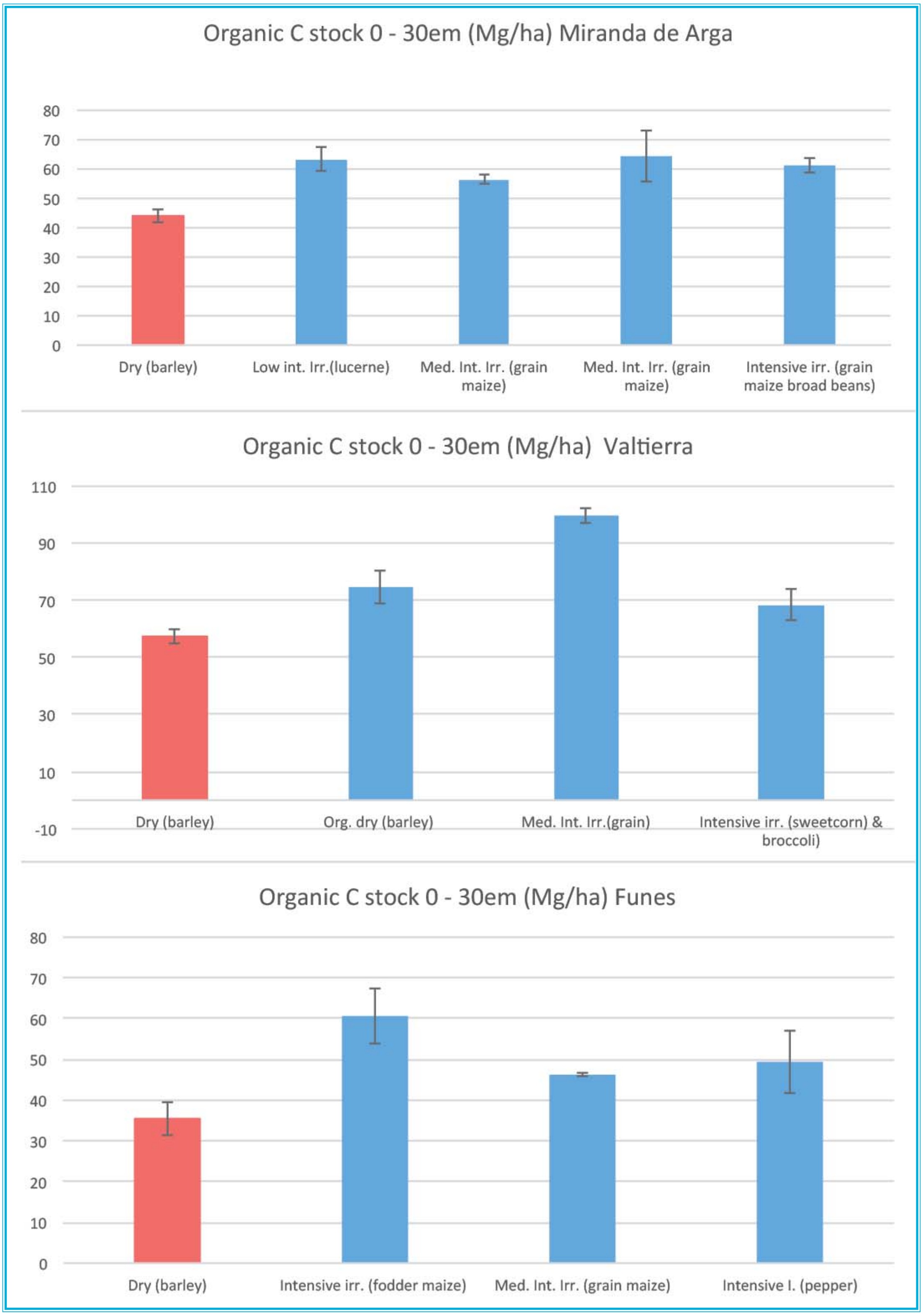

Figure 9: Soil organic C stock (Miranda de Arga – 6 years of irrigated farming; Valtierra - 20 years of irrigated farming; Funes - 13 years of irrigated farming)

In the different areas, the annual average rates of organic C sequestration considering a baseline similar to that of dry farming ranged between 3 and 12 tonnes of CO_2/Ha*year.

