# Improving GHG flux monitoring in agricultural soil through the AGRESTIC prototype: a focus on the assessment of data quality


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***Abstract***

***Measuring at high frequency soil fluxes of carbon dioxide ($CO_2$), and nitrous oxide ($N_2O$) in agricultural soils requires appropriate technology. With this aim, a prototype was developed and tested in agricultural soils for 5 months, within the framework of the LIFE project AGRESTIC. The prototype is composed by two automatic GHG stations for measuring $CO_2$ (LI-COR LI-850) and $N_2O$ (Teledyne GFC-7002TU) fluxes from soil and an IT infrastructure for data management. The two GHG stations were installed one in Ravenna, Italy, (Cà Bosco farm) and the other in Foggia, Italy, (Caione farm), where two different cropping systems were compared. Along the period going from January 1st to May 31st, 2020 the two GHG stations proved to be robust to field conditions (e.g. wind, rain, freeze etc.). The quality of the measurements was different in the two sites, with more than 90% of good measurements in Ravenna and more than 60% in Foggia.***



***Keywords — soil GHG flux, automatic chamber, remote control, $N_2O$, $CO_2$***


## I. Introduction

Monitoring the emissions of greenhouse gases (GHG) from arable land is needed to assess the magnitude of these phenomena and how GHG emissions are affected by different cropping systems. The main GHGs emitted from soil in non-flooded arable land are carbon dioxide ($CO_2$) and nitrous oxide ($N_2O$). $CO_2$ is mainly emitted because of the mineralization of organic matter, while nitrification and denitrification are the main processes in soil leading to $N_2O$ emissions [1]. The emission of GHG from agricultural soils is affected by several factors influencing microbial activity in soil, such as: agricultural practices, soil conditions (e.g. water content, temperature, nitrogen content), and weather conditions. Concerning agriculture, $N_2O$ has gained the attention of researchers due to its high global warming potential and because agricultural soils are its main anthropogenic sources [2].

The design of efficient cropping systems in which the nitrogen (N) use is optimized, is the main strategy for $N_2O$ mitigation. In this view, decision support systems (DSS), may help farmers in the management of N fertilization, e.g. suggesting the dose of the N fertilizers and the most suited period for their application. Furthermore, the inclusion of legumes into crop rotations may be a valuable strategy to reduce the use of external N supply, since it allows the exploitation of biological $N_2$-fixation [3][4].

Thus, within the LIFE project AGRESTIC - Reduction of Agricultural GReenhouse gases EmiSsions Through Innovative Cropping systems (LIFE17 CCM/IT/000062), coordinated by Horta srl, $CO_2$ and $N_2O$ emissions will be measured at least for three years (2019-2022) in two pilot farms located in northern and southern Italy (Ravenna and Foggia). The N-efficient cropping systems designed within the project AGRESTIC are mainly characterized by the introduction of legumes in the rotation and the use of a Decision Support System (DSS).

In each farm, a conventional cropping system (CCS) is compared with an ECS, in order to assess the effectiveness of the GHG mitigation practices.


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The estimation of cumulative GHG emissions (e.g. from sowing to harvest, along the whole crop rotation) will allow to evaluate the impact in terms of GHG emissions of the two cropping systems in the two sites. The main technique used to assess the effect of agricultural practices on GHG emissions from soil is based on the chamber method. Currently, the static chamber with manual sampling and subsequent analysis with gas chromatograph (GC) is the most common methodology used, mainly due to its lower cost for implementation and its suitability to evaluate the spatial variability of fluxes. Nevertheless, this approach is labour-intensive, time-consuming and discontinuous, making it not suited to monitor the temporal variation of fluxes with the resolution needed for an accurate estimation of annual soil GHG budgets [5][6]. The use of automatic chambers is a valuable option to obtain continuous estimation of soil GHG flux data at high temporal frequency (several measurements per days) and at various sampling points in the field.

The aim of this paper is to present an automatic chamber-based prototype, designed for monitoring in continuous $CO_2$ and $N_2O$ soil fluxes in two cropping systems (CCS, ECS) and in two different sites (Ravenna and Foggia). In particular, this work focuses on the development of a standard methodology for data quality assessment in order to minimize biases in the estimation of cumulative GHG emissions.

