REPORT 2025

ATN/RF-21534-RG

Reduction of Greenhouse Gas Emissions in Potato–Pasture Systems of Ecuador and Peru

MINISTRY FOR PRIMARY INDUSTRIES (MPI) OF NEW ZEALAND

GLOBAL RESEARCH ALLIANCE ON AGRICULTURAL GREENHOUSE GASES (GRA)

REGIONAL FUND FOR AGRICULTURAL TECHNOLOGY (FONTAGRO)

Te Kāwanatanga o Aotearoa
New Zealand Government

GLOBAL RESEARCH ALLIANCE ON AGRICULTURAL GREENHOUSE GASES

FONTAGRO

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Abbreviations

MPI: Ministry for Primary Industries of Nueva Zelanda
GRA: Global Research Alliance on Agricultural Greenhouse Gases
GHG: Greenhouse gases
CA: Conservation Agriculture
IRD: Regional Development Institute – Sierra
CO2: Carbon dioxide
CH4: Methane
N20: Nitrous oxide
FONTAGRO: Regional Fund for Agricultural Technology

Executive Summary

The project "Reduction of Greenhouse Gas Emissions in Potato–Pasture Systems of Ecuador and Peru (FTG/ATN/RF-21534-RG)" aimed to reduce greenhouse gas (GHG) emissions through the implementation of Conservation Agriculture (CA) practices in high-Andean production systems. Since its inception, the project has progressed steadily from baseline development and methodological design to the implementation of experimental trials and the generation of primary field and laboratory data, thereby consolidating a solid technical foundation for assessing GHG emissions at both plot and production system levels.

Within Component 1 (Characterization and Typification of Potato–Pasture Systems), a key milestone was achieved during the reporting year with the completion of data collection in Ecuador through the application of structured surveys to 100 producers in San Juan parish, Chimborazo Province, as well as the finalization of the survey instrument for its application in Peru. The collected information was consolidated and cleaned into a structured database, distinguishing qualitative, quantitative, and categorical variables related to production, management, and climate change. These advances provided a robust baseline and constituted a fundamental input for multivariate analysis and producer typification, facilitating the identification of representative systems within the study area.

Component 2 (Evaluation of Conservation Agriculture and Conventional Practices) recorded substantial progress during the reporting year by transitioning from the planning phase to experimental implementation. A total of 20 experimental plots were successfully established in the community of Santa Isabel (Ecuador) and at IRD Sierra (Peru), under a 2×2+1 factorial design integrating tillage and residue management factors. The first crop of the rotation (potato) was established, initial soil physical and chemical properties were sampled, and the first GHG measurement campaign (CO_2, CH_4, and N_2O) was conducted using static chambers and gas chromatography. These results represented a key advance of the project, generating the first comparable data on productivity, soil quality, and GHG fluxes under Conservation Agriculture practices and conventional management.

In Component 3 (Comparison and Integration of GHG Information), although final results depend on the availability of data from the complete crop rotation, an analytical framework was defined during the reporting year. This framework would facilitate the integration of direct GHG measurements with estimates based on IPCC methodologies, as well as the articulation of productive, environmental, and socioeconomic information generated by the project. This methodological progress ensured that, once the experimental cycle is completed, a consistent basis would be available for comparative analysis and upscaling modeling.

Component 4 (Knowledge Management, Transfer, and Capacity Building) delivered concrete results during the reporting period. In October 2025, a project presentation workshop was held in Peru, and in November 2025, a practical training workshop on soil sampling and GHG measurement was conducted in Ecuador, targeting producers and local stakeholders. In addition, technical exchanges between the Ecuadorian and Peruvian teams enabled methodological harmonization and strengthened institutional capacities. These actions contributed to consolidating local ownership of the project and ensured the correct implementation of standardized protocols in both countries.

Overall, the project demonstrated progress consistent with the planned activities, from baseline development to experimental implementation and capacity building. By the end of the first reporting year, operational experimental infrastructure, high-quality primary data, and strengthened technical teams were in place, positioning the project in a strategic phase to generate robust evidence on Conservation Agriculture practices and GHG measurements in potato–pasture systems.

