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Making trees count: Measurement and reporting of agroforestry in UNFCCC national communications of non-Annex I countries

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ABSTRACT

Agroforestry—the integration of trees with crops and livestock—generates many benefits directly relevant to the UNFCCC's Koronivia Joint Work on Agriculture, including: (i) building resilience, (ii) increasing soil carbon and improving soil health, (iii) providing fodder and shade for sustainable livestock production and (iv) diversifying human diets and economic opportunities. Despite its significance to the climate agenda, agroforestry may not be included in measurement, reporting and verification (MRV) systems under the UNFCCC. Here we report on a first appraisal of how agroforestry is treated in national MRV systems under the UNFCCC. We examined national communications (NCs) and Nationally Determined Contributions (NDCs) of 147 countries, REDD + strategies and plans of 73 countries, and 283 Nationally Appropriate Mitigation Actions (NAMAs), as well as conducted interviews with representatives of 12 countries in Africa, Asia and Latin America. We found that there is a significant gap between national ambition and national ability to measure and report on agroforestry. Forty percent of the countries assessed explicitly propose agroforestry as a solution in their NDCs, with agroforestry being embraced most widely in Africa (71%) and less broadly in the Americas (34%), Asia (21%) and Oceania (7%). Seven countries proposed 10 agroforestry-based NAMAs. Of 73 developing countries that have REDD + strategies, about 50% identified agroforestry as a way to combat forest decline. Despite these intentions, however, agroforestry is not visible in many MRV systems. For example, although 66% of the countries reported non-forest trees in the national inventory, only 11% gave a quantitative estimate of number of trees or areal extent. Interviews revealed institutional, technical and financial challenges preventing comprehensive, transparent inclusion of agroforestry in MRV systems. The absence has serious implications. If such trees are not counted in inventories or climate change programs, then a major carbon sink is not being accounted for. Only if agroforestry resources are measured, reported and verified will they gain access to finance and other support. We discuss four recommendations to better match ability to ambition.

1. Introduction

Integrating trees with crops and livestock, agroforestry provides options for mitigating and adapting to climate change (Griscom et al., 2017). Trees create microclimates reducing ambient temperatures and heat stress, conserving soil moisture and producing nitrogen-rich fodder, thus increasing food availability (Dinesh et al., 2017; Thornton et al., 2017). Trees also generate products themselves, such as fuelwood and fruits, which support energy security and micronutrient adequacy, and diversify incomes (Iiyama et al., 2014; Jamnadass et al., 2011). Tree cover at landscape scale alters regional water cycles; trees recycle rainfall, reduce stormflow and recharge aquifers but can deplete

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groundwater depending on species and density of planting, thereby changing the risks and impacts of droughts and floods (van Noordwijk et al., 2014). Lastly, trees on farms and in landscapes help to mitigate climate change, storing carbon in biomass and soils and reducing atmospheric carbon dioxide loads (Kim et al., 2016; Verchot et al., 2007).

Countries have developed large-scale agroforestry-based programs and policies to meet climate goals. For example, countries across Latin America including Peru, Colombia, Brazil and Costa Rica have developed Nationally Appropriate Mitigation Actions (NAMAs) to scale up silvopastoral cattle production – an agroforestry system where trees are interspersed on grazing lands (Gumucio et al., 2015; Canu et al., 2018). Farmer-managed natural regeneration of trees in West Africa and agroforestry homegardens in East Africa are recognized for their ability to provide nutrient-dense foods during lean seasons (Haglund et al., 2011; Reij and Garrity, 2016; Linger, 2014; Abebe et al., 2010). China's Sloping Land Conversion Program has increased tree cover on a larger area of land than recent tree cover increases in the rest of the world combined (Ahrends et al., 2017).

Despite ambitious plans and programs, there is considerable uncertainty surrounding how agroforestry can be accounted for by countries and programs (Minang and van Noordwijk, 2012). Measurement, reporting and verification (MRV) of trees outside forests and agroforestry is poorly developed (de Foresta et al., 2013; Schnell et al., 2015). The United Nations Framework Convention on Climate Change (UNFCCC) and Intergovernmental Panel on Climate Change (IPCC) provide the methodological basis for land-based MRV systems (Intergovernmental Panel on Climate Change (IPCC, 1996, 2006). Within the requirements and guidance for MRV, however, countries have considerable flexibility in the methods they use. This is true for international reporting to the UNFCCC in National Communications (NCs) and Biennial Update Reports (BURs), and for Nationally Determined Contributions (NDCs), Low Emissions Development Strategies (LEDS) and NAMAs. Flexibility has obvious benefits. One consequence, however, is that many countries struggle with design and implementation of MRV systems for agriculture in general and agroforestry in particular due to technical and institutional challenges (Tulyasuwan et al., 2012; Wilkes et al., 2018, 2011).

Measurement, reporting and verification is a precondition for meeting countries' climate and development goals under the Paris Agreement. Improved quantification of emissions and removals identifies sustainable development options that can have mitigation impacts and can inform countries about the progress and effects of mitigation actions (Olander et al., 2014). Including agroforestry in MRV thus provides visibility to the contributions that agroforestry makes to national and international climate objectives. Robust MRV of agroforestry is a critical step in facilitating access to domestic and international sources of finance and other support. With the decision to establish the Koronivia Joint Work on Agriculture (KJWA), the UNFCCC brought agriculture into international climate negotiations through a joint initiative of the Subsidiary Body for Scientific and Technological Advice and the Subsidiary Body for Implementation. Agroforestry is relevant to the KJWA agenda even though it is not explicitly mentioned in it. Therefore, there is an urgent need for guidance on implementation of MRV of agroforestry to improve accounting of greenhouse gas (GHG) emission reductions and removals due to implementation of low-emission, climate-resilient development strategies, especially given the enhanced transparency requirements under the Paris Agreement.

Although no previous work has specifically examined countries' methods and capacities for MRV of agroforestry, several previous studies have assessed the capacity of non-Annex I countries, i.e., mainly developing countries, in tropical regions to undertake forest monitoring for Reducing Emissions from Deforestation and Forest Degradation (REDD+). Based on the United Nations Food and Agriculture Organization (FAO) Forest Resource Assessment (FRA) country reports for 2005, 2010 and 2015, Romijn et al. (2015) assessed the capacity of non-Annex I countries to produce forest area maps and monitor forest area change; capacities for forest inventories to collect data on species and biomass; and capacities to report biomass and carbon pool changes. The assessment judged that 54 out of 99 countries (55%) had good capacities for detecting forest area change using remote sensing, and that capacities were strong in Latin America and Southeast Asia, while capacities in Africa were considerably lower. However, not all the challenges to MRV are technical. Tulyasuwan et al. (2012) surveyed 35 non-Annex I countries across Africa, Asia and the Americas to better understand the institutional arrangements available for MRV of REDD + . The authors analyzed 10 indicators and found that institutional conditions and readiness varied among regions. A similar pattern was evident as for technical capacities, with Africa having the least well-established institutional arrangements and being more externally dependent for technical capacities than other regions. Therefore, lessons from assessment of MRV for REDD + suggest the potential for MRV of agroforestry to face similar technical challenges such as data compilation, analysis and storage, as well as institutional challenges for coordination and implementation of MRV.