The highest rates were observed in fodder crops or medium-intensity crops (one crop per year), although there are variations within these systems depending on the area and handling.

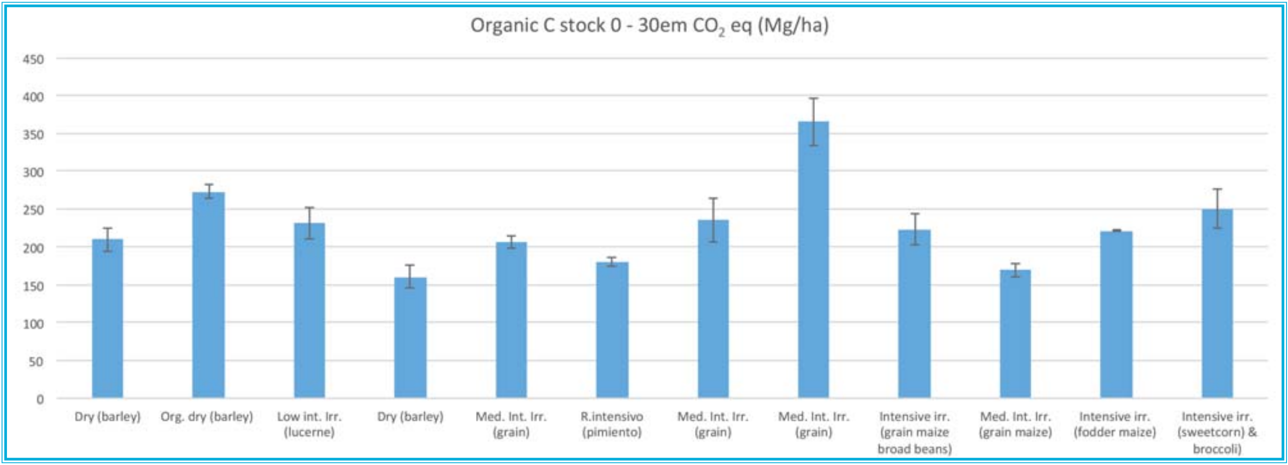

Figure 10: Organic C stock in CO2 equivalents of several arable crops in dry/irrigated parcels in Miranda de Arga, Funes and Valtierra

1.2. GHG EMISSION ESTIMATES

In general, GHG emissions per unit area increase with irrigation, due to the intensive use of different inputs.

