Measuring What Matters: Advancing Agricultural Greenhouse Gases Accounting in Egypt

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Policy Report

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Authors:

Samar Attaher[1] and Ajit Govind[2].

[1]Research Associate and agronomist in soil, water, and agronomy team at ICARDA, Egypt.

[2]Senior climate scientist and systems modeler, and research team leader of GeoAgro Team at ICARDA, Egypt.

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Preface:

This report examines the importance of field-based measurement of greenhouse gas emissions from agriculture in Egypt. It highlights uncertainties in national emission estimates, emphasizes the need for country-specific emission factors, and proposes a measurement-driven framework to support climate-smart agricultural planning, mitigation, adaptation, and robust MRV systems. The report forms part of the undergoing ICARDA's activities to *explore simple measurement protocols for developing country-specific emission factors for agriculture in Egypt*, supported in 2025 by the CGIAR Science Program "Climate Action; CASP", (AoW4).

Executive summary

Agriculture is one of the most climate-sensitive sectors in Egypt and is central to national food security, employment, and economic stability. Climate change is already affecting agricultural systems through shifts in cropping seasons, increased frequency and intensity of extreme events such as heat stress, sand and dust storms, flooding, and through sea-level rise and saltwater intrusion in coastal zones. These impacts are exacerbated by water scarcity, groundwater over-abstraction, and ecosystem degradation. Accordingly, Egypt's *National Climate Change Strategy 2050* and its Updated *Nationally Determined Contribution (NDC)* identify agriculture, irrigation, and water resources as priority sectors for adaptation and resilience building.

Agriculture is also a significant source of national greenhouse gas (GHG) emissions. National inventories submitted to the UNFCCC estimate that agriculture and AFOLU accounted for approximately 15–16% of Egypt's total GHG emissions in 2005 and 2015, driven primarily by nitrous oxide (N_2O) and methane (CH_4) from soils and irrigated systems. However, most estimates rely on IPCC default emission factors due to the absence of country-specific data, introducing substantial uncertainty under Egypt's arid, irrigated conditions.

Country-specific emission factors are essential to improve inventory accuracy, support credible monitoring, reporting and verification (MRV), and guide effective mitigation planning. Field-based GHG measurements provide the empirical foundation for deriving these factors, understanding key emission drivers, validating models for national scaling, and assessing the effectiveness of climate-smart agricultural practices. A phased national measurement strategy; combining standardized protocols, representative field campaigns, and institutional integration into MRV systems; will enable Egypt to reduce uncertainty, strengthen policy decisions, and advance integrated adaptation and mitigation in the agricultural sector.

Climate vulnerability and emission uncertainty in Egypt's agricultural sector

Agriculture is inherently climate-sensitive and is therefore among the sectors most vulnerable to the adverse impacts of climate change (UNFCCC, 2022; Government of Egypt, 2023). In Egypt, climate change impacts are manifested through shifts in agricultural seasons, increased frequency and intensity of extreme weather events; including heat waves and heat stress, sand and dust storms, flooding, and other climate-related shocks; as well as sea-level rise and saltwater intrusion in low-lying coastal areas. These pressures are further exacerbated by the degradation of water resources and ecosystems resulting from groundwater over-abstraction and depletion, posing significant risks to agricultural productivity, food security, and rural livelihoods (Government of Egypt, 2023; FAO, 2022).

In recognition of these challenges, Egypt's "*National Climate Change Strategy 2050"* and its Updated "Nationally Determined Contribution (NDC)" identify agriculture, irrigation, and water resources as priority sectors for climate change adaptation. The national strategy emphasizes enhancing adaptive capacity and resilience to climate change, reducing vulnerability to climate-related risks, and minimizing negative socio-economic impacts, while simultaneously promoting investment in scientific research, technology transfer, knowledge management, and awareness-raising as key enablers for effective climate action (Government of Egypt, 2023; UNFCCC, 2022).

Agriculture constitutes a cornerstone of Egypt's economy and socio-economic structure, employing approximately one-third of the national labor force and supporting the livelihoods of more than 65 percent of the population (CAPMAS, 2024). Even though only about 2.8 percent of the country's total land area is arable, the sector contributes around 14 percent of national gross domestic product and approximately 20 percent of total exports (World Bank, 2020). While the sector is highly vulnerable to climate change impacts, it also contributes to anthropogenic climate change through greenhouse gas (GHG) emissions associated with crop production, soil management, fertilizer use, irrigation practices, and other agronomic activities. This dual role highlights the need for integrated adaptation and mitigation approaches within the agricultural sector, consistent with Egypt's commitments under the UNFCCC and its national climate policy framework (IPCC, 2019; Government of Egypt, 2023).