## II. MATERIAL AND METHODS

### A. Cropping systems

The experimental fields were established in two sites in Italy: Ravenna (Cà Bosco farm), Foggia (Caione farm), both characterized by a silty-clay-loam soil with an organic matter content equal to 1.4% and 2%, respectively. Two conventional 4-year crop rotations (Ravenna CCS: maize, durum wheat, processing tomato, durum wheat; Foggia CCS: durum wheat, barley, durum wheat, sunflower) were improved by (i) replacing maize and one durum wheat with pea and lentil, in Ravenna and Foggia, respectively, (ii) intercropping the other cereals with legumes (Ravenna ECS: pea, durum wheat + alfalfa, processing tomato, durum wheat + alfalfa; Foggia ECS: barley + alfalfa, lentil, durum wheat + alfalfa, sunflower) and (iii) supporting farmers with a model-based DSS. The DSS is designed to support farmer in crop management: sowing time, fertilizer distribution, herbicide treatments, pest and diseases control.

### B. GHG monitoring station

The overall layout of the prototype is reported in Fig. 1.

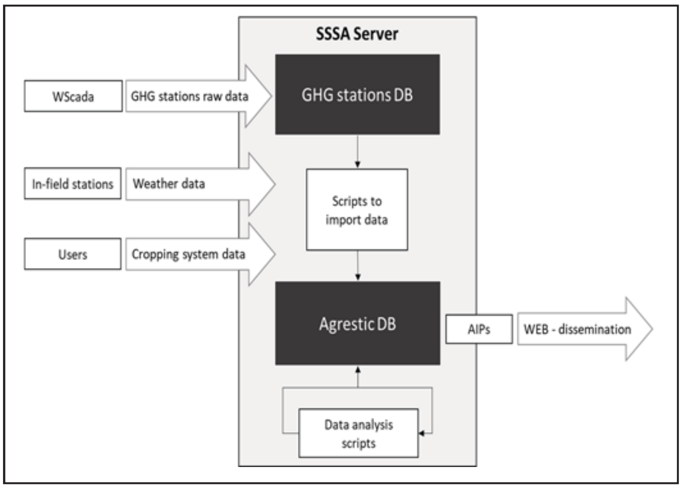


Fig. 1. Overall layout of the AGRESTIC prototype.

The prototype is constituted by two GHG monitoring stations, installed one in each pilot farm, and by an IT infrastructure for data management.

The two GHG monitoring stations are placed within the experimental fields of the two sites (Fig. 2).

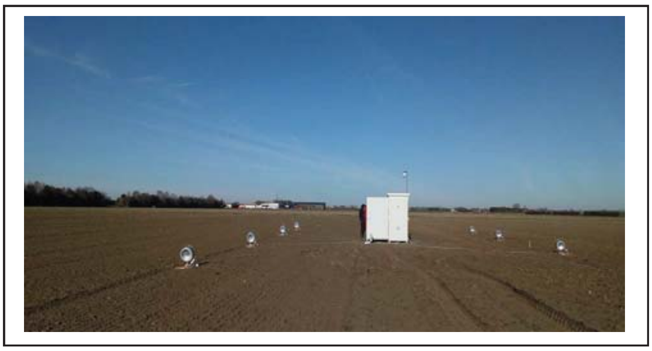

Fig. 2. GHG station in Ravenna.

The GHG station can measure soil fluxes by means of a user defined temporal sequence among the chambers, to save and transmit data.

Each GHG station is composed by a shelter, protecting the analysers, a multiplexer, a local processing unit (LPU), and eight automatic chambers.

In each site, four chambers are placed in CCS and four in ECS, allowing to have for each measurement cycle four replicates per treatment. The Teledyne GFC-7002TU and the LI-COR LI-850 analysers, for the detection $N_2O$ and $CO_2$ concentration respectively, are placed in series within the measurement circuit. An air conditioning system keeps the air temperature within the shelter around 20-22 °C (optimal functioning conditions for the analysers).

The LPU allows to manage measurement cycles, to store raw data on the SD card and to transmit data via GPRS to a server machine.

Each camber is numbered from 1 to 8 and in each measurement cycle the closing of each chamber is programmed at a defined time. Measurement cycles are operated through the multiplexer by selecting the chambers and controlling the flows through a mass flow controller.

The measurement time for each chamber lasts for 10 minutes. Five additional minutes per measurement cycle are for cleaning the circuit while the chamber is open, thus each 15 minutes a new chamber is selected by the multiplexer (Fig. 3).

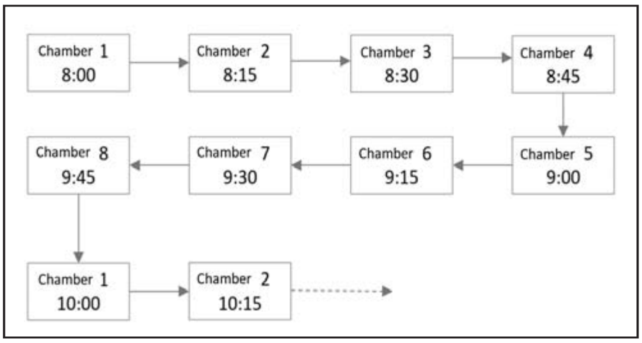


Fig. 3. Measurement cycle of the eight automatic chambers.