FONTAGRO-MPI-GRA: Partnering for Innovation and Sustainability

FONTAGRO gratefully acknowledge the Ministry for Primary Industries (MPI) of New Zealand and the Global Research Alliance on Agricultural Greenhouse Gases (GRA) for their support of the project "Reduction of Greenhouse Gas Emissions in Potato–Pasture Systems of Ecuador and Peru (FTG/ATN/RF-21534-RG)". Their contribution has been instrumental in enabling rigorous field experimentation and harmonised measurement protocols across two high-Andean production contexts, strengthening the scientific basis for mitigation options in potato–pasture rotations and accelerating the generation of comparable evidence on CO_2, CH_4 and N_2O dynamics. Beyond funding, MPI–GRA support anchors this work within an international community of practice focused on practical, science-based solutions for agricultural emissions, reinforcing collaboration, methodological consistency, and the capacity of research teams and local stakeholders to implement and sustain high-quality emissions monitoring under real farming conditions.

This project delivers direct value to New Zealand by expanding the global evidence base and methodological toolkit that underpin New Zealand's own agricultural emissions mitigation and accounting efforts. First, the work strengthens measurement and inventory relevance: the project's direct, plot-scale quantification of N_2O, CH_4, and CO_2 using standardised field chambers and gas chromatography supports the kinds of datasets needed to refine emission factors, validate mitigation performance under diverse soils and climates, and improve confidence in reporting frameworks, all aligned with New Zealand's priorities regarding agricultural GHG inventory and mitigation work.

Second, the project advances nitrogen and soil-management mitigation knowledge that is highly pertinent to New Zealand's pastoral and horticultural systems—especially around reducing nitrous oxide losses through management of tillage intensity, residue cover, and rotations, complementing New Zealand research streams on nitrification inhibitors and other N-loss mitigation technologies. Third, it strengthens New Zealand's international research leadership and partnerships through the GRA and New Zealand's Climate Smart Agriculture (CSA) engagement, building durable capability, shared protocols, and networks with Latin American partners—helping accelerate innovation diffusion and increasing the global impact of New Zealand's investment in mitigation science.

I. Introduction

Agriculture faces the growing challenge of increasing food production and sustaining rural livelihoods while simultaneously reducing its contribution to climate change. In this context, agricultural systems in the high-Andean regions of Latin America—particularly those based on potato–pasture rotations—play a strategic role in food security, rural economies, and the provision of ecosystem services. However, these systems also exhibit high environmental vulnerability and a significant potential for greenhouse gas (GHG) emissions, mainly associated with intensive soil management, the use of nitrogen fertilizers, and soil organic matter dynamics.

In Ecuador and Peru, potato–pasture systems represent one of the main forms of land use in mountainous areas characterized by contrasting edaphoclimatic conditions, steep slopes, and high ecological fragility. Conventional management practices, based on intensive tillage and residue removal, have historically contributed to soil degradation processes, losses of soil organic carbon, and increased GHG emissions. In this context, Conservation Agriculture (Conservation Agriculture) emerges as a technically viable alternative to improve productive sustainability, strengthen system resilience, and contribute to climate change mitigation through reduced soil disturbance, maintenance of vegetative cover, and diversification of crop rotations.

The project "Reduction of Greenhouse Gas Emissions in Potato–Pasture Systems of Ecuador and Peru (ATN/RF-21534-RG)", funded by the Regional Fund for Agricultural Technology (FONTAGRO) with the support of the Ministry for Primary Industries (MPI) of New Zealand and the Global Research Alliance on Agricultural Greenhouse Gases (GRA), aims to generate robust scientific evidence on the effects of Conservation Agriculture practices on productivity, soil properties, economic benefits, and GHG emissions in high-Andean potato–pasture systems.

The project's approach integrates the characterization and typification of production systems, the implementation of experimental trials under real field conditions, the direct measurement of GHG emissions using standardized methodologies, and the comparison of these results with estimates based on IPCC methodologies. In addition, the project incorporates a cross-cutting component of knowledge management and capacity building, targeting researchers, producers, and local stakeholders in order to promote the informed adoption of sustainable practices.

This report describes the progress and results achieved during the reporting period, highlighting the project's progression from its initial design and baseline phase to experimental implementation and the generation of primary field and laboratory data. The information presented constitutes a key input for assessing the mitigation potential of Conservation Agriculture in potato–pasture systems and for guiding future policy, research, and development decisions in the context of climate change and sustainable agriculture in the Andean region.

