Synthesis and Review: Advancing agricultural greenhouse gas quantification

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# Synthesis and Review: Advancing agricultural greenhouse gas quantification

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## Abstract

Reducing emissions of agricultural greenhouse gases (GHGs), such as methane and nitrous oxide, and sequestering carbon in the soil or in living biomass can help reduce the impact of agriculture on climate change while improving productivity and reducing resource use. There is an increasing demand for improved, low cost quantification of GHGs in agriculture, whether for national reporting to the United Nations Framework Convention on Climate Change (UNFCCC), underpinning and stimulating improved practices, establishing crediting mechanisms, or supporting green products. This ERL focus issue highlights GHG quantification to call attention to our existing knowledge and opportunities for further progress. In this article we synthesize the findings of 21 papers on the current state of global capability for agricultural GHG quantification and visions for its improvement. We conclude that strategic investment in quantification can lead to significant global improvement in agricultural GHG estimation in the near term.

Keywords: greenhouse gas reductions, climate smart agriculture, GHG quantification tools and models, national GHG accounting

## Introduction

Reducing emissions of agricultural greenhouse gases (GHGs), such as methane and nitrous oxide, and sequestering carbon in the soil or in living biomass can help reduce the impact of agriculture on climate change while improving productivity and reducing resource use. In Zheijiang Province, China, for example, farmers who drain their irrigated rice fields mid-season reduce methane emissions by up to 50% and water needs by up to 30% without compromising yields (Gaihre et al 2011). Midseason drainage not only supports more efficient—and presumably more resilient—resource use while

reducing GHG emissions, but can also earn farmer income from carbon credits (FAO 2011). Agricultural practices such as these, which maintain or increase productivity while enhancing livelihood resilience and reducing emissions, can help meet the demand for 70% more food by 2050 while also minimizing impacts on the climate (Godfray et al 2010).

Yet identifying and monitoring these beneficial practices requires adequate quantification of GHG emissions, which in agriculture has been costly and often imprecise. There is an increasing demand for improved, low cost quantification of GHGs in agriculture, whether for national reporting to the United Nations Framework Convention on Climate Change (UNFCCC), underpinning and stimulating improved practices, establishing crediting mechanisms, or supporting green products (Murphy et al 2010, CCAFS (Climate Change, Agriculture and Food Security) 2011,

FAO 2011, EP 13514, Consumer Goods Forum, IFC, International Finance Corporation 2011). Because food is essential to human life, the need for linking GHG estimates to measures of agricultural productivity and resilience has also emerged as a distinctive feature of this sector (Olander *et al* 2013).

This ERL issue highlights GHG quantification to call attention to our existing knowledge and opportunities for further progress. In this article we synthesize the findings of 21 papers on the current state of global capability for agricultural GHG quantification and visions for its improvement. We address the three themes around which the articles were organized: (1) improving measurement while reducing costs, especially for low-income countries; (2) accounting approaches from the national to the farm scale; and (3) potential synergies and tradeoffs among food productivity, resilience and GHG mitigation[5]. We conclude that strategic investment in quantification can lead to significant global improvement in agricultural GHG estimation in the near term (Olander *et al* 2013, Berry and Ryan 2013, Wollenberg *et al* 2014 (in press).

## Quantifying emissions and mitigation opportunities —what do we know?

The International Panel on Climate Change (IPCC) guidelines and guidance (IPCC 1996, 2000, 2003, 2006a, b) provides the foundation for estimating GHG emissions from agricultural practices, as well as from associated land use changes, like deforestation. While these methods were developed for national level inventories, they provide a starting point for quantification at other scales and purposes (e.g., carbon projects, nationally appropriate mitigation actions–NAMAs). Inherent variability in emissions and removals, a lack of quality data, inconsistent field techniques and limited capacity for measurement has continued however to yield results with high uncertainty. For Annex I countries signatory to the Kyoto protocol, national agriculture emissions inventories have uncertainties that may range from −30 to +70% (FAO 2014). Detailed quantification of underlying activity data and high measurement costs continue to constrain GHG quantification, so attention has been given, on the one hand, to creation of capacity development programs to improve rural statistics, and on the other, to improved modeling and use of other sources of data, such as remote sensing or global databases to reduce field data needs.