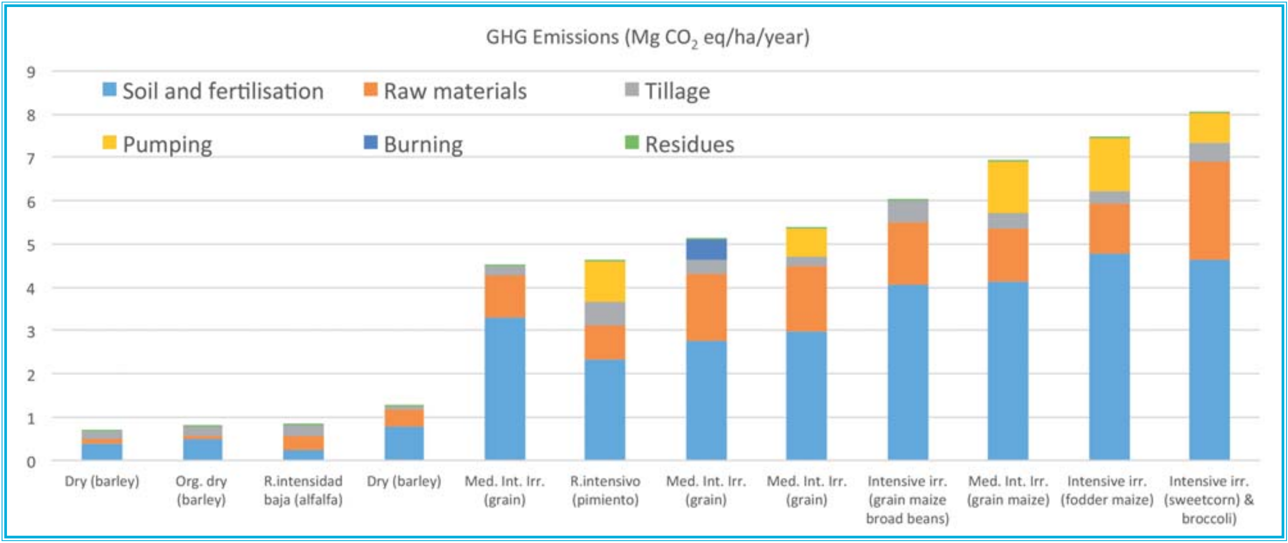

Figure 11: Greenhouse gas emissions (Mg CO_2 eq/Ha and year) calculations for several parcels of irrigated arable crops in Miranda de Arga, Funes and Valtierra

Major sources of emissions are those associated with fertilisation and soil respiration, in all cases, and those associated with the raw materials used during crop cycle or with irrigation water pumping.

Net emission balance (emissions compared with annual sequestration rates) of low-intensity crops in irrigated farming such as fodder crops or corn in annual crops can be null or negative (net gain of CO_2 equivalent vs. emissions) for a longer period of time because of the high potential for sequestration vs. emissions.

An annual irrigated crop is therefor capable of compensating, for several years, the increase in GHG emissions associated to its management with a higher CO_2 sequestration rate of the system, thus obtaining favourable balances. **The incorporation of cultivation techniques allowing to optimise this capital, thus attaining increased sequestration rates and reduced emission rates are most promising in this sense.**

2. Green covers in irrigated permanent crops (olive and vine)

2.1. ORGANIC C STORAGE

The use of green covers in woody crops such as olive and vine can be an effective practice in the fight against climate change as it offers several agronomic advantages.

The incorporation of green covers increases organic C inputs in the soil as it increases the organic matters supplied by cover residues and roots.

Additionally, covers in irrigated crops provide several agronomic benefits: facilitated cultivation operations due to soil moisture, reduced maintenance costs compared to those of bare soils, increased biodiversity of soils and agrosystem – and in the case of vine it is used to control the development of the crop itself.

The project has demonstrated that **the incorporation of covers favours organic C storage, if maintained over time,** especially over 10 years.