While previous assessments for REDD + hint at possible challenges and opportunities for agroforestry MRV, agroforestry has unique attributes that increase the challenge. First, agroforestry occurs in combination with multiple land use types and is not defined by the IPCC as a land-use category in and of itself (Intergovernmental Panel on Climate Change (IPCC, 1996, 2006). Forthcoming refinements to the IPCC guidelines may help. The 2019 Refinement, to be released soon, will provide guidance for eight categories of agroforestry (Cardinael et al., 2018). However, matching local systems to IPCC classifications is not trivial, so emission impacts remain challenging. The presence of agroforestry across land uses may present technical challenges to its treatment in MRV systems, as well as institutional challenges caused by overlapping or unclear institutional mandates for reporting or lack of clear budget allocations. Second, agroforestry trees themselves often occur over relatively small land areas, making it technically challenging to measure given the diversity of agroforestry systems, the spatial resolution of satellite imagery required to detect small plots or scattered trees, and the lack of existing agroforestry-specific allometric equations, a situation that precludes easy reporting based on either land use inventory or remote sensing (Schnell et al., 2015; Kuyah et al., 2016). Third, unlike forestry and REDD+, agroforestry does not have an international initiative recognized by the UNFCCC that directs attention and resources toward addressing technical and capacity challenges identified by technical bodies and programs such as the FAO Forest Resource Assessment (FRA), United States Agency for International Development's (USAID) SilvaCarbon program or the Global Forest Observations Initiative (GFOI).

Given the political intent communicated by many non-Annex I countries, the technical and institutional challenges, and the importance of agroforestry for UNFCCC objectives, this study reviews how developing countries integrate agroforestry in existing MRV systems. We specifically examined national communications (NCs) and Nationally Determined Contributions (NDCs) of 148 and 147 non-Annex I countries, respectively and conducted interviews with representative of 12 countries in Africa, Asia and Latin America to understand: (1) countries' intentions to promote agroforestry as a climate response, (2) the ways agroforestry is or is not currently represented in MRV systems (i.e., is agroforestry visible in MRV systems?), (3) what methods of measurements are being used, and (4) factors that constrain or enable MRV of agroforestry.

2. Methods

2.1. Conceptual approach

Our assessment focuses only on national-level MRV systems used by Parties to the UNFCCC, including measurement and reporting of national GHG inventories through NCs and BURs. Previous work cited

Fig. 1. Nationally Determined Contributions (N = 147) and National Communications (N = 148) reviewed.

above examined MRV capacities under REDD + processes. Agroforestry in REDD + MRV is also reported elsewhere (Rosenstock et al., 2018). Seven countries including Colombia, Costa Rica, Dominican Republic, Indonesia, Kenya, Rwanda and Uganda have proposed agroforestry-related NAMAs, but MRV systems are yet nascent or undocumented. The Clean Development Mechanism (CDM) and some voluntary market standards have created considerable experience of agroforestry MRV at the project scale (Lee et al., 2018). However, the links between project-scale interventions and MRV of national initiatives under the evolving UNFCCC MRV framework are not yet clear and thus are not considered here.

There are many ways agroforestry is practiced, ranging from living fences and home gardens to woodlots and multi-strata agroforestry. Current definitions emphasize the roles trees play in integrated ecosystem management connecting trees, forests, farms, livelihoods, landscapes and governance (van Noordwijk et al., 2016). Historically, however, narrower definitions focused tightly on trees planted or intentionally managed on croplands and rangelands were more common (Nair and Nair, 2003). Given the wide range of species (e.g., leguminous versus non-leguminous), planting configurations (e.g., intercropping versus boundary planting) and agro-ecologies, there are numerous permutations of agroforestry. We take an inclusive definition of agroforestry that includes common typologies of agroforestry systems such as: agrisilviculture, crop-tree combinations in spaces that include intercrops, parklands and others; silvopastoral, integrated production of livestock and trees on rangelands and pasture; boundary planting, tree-crop-livestock combinations including living fences, windbreaks, etc.; improved fallows, crop-tree combinations rotated in time; shadow systems, crops grown under shade trees; home gardens, tree-crop-livestock combinations around settlements; woodlots, and trees producing other products that occur within a broader farm matrix of mixed crop-livestock-tree production (Feliciano et al., 2018). IPCC Guidelines serve as the framework for inventory compilation (and other MRV systems) in the land use sector. These guidelines include six types of land use: forests, settlements, cropland, grazing, wetland and other lands. It often goes unrecognized that some type of agroforestry can be found on each of these six types of land use (Sinclair, 1999).

While the UNFCCC guidelines for MRV allow for flexibility, they also are designed to ensure adherence to core principles. Specifically, the UNFCCC guidelines for MRV and IPCC guidelines for GHG inventories are based on the principles of consistency, transparency, accuracy, comparability and completeness. A precondition for assessing the application of these principles to agroforestry is that agroforestry must be explicitly represented in reporting. IPCC guidance on consistent representation of lands is intended to ensure that inventories are able to represent land-use categories and land-use conversions consistently over time for complete representation of all land in a country, with data sources, definitions, methodologies and assumptions clearly described to ensure transparency and to ensure that GHG emissions and removals are neither over- nor underestimated. Given that adherence to these principles can be assessed only if agroforestry is explicitly represented, this analysis focuses on analyzing the visibility of agroforestry in NCs.

Following the analysis of visibility, we reviewed the methods used to represent lands and to convert land uses and land-use changes into emissions estimates. To estimate GHG emissions and carbon sequestration requires two pieces of information: first, 'activity data' describing the type and areal extent of a land use, and, second, carbon stock change or GHG emission factors relevant to the expected change over time. MRV systems, therefore, rest on the ability to document and represent the extent of agroforestry in ways that are relevant for reporting (i.e., equivalent to or nested within IPCC land uses) and that register the impacts of agroforestry systems on GHG emissions and removals.

2.2. Data sources and analysis

We conducted a desk review and key informant interviews to compile data on practices and data sources used for MRV. Desk reviews examined developing countries' submissions of NCs (N = 147) and NDCs (N = 148) (Fig. 1). Countries were considered based on non-Annex I classification. Documents were read cover-to-cover and examined by keyword search. Google Translate was used to interpret the text of documents in languages other than English. Each document was examined against criteria indicating whether agroforestry was explicitly or potentially (1) mentioned as a climate action; (2) reported; and (3) what methods were used to quantify and represent it in reports. The project team had weekly meetings to discuss challenges with data extraction and build coherence in approaches (e.g. regarding keywords, data capture, table SI1). Data were summarized by descriptive statistics in Microsoft Excel, and maps were made in ArcGIS.

