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PERSPECTIVE

Toward a protocol for quantifying the greenhouse gas balance and identifying mitigation options in smallholder farming systems

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Globally, agriculture is directly responsible for 14% of annual greenhouse gas (GHG) emissions and induces an additional 17% through land use change, mostly in developing countries (Vermeulen *et al* 2012). Agricultural intensification and expansion in these regions is expected to catalyze the most significant relative increases in agricultural GHG emissions over the next decade (Smith *et al* 2008, Tilman *et al* 2011). Farms in the developing countries of sub-Saharan Africa and Asia are predominately managed by smallholders, with 80% of land holdings smaller than ten hectares (FAO 2012). One can therefore posit that smallholder farming significantly impacts the GHG balance of these regions today and will continue to do so in the near future.

However, our understanding of the effect smallholder farming has on the Earth's climate system is remarkably limited. Data quantifying existing and reduced GHG emissions and removals of smallholder production systems are available for only a handful of crops, livestock, and agroecosystems (Herrero *et al* 2008, Verchot *et al* 2008, Palm *et al* 2010). For example, fewer than fifteen studies of nitrous oxide emissions from soils have taken place in sub-Saharan Africa, leaving the rate of emissions virtually undocumented. Due to a scarcity of data on GHG sources and sinks, most developing countries currently quantify agricultural emissions and reductions using IPCC Tier 1 emissions factors. However, current Tier 1 emissions factors are either calibrated to data primarily derived from developed countries, where agricultural production conditions are dissimilar to that in which the majority of smallholders operate, or from data that are sparse or of mixed quality in developing countries (IPCC 2006). For the most part, there are insufficient emissions data characterizing smallholder agriculture to evaluate the level of accuracy or inaccuracy of current emissions estimates. Consequentially, there is no reliable information on the agricultural GHG budgets for developing economies. This dearth of information constrains the capacity to transition to low-carbon agricultural development, opportunities for smallholders to capitalize on carbon markets, and the negotiating position of developing countries in global climate policy discourse.

Concerns over the poor state of information, in terms of data availability and representation, have fueled appeals for new approaches to quantifying GHG emissions and removals from smallholder agriculture, for both existing conditions and mitigation interventions (Berry and Ryan 2013, Olander *et al* 2013). Considering the dependence of quantification approaches on data and the current data deficit for smallholder systems, it is clear that *in situ* measurements must be a core part of initial and future strategies to improve GHG inventories and



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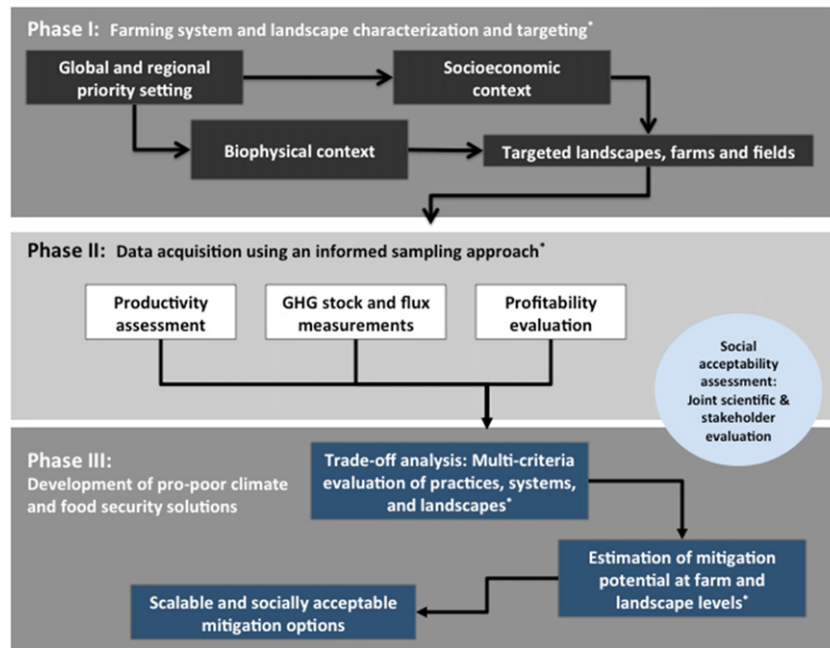


Figure 1. The quantification approach. The protocol includes comparative evaluation of various methodologies for each element (e.g., biophysical context, profitability evaluation, etc), recommend methods specific for end users objectives and constraints, and field manuals for implementation of recommended methods. Items with an asterisk indicate novel aspects of this protocol by comparison to others.

develop mitigation measures for smallholder agriculture. Once more data are available, especially for farming systems of high priority (e.g., those identified through global and regional rankings of emission hotspots or mitigation leverage points), better cumulative estimates and targeted actions will become possible.

Greenhouse gas measurements in agriculture are expensive, time consuming, and error prone. These challenges are exacerbated by the heterogeneity of smallholder systems and landscapes and the diversity of methods used. Concerns over methodological rigor, measurement costs, and the diversity of approaches, coupled with the demand for robust information suggest it is germane for the scientific community to establish standards of measurements—‘a protocol’—for quantifying GHG emissions from smallholder agriculture. A standard protocol for use by scientists and development organizations will help generate consistent, comparable, and reliable data on emissions baselines and allow rigorous comparisons of mitigation options. Besides enhancing data utility, a protocol serves as a benchmark for non-experts to easily assess data quality. Obviously many such protocols already exist (e.g., GraceNet, Parkin and Venterea 2010). None, however, account for the diversity and complexity of smallholder agriculture, quantify emissions and removals from crops, livestock, and biomass together to calculate the net balance, or are adapted for the research environment of developing countries; conditions that warrant developing specific methods. Here we summarize an approach being developed by the Consultative Group on International Agricultural Research’s (CGIAR) Climate Change, Agriculture, and Food Security Program (CCAFS) and partners.