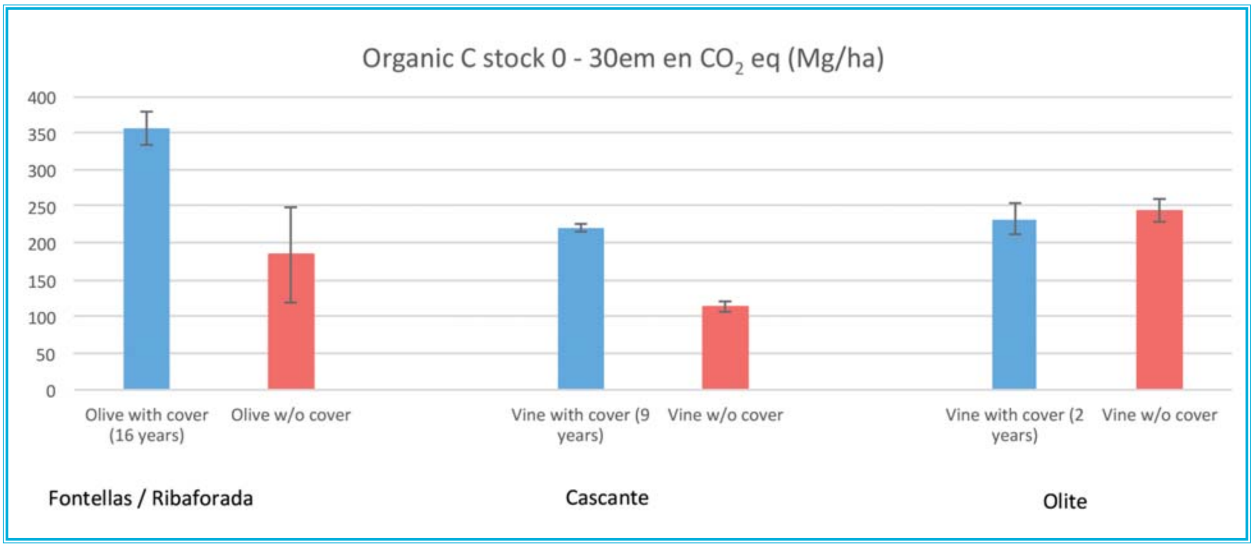

Figure 12: Organic C stock in soils (Ribaforada/Fontellas - 16 years; Cascante - 9 years; Olite - 2 years)

Green covers in permanent crops have a positive impact in terms of climate change mitigation in the medium and long term.

2.2. *GHG EMISSION ESTIMATIONS*

In general, as regards emissions, small differences are observed compared to land handling with no covers, lower than in arable crops.

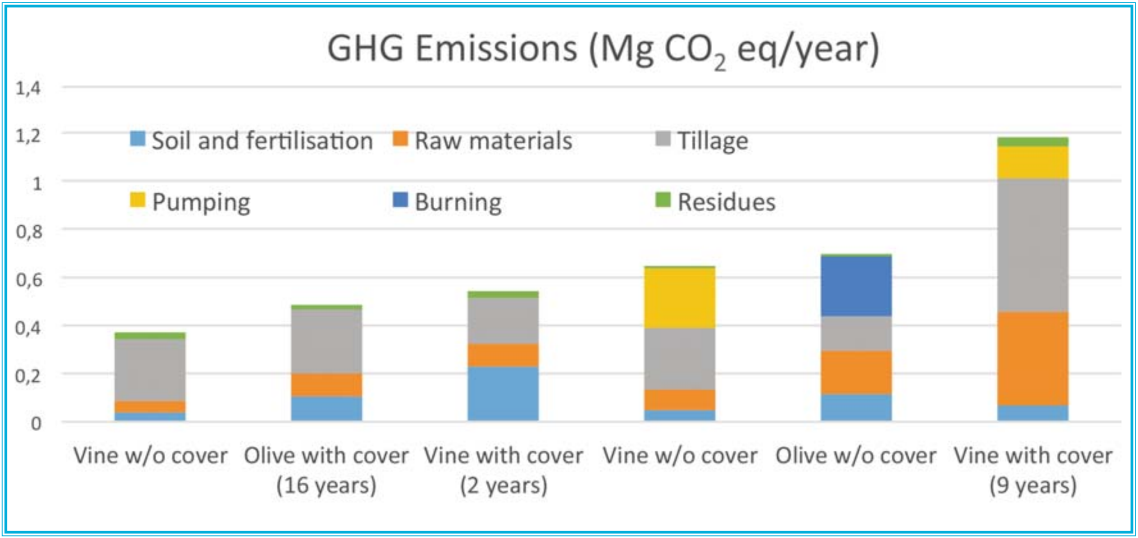

Figure 13: GHG Emissions

3. Efficient nitrogen use to reduce GHG emissions (organic/inorganic fertilisers)

The use of organic fertilisers is a most interesting practice as it allows to connect agriculture and livestock farming and to reduce the volume of waste whilst securing the proper supply of nutrients to crops.

Organic fertilisation using pig slurry, chicken litter, liquid and solid fraction of digested cow slurry and sludge from Wastewater Treatment Plants is a feasible practice for the proper development of crops, as it supplies micro-nutrients and organic matter.

It likewise provides several agri-environmental benefits, as by definition it promotes circularity by allowing livestock manure to be recovered as organic fertiliser.