National inventory data submitted to the UNFCCC indicate that Egypt's total greenhouse gas emissions were estimated at 247.98 Mt CO_2e for the year 2005, comprising 167.6 Mt CO_2 (67.6%), 35.0 Mt CH_4 (14.1%), and 28.74 Mt N_2O (11.6%). In the same inventory year, the agriculture sector accounted for approximately 39.45 Mt CO_2e, representing about 16% of total national emissions (Government of Egypt, 2016). More recent Biennial Update Reports show that in 2015 the Agriculture, Forestry and Other Land Use (AFOLU) sector emitted approximately 48,390 Gg CO_2e (48.39 Mt CO_2e), corresponding to about 14.9% of national emissions (Government of Egypt, 2018).

These national reports also indicate that the majority of agricultural emission estimates were derived using IPCC default emission factors and Tier 1 methodologies due to the limited availability of country-specific measurement data. While such approaches are consistent with UNFCCC reporting guidance, they introduce significant uncertainty in emission estimates, particularly for soil N_2O and CH_4 emissions that are highly sensitive to local climate, soil properties, irrigation regimes, and agronomic practices. Consequently, the absence of validated national emission factors constrains the accuracy of agricultural GHGs inventories and limits the effectiveness of mitigation planning and policy prioritization.

The case for nationally representative emission factors in agriculture

GHGs factors for agricultural systems are not universal constants; rather, they are highly context-dependent and controlled by complex interactions among climatic, soil, hydrological, and management variables. Emission rates from agricultural soils; particularly nitrous oxide (N_2O), methane (CH_4), and carbon dioxide (CO_2), are strongly influenced by temperature, soil moisture dynamics, texture, organic carbon content, and redox conditions, all of which regulate microbial processes such as nitrification, denitrification, methanogenesis, and soil respiration (IPCC, 2019; Butterbach-Bahl et al., 2013). Egypt's predominantly arid to semi-arid climate, characterized by high temperatures, low and variable precipitation, and intensive irrigation, fundamentally differs from the temperate environments in which many internationally applied default emission factors were developed. In particular, surface irrigation and expanding groundwater-fed systems create unique soil moisture regimes that can substantially alter GHGs fluxes, rendering the direct transfer of IPCC standard emission coefficients scientifically inappropriate (FAO, 2022; IPCC, 2019).

In addition to biophysical conditions, emission factors are highly sensitive to agronomic management practices. Fertilizer formulation (synthetic versus organic), nitrogen application rates, timing and placement methods, fertilizer incorporation, tillage intensity, residue retention or removal, and crop rotation patterns all exert strong controls on soil GHGs emissions (IPCC, 2019; Smith et al., 2014). In Egypt, crop production systems are shaped by year-round cultivation, high cropping intensity, specific rotations (e.g. wheat-maize and rice-based systems in the Delta), and distinct fertilizer and irrigation practices that differ markedly from those in Europe or North America. Consequently, emission factors derived under temperate management regimes may misrepresent actual emissions under Egyptian conditions, leading to biased national estimates and ineffective mitigation prioritization.

The implications of such inaccuracies extend beyond inventory reporting and have direct policy and financial consequences. Reliable, country-specific emission factors form the evidentiary basis for the design and appraisal of agricultural mitigation interventions, including improved fertilizer management, conservation agriculture, soil carbon enhancement, and water-saving practices such as alternate wetting and drying in irrigated rice systems. They are also critical for robust carbon accounting, cost-benefit analyses, and the development of bankable mitigation projects capable of accessing international climate finance mechanisms and results-based payment schemes (FAO, 2023; UNFCCC, 2022).

Finally, country-specific emission factors are essential for effective targeting, monitoring, and evaluation of mitigation actions. Accurate baseline emission estimates enable the identification of high-emission practices and regions, support the prioritization of interventions with the greatest mitigation potential, and underpin credible monitoring, reporting and verification (MRV) systems. Without empirically derived national factors, MRV frameworks risk overstating or understating mitigation outcomes, thereby weakening policy credibility and limiting Egypt's ability to demonstrate measurable progress toward its climate commitments under the UNFCCC and its Updated NDC (IPCC, 2019; Government of Egypt, 2023).

