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OPINION

Reducing greenhouse gas emissions and adapting agricultural management for climate change in developing countries: providing the basis for action

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Abstract

Agriculture in developing countries has attracted increasing attention in international negotiations within the United Nations Framework Convention on Climate Change for both adaptation to climate change and greenhouse gas mitigation. However, there is limited understanding about potential complementarity between management practices that promote adaptation and mitigation, and limited basis to account for greenhouse gas emission reductions in this sector. The good news is that the global research community could provide the support needed to address these issues through further research linking adaptation and mitigation. In addition, a small shift in strategy by the Intergovernmental Panel on Climate Change (IPCC) and ongoing assistance from agricultural organizations could produce a framework to move the research and development from concept to reality. In turn, significant progress is possible in the near term providing the basis for UNFCCC negotiations to move beyond discussion to action for the agricultural sector in developing countries.

Keywords: agriculture, climate change adaptation, emission factors, greenhouse gas emissions inventory, greenhouse gas mitigation, United Nations Framework Convention on Climate Change

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Agriculture and UN climate change negotiations

Agriculture in developing countries has attracted increasing attention in international negotiations within the United Nations Framework Convention on Climate Change (UNFCCC) for both adaptation to climate change and greenhouse gas (GHG) mitigation (Beddington *et al*., 2012). Developing countries are concerned about the significant challenges associated with adapting their production systems for more extreme weather conditions and longer term shifts in climate (Godfray *et al*., 2011; Smith *et al*., 2013). In turn, developed countries have expressed a willingness to assist with this challenge by coupling adoption of new practices and technologies with payments for mitigation of GHG emissions. While financial support is welcome, developing countries understandably view potential commitments to mitigate GHG emissions, even if they are voluntary, as a barrier for increasing food production to feed growing populations. At the same time, a program in agriculture that depends on funding from developed countries would likely need performance-based indicators of outcomes, particularly quantification of GHG emissions, similar to the initiative for reducing GHG emissions from deforestation and forest degradation (REDD+). To provide credible quantification of emissions, there would need to be improvements in GHG estimation systems.

The good news is that the global research community could provide the support needed to address these issues. Further research could evaluate the synergy between climate change adaptation and GHG mitigation associated with promising management options,

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along with impacts on food production (Smith *et al.*, 2013). In addition, reliable performance-based indicators of outcomes could be developed with a small shift in strategy by the Intergovernmental Panel on Climate Change (IPCC) to provide improved emission factors, and ongoing assistance with data collection from international and national agricultural organizations, such as the UN Food and Agriculture Organization (FAO). In turn, significant progress is possible in the near term providing the basis for a more robust, knowledge and evidence-based platform that would allow UNFCCC negotiations to move beyond discussion to action for the agricultural sector in developing countries.

Greenhouse gas mitigation and climate change adaptation

Agriculture directly contributes 10–12% of global anthropogenic GHG emissions (Smith *et al.*, 2008). Many of the same practices that reduce GHG emissions can also improve efficiency of resource use, and create synergy with rural development and food security goals (Lal, 2004; FAO, 2012; Smith *et al.*, 2013). However, less research has focused on evaluating the influence of management for both GHG mitigation and adaptation to climate change (Table 1). An example is agroforestry in coffee plantations that creates a multilevel canopy with coffee plants in the lower portion. This practice stores more carbon compared to conventional plantations, and thus mitigates GHG emissions (Hergoualc'h *et al.*, 2012). At the same time, shading of coffee in the lower canopy produces a microclimate that can reduce maximum leaf temperatures by as much as 5 °C, and buffer the coffee plants against extreme temperature increases that are expected to occur in coming decades (Siles *et al.*, 2009).

Another example is planting cover crops between growing seasons in maize-based systems of North America, which has been shown to enhance net primary productivity and mitigate GHG emissions by increasing soil carbon stocks (Eagle & Olander, 2012). Cover crops are also adaptive for climate change because they improve soil physical structure and water retention, chemical composition, and faunal activity, which will enable the system to recover from stress caused by more extreme weather conditions due to climate change. The benefits have been particularly important during recent droughts in the region where corn and soybean yields have been 9.6% and 11% higher, respectively, for farmers who had used cover crops compared to conventional management (CTIC, 2013).