The additional supply of organic matter allows to increase C fixation, thus reducing soil erodability whilst increasing its functional biodiversity.

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Key factors for the proper application of organic fertilisers:

1- Adjusted calculation of nitrogen fertilisation needed by the crop, adapted to the vegetative stage of the crop.

2- Need to assess the soil's contribution, i.e. nitrogen availability in the soil and foreseen nitrogen supply from the mineralisation of the different sources of organic matter.

3- Preventing nitrogen losses caused by leaching, by planning irrigation and doses to prevent losses by washing.

4- Reducing losses by volatilisation when applying the organic fertiliser (best done on cool and humid days). Avoid applications on windy days and use techniques such as 24-hour sealing in soils or drag hoses.

5- Compositional analysis of organic fertilisers. Need to assess the coefficient of equivalency of its nitrogen content to draw up a fertilisation plan (see table below).

Type of organic fertiliser	*Coefficient of N Equivalency (%)*	
	1 year after application	*2 years after application*
Pig slurry	41	
Chicken litter	29	
Solid fraction of digested cow slurry	33	15
Liquid fraction of digested cow slurry	39	
WWTP sludge	26	7

*Data obtained from actual tests (data are similar to those in bibliography, except for pig slurry and chicken litter – these range between 50% and 60% according to bibliography)

The coefficient of N equivalency in organic fertilisers is construed as fertiliser units of N applied with urea that the total N applied with each organic fertiliser is equivalent to. For instance, if we apply a dose of pig slurry containing a total 100 kg of N, this is equivalent to applying 41 kg of urea containing 46% N, i.e. 41% of the total N of the slurry is recovered within the same year.

Results show that it is possible to partially substitute mineral fertilisers with organic fertilisers while preserving crop yields. The strategy to follow in a fertilising plan for a corn crop would be to apply a base dressing of organic fertiliser equivalent to 250 fertilising units of nitrogen. This base supply would cover, in the case of most organic fertilisers studied, the phosphorus and potassium requirements of the crop, and part of its N requirements. For instance, if we apply 50 m of pig slurry containing 5 kg of N per m, we are applying 250 kg N/Ha. By applying the coefficient of equivalency, this is equivalent to applying 103 *kg* of N/Ha (250 x 41/100) with urea. The remaining N to cover the N requirements of corn (300 kg N/Ha for a yield of 14 t/Ha of corn) would be applied with urea (in the above example 197 *kg* of N/Ha equivalent to 428 *kg* of urea 46% N per hectare).

However, the use of organic fertilisers does not reduce GHG emissions compared with the use of inorganic fertilisers. Both fertilisation systems result in similar GHG emissions. This is so because GHG emissions are calculated using the total amount of nitrogen supplied, not only that which is efficient for the crop. In the above example, if we apply 250 kg N/Ha using pig slurry (of which the crop only recovers 41%) and supplement it with 197 kg of N/Ha with urea 46% N, the calculation of GHG emissions takes into consideration the sum of both, i.e. 447 kg of N/ha. If the fertilisation plan used only urea 46% N, this would involve applying 300 kg of N/Ha. This difference in total kg of N is what increases GHG emissions resulting from the use of organic fertilisers. For this reason, as regards emissions, it is interesting to use organic fertilisers with a high coefficient of nitrogen equivalency. When calculating emissions, those resulting from the transportation of urea from the point of production to the farmer's point of supply are not taken into consideration. Yet, this distance can be very large if compared with the distance of transport of organic fertilisers, which are applied near where they are produced. **If this were taken into account, GHG emissions of organic fertilisers would likely be lower. Additionally, applying organic fertilisers supplies organic matter to the soil, thus contributing to carbon fixation.**

Economically speaking, organic fertilisation may prove more cost-effective, although such cost-effectiveness will ultimately depend on the cost of the organic fertiliser plus the distance between the point of production and the point of supply. A preliminary study should therefore be performed in advance.