II. Project Portfolio Execution and Results

Reduction of Greenhouse Gas Emissions in Potato–Pasture Systems of Ecuador and Peru (FTG/ATN/RF-21534-RG)

II.1 Objective

To reduce greenhouse gas (GHG) emissions through the use of Conservation Agriculture (CA) practices in potato–pasture production systems in Ecuador and Peru.

II.2 Summary of Project Activities

Within Component 1, progress was made in the characterization of potato–pasture systems through the systematic review of secondary information, the definition of the sampling framework, and the design, validation, and field implementation of a digital survey. This process resulted in cleaned and structured databases that would enable qualitative and quantitative typification through multivariate analysis.

Under Component 2, a total of 20 experimental plots were established in Santa Isabel (Ecuador) and at IRD Sierra (Peru) following a 2×2+1 factorial design, incorporating a cover crop and establishing the first crop of the rotation (potato). Within these trials, soil sampling was conducted to assess physical and chemical parameters, along with weekly measurements of greenhouse gases (CO_2, CH_4, and N_2O). Gas sampling in each plot was carried out using static chambers, and GHG concentrations were quantified through gas chromatography in the laboratory. These activities generated comprehensive technical data to evaluate productive and environmental performance under Conservation Agriculture and conventional management.

Within Component 4, a project presentation workshop was held in Peru at the IRD Sierra auditoriums on October 24, 2025, with the participation of 22 attendees. In Ecuador, the first training workshop on soil sampling and GHG measurement was conducted on November 26, 2025, in the community of Santa Isabel, with the participation of 50 farmers. The project's technical team trained producers and local stakeholders through theoretical sessions on monitoring procedures and field practices, including the use of sampling tools and the installation of chambers for the capture of CO_2, CH_4, and N_2O. These activities strengthened local capacities and facilitated knowledge transfer in environmental assessment techniques.

Table 1: Project components and activities

Component	Activities	Results	Current Status
Component 1: Baseline study through the characterization and typification of potato–pasture production systems in Ecuador and Peru.	Activity 1.1. Characterization of the prevailing potato–pasture production systems in Chimborazo Province (Ecuador) and Jauja Province (Peru).	Technical note on the characterization of the communities of San Juan in Ecuador and Jauja in Peru.	Execution
	Activity 1.2. Typification of the prevailing potato–pasture production systems in the study areas of Ecuador and Peru.	Technical note on the typification of the communities of San Juan in Ecuador and Jauja in Peru.	Execution
Component 2: Study of the effects of Conservation Agriculture and conventional practices on crop productivity, soil nutrients, economic benefits, and greenhouse gas (GHG) fluxes.	Activity 2.1. Evaluation of Conservation Agriculture and conventional practices on crop productivity, soil nutrients, and economic benefits.	GHG sampling using static chambers at IRD Sierra and Santa Isabel.	Execution
	Activity 2.2. Quantification of greenhouse gas (GHG) emissions through gas chromatography of samples collected from experimental plots established under Conservation Agriculture practices and conventional management.	GHG sampling using static chambers at IRD Sierra and Santa Isabel.	Execution
Component 3: Comparison and integration of greenhouse gas (GHG) emissions data generated by Conservation Agriculture and conventional practices in the potato–pasture production system.	Activity 3.1. Comparison of greenhouse gas (GHG) emissions measured through gas chromatography with estimates derived from IPCC methodologies.	The results of this activity depend on the data collected from gas sampling in each experimental trial.	Execution
	Activity 3.2. Integration of the productive, socio-economic, and environmental information generated by the project in order to extrapolate it to other scales through mathematical models..	The results of this activity depend on the data obtained from gas sampling in each experimental trial.	Execution
Component 4: Knowledge management, transfer, and capacity building.	Activity 4.1. In-person or virtual training workshops for capacity building and dissemination of the results and knowledge generated by the project.	A project presentation workshop in Peru and a training workshop in Ecuador on soil sampling and greenhouse gas (GHG) measurement, targeted at producers in the areas where the experimental trials are being implemented.	Execution
	Activity 4.2. Capacity building for researchers.	Researchers from Ecuador traveled to Universidad Agraria La Molina in Peru to hold meetings aimed at harmonizing methodologies between the two countries. This visit contributed to strengthening the capacities of the researchers involved in the project.	Execution
	Activity 4.3. Technical notes and other dissemination products for the communication of project results.	Technical note containing the technical and scientific documents produced.	Execution
		Technical note presenting the most relevant results of the theses developed.	Execution

III. Project Implementation and Results

III.1 Component 1

Baseline study through the characterization and typification of potato–pasture production systems in Ecuador and Peru.