Key informant interviews complemented the desk reviews. Key informants were typically persons who had some responsibility for national MRV systems related to the UNFCCC. Interviews were based on a set of predetermined questions (table SI2). However, prior to each interview, we used information from the document review and other sources, such as peer-reviewed literature, to provide additional details about the country context and identify topics of particular relevance to each country and stakeholder interviewed. In total, 12 people from 12 countries were interviewed. Countries were selected from those that had significant known interest in agroforestry such as a policy (e.g., Nepal), a relevant agroforestry-based action under development (e.g., Colombia), or a considerable number of explicit mentions of agroforestry in the document review (e.g., Rwanda and Togo). Responses to interview questions and topics discussed were categorized into broad categories of enabling and constraining factors mentioned.

3. Results

3.1. Agroforestry ambitions

Many non-Annex I countries either are already using, or plan to use agroforestry to meet climate goals. Of 148 National Communications (NCs) reviewed, 105 either explicitly mention agroforestry or discuss interventions that could include agroforestry ('potential mentions'). More than 80% of those countries (88 of 105) explicitly refer to agroforestry, with 69% (61 of 88) mentioning it as a solution for mitigation, 72% (63 of 88) for adaptation and 41% (36 of 88) mentioning it for both. Interest in agroforestry is particularly evident in Africa, where some 36 of the 50 countries (71%) analyzed include agroforestry as a climate response measure. However, interest in agroforestry is also apparent in the Americas, where 34% (11 of 32) of countries mention agroforestry (Fig. 2).

As in NCs, agroforestry is mentioned in many developing country NDCs. Out of 148 NDCs examined, 59 (40%) explicitly mention agroforestry as a measure for climate-change mitigation or adaptation. Mentions include: 71% (36 of 50) of African NDCs, 34% (11 of 32) of Americas NDCs, 21% (9 of 44) of Asian NDCs, 7% (1 of 14) of Oceania NDCs and 17% (1 of 6) of European NDCs (Fig. 2).

3.2. Reporting on agroforestry

Virtually all (99 out of 105, or 94%) of the reviewed GHG inventories reported on changes in forest carbon stocks as part of the land-use change and forestry (LUCF) sector inventory. Our review found that 74 or 105 countries (70%) included some non-forest trees in the national GHG inventory. More than 229 terms were used to describe non-forest trees (Fig. 3). The majority of non-forest trees included in NCs are plantation and tree crops, though in some cases trees in pastures were mentioned. However, only sixteen countries gave a quantitative estimate of either the number of trees (range: 300,000 trees in Nepal to 405,104,918 trees in Niger) or the areal extent of trees outside forests (range: 250 ha in Nauru to 2.2 million ha in Tunisia).

The IPCC 1996 Guidelines place reporting of woody biomass carbon dioxide removals within the category "forest and other woody biomass" (Intergovernmental Panel on Climate Change (IPCC, 1996). Trees on lands that do not meet national forest definitions, including various forms of agroforestry, are considered "other woody biomass" and are to be reported in category 5A5, "other woody biomass". IPCC Good Practice Guidance (GPG) (2006) uses a narrower definition of agroforestry systems as woody biomass on croplands that do not meet national definitions for forest land (reporting category 3B2). This definition is consistent with a narrow definition of agroforestry as trees planted or intentionally managed on farms and ranches (Nair et al., 2003). Many countries report only aggregate estimates of emissions and removals from LUCF (i.e., reporting category 5 in Intergovernmental Panel on Climate Change (IPCC, 1996), or a summary figure for category 5A, "changes in forest and other woody biomass stocks" (Fig. 4). More than one third of countries (41 of 105) clearly reported estimated carbon removals for some subcategories of 5A, such as "forest remaining forest" or "cropland remaining cropland", but even fewer reported detailed subcategories within different types of land use or land-use change. Just over 60% (64 of 105) of countries did not report any carbon removal estimates for subcategories of 5A. However, of these countries, 24 did provide either Supplementary tables or narrative explanation that identified trees outside forests (some of which may be agroforestry) as having been included in the estimate of emissions in category 5A.

3.3. Activity data

Area of land use is the primary activity data necessary for calculating inventories for croplands, grasslands, wetlands, forestry and other land uses. The most common data sources used for estimating the areal extent of tree cover in GHG inventories were national forest inventories and analysis of satellite imagery, which were used by 50% and 37%, respectively, of all countries assessed (Table 1). Other data sources included aerial photographs, land cadasters, land-use and vegetation maps, and national statistics. Of the 79 countries that reported a data source for LUCF activity data in their GHG inventory, 42 used two or more data sources. For example, some countries (e.g., Chile and Vietnam) used satellite imagery to assess the area of forest along with statistics reported by government agencies to estimate the area of cropland under orchards or other trees.

Most countries used Tier 1 approaches to quantify carbon stocks and carbon stock changes in the LUCF sector. Tier 1 is the least methodologically complex approach described by IPCC guidelines and makes use of globally representative emission or carbon stock change factors

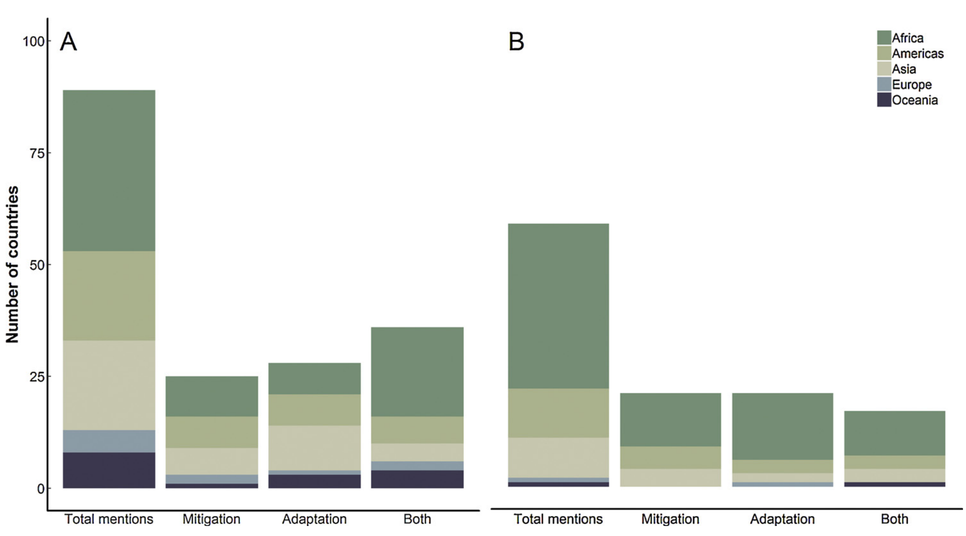

Fig. 2. Explicit mentions of agroforestry in NCs (A) and NDCs (B). "Total mentions" refers to all documents that mention agroforestry irrespective of whether it appeared as a solution for mitigation or adaptation. "Mitigation" are all NDCs or NCs that refers to agroforestry as solution for mitigation while "adaptation" were those that used it as solutions for adaptation. "Adaptation & Mitigation" were those that mentioned Agroforestry as a solution for both.

