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PERSPECTIVE

Advancing agricultural greenhouse gas quantification*

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1. Introduction

Better information on greenhouse gas (GHG) emissions and mitigation potential in the agricultural sector is necessary to manage these emissions and identify responses that are consistent with the food security and economic development priorities of countries. Critical activity data (what crops or livestock are managed in what way) are poor or lacking for many agricultural systems, especially in developing countries. In addition, the currently available methods for quantifying emissions and mitigation are often too expensive or complex or not sufficiently user friendly for widespread use.

The purpose of this focus issue is to capture the state of the art in quantifying greenhouse gases from agricultural systems, with the goal of better understanding our current capabilities and near-term potential for improvement, with particular attention to quantification issues relevant to smallholders in developing countries. This work is timely in light of international discussions and negotiations around how agriculture should be included in efforts to reduce and adapt to climate change impacts, and considering that significant climate financing to developing countries in post-2012 agreements may be linked to their increased ability to identify and report GHG emissions (Murphy *et al* 2010, CCAFS 2011, FAO 2011).

2. Agriculture and climate change mitigation

The main agricultural GHGs—methane and nitrous oxide—account for 10%–12% of anthropogenic emissions globally (Smith *et al* 2008), or around 50% and 60% of total anthropogenic methane and nitrous oxide emissions, respectively, in 2005. Net carbon dioxide fluxes between agricultural land and the atmosphere linked to food production are relatively small, although significant carbon emissions are associated with degradation of organic soils for plantations in tropical regions (Smith *et al* 2007, FAO 2012). Population growth and shifts in dietary patterns toward more meat and dairy consumption will lead to increased emissions unless we improve production efficiencies and management. Developing countries currently account for about three-quarters of direct emissions and are expected to be the most rapidly growing emission sources in the future (FAO 2011).

Reducing agricultural emissions and increasing carbon sequestration in the soil and biomass has the potential to reduce agriculture's contribution to climate change by 5.5–6.0 gigatons (Gt) of carbon dioxide equivalent (CO₂eq)/year.



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* We dedicate this special issue to the memory of Daniel Martino, a generous leader in greenhouse gas quantification and accounting from agriculture, land-use change, and forestry.

Economic potentials, which take into account costs of implementation, range from 1.5 to 4.3 GT CO₂eq/year, depending on marginal abatement costs assumed and financial resources committed, with most of this potential in developing countries (Smith *et al* 2007). The opportunity for mitigation in agriculture is thus significant, and, if realized, would contribute to making this sector carbon neutral. Yet it is only through a robust and shared understanding of how much carbon can be stored or how much CO₂ is reduced from mitigation practices that informed decisions can be made about how to identify, implement, and balance a suite of mitigation practices as diverse as enhancing soil organic matter, increasing the digestibility of feed for cattle, and increasing the efficiency of nitrogen fertilizer applications. Only by selecting a portfolio of options adapted to regional characteristics and goals can mitigation needs be best matched to also serve rural development goals, including food security and increased resilience to climate change.

Expansion of agricultural land also remains a major contributor of greenhouse gases, with deforestation, largely linked to clearing of land for cultivation or pasture, generating 80% of emissions from developing countries (Hosonuma *et al* 2012). There are clear opportunities for these countries to address mitigation strategies from the forest and agriculture sector, recognizing that agriculture plays a large role in economic and development potential. In this context, multiple development goals can be reinforced by specific climate funding granted on the basis of multiple benefits and synergies, for instance through currently negotiated mechanisms such as Nationally Appropriate Mitigation Actions (NAMAs) (REDD+, Kissinger *et al* 2012).

3. Challenges to quantifying GHG information for the agricultural sector

The quantification of GHG emissions from agriculture is fundamental to identifying mitigation solutions that are consistent with the goals of achieving greater resilience in production systems, food security, and rural welfare. GHG emissions data are already needed for such varied purposes as guiding national planning for low-emissions development, generating and trading carbon credits, certifying sustainable agriculture practices, informing consumers' choices with regard to reducing their carbon footprints, assessing product supply chains, and supporting farmers in adopting less carbon-intensive farming practices. Demonstrating the robustness, feasibility, and cost effectiveness of agricultural GHG inventories and monitoring is a necessary technical foundation for including agriculture in the international negotiations under the United Nations Framework Convention on Climate Change (UNFCCC), and is needed to provide robust data and methodology platforms for global corporate supply-chain initiatives (e.g., SAFA, FAO 2012).

Given such varied drivers for GHG reductions, there are a number of uses for agricultural GHG information, including (1) reporting and accounting at the national or company level, (2) land-use planning and management to achieve specific objectives, (3) monitoring and evaluating impact of management, (4) developing a credible and thus tradable offset credit, and (5) research and capacity development. The information needs for these uses is likely to differ in the required level of certainty, scale of analysis, and need for comparability across systems or repeatability over time, and they may depend on whether descriptive trends are sufficient or an understanding of drivers and causes are needed. While there are certainly similar needs across uses and users, the necessary methods, data, and models for quantifying GHGs may vary. Common challenges for quantification noted in an informal survey of users of GHG information by Olander *et al* (2013) include the following.