Activity 1.1. Characterization of the prevailing potato–pasture production systems in Chimborazo Province (Ecuador) and Jauja Province (Peru).

With the aim of characterizing the potato–pasture system and identifying producer typologies in order to develop a comprehensive understanding of producers' needs and capacities, surveys were administered to 100 farmers in San Juan Parish, Chimborazo Province, Ecuador, and will be administered to 73 farmers in the communities of San José de Apata, San Lorenzo, San Juan de Yanamuclo, and El Mantaro in Peru. For field data collection, a digital survey was designed using KoboToolbox, comprising a total of 89 questions, including single-choice multiple-option questions, multiple-choice questions with multiple responses, and open-ended questions. The survey was structured into three sections: producer identification, farm information, and climate change. The information collected was consolidated and cleaned into a database, differentiating qualitative, quantitative, and categorical variables (Table 2).

Table 2. Selected variables for the analysis.

Quantitative	Categorical	Current Status
Varieties used	Total farm area	Production practices
Soil management practices	Area allocated to potato cultivation	Access to training
Technology used	Yield	Membership in associations
Needs		Marketing channels
Climatic variables		

Activity 1.2. Typification of the prevailing potato–pasture production systems in the study areas of Ecuador and Peru.

Producer typification will be conducted through multivariate analysis, with the objective of identifying homogeneous groups of production systems based on productive, socioeconomic, and management information obtained through structured surveys. Prior to the analysis, the database will be cleaned and variables with high discriminatory power will be selected, avoiding redundancy and collinearity.

Quantitative variables will be standardized using Z-scores, while qualitative variables will be transformed into dichotomous variables (0/1) in order to eliminate scale effects and ensure comparability among observations. Subsequently, a Principal Component Analysis (PCA) will be applied to reduce the dimensionality of the dataset and to synthesize the variability of the production system.

Based on the principal components, a hierarchical cluster analysis will be performed using Ward's method and Euclidean distance. The optimal number of clusters will be determined through interpretation of the dendrogram and technical criteria of agronomic and statistical coherence. Finally, the resulting clusters will be characterized using descriptive statistics, enabling the identification of differentiated producer typologies according to levels of intensification, production management, and system vulnerability.

III.2 Component 2

Study of the effects of Conservation Agriculture and conventional practices on crop productivity, soil nutrients, economic benefits, and greenhouse gas (GHG) fluxes.

Activity 2.1. Evaluation of Conservation Agriculture and conventional practices on crop productivity, soil nutrients, and economic benefits.

III.2.1. Characteristics of the study areas

The two experimental trials have been implemented at IRD Sierra in Peru and in the community of Santa Isabel in Ecuador. The characteristics of the study areas are presented in Tables 3 and 4.

Table 3. Political and geographic location and edaphoclimatic characteristics of the community of Santa Isabel in Ecuador.

Location	Description
Province	Chimborazo
Canton	Riobamba
Parish boundary	San Juan
Altitude	3 476 m a. s. l.
Latitude	1° 34' 47.31'' S
Longitude	78° 47' 55.64'' W
Average annual precipitation (mm)	700-800
Average annual temperature (°C)	13.2
Average annual maximum temperature (°C)	14.1
Average annual minimum temperature (°C)	12.2
Soil texture	Loam soil
Slope (%)	25 to 40
Effective soil depth (cm)	>100
Soil pH	6.5 to 7.5

Table 4. Political and geographic location and edaphoclimatic characteristics of IRD Sierra in Peru.

Location	Description
Department	Junín
Province	Jauja
Altitude	3 303 m a. s. l.
Latitude	11°51'25"S
Longitude	75°23'49"W
Average annual precipitation (mm)	375.8 mm
Average annual temperature (°C)	9
Average annual maximum temperature (°C)	24
Average annual minimum temperature (°C)	-6
Soil texture	Clay loam
Slope (%)	0
Effective soil depth (cm)	30
Soil pH	8.4
Soil pH	6.5 to 7.5

III.2.2. Factors under study

Tables 5 and 6 describe the factors under study: tillage (L) and cover (C).

Table 5. Description of the tillage type.