Fig. 3. Common descriptors of non-forests trees in NCs. Size of word is relative to the number of mentions of each term out of 229 terms used to describe trees outside forests in 74 NCs. Largest and smallest words have 21 and 1 mentions, respectively.

and is recommended for those sinks and sources whose sum accounts for less than 5% of the total GHG inventory in order to reduce the data demands of GHG inventory compilation. In our assessment, 95 out of 147 countries' NCs reported using Tier 1 approaches for estimating at least some land-use emissions and removals. Only 18 countries reported using some Tier 2 approaches, where Tier 2 represents country-specific factors and calculations. Tier 2 approaches would allow countries to set more accurate baselines and better enable them to track change in emissions or removals due to mitigation actions contributing to NDC targets. No countries reported GHGs other than carbon dioxide (e.g., nitrous oxide) from LUCF.

3.4. Perceptions of enabling and constraining conditions

Concerns expressed by the 12 country representatives about agroforestry MRV related to three categories of issues: (1) institutional arrangements and the enabling environment, (2) technical capacity and facilities, and (3) finance. Within these categories key informants identified 10 factors as either an enabler of agroforestry MRV or a constraint (Table 2). The opinions from key informants were diverse. No single factor was discussed by more 50% of the 12 interviewees. The availability of locally relevant carbon stock change factors was discussed most often. A few of the factors were clear constraints. All countries mentioned a lack of sustained funding for MRV, changes in government mandates, and interest and human capacity for data collection and processing as factors limiting the potential to implement MRV for agroforestry. Institutional constraints included the common situation that no single agency is responsible for agroforestry, making it vulnerable to changes in government policies, structures and mandates. Some responses illustrated the different stages of MRV development among the countries, where an enabler for one country was a constraint for another. For example, Nepal mentioned that a relatively low forest threshold (0.5 ha, 10% tree cover) facilitates the inclusion of agroforestry in MRV. The opposite was the case in Bangladesh, where trees outside forests (some of which are agroforestry) were excluded from the forest definition.

4. Discussion

4.1. Visibility in greenhouse gas inventories

Many countries plan to scale up agroforestry to meet climate goals. Forty percent of developing countries explicitly proposed agroforestry as a measure in their NDCs, and that interest is especially high in Africa. The level of stated ambitions for agroforestry found during this assessment was consistent with previous reviews of NDCs (Richards et al., 2015; FAO, 2016) and provides additional evidence of national interest identified from the analysis of NCs. The ambitions to use agroforestry for climate action are further evident as seven countries have registered 10 agroforestry-based NAMAs and about 62% out of 73 REDD + developing countries identify agroforestry as a response measure to combat drivers of forest loss and degradation (Rosenstock et al., 2018).

The level of interest contrasts starkly with the level and quality of current practice. Very few (only two) countries have explicitly provided an estimate of carbon stock or carbon stock changes in non-forest trees in their latest GHG inventories. That a GHG inventory does not provide

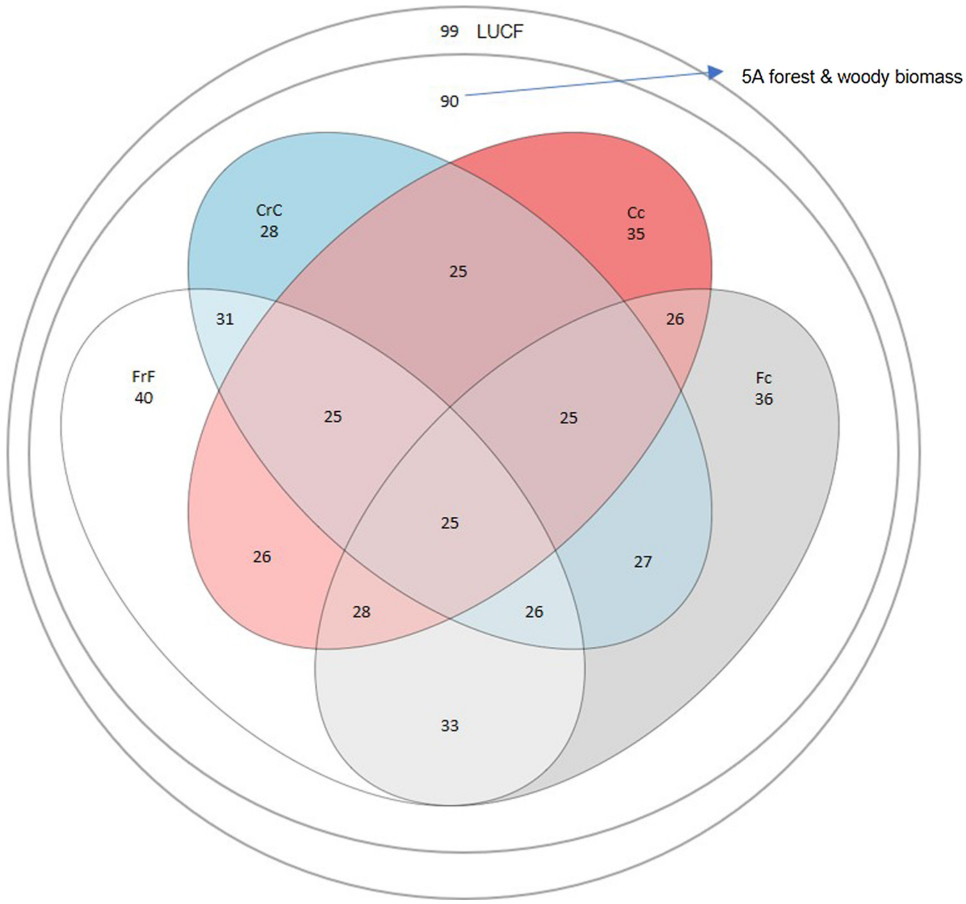

Fig. 4. Frequency of countries reporting at different levels of disaggregation for changes in forest and other wood biomass stocks ($N = 99$). Values refer to the number of countries that report each level. FrF = Forest remaining forests, CrC = Cropland remaining cropland, Cc = Conversion to cropland, Fc = Conversion to Forest.

Table 1
Frequency of countries using various data sources for LUCF activity data in GHG inventories ($N = 105$).

	Trees outside of forests	
	Included	Not included
No. of countries	65	40
Report data sources	50	29
Among countries stating data sources		
National forest inventory	26	11
Satellite imagery	18	12
Global database	12	7
Ministries	30	19
Land cadaster	4	0
Non-Governmental Organization	3	2
Peer review literature	5	8
Other	17	10

explicit quantification of agroforestry or related carbon stock changes does not mean, however, that agroforestry was not quantified in compiling the inventory. Woody biomass not occurring on forest land (as defined in national forest definitions) or cropland may be reported under grassland, wetland, settlements or other land categories (i.e., reporting categories 3B3-3B6 in the Intergovernmental Panel on Climate Change (IPCC, 2006 Guidelines), but may also have characteristics of agroforestry.

