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PERSPECTIVE

Bridging the data gap: engaging developing country farmers in greenhouse gas accounting

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For many developing countries, the land use sector, particularly agriculture and forestry, represents a large proportion of their greenhouse gas (GHG) emissions, making this sector a priority for GHG mitigation activities. Previous global surveys (e.g., IPCC 2000) as well as the most recent IPCC assessment report clearly indicate that the greatest technical potential for carbon sequestration and reductions of non-CO_2 GHG emissions from the land use sector is in developing countries. Estimates that consider economic feasibility suggest that agriculture and forestry together provide among the greatest opportunities for short-term and low-cost mitigation measures across all sectors of the global economy[1] (IPCC 2007). In addition, it is widely recognized that the ecosystem changes entailed by most mitigation practices, i.e., building soil organic matter, reducing losses and tightening nutrient cycles, more efficient production systems and preserving native vegetation, are well aligned with goals of increasing food security and rural development as well as buffering land use systems against climate change (Lal 2004). Hence, there is growing interest in jump-starting the capacity for broad-based engagement in agriculturally-based GHG mitigation projects in developing countries.

Against this favorable background, there are a number of significant challenges—in addition to the fundamental need for comprehensive mandatory reduction policies—to accelerating the involvement of agriculture in GHG mitigation. As detailed by articles in this special issue, quantifying emissions and emission reductions/sequestration of agricultural sources of CO_2, N_2O and CH_4 is difficult. Emissions and C sequestration are distributed across the landscape, with high spatial and temporal variability and with multiple and interacting climate, soil and management factors that affect rates. In most cases, this makes instrument-based measurement of fluxes and C stock changes in agricultural environments difficult, expensive and impractical for routine project-scale deployment. However, there is growing acceptance in the use of models—ranging from simple empirical emission factors to dynamic process-based models—for quantifying emissions and stock changes at project scales[2]. This approach relies on the strategic use of direct instrument-based measurements carried out by university and government researchers (Jawson *et al* 2005, Skiba *et al* 2009) to calibrate and validate appropriate models, in which the models represent the relationship between key environmental variables (e.g., precipitation, temperature, soil texture and mineralogy, etc) and land management practices (e.g., fertilizer use, tillage, crop selection, residue management, land cover

[1] About 4.7 Pg CO_2eq yr^{-1}, at \$50 $tonne^{-1}$ CO_2eq.

[2] In practice, virtually all emission estimates in national GHG inventories rely fully or partially on model-based methods. At project scales, one of the few examples of direct instrument-based measurement approaches in agriculture is that of methane abatement from manure management, in which enclosed storage facilities allow gases to be collected and measured as a point source.

changes, etc) that determine anthropogenic GHG fluxes. National or regional scale monitoring networks can provide additional, independent measurements to estimate model-based uncertainties and to incrementally improve model performance (van Wesemael *et al* 2011).

In many developing countries the information infrastructure to support model-based GHG estimates is just beginning to emerge; however initiatives such as the World Digital Soils Map project (Sanchez *et al* 2009) and growing availability of free or low-cost climate data sets and remote sensing data (e.g. land cover/land use, fire, vegetation condition, etc) suggest that our knowledge of many of the environmental variables controlling GHG emissions and C sequestration will increase greatly in the next few years. However, the other key ingredient to GHG quantification—knowing where and what land management activities are actually occurring on the landscape—will require its own technological breakthrough.

In its most basic form, the emission rate of a greenhouse gas can be expressed as the product of an emission factor and a measure of the activity that is causing the emission. In this simplified depiction, the emission factor embodies the set of research-based measurements, environmental variables, process models and monitoring networks described above. The second part of the equation is generally referred to as activity data, which includes the type and amount of human-activities (i.e., management) responsible for the emissions. In most developed countries, there is a well-developed infrastructure to collect and analyze data on land use and management activities that are used for a variety of purposes, including greenhouse gas inventories. For example, the US Department of Agriculture's (USDA) National Agricultural Statistical Service (NASS) conducts a variety of surveys of farmers to collect information on management practices as well as economic and demographic data; other entities such as USDA National Resource Inventory use remote sensing and field visits to gather agricultural resource use data. These and other data sources are utilized for the national agricultural emissions inventory in the US (EPA 2012). However, even these well-established and resourced (e.g., 2011 NASS budget was \$165 million) data collections lack some variables of interest for GHG estimates and more importantly tend to be available only as aggregated averages (e.g., state or county level) that do not fully capture the *local* interaction of environmental variables (e.g. climate and soil properties) and management practices that determine GHG emissions.