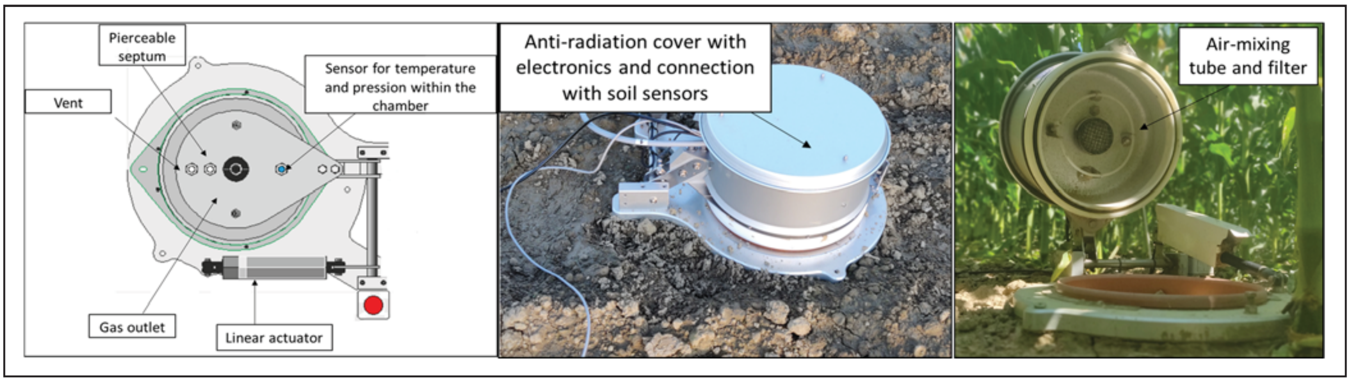


Fig. 4. Details of the components of the automatic chamber.

One complete cycle lasts two hours, and 12 complete cycles occur in a day.

The eight flow-through non-steady-state automatic chambers are connected to the shelter through a double pipe (inlet and outlet) 15 m long. Each automatic chamber (Fig. 4) is in aluminium alloy and it has an internal radius of 15 cm, an area of 697.5 $cm^2$ and volume of 9,218 $cm^3$.

Each chamber is equipped with an air-mixing tube which guarantee the homogeneity of gases concentration within the chamber, a dust filter, a pressure controller (vent), a sensor to measure air temperature and pressure within the chamber and a pierceable septum to be used in case of manual sampling with syringe. The chamber is also equipped with a gasket to avoid air leakage during the closing period. An anti-radiation cover is placed on top of the chamber to avoid the heating of the internal volume of the chamber during closing. The anti-radiation cover contains electronics and the connection with the soil sensors. A PVC collar of 10 cm height is inserted for about 6 cm in the soil and the chamber is closing and opening on top of the collar. The opening and closing of the chamber are guaranteed by a linear actuator.

The automatic chambers are removed only in case of tillage, sowing and harvesting operations, and they are relocated in a short time (e.g. maximum in 1-2 days). In fact, reducing the movement of the chambers allows (i) to reduce both the possibility of damage to the instrumentation and the interruption of the monitoring activity, (ii) to guarantee a good quality of collected data and (iii) to not disturb crop growth excessively.

Soil temperature and water content are measured by two probes inserted in the soil beside each chamber. The soil temperature sensor (PT100) is 20 cm long. The soil water content sensor (Campbell Scientific CS616) is 30 cm long. Both sensors are inserted in the soil in vertical position.

The correct functioning of the two stations is monitored by remote using the Web Scada utility (WScada), able to control the parameters of the stations in real-time and sending alerts in case of malfunctioning.

In particular, the correct opening and closing of the chamber is recorded under the parameter "ac_status": 0 (ok), 1 (not fully closed), 2 (not fully opened), 3 (not fully closed + not fully opened), 4 (the chamber does not respond), 5 (the multiplexer does not respond).