Tillage factor (L)	Description
Conventional tillage (l1)	An agricultural practice consisting of soil preparation through deep tillage and profile inversion, typically using disc plows or harrows, with the objective of loosening the soil, controlling weeds, and preparing the seedbed. In this system, mechanical soil disturbance is intense, with the surface layer being disturbed to a depth of approximately 20–30 cm, which promotes aeration and facilitates crop establishment (Peng et al., 2023).
Reduced tillage (l2)	It is a soil management system in which minimal mechanical disturbance is applied, generally limited to a depth of 10–15 cm, without complete inversion of the soil profile. This system aims to preserve soil structure, maintain crop residues on the soil surface, and reduce erosion, compaction, and organic matter losses typically associated with conventional tillage. In addition, reduced tillage improves infiltration, conserves soil moisture, and promotes biological activity, constituting a key technical pillar of Conservation Agriculture (FAO, 2021).

The conventional tillage with residues treatment retains its methodological character by employing intensive tillage practices to prepare the soil using implements such as moldboard plows or disc plows, which produce deep profile inversion and significant mechanical disturbance characteristic of this system (Srivastava, 2025). In this process, the presence of residues does not alter the fundamental concept of conventional tillage, as this type of operation incorporates or buries most crop residues as part of seedbed preparation, a practice commonly described in traditional management systems (Ecology WA, 2024). Therefore, residues left on the soil surface prior to tillage may be partially incorporated during the operation and, after its completion, repositioned on the surface to comply with the experimental treatment, without transforming the system into reduced or conservation tillage, which requires minimal soil disturbance and the maintenance of residues on the soil surface (FAO, 2021).

On the other hand, reduced tillage is defined exclusively by the degree of mechanical soil disturbance, that is, by minimal alteration without profile inversion and with shallow soil disturbance (generally < 15 cm). This characteristic does not necessarily depend on the presence of surface residues, but rather on the type of implement used and the depth of tillage (FAO, 2021). The absence of residues does not alter the nature of the tillage system because “the criterion that defines the system is the intensity of disturbance, not the presence or absence of cover” (Hobbs, Sayre, and Gupta, 2008).

Table 6. Description of the cover type.

Cover factor (C)	Description
Residue cover (c1)*	A practice consisting of maintaining a continuous layer of plant material (residues from the previous crop) on the soil surface in order to protect it from erosion, conserve soil moisture, improve soil structure, maintain or increase soil organic matter, and promote soil fertility and edaphic biodiversity (FAO, 2021).
No cover (no residues) (c2)	Contrary to the previous description, no residues from the previous crop will be left on the soil surface.

*This cover will exceed 75% in the plots under this factor, in accordance with FAO (2021), which indicates that, to be considered a Conservation Agriculture practice, surface cover must be at least 30%.

III.2.3. Treatments

The trial will consist of five treatments (Table 7).

Table 7. Treatments under study to evaluate the effect of Conservation Agriculture practices through greenhouse gas (GHG) emissions in potato (Solanum tuberosum) cultivation.

Treatment	Combination	Description	
T1	l1c1	Conventional tillage, without residues	Without residues: residues are removed and used to feed livestock or sold.
T2	l1c2	Conventional tillage, with residues	With residues: residues are cut and left on the soil surface.
T3	l2c1	Reduced tillage, without residues	
T4	l2c2	Reduced tillage, with residues	
T5		Control	Farmer management

III.2.4. Experimental unit

The experimental unit at IRD Sierra consists of a 60.0 m² plot, while at Santa Isabel it consists of a 65.0 m² plot. The characteristics of the plots are presented in Tables 8 and 9, and their field layout is shown in Figures 1 and 2.

Table 8. Characteristics of the experimental plot at IRD Sierra.

Description	Unit
Number of treatments:	5
Number of replications:	4
Number of plots:	20
Number of furrows per plot (total):	6
Number of furrows per net plot:	6
Planting sites per furrow:	28
Distance between furrows (m):	0.9
Distance between plants (m):	0.35
Experimental unit area (m²):	60.0 (10.0 m x 6.0 m)
Net plot area (m²):	54 (5.4 m x 10.0 m)
Path width (m):	1.0
Total experimental area (m²):	1924

Table 9. Characteristics of the experimental plot in the community of Santa Isabel.