Despite the likelihood of positive outcomes for mitigation and adaptation, and possible co-benefits for food production, there are few studies that have investigated the benefits of practices for both mitigation and adaptation in an integrated manner with controlled experimental designs. The relative scarcity of integrated research on these topics is arguably a critical gap in the research surrounding climate change.

Limitations in current GHG quantification systems

Quantifying GHG emissions from the agricultural sector in a country begins with the national GHG inventory. A robust national inventory creates a strong linkage between GHG emissions data and associated policy planning and implementation. In turn, this provides the opportunity for development of accurate emission baselines and monitoring of trends for reporting reductions as part of a country's national communication to the UNFCCC. Fundamentally, a robust national inventory system requires accurate emission factors, i.e., the emission rate per unit of managed land area or animal activity, along with a complete set of activity data for tracking key management practices in agricultural production systems.

The IPCC has developed GHG inventory guidelines that are used by countries for reporting emissions to the UNFCCC (IPCC, 2006). The IPCC guidelines outline a three-tier methodological approach for conducting a national inventory. Tier 1 relies on default equations and emissions factors. The default factors are generally representative of average emissions at global or continental scales, and consequently can lead to biases in national inventories. The IPCC has recognized the deficiencies with Tier 1 methods, and recommends that countries use country-specific emission factors for the largest emission sources, i.e., a Tier 2 method, or even country-specific equations and emissions factors, i.e., a Tier 3 method. The IPCC has also developed an Emissions Factors Database to support the development of Tier 2 methods (http://www.ipcc-nggip.iges.or.jp/EFDB/main.php).

Yet, current reporting of agricultural GHG emissions by developing countries are largely based on Tier 1 methods, even for the largest GHG emission sources (http://unfccc.int/national_reports/items/1408.php). Three of the largest emission sources from the agricultural sector include enteric and manure methane emissions from livestock systems, and agricultural soil nitrous oxide emissions from croplands and grasslands. Enteric methane emissions are either not reported or reported using Tier 1 methods by 76% of the developing countries according to national communications that governments have provided to the UNFCCC (Fig. 1a). Similarly, manure methane and soil nitrous oxide emissions are not reported or are based on Tier 1 methods in 81% and 93% of the developing countries,

Table 1 Selected examples of specific management options and their influence on GHG mitigation and climate change adaptation. GWP values are in Mg CO_2 equivalent ha^{-1} yr^{-1}, except for improved diets which are in units of Mg CO_2 equivalent kg per milk.

Management measure	Specific management options: Common	Specific management options: Alternative	Location	GHG mitigation effect (ΔGWP)	Climate change adaptation	Reference
Cropland management						
Agroforestry	Conventional maize	Intercropped *Gliricidia sepium* (nitrogen fixing tree) with maize	Malawi	−3.5 to −4.1	Increase soil organic matter through plant litter additions having positive effects on soil structure and water dynamics	Lin (2007), Beedy *et al.* (2010), Kim (2012), Sileshi *et al.* (2012)
	Coffee monoculture	Multistrata coffee	Costa Rica	−10.8	Creates microclimates that buffer against extreme temperatures and maintain soil moisture	Siles *et al.* (2009), Hergoualc'h *et al.* (2012)
Agronomy	Bare fallows between crops in corn-based systems	Use of winter cover crops during fallow periods in corn-based systems	United States	−1.46	Dampens the impact of drought by enhancing soil chemical, physical, and biological properties though increased net primary productivity	Dabney *et al.* (2001), Eagle & Olander (2012), CTIC (2013)
	Conventional maize	Maize grown with conservation agriculture	Mexico	−7.6	Conserves soil moisture which may help bridge short-term, midseason drought periods	Dendooven *et al.* (2012), Verhulst *et al.* (2012)
Livestock and grazing land management						
Improved feeding practice	Low-quality native grass-based diets for dairy cattle	Improved diets of dairy cattle including some high-quality forages	Kenya	−1.4 to 0.03	Increases net revenue allowing smallholder farmers to purchase food in times of shortage enabling alternative livelihood strategies	Bryan *et al.* (2011, 2012), only addresses CH_4 emissions from enteric fermentation
Grazing intensity	Heavily grazed native pasture	Moderately grazed native pasture	United States	−0.2	Reduces the impact of droughts on pasture resources and helps pasture recover more quickly	Liebig *et al.* (2009), only addressed soil GHG emissions