In most developing countries, this type of agricultural activity data is much scarcer and most countries do not have the resources to collect extensive survey data on agricultural practices as in the developed world. Country-level statistics such as compiled in FAOSTAT provide a useful first-order estimate of agricultural activities that can be used in national and global GHG accounting (see Tubiello *et al* 2013), but are inadequate for finer scale and more accurate emissions estimates. Given financial and resource constraints, there is little expectation of dramatic near-term improvements in the availability of data on agricultural management practices in many developing countries using traditional top-down agency-directed surveys.

So how do we overcome this critical data gap, which I would argue is a prerequisite for broad-based implementation of GHG mitigation policies and projects in the developing world. A potential answer—have the farmers tell us themselves!

The explosive growth in mobile phone accessibility and use in developing countries has been widely noted and has begun to be exploited for a variety of purposes to support rural development (Qiang *et al* 2011). To date, applications have centered mainly on providing market information to farmers so that they can make more profitable decisions on where and when to market their products. Dissemination of advice, such as weather forecasts and management recommendations is another area of development.

The use of mobile device technology for 'crowd-sourcing' of land management data to support local-scale greenhouse gas accounting is still very much 'on-the-drawing board' (Paustian 2012); however, several factors argue in favor of the viability of this type of approach. First, is the fact that many key variables driving agricultural emissions (e.g., fertilizer applications, manure management) cannot be obtained by means other than asking the farmers themselves—either by traditional survey methods or through self-reporting. Remote sensing can provide data on variables such as land cover and land cover change, as well as some 'within land cover' management variables such as crop species, crop residue coverage, extent and periodicity of flooding (e.g. for rice) (NAS 2010). However, these latter observations are still highly uncertain and particularly challenging in the heterogeneous, fine-grained, land use mosaics that are typical for small-holder agriculture in the tropics. Hence, most of the management information needed as activity data, e.g., land area farmed, amount, type and timing of fertilizer applied, tillage implements used, crops growth, etc, are best known by the land users themselves.

At present, second generation (2G) mobile phones predominate in developing countries (Qiang *et al* 2011), but with the likely increase in future smart phone usage, the possibility for powerful applications for data collection as well as computation and reporting (e.g., for GHG mitigation project participants) is far-reaching. Capabilities include geo-referencing of locations, uploading photos for image analysis (e.g., crop species present, canopy density, surface coverage by crop residues) and wireless connection to remote sensing imagery, geospatial databases and cloud-computing. Sophisticated web-based applications for GHG accounting are becoming available in the US and Europe (Denef *et al* 2012, Paustian *et al* 2012) which opens the opportunity for similar deployments to support GHG mitigation projects in developing countries (Milne *et al* 2013).

Incentivizing farmers to supply management information and ensuring timely and accurate reporting are two major challenges to a 'crowd-sourcing' system for activity data collection. A logical place to start might be with participants or field coordinators of GHG offset projects or other funded agricultural development projects, as they would have a direct incentive to provide data as a condition of project participation. However, a cost-effective means of collecting land use data might also be of interest to governmental and regulatory agencies, in which case direct financial incentives for reporting could be developed. Compensation such as awarding cell phone minutes would be an alternative that would entail minimal transaction costs. Data quality control would be an important component, requiring careful formulation of the data gathering procedures (i.e., the design of a mobile-app based survey) as well as data screening for outliers and independent resampling of a portion of the responses. However, QA/QC procedures for traditional self-reporting and polling methods (which face the same challenges) are well-developed and could be adapted to a mobile-app system. Finally, opportunities for incorporating graphics/pictures as a substitute or complement to text, as well as increasingly sophisticated voice recognition capabilities, could provide added benefits for working with populations having low literacy and education levels.

Many issues remain to be resolved for improving our capabilities to quantify emissions and emission reductions from agriculture—both in developed and developing parts of the globe—including improvements in emission factors/models, better geospatial databases for soils and climate, and deployment of distributed monitoring networks. Similarly, a crowd-sourcing approach to compile activity data on agricultural management practices faces challenges such as making applications simple and locally relevant, literacy barriers, data quality control, and incentivizing the data providers. However, the growing use by developing country farmers of mobile apps for marketing, financing and extension services, suggests that engaging them directly, as the true experts of what is happening on the landscape, could be a key to bridging the data gap and realizing the potential for agricultural GHG mitigation.

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