The Food and Agricultural Organization (FAO) pulled together nationally reported statistics on agricultural activity data and used IPCC default values to better estimate and compare agricultural GHG emissions by country (http://faostat3.fao.org/faostat-gateway/go/to/browse/G1/*/E). Using

FAO data, global emissions in 2010 are estimated to be 5.3 Gt $CO_2$ $yr^{-1}$. Emissions from agriculture grew annually by 1.1% between 2000 and 2010, and were consistently larger than those from net deforestation—by about 1.2 Gt $CO_2$ $yr^{-1}$ in 2010 (Tubiello *et al* 2013, FAO 2014). These data can provide a reference for a first-order assessment of current emission hotspots within countries and regions, and help better plan future mitigation action.

Estimates of mitigation potential remain sparse, although much work is in progress, especially in countries seeking to reduce their emissions from high impact commodities such as livestock and sugarcane (Signor *et al* 2013, Silva-Olaya *et al* 2013 and Burzaco *et al* 2013). Gaps remain, especially in understanding mitigation outcomes of diverse combinations of management practices at the farm and landscape scales, which in some regions can include annual crops, tree crops, and animals (Smith *et al* 2013, Wollenberg *et al* 2012, Eagle and Olander *et al* 2013).

The integration of information to support management for multiple objectives is also needed. While yield and productivity outcomes from mitigation actions are often tracked, emissions data do not necessarily include this information. In addition, resilience is not yet codified with any standard measurement guidance that would enable relative resilience to be determined (Meridian Institute 2011). Integrated measures that track changes in emissions or removals relative to yields, often called 'intensity' or efficiency measures', can help integrate information relevant to managing for multiple objectives—productivity, resilience and mitigation.

## Discussion of articles

*Quantifying GHGs in agricultural systems: scale and cost*

Researchers have developed a range of methods for quantifying—measuring and modeling—GHGs from agricultural systems, however, field sampling can be costly especially for larger scales and models may not have sufficient calibration and validation data to be applied in new areas. The articles in this issue identify innovations that can advance the field.

Vägen and Winowiecki (2013) demonstrate methods for using cumulative soil mass (calculated as the product of bulk density and soil depth per unit ground area) to estimate soil organic carbon stocks, which is simpler and more robust statistically than typical measures of bulk density to a fixed depth. Field sampling determines the relationship between carbon and soil type and can be linked to satellite data for landscape-scale assessment of soil carbon and drivers of soil loss to target management options. Mapping soil carbon patterns using satellite data and calibrating this with landscape level field sampling of soils is a leap forward.

Quantifying nitrous oxide fluxes[6] is challenging because of high costs of equipment that can be easily damaged in the

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[5] These themes and much of the synthesis originated in a 2012 workshop sponsored by the United Nations Food and Agricultural Organization (FAO), CCAFS and Duke University, in which many authors in this issue participated.

[6] Nitrous oxide is long lived and has a high GWP, 298 times (100-year time horizon) more potent than carbon dioxide (UNFCC 2009a, b).

field, and high spatial and temporal variability of fluxes. Fluxes are highest around brief wetting or freeze-thaw events, with most of the annual flux occurring in only a few days. Current methods involve chambers placed on fields, which are good for detecting relative differences across treatments and hence explaining processes. However, they also have low spatial and temporal resolution, which makes accurate quantification of field-level emissions difficult or requires expensive sampling. Micrometeorological methods (Eddy flux towers) can be used for integrated measurements over large areas, but are limited to landscapes with uniform surfaces and are expensive. Where research infrastructure is minimal, Hensen *et al* (2013) suggest low-cost mass balance and plume methods to measure localized significant sources. Rapid advancements in analytical technologies are expected to allow improved field measurements in the next few years (Hensen *et al* 2013).