4. Irrigation layout and materials used in sprinkling irrigation to reduce energy expenditure and GHG emissions

The objective of this action is to know and demonstrate the relationship between variants of design, establishment and operation of irrigation systems in parcels and energy consumption, to assess the efficiency of water application and the economic cost of each variant and to determine the Carbon Footprint of the possible variants. Energy consumption in irrigated farming is given by the energy that is required to pump the water. **Adjusting the design of the irrigation system allows to reduce the load losses and pressure requirements of the system, consequently leading to a decrease in associated energy consumption and GHG emissions.**

The **design stage of irrigation systems in land parcels** is considered crucial when defining the cost-effectiveness of the holding. As a matter of fact, the higher the value of the uniformity coefficient, the lower the amount or irrigation water required to attain maximum yield. It is clear then that a well designed and handled system can result in substantial water and energy savings, thus increasing the cost-effectiveness of the crop.

According to the demonstrative experiences conducted to compare 18 x 15T and 12 x 15T irrigation layouts, **12 x 15T has proven to be an alternative** for operating pressures in sprinkling systems from 25 to 30 mWc. In new irrigation networks the scaling of the network to a 12 x 15T layout would involve **a saving in pressure of 5 mWc.** This irrigation layout maintains the uniformity coefficient of the 15x18 layout in most situations. It can also be an interesting option for irrigation systems requiring pumping: since it requires less pressure in the header it consequently requires less energy to pump the water, thus reducing GHG emissions. It can also prove an interesting option in irrigation systems where no pumping is required but where the pressure in the header is not sufficient for a 15x18 m layout.

- As regards CO_2 emissions at **irrigation parcel systems** level it has been established that **GHG emissions in 12 x 15T layouts are higher** than in 18 x 15T irrigation layouts; the **increase** in Carbon Footprint amounts to **294.12 kg CO_2/*ha*** (approximately 5%). This is so because establishing a 12 x 15 m layout requires more materials than in the case of a 15 x 18 m layout, and GHG emissions associated to the manufacturing of materials and their installation are higher. Therefore, from a GHG emission perspective, this would not be an interesting option for irrigated parcels where natural pressure at the header is not a limiting factor.

As far as installing irrigation system in parcels is concerned, the stage of design and the choice of materials provide the opportunity to reduce load losses. Here are the most relevant aspects:

- In all the headers covered by the study, **higher uniformity values** were attained by using sectoral sprinklers with **double nozzles.** Under no wind conditions, **the highest uniformity value** was obtained in the test using **a header at 10 m** and sectoral sprinklers with **2 nozzles.**

- **Most efficient options** in terms of load losses are installations using **PE 125 mm pipes** and **110 mm fittings.** The installation of **buried valves with no supply lines** manages to decrease the pressure required at the header as no load losses occur to and from the valves. However, **the highest Carbon Footprint value** as regards materials is attained by the option using **PE 125 connectors and nodes..**

Extending the scope of the study from the parcel level to the **collective irrigation network level,** thus including the entire irrigable area of the Navarre Canal in its first stage, for a reference pressure requirement decreased by 5 mWc (corresponding to a 12 x 15T layout) the Carbon Footprint is reduced in average by 10.09 % compared to CO2 emissions of materials used in the collective network for the 18 x 15T layout alternative. Translating these figures in terms of hectares of irrigated land, a **402.76 kg CO2 reduction in emissions is attained when shifting to the 12 x 15T layout.**

Consolidating the above two scopes of study, i.e. irrigation at parcel level and at the level of the collective irrigation network of the irrigable area covered by the Navarre Canal in its first stage, when shifting from a 18 x 15T irrigation layout to a 12 x 15T irrigation layout in energy-dependent networks the **global saving in CO_2** would amount to **21.90 kg CO_2/*ha* per year.** For calculating this global saving the useful life of installations has been estimated at 30 years.