3.1. Need for user-friendly methods that work across scales, regions, and systems

Much of the data gathered and models developed by the research community provide high confidence in data or indicators computed at one place or for one issue, thus they are relevant for only specific uses, not transparent, or not comparable. These research approaches need to be translated to practitioners through the development of farmer friendly, transparent, comparable, and broadly applicable methods. Many users noted the need for quantification data and methods that work and are accurate across region and scales. One of the interviewed users, Charlotte Streck, summed it up nicely: ‘A priority would be to produce comparable datasets for agricultural GHG emissions of particular agricultural practices for a broad set of countries . . . with a gradual increase in accuracy’.

3.2. Need for lower cost, feasible approaches

Concerns about cost and complexity of existing quantification methods were raised by a number of users interviewed in the survey. In the field it is difficult to measure changes in GHGs from agricultural management due to spatial and temporal variability, and the scale of the management-induced changes relative to background pools and fluxes. Many users noted data gaps and inconsistencies and insufficient technical capacity and infrastructure to generate necessary information, particularly in developing countries. The need for creative approaches for data collection and analysis, such as crowd sourcing and mobile technology, were noted.

3.3. Need for methods that can crosswalk between emission-reduction strategy and inventories or reporting

A few users emphasized the need for information and quantification approaches that cannot only track GHGs but also help with strategic planning on what to grow where and when to maximize mitigation and adaptation benefits. Methods need to incorporate the quantification context, taking into account climate impacts, viability, and cost of management options. Thus, data and methods are needed that integrate climate impacts into models used to assess the potential and costs of GHG mitigation strategies.

3.4. Need for confidence thresholds and rules that are appropriate for use

Users noted that national inventories through the UNFCCC or Intergovernmental Panel on Climate Change (IPCC) require 95% confidence, while some offset market standards leave confidence levels to the discretion of the developer, using discounts in value for greater uncertainty. Nonetheless, these standards tend to have expectations of 20% confidence or better. In fact, both regulatory and voluntary reporting suffer from large uncertainties in the underlying activity data as well as in emission factors. In some circumstances emissions factors may add as much as 50–150% uncertainty to GHG estimates (IPCC 2006). Uncertainty clearly needs to be assessed in implementing projects and programs. In some cases there are uncertainty thresholds, while in others uncertainty is assessed and used as part of the quantification process. What is not always clear is where uncertainty thresholds are necessary to maintain the usefulness of the information and where they are hindering early progress.

3.5. Easily understood and common metrics for policy and market users

Inventories usually track tons of CO₂ equivalents, while supply-chain and corporate reporting are more likely to track efficiency metrics, such as GHG emissions per unit of product; offsets protocols may combine both approaches. As demand for food rises, efficiency of production becomes an increasingly important metric, even if total CO₂ equivalents need to be tracked in parallel to assess climate impacts. For livestock systems it is unclear which metrics are most important to track, GHGs per unit of meat or milk or perhaps per calorie? Different metrics are likely needed for different uses.

3.6. Capacity development in developing countries

There is need to improve on the current lack of capacities to monitor land use and land-use change and their associated GHG emissions and removals for national inventories (UNFCCC 2008, Romijn *et al* 2012). Since there are ongoing efforts to improve, data, methods and capacities for monitoring forests in the context of REDD+ (Herold and Skutsch 2011), synergies should be sought to use and build upon joint data sources and approaches, such as remote sensing, field inventories, crowd sourcing, and human capacities to estimate and report on GHG balance in both forests and agriculture.

A number of specific objectives to meet these challenges are discussed in this special issue.

- Improve the accuracy of emissions factors across regional differences.
- Improve national inventory data of management activities, crop type and variety, and livestock breeds.
- Use historical data and data collection over time to show trends.
- Test the extent of model applications through field validation (e.g., can they be used in regions with less data?).
- Enhance technical capacity and infrastructure for data acquisition and for application of mitigation strategies in field programs.
- Increase understanding of which mitigation practices result in more resilient systems.
- Improve understanding of the GHG tradeoffs of expanding fertilizer use.

While data sources and methods are improving and research and operational monitoring are increasing, the international community can be strategic in targeting support for this work and coordinating data and information collection to move toward revised good practice guidelines that would address the particular circumstances and practices dominant in developing countries.

4. Current data infrastructure and systems supporting GHG quantification in the agricultural sector

To understand the challenges facing GHG quantification it is helpful to understand the existing supporting infrastructure and systems for quantification. The existing and developing structures for national and local data acquisition and management are the foundation for the empirical and process-based models used by most countries and projects currently quantifying agricultural greenhouse gases. Direct measurement can be used to complement and supplement such models, but this is not yet sufficient by itself given costs, complexities, and uncertainties.

One of the primary purposes of data acquisition and quantification is for national-level inventories and planning. For such efforts countries are conducting

national-level collection of activity data (who is doing which agricultural practices where) and some are also developing national or regional-level emissions factors.