Wetlands—including flooded lands, irrigated rice and mangrove fisheries—are challenging for their complexity and variability due to changing hydrological conditions and large gaps in knowledge. Lloyd *et al* (2013) provide guidance on combining field measurement, modeling and remote sensing. They use automatic weather station data in simple energy and GHG exchange (SVAT) models, with Eddy covariance data over two to three days to calibrate the model during pivotal periods. Remote sensing is used to validate the results. Used together, the models and remote sensing can extend estimates to landscape and regional scales.

Paustian (2013) discusses the potential for biogeochemical modeling to rapidly advance quantification. The information to support these models in low income countries is just beginning to emerge with resources like the World Digital Soils Map (Sanchez *et al* 2009) and climate and remote sensing data. At the same time, improving the quality and the quantity of underlying activity data—the type and amount of different crops, animals and management practices—is also critical for modeling. While available (but incomplete) in well-resourced countries like the United States, and available in the form of long-term national statistical information at FAO (FAOSTAT 2014), some critical information may be virtually absent in many low-income countries. Paustian (2013) proposes collecting activity data through existing mobile telephones to crowd-source geo-referenced land management data (Paustian 2012). A crowd sourcing iPhone app successful in collecting soils data across the UK, has now been expanded to the EU and is planned for introduction into Africa (Shelley *et al* 2013, Robinson 2013). Similar activities are being tested at FAO, as an extension of already successful crowdsourcing technologies used to collect price data (www.amis-outlook.org/). Combining farmer-provided activity data with new data sources on soils and climate may greatly improve models.

*Improving accounting approaches*

Agricultural emissions are tracked and monitored at different scales—national, landscape, production system and farm –for many purposes, including national GHG reporting to the UNFCCC, corporate sustainability, or income generation (e.g., voluntary market or international investment). Most approaches track single gases and some do not address system-level effects such as leakage or interactions among management practices.

National statistics are not consistent or compiled regularly and the last global emissions assessment was almost ten years ago (Tubiello *et al* 2013). FAO's new global GHG database provides a time series of country-level statistics from 1961 to present for agriculture, and 1990–2010 for land use change, based on FAOSTAT activity data and IPCC Tier 1 methodology. The database also provides emission projections for 2030 and 2050. Available to anyone with Internet access, the database can be used to update information on agricultural emissions, compare sources of emissions or look at trends– critical information for national, regional and global strategies to address climate change. Given that the FAO-STAT database can only be as accurate as its underlying activity data, countries have an added incentive to promote national coordination processes among relevant agencies in order to collect and report improved country-level activity data.

National reporting of emissions, including from agriculture, will be required for all countries starting in 2014, with biennial update reports. As agriculture is the major source of emissions in many developing countries, better quantification and reporting capacity is needed for tracking national emissions and managing viable mitigation responses. The IPCC guidelines are applicable to all countries, but inventories require knowing which data to collect, where to find it in censuses and surveys, and how to use modeling to extrapolate and target priorities for field data collection. Many low-income countries lack these capacities and suffer from high turnover in their inventory teams, making it difficult to maintain a consistent, repeatable system. One approach is to begin building robust Tier 1 inventories, using nationally available agriculture statistics reported to FAO. This process provides a valid mechanism to begin identifying data gaps, and can still be useful when developing qa/qc data analyses with higher Tier inventories (FAO 2014). At the same time, countries should be encouraged to develop higher tier inventories and move beyond national level scales. Dedicated software products can guide the inventory process and make them more consistent and manageable (Ogle *et al* 2013).

National inventories would be significantly improved with targeted investments from the international community to improve and consolidate information in two areas: (1) enhance national agency collaboration, for example between ministries of agriculture and environment to bridge fundamental institutional gaps towards the development of coherent national data systems; and (2) augment the IPCC Emissions Factor Database with more accurate country-specific or IPCC 'Tier 2' factors, especially for high emission activities (IPCC EFDB). Sharing innovations for producing Tier 2 factors will support these aims. For example, Canadian researchers track how

emissions change with management on the farm by collecting at least one year of data from representative farms that reflect the diversity of farm management practices and regional climates nationally to develop country-specific emission factors. They also collect information directly from farmers on manure management practices that mitigate emissions, like improved storage of manure (VanderZaag *et al* 2013).