Moreover, agroforestry does not occur only on lands outside forests. The IPCC Good Practice Guidance (2000) and IPCC (2006) encourage the use of national forest definitions in classifying forests. These vary considerably based on self-determined thresholds for minimum area (measured in ha), tree cover (measured in percent of land surface), and tree height (measured in meters). The consequence is that many types of agroforestry are included in the “forest” category where national forest definitions are met (i.e., reporting categories 5A1-5A3 in the Intergovernmental Panel on Climate Change (IPCC, 1996 Guidelines or 3B1 in the Intergovernmental Panel on Climate Change (IPCC, 2006 Guidelines). For example, in Cameroon, cacao agroforests have as much as 88% tree cover (Bisseleua et al., 2009) and therefore meet the forest definition. In addition, some countries' systems for representation of lands distinguish between forested forest land and non-forested forest land (i.e., land considered forest land but without trees meeting national forest definitions, such as recently afforested land). Thus, while some types of agroforestry are accounted for under these systems, the nature of the categories used inhibits transparency about the nature of the agroforestry system in reporting.

Limited visibility of agroforestry may be in part a consequence of the reporting mechanism. National communications present only a summary of the national GHG inventory, and many countries report only aggregate estimates of emissions and removals from LUCF. Even when agroforestry has been quantified, it may not appear explicitly within the inventory because disaggregated sub-categories of LUCF are not presented. However, we found that where countries did report methods or land use categories more transparently and according to more granular categories, sub-categories of forest and woody biomass stocks, including agroforestry, become more visible. This is a challenge because only if trees are explicitly recognized and counted will investments be directed toward this mitigation option. For other countries, transparency often falls victim to the constraints of reporting

Table 2
Factors that constrain and enable MRV of agroforestry mentioned during key informant interview. Constraints = orange, Enablers = green, Items identified as both at different points in the interview = grey. (For interpretation of the references to colour in this table, the reader is referred to the web version of this article.)

Factor	Ethiopia	Bangladesh	Bolivia	Chile	Colombia	Indonesia	Nepal	Peru	Rwanda	St. Lucia	Togo	Vietnam
Institutional arrangement and enabling environment												
Political support		orange								green		
Definitions of forest	orange	orange					green			grey		
Changes in government mandates and interest			orange						orange	orange		
Conflicting or unclear mandates			orange			grey		orange	orange			
Technical facilities and capacities												
Clear representation of land		green	orange			grey				orange		
Resolution of available satellite imagery		green	orange			orange		green	orange	orange		
Availability of locally relevant stock change factors			green	grey	green			orange	orange			orange
Human capacity for data collection or processing	orange		orange						orange	orange	orange	
Project-level experience with MRV					grey	green						
Finance												
Sustained funding or cost of MRV	orange					orange				orange	orange	orange

methods, with the consequence that it is virtually impossible to determine whether agroforestry plays any significant role in the GHG inventories of most countries, even though they are reporting changes in standing stocks of carbon.

4.2. Methods for quantification

Estimates of GHG emissions and carbon sequestration require two pieces of information: activity data and carbon stock change factors relevant to the expected change over time. Quantification of the changes due to agroforestry, therefore, rests on the ability to document and represent the extent of agroforestry in ways that are relevant for reporting and that register the impacts of agroforestry systems on GHG emissions and removals.

National forest inventories are most the most common data source used by countries to classify land use. National definitions of forest vary, as does the scope of forest inventories. However, inclusion of non-forest lands in national forest inventories has been increasing over time. Reporting on the category of ‘other land with tree cover’ (OlwTC) increased from 61 countries in UN FAO Forest Resource Assessment 2005 to 77 in 2010 and 79 in 2015 (Forest Land Use Data Explorer (FLUDE, 2017). In addition, in the 2015 Global Forest Resources Assessment (FAO, 2015), 167 countries reported on ‘other wooded land’, i.e., land not defined as ‘forest’ covering more than 0.5 ha with trees higher than 5 m and canopy cover 5–10% not predominately under agriculture or urban land use. Inclusion of agroforestry in categories mapped to national forest inventories therefore supports the inclusion of these types of agroforestry in national GHG inventories.

Satellite imagery is another common data source commonly used to classify land use. The resolution of the satellite imagery has a significant impact on the ability to identify trees outside forests and agroforestry (Schnell et al., 2015). For example, the resolution of imagery necessary for picking up scattered trees may be high (2.5 m or less) while moderate resolution imagery (30 m) may be adequate for picking up stands of trees or those in boundary planting. Some countries (e.g., Bangladesh) have completed specific studies of trees outside of forest using remote-sensing imagery, indicating the high potential of this kind of analysis to contribute to inventory improvements (Potapov et al., 2017). By overlaying vegetation map layers on land-use layers, trees or shrubs outside administratively defined forests (e.g., on croplands or in settlements) may be clearly distinguished, enabling quantification of the contributions of agroforestry to carbon-stock changes at the national level (Zomer et al., 2016).

Guidelines suggest that many, though not all, countries ought to use Tier 2 methods for quantifying the contribution of agroforestry, and yet very few do. We found that countries overwhelmingly use IPCC Tier 1 approaches to quantify forest carbon stocks and stock changes. This finding is consistent with other studies that suggest capacities for reporting carbon pools at higher tiers are limited in tropical developing countries (Romijn et al., 2015). The pattern of using Tier 1 emission factors begets the question of whether these are sufficient to accurately represent agroforestry in MRV systems. Stock change factors are included in IPCC guidance according to the land use. When agroforestry meets the forest definition and the land was previously forest, stock change factors relevant for forests remaining forests would be applicable (e.g., Tables 4.7–4.12, IPCC (2006)) and are provided as ranges of Mg C/ha/yr based on climate, ecological zone and age by continent. Values range from 0.4 Mg C/ha/yr (natural boreal forests) to 15.0 Mg C/ha/yr (tropical forest plantations). However, when agroforestry occurs on other land uses such as cropland, biomass accumulation rates are lower (1.8–10.0 Mg C/ha/yr) depending on climate and moisture. One recent meta-analysis looking at carbon sequestration (e.g., stock change) rates in agroforestry systems globally found that rates average 8.4 Mg C/ha/year, with approximately 75% being biomass (above and belowground) (Kim et al., 2016). Another meta-analysis suggested that stock change rates could be either lower or higher, ranging between 0.52–12.63 Mg C/ha/yr for aboveground biomass C depending on the climate and system (Feliciano et al., 2018). Comparison of these values suggests that Tier 1 stock change factors in the IPCC generally cover the range of values found in specific studies on aboveground carbon accumulation by different species. However, there is significant variation in the rate of C stock change by region and system. In some systems, the variance is 100% of the mean, suggesting significant uncertainty when using values derived from other locations (Cardinael et al., 2018). High variability increases the uncertainty in estimates of agroforestry carbon stock changes where Tier 1 estimates are used and highlights the potential benefits of using national data for carbon stock change factors (Tier 2) when carbon removals by agroforestry are likely to be a key category in the GHG inventory. Countries without country-specific data will be supported in accounting for agroforestry by the provision in the upcoming 2019 Refinement to the IPCC Guidelines of Tier 1 estimates disaggregated by agroforestry systems and land use.