### C. Data management

An IT infrastructure was developed for the collection, management and the elaboration of data from the two GHG stations. Beside the WScada utility package, the IT infrastructure is composed by:

1) a raw-data database based on PostgreSQL dedicated to the storage of raw data downloaded directly from the two GHG stations via GPRS;

2) the Agrestic-DB, also developed in PostgreSQL, which is the container of all the project data: input raw data, routines, elaborations and ancillary information about crop management and weather;

3) a set of scripts that import in the Agrestic-DB data coming from the measurement sensors (chambers and probes of each GHG station and weather stations) of the GHG stations and the weather stations (one for each site);

4) data analysis scripts in R language used to calculate fluxes and assess data quality (*D. Analysis of GHG data*);

5) the Agrestic APIs (Application Programming Interfaces), by which all raw and elaborated data are accessible via Web interface and to ensure the data interoperability with other systems;

6) a Web interface allowing users, according with their role, to access project data and elaborations.

### D. Analysis of GHG data

Before flux calculation, the best interval to calculate fluxes is selected, paying attention to the identification of the lag-phase duration after chamber closing (dead band) and selecting a total period of 240s for $CO_2$ and the overall chamber closing time for $N_2O$. Furthermore, elaboration procedures include: the estimation of fluxes using linear and non-linear models; the selection of the best model to estimate fluxes; the quality check of fluxes, assigning them a flag according to a quality level.

Soil flux estimation is carried out using the R package "gasfluxes" [7] [8]. The function *gasfluxes* of the package allows to calculate fluxes using different models and for each model returns the calculated flux and statistical parameters of the fits. Afterwards, *gasfluxes* is applied with two methods: (i) "linear" fits a linear model to concentration - time data and (ii) "HMR" fits the HMR model using the Golub-Pereyra algorithm for partially linear least-squares models [9]. A series of rules were applied to select the best fitting model for each run. In particular, the HMR model is automatically applied when (i) p-value and Akaike information criterion (AIC) are lower for HMR than for the linear model; (ii) the flux calculated with HMR is not more than 4 times higher/lower than the flux calculated with the linear model [10], since nonlinear models are very sensitive to noise at the beginning of the chamber deployment time resulting either in flux over- or underestimation.

Quality control of flux estimates is done using the parameters of the $CO_2$ flux estimates as indicator, since $CO_2$ flux is usually higher and more robust than the $N_2O$ flux which is characterized by an episodic nature [11].

Moreover, even in case a HMR model is chosen, the $r^2$ of the linear fit is used to check the quality of the measurement (e.g. no leakage and correct closure of the chamber). Thus, both $N_2O$ and $CO_2$ fluxes of each measurement are flagged according to the following rules:

flag=10 when $CO_2$ flux>0 and $r^2 \geq 0.8$

flag=5 when $CO_2$ flux>0 and $r^2 < 0.8$

flag=-5 when $CO_2$ flux<0 and $r^2 \geq 0.8$

flag=-10 when $CO_2$ flux<0 and $r^2 < 0.8$

After the estimation of the fluxes and their quality check, the completeness of the hourly data is checked within each day. Data of the Agrestic-DB are available using a set of APIs integrated within the website and other tools.

## III. RESULTS AND DISCUSSION

Along the period going from January 1st to May 31st, 2020 the two GHG stations proved to be robust to field conditions (e.g. wind, rain, freeze etc.), since we recorded only one interruption in the measurement in Foggia due to the breakdown of the router caused by a storm. Evaluating the completeness of the dataset collected from each chamber in a day, we highlighted that about 95% of the daily data from each chamber were complete (12 measurements), with a low percentage (about 4%) of occurrences with less than 10 measurements per chamber/day.

The closing and opening of the chamber were correct for about 99% of the measurements, with a very low percentage of events indicating a chamber status equal to "not fully closed" of "not fully opened" (Tab. 1). Most of the errors in chamber closing or opening were due to mechanical obstacles, such as leaves of the surrounding plants.

The dead band selected to optimize the interval for flux calculation was between 5 s and 25 s for about 80% of the measurements, with about 40-50% of the measurements in which 5 s was selected. This highlighted that a short time is usually needed to restore the pressure equilibrium between the chamber headspace and the ambient air after the disturbance due to chamber closing [12].

The relationship between $N_2O$ and $CO_2$ accumulation in the chamber and the duration of the measurement was better fitted by the linear model in all the measurements. Thus, even if the GHG flux rate is recognized to decrease in time due to the decreasing diffusion gradient between the air-filled soil pore space and the chamber headspace [13], it was reported that measurements collected with a chamber closing period lower than 5 minutes can be safely evaluated with a linear model [12], since the gases accumulation does not turn down to saturation. However, due to a high frequency of low $N_2O$ emissions, longer chamber deployment time will be tested to calculate soil $N_2O$ flux, since longer measurement periods are often needed to reach reliable measurements at low fluxes.