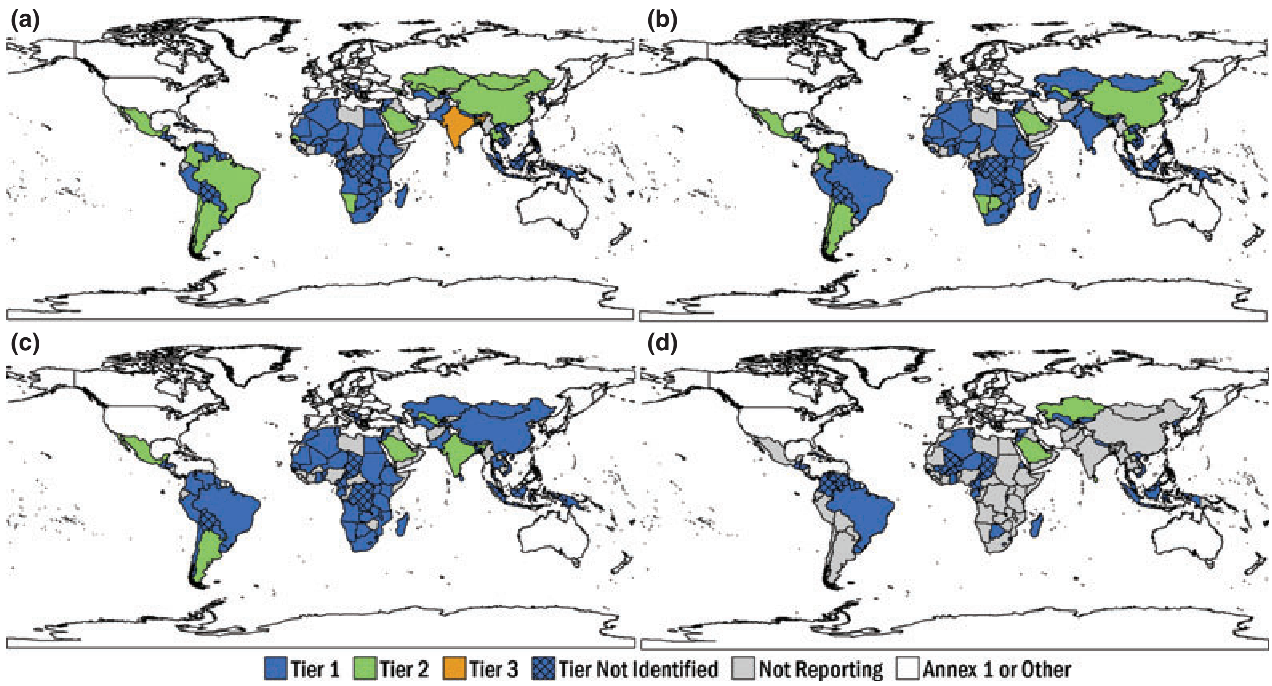

Fig. 1 National GHG Inventory methods that are used in developing countries for estimating emissions from enteric methane (a), manure management (b), agricultural soil N_2O (c), and soil carbon stock changes (d). The data are based on national communications from the countries to the UNFCCC (http://unfccc.int/national_reports/items/1408.php).

respectively (Fig. 1b and c). Moreover, less than one-third of the countries conduct inventories for soil carbon stock changes in agricultural lands (Fig. 1d) (which is reported as part of the land use, land-use change, and forestry sector under the UNFCCC reporting guidelines), even though globally this option has the most potential for reducing GHG emissions from the agricultural sector through restoration of degraded soils and grasslands (Smith *et al.*, 2008). It is noteworthy that developed countries also rely on Tier 1 methods to a certain extent for reporting emissions to the UNFCCC, so this problem is not unique to developing countries (Lokupitiya & Paustian, 2006). Moreover, deriving emission factors for higher tier methods is not a trivial task, requiring adequate emissions data collection, and possibly model development and testing (Ogle *et al.*, 2013).

In addition to emissions factors, a complete set of activity data are required to accurately estimate emissions from the agricultural sector. Activity data provide information on the management of production systems, such as fertilizer usage; livestock population characteristics and manure management; in addition to crop and grazing land management practices (IPCC, 2006). Some of these data are available from a country's national census, remote-sensing data products or surveys. However, there are often gaps due to no data, limited data or only some data on management practices. In turn, this limits GHG reporting to a subset of emission sources from the agricultural sector, or potentially compromises the reported estimates for some sources because the estimation method did not incorporate activity data on all key practices.