The utility of using a higher tier carbon stock change factor (i.e., Tier 2), is clear only if the land use is classified at a resolution to match the stock change factors. Analysis of national GHG inventory capacities suggests that many developing countries still face challenges with the adequate and consistent representation of lands. Although countries could improve the accuracy of GHG estimates for agroforestry by adopting Tier 2 carbon stock change factors, the representation of land uses at an appropriate resolution is a precondition for their application. Further analysis is needed to compare the relative costs and benefits, in terms of increased accuracy and reduced uncertainty, of improving representation of agroforestry or moving toward nationally specific stock change factors considering also the policy needs of the country beyond UNFCCC reporting. The high level of policy interest in agroforestry, however, suggests that more explicit representation of agroforestry in GHG inventories would have benefits for formulation and monitoring of policies and programs.

Our assessment of the representation of lands and stock change factors also identified some concerns with transparency and completeness, two key principles for MRV. For example, a fourth of the countries did not report the methods used for representing lands in their inventories, making it difficult to know what was included. If agriculture, forestry and other land use (AFOLU) response options are implemented as part of countries' NDCs and reported on through national GHG inventories, transparency in representation of land uses is imperative to represent the changes attributed to climate actions over time.

4.3. Enabling environment for agroforestry MRV

Key informants identified ten factors that either constrain or enable MRV of agroforestry. Many of the factors were common across countries, calling attention to certain more universal issues, while others were identified by only one country. The fact that ten unique factors were identified in only 12 interviews speaks to the diversity of challenges countries face in attempting to better represent agroforestry in MRV. Though 12 interviews cannot be considered exhaustive, the conversations quickly converged around the identified constraints, thereby indicating generalizable issues that will require attention. Nevertheless, a more detailed survey of a larger number of countries, perhaps analogous to Tuyasuman et al. (2012), is needed to better hone in on specific obstacles in different country contexts and develop appropriate guidance for countries.

Technical capacity was one of the most widely stated constraints. Specific constraints mentioned included lack of access to costly high-resolution satellite imagery and unreliable statistical reporting methods. Multiple countries also cited the definition of forest as a significant influence, both enabling and constraining MRV of agroforestry. Meanwhile, inconsistencies among the local definition, FAO definition and IPCC definition caused confusion and asymmetry between national and international reporting systems. Where countries have made progress on including agroforestry in GHG inventories, they have managed to overcome some of these technical constraints, for example by including agroforestry in regular statistical reporting, finding ways to access high-resolution satellite imagery, and using multiple data sources for different types of forests.

Beyond data and techniques, inventory improvement requires a supportive institutional environment. A number of respondents noted challenges related to the institutional and political environment surrounding MRV of agroforestry. Institutional arrangements have been identified as a key factor for success of MRV of REDD+ (Romijn et al., 2012; Ochieng et al., 2016; Neeff et al., 2017), and Tulyasuwan et al. (2012) report on 10 key factors and institutional arrangements that constrain REDD + monitoring, many of which are consistent with the challenges found here, such as weak coordination among government agencies or GHG inventory compilation agencies that are dependent on external capacities. Multi-institution coordination around land use and a supportive legal and policy environment for integrative land use provide political impetus for the GHG inventory to improve the quantification of biomass stocks on different land use types. Inventory improvements have also been facilitated by the involvement of diverse stakeholders; the involvement of research organizations as well as farmer and producer organizations; and the delegation to ministries of responsibilities for monitoring progress towards NDC targets. In short, the interviews suggested that inclusion of agroforestry in MRV systems and improvement in MRV of agroforestry relies on a supportive legal and policy environment for integrative land use; when mandates for GHG quantification are clear; when stakeholders clearly perceive the benefits of investing in MRV; and when institutional arrangements are put in place to support collaboration.

Finance remains a persistent challenge for developing countries' MRV activities, with most countries interviewed mentioning funding as a constraint. Countries lacked sufficient funds to organize meetings to build consensus around definitions and methods and to purchase high-resolution satellite imagery capable of capturing scattered trees or retain staff after donor-funded MRV projects come to an end. Some MRV of trees outside forests clearly benefited from internationally supported programs, such as USAID's SilvaCarbon program, or where funds were available for development of specific investment proposals. GHG inventory preparation often has been funded by the Global Environment Facility (GEF), and additional funds have become available through the GEF-managed Capacity Building Initiative for Transparency. However, in the near term, finance is likely to remain the key practical constraint for MRV of agroforestry.

5. Conclusions: recommendations for improvement

Our review of MRV practices under the UNFCCC illustrates both the technical and institutional challenges to measuring the GHG effects of agroforestry and trees outside forests and highlights the frequent gaps between national ambitions and national capabilities. That gap is smaller in some countries than in others, but no non-Annex I country has succeeded in fully closing it. Major challenges include but are not limited to the need to: clarify and refine land-use definitions to include agroforestry; define institutional mandates as they relate to agroforestry; strengthen technical capacities and resources for data collection and management; and improve transparency in reporting. Further research and investment are needed to operationalize broad-scale MRV of agroforestry. We make four recommendations:

1 *Develop accessible approaches for representation of lands with agroforestry*. Costs, time, capacity and complexity stand in the way of countries including agroforestry in MRV in a consistent and comprehensive way. Development of cost-effective and lower-technology ways to represent lands with agroforestry will be essential. Recent progress with remote sensing is promising. However, many of the advances in representing and documenting the extent of agroforestry are still far beyond the capacities of many countries. Approaches that can leverage freely available high-resolution imagery and local knowledge should be further explored (Bey et al., 2016; Kelley et al., 2018). Capacity building of technicians and institutions will be needed irrespective of the technological methods advanced.

2 *Create guidelines for agroforestry reporting to improve relevance to national policy and transparency*. We found that even if agroforestry had been quantified, it would not have been found in 60% of the inventories due to the way the inventories and NC document are structured. That is, agroforestry may be captured in other land use categories but not necessarily identified as agroforestry. This represents a missed opportunity when the contributions of agroforestry are being quantified and included, and an imperative for change when they are not. Both situations require adjustments in the coming years given recent decisions on the transparency framework under the Paris Agreement, the need for consistency and completeness in the compilation of inventories, and the need for

reporting on NDCs. Building on the finding of this assessment, guidelines are needed to support increased transparency in reporting. The guidelines should be designed to align with commonly used reporting software and IPCC Guideline revisions.

3 *Develop carbon stock change and emission factor data and databases relevant for reporting requirements*. Many countries report using Tier 2 emission factors within REDD + MRV and often state that much of the information is available not in scientific literature but rather in grey literature. These data are often at the lowest level of species allometries which do not match the ways countries (and projects) need to apply them, which is typically aggregated to the coarse level of the typology, if not to the land use level. Recent meta-analyses by Cardinael et al. (2018); Feliciano et al. (2018) and Kim et al. (2016) compiled the available stock change and emission factors using a consistent typology of agroforestry systems. These analyses could be built upon. Investment in compiling information from countries' grey literature and linking the data to climate, agroecosystem and agroforestry systems would provide a readily available resource and encourage international collaboration for more consistent and transparent reporting.