When moving to smaller scales, lack of local activity data and relevant emissions factors can reduce accuracy. Quantification at the landscape scale–smaller than a region, but larger than a few farms—can help aggregate changes in emissions or removals across diverse land uses and enhance flexibility in mitigation options. Little attention has been given to landscape scale accounting. While direct measurements using Eddy flux towers or chamber-based measurements seem appealing, they are costly and have limited feasibility in complex landscapes. Milne *et al* (2013) thus suggest using remote sensing to stratify the landscape and develop a nested sampling scheme, followed by targeted measurement to calibrate a model that can be used to estimate emissions.

Accounting at farm scales often serves multiple objectives that reflect farmers' needs for food security and livelihoods. Rosenstock *et al* (2013) are building a protocol for low-cost standard measurement of GHG emissions of smallholder agriculture that integrates emissions with production and cost information. Berry and Ryan (2013) use a simplified biogeochemical model–the Small-Holder Agriculture Monitoring and Baseline Assessment (SHAMBA) methodology—to reduce cost and effort, while accepting higher levels of uncertainty. The methods were developed for the Plan Vivo Standard, which values emissions generated as a co-benefit to development and hence does not require precise estimates (Plan Vivo 2012). Where higher uncertainty is tolerable, such lower cost models and methods could remove barriers to accounting and support broader participation.

Many calculators and tools have been developed for agricultural emissions. Colomb *et al* (2013) reviewed 18 calculators that were developed for raising farmers' awareness, informing management, reporting, determining carbon credits for markets, or assessing products. They operate at the farm, regional or supply chain scales. Many calculators did not fully account for land use change emissions (e.g., soil C loss with conversion to a new land use)—and those that did, only included direct land use change (no indirect calculated due to displaced activities). Some only had a partial accounting of nitrous oxide sources. Only five calculators included a measure of uncertainty. The authors suggest that given the variability in calculators, certifying calculators or assessors who use them would be needed to enhance quality assurance. More inter-tool and model comparison can also assist in guiding their use. Seebauer (2014) compared the 'Sustainable land management practices' (SALM) methodology from the Verified Carbon Standard (VCS) to the Cool Farm Tool, a simple spreadsheet, to account for emissions due to changes in residue burning, fertilizer use, mulching,

composting, and tree planting in farms in Western Kenya. Despite differences, both tools predicted significant net GHG benefits of the applied practices across the farms and in most cases captured this across the variability of farms and practices.

Common units are needed for comparing outcomes in accounting. Global warming potentials (GWP), allow aggregating the impacts of gases in units of $CO_2$ equivalents, by using weighting factors (UNFCCC 2009a, b). However, outside of current UNFCCC agreements, alternative weighting approaches are being explored that might better represent the potential for temperature change. An alternative that weights methane as four times the value of $CO_2$ versus the conventional twenty five (Manning and Reisinger 2011) would significantly affect agricultural emissions calculations. Reisinger and Ledgard (2013) explored the implications of this weighting for New Zealand dairy farms and found that the significance of individual gases would change as would the total emissions, but relative effectiveness of different management strategies would remain unchanged.

### Integrating information on resilience and food security

If farmers' objectives are to achieve food security and/or optimal production of food under both current and changing climate conditions, can this be achieved in a way that also reduces emissions? Quantification approaches and models to assess the multiple objectives of food security, resilient agriculture, and GHG mitigation are still emerging.

Lobell *et al* (2013) explore how much GHG mitigation would result from investment in adapting agriculture to climate change. The enhanced crop productivity and thus reducing clearing of land for agriculture are assumed to reduce emissions from forest clearing. The authors estimate that a $225 billion USD investment in adaptation would result in 61 Mha less conversion globally, resulting in 15 Gt $CO_2$e less emissions by 2050, at costs comparable or less than direct investment in mitigation activities. The authors' results highlight the high uncertainty of current model estimates, with a need for improved estimates of emissions factors for converting land to agriculture, price elasticity of land supply, and elasticity of substitution between land and non-land inputs (e.g., fertilizer, labor).

