GHG Emission Assessment Guideline
Volume I: Soil Carbon and Nitrogen Stock Assessment in Agricultural Land and Agroforestry Systems

Field Guide for Practitioners

FEDERAL DEMOCRATIC REPUBLIC OF ETHIOPIA
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TABLE OF CONTENTS

ACRONYMS

GHG	Greenhouse Gas
GPG	Good Practice Guide
GPS	Geographical Positioning System
IPCC	Intergovernmental Panel on Climate Change
LULUCF	Land Use, Land Use Cover Change and Forestry
MRV	Measurement, Reporting and Verifications
NAMAs	Nationally Appropriate Mitigation Actions
PDD	Project Design Document
PIN	Project Idea Note
SOC	Soil Organic Carbon
SIC	Soil Inorganic Carbon
UNFCCC	United Nations Framework Convention on Climate Change

USERS OF THE MANUAL

This manual is compiled to serve as a field guide for practitioners, who conduct soil Carbon and Nitrogen stock assessment in different land use types in Ethiopian Agricultural systems. The manual can also be used in similar landscapes in the tropics. Besides, academic institutions and researchers may find it as a useful reference material to offer short-term courses on soil carbon and nitrogen stock assessment for students and practitioners.

PREFACE

The manual presents roles of soil and agricultural practices in climate change mitigation, steps to be followed to collect relevant field data the field and computational procedures for accurate soil carbon and nitrogen stocks estimations in different agricultural systems and practices.

Relevant materials on climate change, soil carbon and nitrogen stock assessment including sourcebooks, guidelines, procedures, etc. were consulted to enrich the manual. The manual is expected to provide practical guidance for practitioners who would like to conduct soil carbon and nitrogen stock assessments for emission trading, and other research activities in Ethiopia.

The manual is specifically designed to capture the local context in Ethiopia, based on its unique landscape and vegetation. The soli carbon and nitrogen stock assessment methods and techniques described in this manual are consistent with the IPCC (2003) GPG and (2006) GPG for Land Use, Land-Use Change and Forestry. The manual, however, shouldn't be considered as an exhaustive document. Users are advised to consult relevant references, IPPC guidelines, and the like for further details

I. INTRODUCTION

Soils are among the largest terrestrial reservoirs of carbon and hold potential for expanded Carbon sequestration. Soils sink carbon and release to the atmosphere when the equilibrium (i.e. inflow and outflow) carbon content is disrupted due to human actions such as land use change, precipitation, temperature, etc. During this process, soil may act as a carbon source or a carbon sink according to the ratios between inflows and outflows. Thus, they are critically important in determining global carbon cycle dynamics and can provide a potential way to reduce atmospheric concentration of carbon dioxide.

Soil carbon pool comprises of Soil Organic Carbon (SOC) and Soil Inorganic Carbon (SIC). The SOC pool includes highly active humus to relatively inert charcoal Carbon. The SIC pool includes elemental Carbon and carbonate minerals (e.g. gypsum, calcite, dolomite, aragonite and siderite). The SOC pool represents a dynamic balance between gains and losses. The amount changes over time depending on photosynthetic Carbon added and the rate of its decay. Under undisturbed natural conditions, inputs of carbon from litter fall and root biomass are cycled by output through erosion, organic matter decomposition, and leaching. Soils in tropical regions are low in SOC particularly those under the influence of arid, semiarid and sub-humid climates and this are a major factor contributing to their poor productivity. Therefore, proper management of SOC is important for sustaining soil productivity and ensuring food security as well as protection from land degradation.

II. SOIL CARBON STOCK ASSESSMENT METHODS

Soil carbon assessment in different parts of the world requires methods that are appropriate to the circumstances. Many different methods have been tested in a number of countries, but effort is required to ensure that the methods are comparable. Furthermore, for carbon projects, credible and cost-effective techniques of monitoring changes in soil carbon are required. Soil carbon assessment methods can be broadly classified into direct and indirect methods depending on whether carbon content in soil samples is directly measured or inferred through a proxy variable. There are several factors, which should be taken into consideration when selecting a method for the determination of soil organic carbon. These factors include the ease of use, health and safety concerns, cost, sample throughput, and comparability to standard reference methods. These factors are a concern for both the sample preparation and sample quantitation phases of SOC determinations.

II.1 THE DIRECT METHOD

The direct soil organic carbon assessment entails collecting soil samples in the field and analyzing them in the laboratory using combustion techniques. The direct methods of measuring carbon in soils in LULUCF projects are based on commonly accepted principles of soil sampling, and ecological surveys. The methods, however, haven't been universally applied to all projects, and not standardized. In the specific case of soils, the depth to which soil carbon pool should be measured and monitored may vary according to project type, site conditions, species, and expected depth at which change will take place. Because the highest concentration of soil organic carbon is in the upper layer of the soil, and it decreases exponentially with increasing depth. The IPCC (2006) recommends the sampling of the top 0.3-m depth of soil for SOC stock measurement or estimation since changes in SOC stock due to land-use change or management are primarily confined to the top 0.1- or 0.3-m depths in most soils. In other words, this is the depth where typically the changes in soil carbon pool are likely to be fast enough to be detected during the project period. Direct methods are more precise and accurate but also more time and labor intensive, involves technically challenging field sampling process as well as very expensive. Most assessments typically involve a combination of direct and indirect techniques. Some *in situ* soil carbon analytical methods are being developed with the objective of offering increased accuracy, precision, and cost-effectiveness over conventional *ex situ* methods. The in situ soil carbon analytical methods include mid-infrared (IR) spectroscopy, near-IR spectroscopy, laser-induced breakdown spectroscopy (LIBS), and inelastic neutron scattering (INS). While LIBS and INS technologies are still in their infancy, IR spectroscopy has proven valuable in developing soil spectral libraries and for rapid characterization of soil properties for soil quality monitoring and other agricultural applications in developed and developing countries.