4 *Navigate the institutional arrangements needed to include agroforestry in MRV*. Interviewees called attention to a range of institutional conditions that support or discourage the inclusion of agroforestry in MRV systems. Capacity building on good practices for cross institutions collaboration that address and clarify institutional arrangement would help catalyze change.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.agee.2019.106569.

References

Abebe, T., Wiersum, K.F., Bongers, F., 2010. Spatial and temporal variation in crop diversity in agroforestry homegardens of southern Ethiopia. Agroforest. Syst. 78, 309–322. https://doi.org/10.1007/s10457-009-9246-6.

Ahrends, A., Hollingsworth, P.M., Beckschäfer, P., Chen, H., Zomer, R.J., Zhang, L., Wang, M., Xu, J., 2017. China's fight to halt tree cover loss. Proc. R. Soc. B. 284, 20162559. https://doi.org/10.1098/rspb.2016.2559.

Bey, A., Díaz, A.S.P., Maniatis, D., Marchi, G., Mollicone, D., Ricci, S., Bastin, J.F., Moore, R., Federici, S., Rezende, M., Patriarca, C., Turia, R., Gamoga, G., Abe, H., Kaidong, E., Miceli, G., 2016. Collect earth: land use and land cover assessment through augmented visual interpretation. Remote Sens. 8. https://doi.org/10.3390/rs8100807.

Bisseleua, D.H.B., Missoup, A.D., Vidal, S., 2009. Biodiversity conservation, ecosystem functioning, and economic incentives under cocoa agroforestry intensification. Conserv. Biol. 23, 1176–1184. https://doi.org/10.1111/j.1523-1739.2009.01220.x.

Canu, F.A., Wretlind, P.H., Audia, I., Tobar, D., Andrade, H.J., 2018. Nama for a Low Carbon and Climate Resilient Livestock Sector in Honduras.

Cardinael, R., Umulisa, V., Toudert, A., Olivier, A., Bockel, L., Bernoux, M., 2018. Revisiting IPCC Tier 1 coefficients for soil organic and biomass carbon storage in agroforestry systems. Environ. Res. Lett. 13, 124020. https://doi.org/10.1088/1748-9326/aaeb5f.

de Foresta, H., Somarriba, E., Temu, A., Boulanger, D., Feuilly, H., Gauthier, M., 2013. Towards the Assessment of Trees Outside Forests, Forests, Trees and Livelihoods. Rome. .

Dinesh, D., Campbell, B.M., Bonilla-findji, O., Richards, M., 2017. 10 Best Bet Innovations for Adaptation in Agriculture: A Supplement to the UNFCCC NAP Technical Guidelines 70.

FAO, 2015. Global Forest Resources Assessment. Food and Agriculture Organization of the United Nations, Rome.

FAO, 2016. The Agriculture Sectors in the Intended Nationally Determined Contributions. Rome. .

Feliciano, D., Ledo, A., Hillier, J., Nayak, D.R., 2018. Which agroforestry options give the greatest soil and above ground carbon benefits in different world regions? Agric. Ecosyst. Environ. Appl. Soil Ecol. 254, 117–129. https://doi.org/10.1016/j.agee.2017.11.032.

Forest Land Use Data Explorer (FLUDE). 2017. http://www.fao.org/ecosystem-services-biodiversity/resources/resources-archive/en/?page=10&ipp=10&no_cache=1&tx_dynalist_pi1[par]=YToxOntzOjE6IkwiO3M6MToiMCI7fQ==. (Accessed 6 August 2017).

Griscom, B.W., Adams, J., Ellis, P.W., Houghton, R.A., Lomax, G., Miteva, D.A., Schlesinger, W.H., Shoch, D., Siikamäki, J.V., Smith, P., Woodbury, P., Zganjar, C., Blackman, A., Campari, J., Conant, R.T., Delgado, C., Elias, P., Gopalakrishna, T., Hamsik, M.R., Herrero, M., Kiesecker, J., Landis, E., Laestadius, L., Leavitt, S.M., Minnemeyer, S., Polasky, S., Potapov, P., Putz, F.E., Sandermanc, J., Silvius, M., Wollenberg, E., Fargione, J., 2017. Natural climate solutions symposium. Proc. Natl. Acad. Sci. 114, 1–6. https://doi.org/10.1073/pnas.1710465114.

Gumucio, T., Mora Benard, M.A., Clavijo, M., Hernández, M.C., Tafur, M., Twyman, J., 2015. Silvopastoral Systems in Latin America: Mitigation Opportunities for Men and Women Livestock Producers. CCAFS Policy Brief. CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS), Copenhagen. https://hdl.handle.net/10568/69151.

Haglund, E., Ndjeunga, J., Snook, L., Pasternak, D., 2011. Dry land tree management for improved household livelihoods: farmer managed natural regeneration in Niger. J. Environ. Manage. 92, 1696–1705. https://doi.org/10.1016/j.jenvman.2011.01.027.

Iiyama, M., Neufeldt, H., Dobie, P., Njenga, M., Ndegwa, G., Jamnadass, R., 2014. The potential of agroforestry in the provision of sustainable woodfuel in sub-Saharan Africa. Curr. Opin. Environ. Sustain. 6, 138–147. https://doi.org/10.1016/j.cosust.2013.12.003.

Intergovernmental Panel on Climate Change (IPCC), 1996. Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories. Available at:. http://www.ipcc-nggip.iges.or.jp/public/gl/invs1.html.

Intergovernmental Panel on Climate Change (IPCC), 2000. In: Penman, J., Kruger, D., Galbally, I., Hiraishi, T., Nyenzi, B., Emmanuel, S., Buendia, L., Hoppaus, R., Martinsen, T., Meijer, J., Miwa, K., Tanabe, K. (Eds.), Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories. IPCC/OECD/IEA/IGES, Hayama, Japan.

Intergovernmental Panel on Climate Change (IPCC), 2006. In: Eggleston, H.S., Buendia, L., Miwa, K., Ngara, T., Tanabe, K. (Eds.), 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Prepared by the National Greenhouse Gas Inventories Programme. Published: IGES, Japan.

Jamnadass, R.H., Dawson, I.K., Franzel, S., Leakey, R.R.B., Mithöfer, D., Akinnifesi, F.K., Tchoundjeu, Z., 2011. Improving livelihoods and nutrition in sub-Saharan Africa through the promotion of indigenous and exotic fruit production in smallholders' agroforestry systems: a review. Rev. Int. Serv. Sante Forces Armees 13, 338–354. https://doi.org/10.1505/146554811798293836.

Kelley, L.C., Pitcher, L., Bacon, C., 2018. Using google earth engine to map complex shade-grown coffee landscapes in Northern Nicaragua. Remote Sens. 10, 952. https://doi.org/10.3390/rs10060952.

Kim, D., Kirschbaum, M.U.F., Beedy, T.L., 2016. Carbon sequestration and net emissions of CH_4 and N_2O under agroforestry: Synthesizing available data and suggestions for future studies. Agriculture, Ecosyst. Environ. 226, 65–78. https://doi.org/10.1016/j.agee.2016.04.011.