Description	Unit
Number of treatments:	5
Number of replications:	4
Number of plots:	20
Number of furrows per plot (total):	8
Number of furrows per net plot:	6
Planting sites per furrow:	13
Distance between furrows (m):	1.2
Distance between plants (m):	0.5
Experimental unit area (m²):	65.0 (10.0 m x 6.5 m)
Net plot area (m²):	46.8 (7.2 m x 6.5 m)
Path width (m):	1.0
Total experimental area (m²):	1300

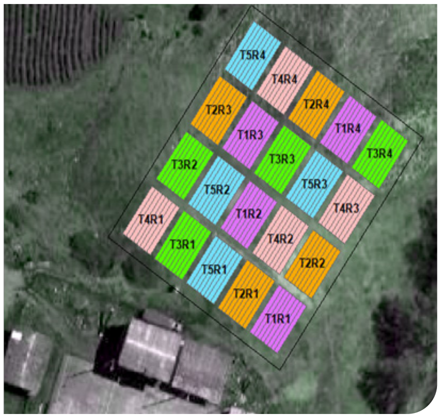


Figure 1. Layout of the experimental plots at IRD Sierra.
Figure 2. Layout of the experimental plots at Santa Isabel.

III.2.5. Experimental design and data analysis

A Randomized Complete Block Design (RCBD) will be used, with five treatments and four replications, resulting in a total of 20 experimental units (Table 10). Prior to statistical analysis, data normality will be assessed using the Shapiro–Wilk test. In addition, homoscedasticity of variances among treatments will be evaluated using Levene's test. When both assumptions (normality and homogeneity of variances) are met, a simple analysis of variance (ANOVA) will be performed. Otherwise, data transformation and/or the application of a non-parametric analysis of variance will be considered, depending on the nature of the variables evaluated (Cuesta, 2020).

When statistically significant differences among treatments were detected, mean separation tests were applied (Tukey's test at 5%). To determine statistical differences among the levels of each evaluated factor, the Least Significant Difference (LSD) test was used, which allows identification of treatments that differ from one another when the ANOVA is significant. Data analysis will be conducted using the INFOSTAT statistical software (Di Rienzo et al., 2008).

Table 10. Scheme of the analysis of variance to evaluate the effect of Conservation Agriculture practices through greenhouse gas (GHG) emissions in potato (*Solanum tuberosum*) cultivation.

Sources of variation	Degrees of freedom
Total	19
Blocks	4
Treatments	5
Tillage (L)	1
Cover (C)	1
LXC	1
Control vs. treatments	1
Experimental error	12

III.2.6. Variables and evaluation methods

To evaluate the agronomic performance of the potato crop, the following variables are analyzed:

1. Plant height

2. Number of tubers per plant

3. Tuber weight per plant

4. Tuber weight per plot

5. Total yield

6. Dry matter of harvested biomass

To determine the effect of the treatments on soil physical properties, the following variables will be analyzed:

1. Gravimetric moisture content

2. Bulk density

3. Volumetric moisture content

To determine the effect of the treatments on soil chemical properties, the following variables will be analyzed:

1. Ammoniacal nitrogen

2. Nitrate nitrogen

3. Total nitrogen

4. Phosphorus, potassium, calcium, and magnesium

5. Copper, iron, manganese, and zinc

6. Organic matter

III.2.7. Measurement of greenhouse gases (GHG) in farmers' fields

For the measurement of greenhouse gas (GHG) emissions in the field in Ecuador, a static chamber was used for each treatment. The chamber consists of three parts (base, extension, and lid) (Figure 3) and is constructed of stainless steel (INOX). The chamber is equipped with two ports located on the upper lid: one for gas sampling and another for temperature measurement.

Figure 3. Static chamber for field GHG measurements in Ecuador.

In Peru, the chambers were constructed using 80-liter polyethylene oil containers as the base. These chambers are equipped with a fan to homogenize the gases inside the chamber, a probe thermometer, and a hose fixed vertically from the base to the top of the chamber. The hose is perforated at five points to allow gas sampling at different heights within the chamber.