Field-based evidence as the foundation of agricultural GHGs accounting

Field measurements represent the cornerstone of scientifically robust greenhouse gas (GHGs) accounting in agriculture and are indispensable for the development of reliable, country-specific emission factors and the reduction of uncertainty in national greenhouse gas inventories. Agricultural GHGs emissions arise from complex and highly variable biogeochemical processes that respond dynamically to climate, soil properties, hydrological conditions, and management practices. As emphasized by the IPCC, default emission factors provide only generalized estimates and must be progressively replaced or complemented by measurement-based national data to improve inventory accuracy and policy relevance (IPCC, 2019).

One of the primary functions of field measurements is the empirical derivation of emission factors that are representative of dominant crop–soil–management combinations. Direct measurement techniques, including static and automated chamber systems and micrometeorological approaches such as eddy covariance flux towers, enable the quantification of CO_2, CH_4 and N_2O fluxes under real farming conditions (Butterbach-Bahl et al., 2013; Oertel et al., 2016). When implemented across different agroecological zones and over multiple growing seasons, such measurements capture both spatial and temporal variability in emissions, thereby allowing the derivation of emission factors that reflect national production systems rather than experimental or foreign analogues.

Beyond factor development, field measurements are essential for identifying and quantifying the key drivers and modifiers of agricultural GHG emissions. Carefully designed field campaigns provide empirical evidence on how soil moisture dynamics, irrigation methods (e.g. flood, sprinkler, or drip irrigation), fertilizer chemical form, application rate, placement, and timing influence emission pathways. This is particularly relevant in irrigated and arid environments, such as those prevalent in Egypt, where water management strongly regulates soil aeration, redox conditions, and nitrogen transformation processes, with direct implications for both N_2O and CH_4 emissions (Smith et al., 2014; FAO, 2022).

Field-based observations also play a critical role in the calibration, validation, and improvement of models used to upscale emissions from the plot level to regional and national scales. Process-based and empirical models are widely applied within national inventory systems to extrapolate limited observations across heterogeneous landscapes; however, their performance is highly dependent on the availability of local measurement data for parameterization and validation. Without systematic field measurements, model-derived estimates remain highly uncertain and difficult to justify within UNFCCC reporting frameworks or national decision-making processes (Ogle et al., 2014; IPCC, 2019).

Finally, field measurements provide the only robust basis for assessing the effectiveness of mitigation practices in real-world agricultural systems. Comparative field trials that evaluate alternative management options—such as optimized fertilizer application, the use of nitrification inhibitors, cover cropping, reduced or conservation tillage, and improved irrigation scheduling—allow direct quantification of emission reductions alongside impacts on crop productivity, water and nutrient use efficiency, and potential trade-offs.

From evidence to action: A national framework for measuring agricultural GHGs Emissions

A pragmatic national strategy for measuring greenhouse gas (GHG) emissions from agriculture in Egypt should be implemented through a tiered and phased approach, consistent with IPCC good practice guidance and UNFCCC inventory development pathways (IPCC, 2019; UNFCCC, 2022). Such an approach allows Egypt to progressively improve data quality and methodological rigor while aligning investments with existing institutional capacities.

The first phase should focus on establishing a robust baseline through a comprehensive survey of existing measurement efforts, research stations, and relevant national and international partners. This phase should also prioritize the development and harmonization of standardized measurement protocols for soil and gas flux monitoring, including chamber-based methods, soil sampling procedures, and the systematic collection of supporting metadata such as soil characteristics, moisture status, crop phenology, irrigation method, and management practices. Protocol standardization is essential to ensure data comparability across sites and over time and to facilitate integration into national inventory systems (IPCC, 2019; Ogle et al., 2014).

Building on this foundation, the second phase should consist of representative field measurement campaigns across Egypt's major agroecological zones, including the Nile Delta, Nile Valley, Upper Egypt, and reclaimed desert lands. These campaigns should target dominant cropping systems such as wheat, maize, rice, cotton, and horticultural crops, which together account for a large share of cultivated area and agricultural emissions. Repeated flux measurements should be conducted across seasons and management regimes to capture temporal variability and management effects. Where feasible, paired field trials should be incorporated to compare conventional and improved practices, thereby generating empirical evidence on mitigation options under local conditions (FAO, 2022; Smith et al., 2014).