Kuyah, S., Mbow, C., Sileshi, G.W., van Noordwijk, M., Tully, K.L., Rosenstock, T.S., 2016. Quantifying tree biomass carbon stocks and fluxes in agricultural landscapes. Methods for Measuring Greenhouse Gas Balances and Evaluating Mitigation Options in Smallholder Agriculture. https://doi.org/10.1007/978-3-319-29794-1.

Lee, D., Llopis, P., Waterworth, R., Roberts, G., Pearson, T., 2018. Approaches to REDD+ Nesting: Lessons Learned From Country Experiences. Washington, D.C.. .

Linger, E., 2014. Agro-ecosystem and socio-economic role of homegarden agroforestry in Jabithenan District, North-Western Ethiopia: implication for climate change adaptation. Springer Plus 3, 154. https://doi.org/10.1186/2193-1801-3-154.

Minang, P.A., van Noordwijk, M., 2012. Design challenges for achieving reduced emissions from deforestation and forest degradation through conservation: leveraging multiple paradigms at the tropical forest margins. Land Use Policy 31, 61–70. https://doi.org/10.1016/j.landusepol.2012.04.025.

Nair, P.R., Nair, V.D., 2003. Carbon storage in North American agroforestry systems. In: Kimble, J.M., Lal, R., Birdsey, R., Heath, L.S. (Eds.), The Potential of US Forest Soils to Sequester Carbon and Mitigate the Greenhouse Effect. CRC Press, Boca Raton, USA, pp. 333–346.

Neeff, T., Somogyi, Z., Schulthesis, C., Mertens, E., Rock, J., Brötz, J., Dunger, K., Oechmichen, K., Federici, S., 2017. Assessing progress in MRV capacity development: experience with a scorecard approach. Clim. Pol 1-11.10.1080/14693062.2015.1075375.

Ochieng, R.M., Visseren-Hamakers, I.J., Arts, B., Brockhaus, M., Herold, M., 2016. Institutional effectiveness of REDD+ MRV: countries progress in implementing technical guidelines and good governance requirements. Environ. Sci. Technol. 61, 42–52. https://doi.org/10.1016/j.envsci.2016.03.018.

Olander, L.P., Wollenberg, E., Tubiello, F.N., Herold, M., 2014. Synthesis and review: advancing agricultural greenhouse gas quantification. Environ. Res. Lett. 9, 075003. https://doi.org/10.1088/1748-9326/9/7/075003.

Potapov, P., Siddiqui, B.N., Iqbal, Z., Aziz, T., Zaman, B., Islam, A., Pickens, A., Talero, Y., Tyukavina, A., Turubanova, S., Hansen, M.C., 2017. Comprehensive monitoring of Bangladesh tree cover inside and outside of forests, 2000–2014. Environ. Res. Lett. 12, 104015. https://doi.org/10.1088/1748-9326/aa84bb.

Reij, C., Garrity, D., 2016. Scaling up farmer-managed natural regeneration in Africa to restore degraded landscapes. Biotropica 48, 834–843. https://doi.org/10.1111/btp.12390.

Richards, M., Gregersen, L., Kuntze, V., Madsen, S., Oldvig, M., Vasileiou, I., 2015. Agriculture's Prominence in the INDCs. CCAFS InfoNote, Copenhagen.

Romijn, E., Herold, M., Kooistra, L., Murdiyarso, D., Verchot, L., 2012. Assessing capacities of non-Annex I countries for national forest monitoring in the context of REDD+. Environ. Sci. Policy 19, 33–48.

Romijn, E., Lantican, C.B., Herold, M., Lindquist, E., Ochieng, R., Wijaya, A., Murdiyarso, D., Verchot, L., 2015. Assessing change in national forest monitoring capacities of 99 tropical countries. For. Ecol. Manage. 352, 109–123. https://doi.org/10.1016/j.foreco.2015.06.003.

Rosenstock, T., Wilkes, A., Jallo, C., Namoi, N., Bulusu, M., Mboi, D., 2018. Making Trees Count in Africa: Improved MRV is Needed to Meet Africa's Agroforestry Ambitions. CCAFS Info Note. CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS), Wageningen, The Netherlands. https://hdl.handle.net/10568/98831.

Schnell, S., Kleinn, C., Stahl, G., 2015. Monitoring trees outside forests: a review. Environ. Monit. Assess. 187, 600. https://doi.org/10.1007/s10661-015-4817-7.

Sinclair, F.L., 1999. A general classification of agroforestry practice. Agroforest. Syst. 46, 161–180. https://doi.org/10.1023/A:100627892.

Thornton, P.K., Rosenstock, T.S., Förch, W., Lamanna, C., Bell, P., Henderson, B., Herrero, M., 2017. A qualitative evaluation of CSA options in mixed crop-livestock systems in developing countries. Climate Smart Agriculture: Building Resilience to Climate Change. Springer, Netherlands. https://doi.org/10.1007/978-3-319-61194-5.

Tulyasuwan, N., Henry, M., Secrieru, M., Jonckheere, I., Federici, S., 2012. Issues and challenges for the national system for greenhouse gas inventory in the context of REDD+. Greenh. Gas Meas. Manag. 2, 73–83. https://doi.org/10.1080/20430779.2012.716298.

van Noordwijk, M., Namirembe, S., Catacutan, D., Williamson, D., Gebrekirstos, A., 2014. Pricing rainbow, green, blue and grey water: tree cover and geopolitics of climatic teleconnections. Curr. Opin. Environ. Sustain. 6, 41–47. https://doi.org/10.1016/j.cosust.2013.10.008.

van Noordwijk, M., Coe, R., Sinclair, F., 2016. Central Hypotheses for the Third Agroforestry Paradigm within a Common Definition. Bogor, Indonesia. .

Verchot, L.V., van Noordwijk, M., Kandji, S.T., Tomich, T.P., Ong, C., Albrecht, A., Mackensen, J., Bantilan, C., Anupama, K.V., Palm, C.A., 2007. Climate change: linking adaptation and mitigation through agroforestry. Mitig. Adapt. Strateg. Glob. Change 12, 901–918. https://doi.org/10.1007/s11027-007-9105-6.

Wilkes, A., Dijk, Van, S., Reisinger, A., 2018. Measurement, Reporting and Verification of Livestock GHG Emissions by Developing Countries in the UNFCCC: Current Practices and Opportunities for Improvement. Wageningen, Netherlands. .

Wilkes, A., Shiping, W., Tennigkeit, T., Jiexi, F., 2011. Agricultural Monitoring and Evaluation Systems: What Can We Learn for the MRV of Agricultural NAMAs? (No. 126). Nairobi. .

Zomer, R.J., Neufeldt, H., Xu, J., Ahrends, A., Bossio, D., Trabucco, A., Van Noordwijk, M., Wang, M., 2016. Global Tree Cover and Biomass Carbon on Agricultural Land: the contribution of agroforestry to global and national carbon budgets. Sci. Rep. 6, 29987. https://doi.org/10.1038/srep29987. (2016).