Infrastructure that supports these efforts includes intergovernmental panels, global alliances, and data-sharing networks. Multilateral data sharing for applications, such as the FAO Statistical Database (FAOSTAT) (FAO 2012), the IPCC Emission Factor Database (IPCC 2012), and UNFCCC national inventories (UNFCCC 2012), are building greater consistency and standardization by using global standards such as the IPCC's Good Practice Guidance for Land Use, Land-Use Change and Forestry (e.g., IPCC 1996, 2003, 2006). There is also work on common quantification methods and accounting, for example agreed on global warming potentials for different contributing gases and GHG quantification methodologies for projects (e.g., the Verified Carbon Standard Sustainable Agricultural Land Management [SALM] protocol, VCS 2011). Other examples include the Global Research Alliance on Agricultural Greenhouse Gases (2012) and GRACEnet (Greenhouse gas Reduction through Agricultural Carbon Enhancement network) (USDA Agricultural Research Service 2011), which aim to improve consistency of field measurement and data collection for soil carbon sequestration and soil nitrous oxide fluxes.

Often these national-level activity data and emissions factors are the basis for regional and smaller-scale applications. Such data are used for model-based estimates of changes in GHGs at a project or regional level (Olander *et al* 2011). To complement national data for regional-, landscape-, or field-level applications, new data are often collected through farmer knowledge or records and field sampling. Ideally such data could be collected in a standardized manner, perhaps through some type of crowd sourcing model to improve regional—and national—level data, as well as to improve consistency of locally collected data.

Data can also be collected by companies working with agricultural suppliers and in country networks, within efforts aimed at understanding firm and product (supply-chain) sustainability and risks (FAO 2009). Such data may feed into various certification processes or reporting requirements from buyers. Unfortunately, this data is likely proprietary. A new process is needed to aggregate and share private data in a way that would not be a competitive concern so such data could complement or supplement national data and add value.

A number of papers in this focus issue discuss issues surrounding quantification methods and systems at large scales, global and national levels, while others explore landscape- and field-scale approaches. A few explore the intersection of top-down and bottom-up data measurement and modeling approaches.

5. The agricultural greenhouse gas quantification project and ERL focus issue

Important land management decisions are often made with poor or few data, especially in developing countries. Current systems for quantifying GHG emissions are inadequate in most low-income countries, due to a lack of funding, human resources, and infrastructure. Most non-Annex 1 countries reporting agricultural emissions to the UNFCCC have used only Tier I default emissions factors (Nihart 2012, unpublished data), yet default numbers are based on a very limited number of studies. Furthermore, most non-Annex I countries have reported their National Communications only one or two times in the period 1990–2010. China, for instance, has not submitted agricultural inventory data since 1994.

As we move toward the next IPCC assessment report on climate change and while UNFCCC negotiations give greater attention to the role of agriculture

within international agreements, it is valuable to understand our current and potential near-term capacity to quantify and track emissions and assess mitigation potential in the agriculture sector, providing countries—especially least developed countries (LDCs)—with the information they need to promote and implement actions that, while conducive to mitigation, are also consistent with their rural development and food security goals. The purpose of this focus issue is to improve the knowledge and practice of quantifying GHG emissions from agriculture around the globe. The issue discusses methodological, data, and capacity gaps and needs across scales of quantification, from global and national-scale inventories to landscape- and farm-scale measurement. The inherent features of agriculture and especially smallholder farming have made quantification expensive and complicated, as farming systems and farmers' practices are diverse and impermanent and exhibit high temporal and spatial variability. Quantifying the emissions of the complex crop livestock or diverse cropping systems that characterize smallholder systems presents particular challenges. New ideas, methods, and uses of technology are needed to address these challenges. Many papers in this special issue synthesize the state of the art in their respective fields, analyze gaps, identify innovations, and make recommendations for improving quantification. Special attention is given to methods appropriate to low-income countries, where strategies are needed for getting robust data with extremely limited resources in order to support national mitigation planning within widely accepted standards and thus provide access to essential international support, including climate funding.

Managing agricultural emissions needs to occur in tandem with managing for agricultural productivity, resilience to climate change, and ecosystem impacts. Management decisions and priorities will require measures and information that identify GHG efficiencies in production and reduce inputs without reducing yields, while addressing climate resilience and maintaining other essential environmental services, such as water quality and support for pollinators. Another set of papers in this issue considers the critical synergies and tradeoffs possible between these multiple objectives of mitigation, resilience, and production efficiency to help us understand how we need to tackle these in our quantification systems.

Significant capacity to quantify greenhouse gases is already built, and with some near-term strategic investment, could become an increasingly robust and useful tool for planning and development in the agricultural sector around the world.

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editors at FAO in Rome in April 2012 to further develop their ideas, synthesize state of the art knowledge and generate new ideas (<http://nicholasinstitute.duke.edu/ecosystem/t-agg/events-and-presentations>). Additional interesting and important research has come forward through the general call for papers and has been incorporated into this issue.

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