The third phase should focus on scaling and modeling, using field measurements to calibrate and validate process-based and empirical models capable of extrapolating emissions from plot-level observations to regional and national scales. This step should integrate spatially explicit data sources, including remote sensing products and national agricultural statistics on cropped area, fertilizer use, and irrigation practices. Quantification of uncertainty should be an explicit component of this phase, enabling the production of updated country-specific emission factors suitable for higher-tier inventory reporting and policy analysis (IPCC, 2019; Oertel et al., 2016).

The final phase should aim to institutionalize agricultural GHGs measurement within Egypt's national MRV framework. This requires embedding standardized measurement protocols and data flows within the mandates of relevant ministries and national research institutions, alongside targeted investments in capacity building. Training programs for field technicians, the establishment of regional measurement hubs, and the development of centralized data management systems with appropriate quality assurance and quality control (QA/QC) procedures are critical to ensure the long-term sustainability and credibility of the measurement program (UNFCCC, 2022; FAO, 2023).

Evidence-based planning for climate-smart agriculture

Measurement-driven emission factors and improved national inventories provide a critical evidence base for the design, targeting, and scaling of smart agricultural practices in Egypt. Empirical field data make it possible to prioritize mitigation options based on their actual emission reduction potential per unit cost, thereby supporting more efficient allocation of public resources and climate finance. For example, locally derived measurements can identify the relative effectiveness of fertilizer optimization, improved irrigation management, or residue handling practices under specific agroecological conditions (Smith et al., 2014; FAO, 2023).

Furthermore, the successful deployment of smart agriculture technologies; such as precision fertilizer application, variable-rate irrigation, sensor-based soil moisture management, and digital decision-support tools; depends on a clear understanding of local emission responses. Without country-specific emission factors, such interventions may deliver unintended trade-offs or fail to achieve anticipated mitigation benefits. Measurement-based evidence therefore underpins the development of context-specific recommendations that maximize both productivity and environmental performance (FAO, 2022; IPCC, 2019).

Robust measurement systems are also essential for the design of incentive mechanisms and market-based instruments, including carbon crediting schemes, payments for ecosystem services, and targeted public subsidy programs. These mechanisms require credible baselines, transparent accounting rules, and defensible MRV systems to ensure environmental integrity and stakeholder confidence. Country-specific emission factors derived from field measurements strengthen the legitimacy of such instruments and enhance Egypt's ability to access international climate finance (UNFCCC, 2022; FAO, 2023).

Finally, field-validated evidence supports the identification and promotion of practices that deliver adaptation–mitigation co-benefits, such as water-saving irrigation, soil carbon enhancement, and improved nutrient use efficiency. Demonstrating these co-benefits under local conditions is critical for encouraging farmer uptake and ensuring alignment between climate objectives, food security, and rural development priorities (Government of Egypt, 2023; FAO, 2022).

Institutional and policy foundations for agricultural climate action

To operationalize the measurement-led approach outlined above, multi-year field campaigns covering representative agroecological zones and cropping systems are required to generate the empirical evidence necessary for robust emission factor development.

Based on these measurements, Egypt can develop and formally adopt a national set of country-specific emission factors for agricultural soils and key crop systems. These factors should be transparently documented and regularly updated and systematically incorporated into national greenhouse gas inventories and future NDC submissions, in line with IPCC good practice guidance (IPCC, 2019).

Institutional integration is equally critical. Measurement data flows should be formalized between research institutions, the Ministry of Agriculture, and national inventory compilers within the Ministry of Environment to ensure timely and consistent use of improved emission factors. Complementary investments in capacity building and infrastructure; including technician training, regional measurement hubs, and centralized data management platforms with QA/QC protocols; are essential to sustain measurement efforts over time (UNFCCC, 2022; FAO, 2023).

In parallel, measurement programs should be closely linked to farmer-level demonstration projects that showcase climate-smart practices and their impacts on both emissions and productivity. Such demonstrations enhance local credibility and facilitate knowledge transfer. Finally, Egypt should actively mobilize international climate finance, development partners, and private sector engagement to co-finance measurement activities and support the scaling of proven mitigation practices across the agricultural sector.

Key Message

For Egypt to make defensible policy choices, meet international reporting obligations with confidence, and design effective, locally appropriate smart-agriculture interventions, field-based measurement of agricultural GHGs is indispensable. Country-specific emission factors will reduce uncertainty, enable targeted mitigation, and unlock finance and policy options that genuinely benefit productivity and climate resilience.

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