Valin *et al* (2013) explore how much GHG mitigation would result if we focus on increasing crop yield and livestock feed efficiencies. They show that closing yield gaps by 50% for crops and 25% for livestock by 2050 would decrease agriculture and land use emissions by 8% overall or 12% per calorie produced. However, the pathway matters: a fertilizer intensive pathway results in lower GHG reductions; a focus on crop yield rather than livestock productivity would bring larger food benefits, whereas a focus on livestock would bring higher GHG reductions.

Understanding such inevitable trade-offs can guide policy. Hussein *et al* (2013) suggests that policies focused on forest carbon alone, when implemented in low-income countries can increase poverty and reduce food security of the

local populations due to reduced agricultural expansion and increased local food prices.

## Conclusions

Although the fundamental methods for quantifying agricultural GHGs are widely known, opportunities exist to estimate emissions at larger scales, lower costs and in ways that may become more relevant to quantification of indicators that are better linked to food security and rural development goals. The papers in this focus issue provide evidence and opportunities for actions important to policy and further research that would help rapidly refine emissions quantification:

(1) Internationally coordinated, focused investment to (a) build platforms for bridging institutional and technical gaps in activity data, leading to improved national processes and thus increased opportunities for sharing production, land management and land use change data both within countries and globally; (b) expand implementation of robust GHG quality assurance/quality control data processes for GHG inventories, including development of robust Tier 1 inventories as well as more detailed Tier 2 inventories, via production and dissemination of emissions factors, for instance through the IPCC Emissions Factor Database (EFDB); and (c) support for consistent quantification through use of tools like standardized software for national inventories or measurement protocols. These efforts should increase comparability of data and information across countries and scales of application.

(2) Improved models and data gathering and analysis tools aimed at reducing needs for field measurements, better reflecting emissions and mitigation activities in diverse production systems, and enhancing the characterization of associated land use and land use change dynamics. This requires prioritization of regional work based on relevant combined indicators of emission levels, mitigation opportunities and productivity options, and work on implementing a host of specialized data analysis and information technology tools, including integration of geospatial information with statistical tools, calibrating models with regional data, as well as testing the viability of 'data-light' models.

(3) Setting priorities to acquire data and develop emission factors for practices and agroecological systems that are expected to have the highest emissions or mitigation potential, coupled to high opportunities for sustainable rural development. The aim should be to produce high impact, nationally-relevant (i.e., Tier 2) emission factors and mitigation priorities for cost-effective actions. Representative systems could serve as hubs for robust long-term data collection and model development, aimed at capturing diverse management practices and environmental conditions.

(4) In addition to information on emissions and removals, climate, and soils, more detailed information on the underlying activity data and drivers, such as crop yields, crop and livestock productivity, crop varieties, animal breeds and environmental impacts can help policy makers and managers integrate food security, resilience, mitigation and sustainability objectives.

Investing in such improved data and understanding will allow for better consideration of the GHG dimension of agriculture practices and inform more integrated assessments and planning for broader agendas related to climate-smart agriculture and sustainable landscapes that receive increasing attention in national and international policy arenas. Given the significant advances in remote sensing and other data products; computing infrastructure, networking and crowd sourcing capabilities; expanding scope of biogeochemical models; and innovations in other analytical tools, our ability to quantify GHG emissions in the agricultural sector is poised to advance rapidly. Better coordination and targeting of a few critical activities by key institutions with expertise and financial resources such as IPCC, FAO, United Nations Development Programme, UN-REDD Programme, the Multilateral Banks, Global Environment Facility, Climate Change and Clean Air Initiative, and the Global Research Alliance on Agricultural Greenhouse Gases, can result in significant progress in building quantification approaches that provide more accurate and more meaningful estimates across a broader set of geographies and scales.

## Acknowledgments and disclaimers

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