The way forward

First, we propose that agricultural research surrounding climate change could be expanded to assess both mitigation and adaptation with more controlled experiments, and evaluate potential synergies and trade-offs for promising management options. This research is critical to enhance evidence-based climate change policy development in the agricultural sector. A more comprehensive synthesis of past research, such as work conducted through the IPCC Climate Change Assessments, would be the first step to highlight specific gaps and needs, and then new research could build from that knowledge base.

Second, development of more accurate emission factors is possible in the near term to provide performance-based outcomes in support of policy and funding programs. To accomplish this goal, the IPCC organizational structure could be used to form dedicated working groups of scientists who would synthesize data and derive emission factors with a focus on populating the IPCC Emission Factor Database.

Currently, emission factors are added to the database on a voluntary basis, and the full potential has arguably not been realized. The goal would be to produce emission factors that are more specific, and thus better suited for estimating emissions within countries. This contrasts with IPCC default emission factors that are representative of average emissions at global or continental scales. A working group of scientists could produce more spatially disaggregated factors either by conducting meta-analyses of field measurements to derive factors empirically, or using field measurements to evaluate process-based models and derive factors (e.g., Smith *et al*., 2012; Ogle *et al*., 2013). Furthermore, an IPCC technical report on emission factors would highlight critical gaps in measurements, and provide a focus for researchers to collect the data needed most for reducing uncertainties.

Third, quantifying performance-based outcomes will also require filling activity data gaps when national level data are not available for agricultural management. International organizations have relevant information that can be used to fill some of the data gaps in the near term. For example, the FAO has a long track record of compiling agricultural activity data at the national level as communicated by its member countries. Indeed, the IPCC has developed a special report about using the FAO data in national GHG inventories (IPCC, 2010). Recent work by FAO has taken this a step further by providing additional guidance for improving GHG inventories including activity data collection, as well as releasing the FAOSTAT GHG emissions database for benchmarking of national emissions (Tubiello *et al*., 2013). If data are not available through existing surveys and databases, another near-term solution would be a survey of experts to fill data gaps based on the methods provided by the IPCC (IPCC, 2006; Maia *et al*., 2010).

Even if data are available from international organizations or through expert surveys in the near term, countries will eventually need to formalize data collection through a national census or survey, or possibly by combining the two (Ogle *et al*., 2013). Resources are often limited for conducting surveys, but the rapid growth of mobile phone technology in developing countries could provide an opportunity to more efficiently gather information. This technology is already enabling the deployment of new applications that provide management and market information directly to farmers (Qiang *et al*., 2011). Mobile applications could be developed for local surveyors or even farmers to report simple yet critical management information, such as the crops that are grown, the amount of fertilization, or application of farmyard manure. Such information, which is difficult or impossible to collect through remote sensing, could be uploaded into databases, along with geo-referencing based on the phone location, and provide national inventory compilers with improved and real time activity data (Paustian, 2012). This technology has the potential to make data collection on agricultural management practices more feasible and cost-effective.

Fourth, demonstration projects could be promoted to move the research and development from concept to reality through a UNFCCC policy initiative favoring action in developing countries. The goal would be to develop robust frameworks in support of climate change adaptation and GHG mitigation programs for the agricultural sector. An initiative could focus on implementing improvements in the measurement, reporting and verification of agricultural GHG emissions, with the proposed assistance from IPCC and other international and national agricultural organizations. For example, the Consultative Group on International Agricultural Research is developing a low-cost protocol for measuring GHG fluxes and tracking crop production in smallholder farms that are common in developing countries (Rosenstock *et al*., 2013). Such protocols could be deployed more broadly through demonstration projects to collect data and derive new emission factors. In addition, mobile phone applications could be tested for gathering activity data on agricultural systems through these projects. An initiative could also promote more research into the benefit of practices for reducing GHG emissions that also increase resilience of agricultural production to climate change (FAO, 2012). Finally, it would be useful to further evaluate which practices are likely to be adopted by farmers in developing countries, along with the technical assistance and investment that is required.

Agriculture is a significant contributor to global anthropogenic emissions of GHGs, while also offering significant potential for their reduction (Smith *et al*., 2008). With a more thorough scientific assessment and positive outcomes from demonstration projects, governments in developing countries would have a solid basis to promote adoption of promising management practices for climate change adaptation and greenhouse gas mitigation through international cooperation in the UNFCCC.

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