Certain measures can also be taken during the irrigation management stage to reduce GHG emissions. Automating the irrigation network by remote control can be accomplished, in general, at several levels and in different parts of the installation. The degree of automation would be attained by the integrated automation of a collective programmed irrigation system:

- **First level.** Automating the collective irrigation network and its management. The objective is to monitor each irrigation post. Common in irrigation organisations and authorities.
- **Second level.** Automating the irrigation of each parcel. In this sense mobile telephony has led to a deep change in how information is understood and processed, allowing to start/stop irrigation or the parcel, to check past and current irrigation schedules, etc.

At these two levels, the implementation of remote control systems results in GHG emission reductions due to the decreased number of trips required for irrigation management (first level) and programming (second level) purposes.

In addition to this direct saving in kg of CO_2, remote control meets further monitoring requirements such as flow rate, pressure and frequency of supply, thus securing the proper operation of irrigation systems (allowing for a better control of water application rates and consequently for a bigger saving in total amounts). This ultimately leads at the end of the chain in an improved crop yield and quality.

Conducting energy audits is another aspect of irrigation management open to further action. Installations gradually lose their efficiency with the passing of time and require maintenance measures to improve efficiency levels. These audits would allow to identify reductions in efficiency and take remedial actions and to reduce energy consumptions and consequently GHG emissions.

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General recommendations

- **In woody crops, it is recommended to implement green covers in the inter rows.** This enables a substantial increase in soil organic C content, among other things. The effect of green covers is observed more clearly in time, when it is **several years old.**

- As for **irrigated arable crops** no clear differences are observed between the different systems. There is however a more favourable tendency for low- and medium intensity irrigated crops and a less favourable one for intensive irrigation crops:

  1- Regarding **organic matter storage,** in some areas **differences** nearing 40% are observed in some areas, depending on the characteristics of the crop, the soil, the agro-climatic zone and period of irrigation.

  2- Regarding **GHG emissions,** the main source of variation is the type of crop, although values up to 54% higher have been observed in the same crop (grain maize) depending on different parameters namely **major sources of GHG emissions,** in ascending order: soil emissions **due to nitrogen fertiliser application,** followed by **manufacturing and transportation of raw materials** and then emissions due to **tillage.** For this reason the following cultivation techniques are recommended:

    - **Performing only the necessary tillage** required for the best development of the crop or, if possible, eradicate all tillage.

    - **Rotating crops by alternating** intensive campaigns (1.5 or 2 crops per year) and low intensity campaigns (1 crop per year or crops with lower or no tillage requirements).

    - **Applying crop residues to the soil whenever this is possible.**

    - **Including leguminous species, if possible fodder crops, in the rotation of crops,** as these require less tillage and less nitrogen fertilisers.

    - **Using nitrogen fertilisers reasonably,** adjusting the doses and times of application to the needs of the crop.

    - **Using organic fertilisers.** Always taking into account their nitrogen content and the nitrogen that can be recovered by the crop (coefficient of equivalency). Most frequently available organic fertilisers show differences in their efficiency as nitrogen fertilisers (ranging from 26% to 41%). It is therefore necessary to be aware of these factors. GHG emissions produced in the parcel do not decrease, but these fertilisers supply carbon to the soil.

- **Pumping irrigation water** is a **significant source of GHG emissions.** For this reason the following is especially recommended in irrigated parcels where this may be necessary:

  a. **Using more efficient irrigation materials and designs,** i.e. to enable lower load losses and a decreased pressure at the header whilst maintaining irrigation uniformity.

  b. **Automating the management of irrigation networks and irrigated parcels.** This allows to reduce GHG emissions from diesel fuel consumption, as it cuts down the number of trips to the parcel.

Farmers following these recommendations not only contribute to mitigating climate change – they can also save money and efforts, by:

- *Spending less fuel in tillage.*
- *Using fertilisers reasonably.*
- *Improving the structure, condition and quality of the soil by properly managing organic matter, including organic fertilisers.*
- *Investing in an irrigation installation requiring less energy for pumping water.*
- *Avoiding trips to the parcel during the irrigation season..*

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Further information on the project is available at: http://life-regadiox.es/es/