The CGIAR-CCAFS smallholder GHG quantification protocol aims to improve quantification of baseline emission levels and support mitigation decisions. The protocol introduces five novel quantification elements relevant for smallholder agriculture (figure 1). First, it stresses the systematic collection of ‘activity data’ to describe the type, distribution, and extent of land management activities in landscapes cultivated by smallholder. Second, it advocates an

informed sampling approach that concentrates measurement activities on emission hotspots and leverage points to capture heterogeneity and account for the diversity and complexity of farming activities. Third, it quantifies emissions at multiple spatial scales, whole-farm and landscape, to provide information targeted to household and communities decisions. Fourth, it encourages GHG research to document farm productivity and economics in addition to emissions, in recognition of the importance of agriculture to livelihoods. Fifth, it develops cost-differentiated measurement solutions that optimize the relationships among scale, cost, and accuracy. Each of the five innovations is further described below.

Systematizing collection of activity data. Data describing smallholder farming systems, their relative distribution in space and time, and typical management practices are largely unavailable for smallholder agriculture in developing countries. That is significant because empirical or process based models rely on information on the nature and extent of production systems, so called 'activity data'. Without it, it is not possible to run models, scale flux data to larger spatial extents, or target measurements with any certainty. In some cases, uncertainty in the extent and management for farming activities may be equivalent or greater to the uncertainty associated with the GHG fluxes themselves. The CGIAR-CCAFS protocol therefore provides guidelines for using remote sensing, targeted social and soil surveys, and proxies that correlate with socio-ecological condition and farm management to improve the quantity and quality of activity data available.

Informed sampling. Smallholder agriculture typically involves multiple farming activities taking place in a field, nested within higher levels of organization (e.g., farm or landscape), each having interactive impacts on the cumulative GHG balance. To understand the net effect, attention must be paid to the full range of sources and sinks. Yet it is generally too resource intensive to measure them all. The CGIAR-CCAFS protocol deconstructs what is already known about nutrient stock changes and GHG fluxes to guide measurements toward emission hotspots or leverage points (e.g., methane emissions from cows in crop–livestock systems) within complex agroecosystems and landscapes. The premise underlying this approach is that information from other systems can be used to match the intensity of quantification effort with the predicted intensity of the source or sink. By reducing the uncertainty of the largest fluxes, using an informed sampling approach will hypothetically yield a more accurate and more precise estimate of the total systems' GHG balance.

Multi-scale. Farming activities take place at the field level, but climate impacts and decision-making of smallholders extend to larger spatial scales. Households frequently manage farming activities across several fields, while institutions at the village or higher levels can determine land use practices across entire landscapes, as is the case of communal grazing lands or woodlands. Decisions by households and social organizations unite climate impacts across space. It is therefore important to consider spatial scales greater than the farming activity or field to understand GHG impacts and mitigation opportunities. Therefore, the CGIAR-CCAFS protocol targets quantification and mitigation efforts at the whole-farm and landscape levels to align data describing emissions and removals with the decision units of households and communities.

Linking productivity and emissions. Smallholder farmers depend on farm production for food and income, and farm productivity is inextricably linked to food security. The importance of productivity must be taken into account in mitigation decision-making and the GHG research agenda supporting those decisions. So far, livelihood benefits and farmers' own priorities or other social benefits have been mostly ignored in GHG research. Quantification of GHG reductions from mitigation options is arguably irrelevant if the livelihood effects of those mitigation options are ignored, and scaling GHG emissions per unit area

is agronomically meaningless if yields are not considered (Linquist *et al* 2012). Therefore, the CGIAR-CCAFS protocol recommends that future GHG quantification efforts for assessing mitigation options adopt a multi-criteria approach to include data on indicators of household benefits (e.g. productivity and nutrition). In that way, the research captures the balance of benefits between the private landholder and the global public good. Joint assessment of food production and emissions may produce optimal management strategies that balance the competing demands of food production and climate stabilization. For example, nitrous oxide emissions per unit of product are lowest at intermediate (not the lowest) fertilization rates (Van Groenigen *et al* 2010) which differs from the optimal strategy for reducing emissions per unit area. Costs associated with collecting the additional data are likely to be small relative to the operational budget for GHG field research and could viably become standard practice.

Cost-differentiated measurements. Potential end users of the protocol are diverse in their purpose, resources available, and capacity to carry out research. For example, development organizations may want to determine the relative difference in emission impacts between mitigation options while governments may be interested in quantification of impacts across landscapes to develop Nationally Appropriate Mitigation Actions. The most useful approach to quantification therefore lies at the nexus among key constraints: objectives, resources, and capacity. The protocol develops a system of ‘tiered’ entry points for greenhouse gas accounting, with explicit attention directed toward the uncertainty induced from the various measurement selections. The protocol will include decision pathways to help users quickly determine the quantification options suitable for their goals and constraints to optimize the relationship among accuracy, costs, and scale.

The CCAFS-CGIAR protocol is being developed and field-tested in mixed crop–livestock systems of Kenya and intensive rice production in the Philippines, with plans to expand to other sites and agroecosystems in the next year. These initial pilot projects provide a trial of the approach and methods, highlighting technical gaps and promising directions, while generating valuable emissions data.

The role smallholder farming plays in Earth’s climate system is uncertain due to lack of data. Better information is needed to calibrate the research, policy, and development communities’ thinking on the importance of this issue. Generating the high value information that policy makers, development organizations, and farmers demand however pivots on creating accurate, useful, consistent, and meaningful data. The CCAFS-CGIAR protocol will help advance the scientific community’s ability to provide such information by using standard methods of measurement in ways that recognize the data needs and the priorities of smallholder farmers.

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