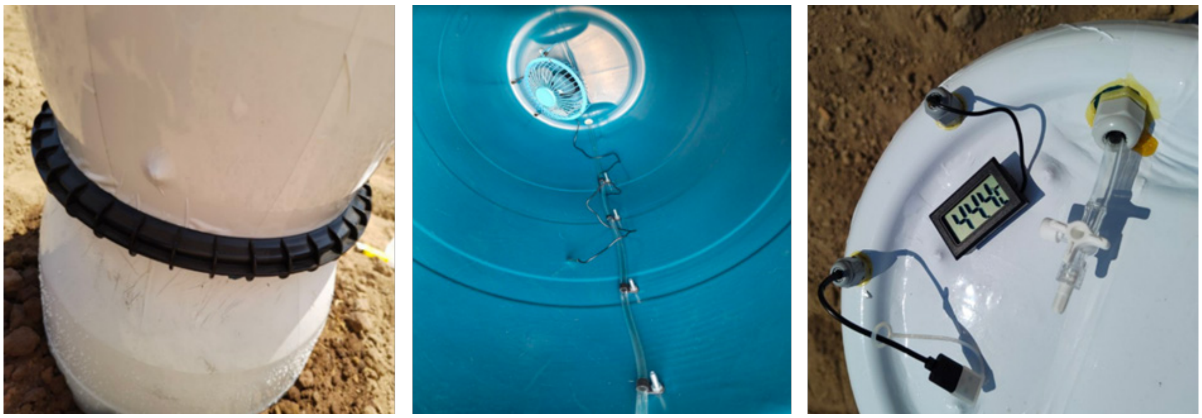


Figure 4. Static chamber for field GHG measurements in Peru.

Prior to each field campaign, sampling materials and instruments were prepared, including pre-labeled evacuated vials, sterile 20 mL syringes, hypodermic needles, three-way valves, digital thermometers, a barometer, racks, forceps, zip-lock bags, and coolers with ice packs to preserve the samples until analysis.

Static chambers were installed in each experimental unit and consisted of a base permanently anchored to the soil throughout the potato crop cycle, an extension in the case of Ecuador (when required due to crop canopy development), and a lid hermetically sealed with a rubber gasket. This configuration ensured a temporarily closed system, preventing air leakage or infiltration and maintaining internal pressure close to atmospheric conditions (Collier et al., 2014).

Gas sampling was carried out by closing the chamber and extracting gas samples using a syringe at intervals of 0, 15, 30, 45, 60, and 75 minutes. Samples were stored in previously conditioned vials, ensuring a linear relationship between concentration and time (Collier et al., 2014; Arenas Calle, 2016). Sampling was conducted in the morning every eight days throughout the entire potato crop cycle, under stable environmental conditions, in order to reduce variability associated with temperature and solar radiation. For this purpose, a meteorological station will be installed at the experimental site.

Subsequently, the samples were transported to the laboratory under refrigerated conditions (< 4 °C) for analysis by gas chromatography.

III.2.8. Laboratory analysis by gas chromatography

This analysis enabled the calculation of fluxes for each gas (CO_2, N_2O, and CH_4) based on the changes in concentration observed during the chamber closure period in the field. For this purpose, the vials were placed in the autosampler and approximately 100 µL of gaseous sample will be injected into a Shimadzu GC-2030 gas chromatograph. Quantification was performed by comparing the peak areas obtained for each gas with their respective standards, and the concentrations of each GHG were reported in milligrams per liter of gas (mg L^{-1}).

Using the concentrations measured for each GHG in each installed chamber, a linear mathematical model was established by correlating gas concentration with time, and the slope of the model was determined in parts per million (ppm) of each GHG per minute. Subsequently, the flux of each GHG emitted to the atmosphere was calculated by relating the slope of each model to the volume of the static chamber used, the atmospheric pressure at the sampling site, the ambient temperature, and the chamber area. Results are expressed as kilograms of each GHG per hectare per hour (kg ha^{-1} h^{-1}).

III.3 Component 3

Comparison and integration of greenhouse gas (GHG) emissions information generated by Conservation Agriculture and conventional practices in the potato–pasture production system.

Component 3 will be analysed once information on trial management and gas sampling is available; therefore, the results of this component will be developed when complete data from the four crops in the rotation (potato, oats, faba bean, and pasture) are available.

III.4 Component 4

Knowledge management, transfer, and capacity building.

Activity 4.1. In-person or virtual training workshops for capacity building and dissemination of the results and knowledge generated by the project.