The quality of the measurements was different in the two sites. In Ravenna 94% of $CO_2$ measurements were flagged with 10 in CCS and 80% in ECS, respectively, while a very low occurrence of negative $CO_2$ slopes (around 4%) was recorded in Ravenna. Differently, in Foggia, in both CCS and ECS, about 60% of the measurements were flagged with 10, and the occurrence of negative $CO_2$ slopes was about 20%. No difference among the two cropping systems were evidenced, and all the chambers behaved similarly. Negative $CO_2$ fluxes were often being associated with chamber leakage, both caused by the failure of the chamber sealing system, or by wind-driven leakage [10] [14]. Wind-driven leakages may be a cause of the higher frequency of negative fluxes recorded at Foggia, since the site is windier than Ravenna. The daily average wind speed in Foggia in the monitoring period was around 2 m/s with peaks of maximum daily wind speed above 10 m/s. Differently, in Ravenna the average wind speed was usually lower than 1 m/s with peaks of maximum daily wind speed around 7 m/s. Moreover, most negative $CO_2$ slopes were recorded during night period, with more than 70% of the negative fluxes recorded between 7 p.m. and 6 a.m. in both sites. High $CO_2$ concentration near soil may occur during night due to little air movement, thus $CO_2$ can accumulate above the surface altering the conditions of equilibrium and diffusion of the biogas between the soil and the surrounding air [15].

Further analyses are required to assess how the filtering of the collected data, based on the quality flag, may affect the quantity of retained measurements and the related calculation of cumulative GHG emissions over a cropping season. Concerning $N_2O$, further analysis will be done in order to: (i) assess the in-field minimum detectable flux mainly used to evaluate if the eventually measured negative fluxes are reliable, (ii) implement in the IT infrastructure a relative set of rules.

TABLE I. EVALUATION PARAMETERS OF PERFORMANCE FOR THE TWO GHG STATIONS

| | **Foggia** | | **Ravenna** | |
|---|---|---|---|---|
| ***flag (%)*** | **CCS** | **ECS** | **CCS** | **ECS** |
| 10 | 56.1 | 64 | 94.2 | 79.8 |
| 5 | 18.2 | 14.8 | 4 | 17.4 |
| -10 | 17.5 | 13.5 | 1.3 | 2.4 |
| -5 | 8.2 | 7.7 | 0.5 | 0.4 |
| ***ac_status (%)*** | | | | |
| 0 | 99.9 | 99.8 | 99.0 | 99.8 |
| 1 | 0.12 | 0.15 | 0.97 | 0.14 |
| 2 | 0.02 | 0.02 | 0.09 | 0.06 |
| ***dead_band (%)*** | | | | |
| 5 | 52.6 | 47.9 | 52.4 | 41.6 |
| 10 | 10.1 | 10.8 | 9.8 | 10.3 |
| 15 | 6.9 | 8.0 | 7.0 | 7.7 |
| 20 | 6.2 | 6.8 | 5.4 | 5.9 |
| 25 | 4.5 | 5.3 | 5.1 | 5.6 |
| 30 | 4.0 | 5.0 | 4.2 | 4.9 |
| 35 | 3.7 | 4.5 | 3.8 | 5.1 |
| 40 | 3.7 | 3.9 | 3.7 | 4.8 |
| 45 | 3.2 | 3.1 | 3.4 | 5.1 |
| 50 | 5.2 | 4.6 | 5.2 | 9.0 |
| ***n_measure chamber/day (%)*** | | | | |
| 12 | 95.4 | 94.9 | 95.0 | 95.3 |
| 11 | 1 | 1.4 | 0.8 | 0.7 |

| | | | | |
|---|---|---|---|---|
| 10 | 0.4 | 0.4 | 0 | 0 |
| <10 | 3.2 | 3.4 | 4.2 | 4 |

## IV. CONCLUSION

Along the tested period, the two GHG stations proved to be robust to field conditions (e.g. wind, rain, freeze etc.). The quality of the measurements was different in the two sites, with more than 90% of good measurements in Ravenna site and more than 60% in Foggia site. These differences are ascribable to different environmental conditions in the two sites. All the $N_2O$ and $CO_2$ fluxes were best-fitted linear.

Further work is needed for testing and selecting a specific procedure to assess the quality of $N_2O$ fluxes. Moreover, flux data of $CO_2$ and $N_2O$ will be used to estimate daily GHG emissions from each cropping system and site. Daly $N_2O$ and $CO_2$ emissions will be subsequently processed through the IT infrastructure for calculating cumulative GHG emissions in user defined periods (e.g. from sowing to harvest) for each cropping system in each site.

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