On October 24, the Ecuadorian team (Dr. Iván Samaniego and Eng. Verónica Suango) visited the facilities of Universidad Agraria La Molina (UNALM) with the objective of conducting the first project workshop of the FONTAGRO ATN/RF-21534-RG project, “Reduction of Greenhouse Gas Emissions in the Potato–Pasture System of Ecuador and Peru.” The visit enabled the sharing and discussion of methodologies for the implementation of Conservation Agriculture plots and for field sampling of greenhouse gases (GHG) using static chambers, as outlined in the project work plan. In addition, the Ecuadorian and Peruvian teams visited IRD Sierra in Huancayo to assess potential sites for the implementation of the experimental trials. These activities aimed to strengthen the technical capacities of the researchers, harmonize methodological criteria, establish implementation commitments, and ensure a shared understanding for the proper execution of the activities planned within the project (Figure 5).

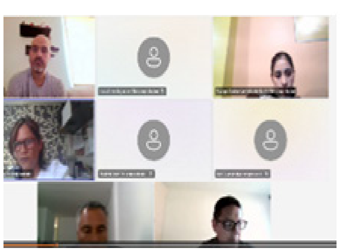
Figure 5. Visit of the Ecuadorian project team to UNALM–Peru and IRD Sierra.

On November 26, a practical workshop was conducted in the community of Santa Isabel, Ecuador (Figure 6), targeting members of the Santa Isabel community and focusing on soil sampling techniques and greenhouse gas (GHG) measurement. During the workshop, procedures, protocols, and key considerations necessary to ensure the quality of the data generated were addressed.

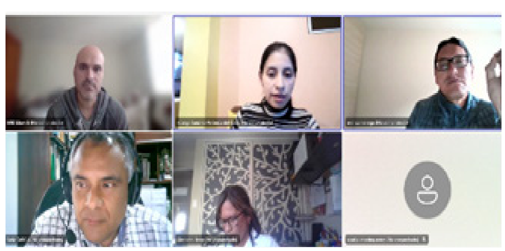
Figure 6. Soil sampling and greenhouse gas (GHG) measurement workshop.

Activity 4.2. Capacity building for researchers.

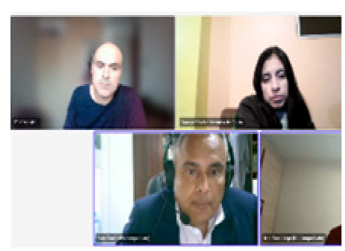
Periodic virtual meetings have been held with the Ecuadorian and Peruvian project teams to coordinate and plan both technical activities and budget execution (Figure 7).



Meeting – October 2



Meeting – October 9



Meeting – November 6

Figure 7. Working meetings between Ecuador and Peru.

IV. Conclusions

• The project demonstrates consistent and verifiable technical progress in accordance with the established timeline and objectives, as evidenced by the consolidation of the baseline, methodological standardization, and the operational implementation of experimental trials in Ecuador and Peru. This progression confirms the effective alignment between scientific design and execution under real conditions of high-Andean potato–pasture systems.

• The characterization and typification of potato–pasture production systems constitute a fundamental methodological foundation for the project's systemic approach, as they integrate productive, edaphoclimatic, socioeconomic, and management variables. The database generated, structured, and cleaned under statistical criteria provides a robust platform for identifying representative typologies within the study area.

• The experimental design implemented in both countries ensures a rigorous evaluation of the individual and combined effects of tillage and soil cover under a randomized complete block design with adequate replication. This methodological approach allows isolation of the effects of Conservation Agriculture practices on crop productivity, soil physical and chemical properties, and greenhouse gas fluxes.

• The direct measurement of greenhouse gas emissions using static chambers and gas chromatography analysis strengthens the scientific quality and international comparability of the results through the use of standardised protocols. The generation of primary CO_2, CH_4, and N_2O data at the plot scale constitutes a key input for evaluating the environmental performance of Conservation Agriculture practices relative to conventional management in high-Andean systems.

• Knowledge management and capacity-building actions have enabled the technical appropriation of methodologies by researchers, ensuring the correct implementation of field and laboratory protocols. Methodological harmonization between Ecuador and Peru enhances regional comparability of results and lays the groundwork for replicability of the approach in other high-Andean contexts.

• The project is currently in an advanced phase of scientific evidence generation, with operational experimental infrastructure and standardized procedures in place. This positions the study favorably to produce robust results on the potential of Conservation Agriculture as a greenhouse gas mitigation strategy. These results will be relevant for public policy formulation, the design of climate-smart agriculture strategies, and contributions to national and international climate change mitigation commitments in the Andean region.

V. Digital Links

Project's web site: https://fontagro.org/en/proyectos/sistemaspapa-pasto

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