II.2 INDIRECT METHODS

The direct method, though more precise and accurate, is quite laborious and very expensive. The indirect methods, which comprise the use of *in situ* analytical methods, and the use of biogeochemical models, reduce cost of soil carbon monitoring. Indirect estimation of soil organic carbon changes over large areas using simulation models has become increasingly important. Indirect methods are needed to fill knowledge gaps about the biogeochemical processes involved in soil carbon sequestration. One of the more important indirect methods involves the use of simulation models that project changes in soil organic carbon under varying climate, soil, and management conditions. Although simulation models can have limited accuracy, particularly in the context of developing countries in which land resources data are scarce, they are a cost-effective means of estimating GHG emissions in space and time under a wide range of biophysical and agricultural management conditions. The data can be particularly useful in scaling-up site-specific information to larger scales of magnitude.

A. Options for Estimating Soil Organic Carbon Stock

Under the UNFCCC, countries must estimate and report GHG emissions and removals, including changes in carbon stocks in all five pools (above- and belowground biomass, dead wood, litter and soil carbon) and associated emissions and removals from land use, land-use change and forestry (LULUCF) activities according to the Good Practice Guide (GPG). Measurement, Reporting and Verification (MRV) gives opportunities to developing countries to claim financial, technical and capacity building supports from developed countries to implement their Nationally Appropriate Mitigation Actions (NAMAs). Understanding these benefits, a growing number of developing countries have drafted, adopted and, in some cases, started implementing national climate action plans. However, lack of a robust method of measuring NAMAs and the technical gaps are serious challenges in developing countries. The IPCC has developed standard methods for estimating soil organic carbon stocks and stock changes. These methods are characterized by flexibility, ranging from the Tier 1default method prescribed by IPCC with fixed default values, to methods that incorporate local information to estimate carbon stock changes at Tier 2 level, and to more advanced modeling and measurement based networks at Tier 3 level. The "Tiers" represent increasing level of data requirement and analytical complexity. Despite differences in approach among the three Tiers, all tiers have common adherence to IPCC good practice concepts of *transparency, completeness, consistency, comparability* and *accuracy.* Soil has much more variability than vegetation and therefore needs more sampling effort, which sometimes may exceed the benefits expected from the increase in stock (IPCC, 2003). Therefore developing locally calibrated models that can use easily collected data can minimize the cost of demonstrating a change in soil organic carbon stock.

Tier 1: methods are designed to be the simplest to use, for which equations and default parameter values (e.g., emission and stock change factors) are provided in this volume. It requires no new data collection to generate estimates of forest biomass. Default values, which are available globally such as deforestation rates, agricultural production statistics, and global land cover maps, fertilizer use, livestock population data, etc. can be obtained from the IPCC emission factor database. Its estimation thus provides limited resolution of how soil carbon varies sub-nationally and has a large error range for growing stock in developing countries. Tier 1 has essentially no data collection needs beyond consulting the IPCC table and Emission Factor Data Base (EFDB), corresponding to broad continental forest types.

Tier 2: can use the same methodological approach as Tier 1 but applies emission and stock change factors that are based on country- or region-specific data, for the most important land-use or livestock categories. Country-defined emission factors are more appropriate for the climatic regions, land-use systems and livestock categories in that country. Higher temporal and spatial resolution and more disaggregated activity data are typically used in Tier 2 to correspond with country-defined coefficients for specific regions and specialized land-use or livestock categories.

Tier 3: higher order methods are used including models and inventory measurement systems tailored to address national circumstances, repeated over time, and driven by high-resolution activity data and disaggregated at sub-national level. These higher order methods provide estimates of greater certainty than lower tiers. Such systems may include comprehensive field sampling repeated at regular time intervals and/or GIS-based systems of age, class/production data, soils data, and land-use and management activity data, integrating several types of monitoring. Pieces of land where a land-use change occurs can usually be tracked over time, at least statistically. In most cases these systems have a climate dependency, and thus provide source estimates with inter-annual variability. Detailed disaggregation of livestock population according to animal type, age, body weight etc., can be used. Models should undergo quality checks, audits, and validations and be thoroughly documented. The tier 3 approach requires long term commitments of resources and personnel, generally involving the establishment of a permanent organization to house the program. It is expensive in the developing countries context.

The tiers should be selected on the basis of goal, cost, and significance of the target source/sink, available data and analytical capability. If Tiers 1 or 2 is used both for the reference period and for future monitoring of emissions from soils, the error margin may be so great that the amount of emissions to be claimed and traded could be small make the effort not worthwhile. The IPCC recommends that it is good practice to use higher tiers for measurement of significant sources/sinks.

B. Key Activities in Soil Carbon Stock Assessment

Monitoring and verifying soil carbon sequestration at the project or regional scale require five activities. These include:

Selection of landscape units suitable for monitoring soil carbon changes:	*The selection of landscape monitoring units is based on the responsiveness of the area to land management practices as determined by climate, soil properties, management history, and availability of historical data.*
Development of measurement protocols:	*Protocols for temporally repeated measurements at fixed locations will generally include stratification and selection of sampling sites, sampling depth and volume, measurement of bulk density, laboratory analyses, other ancillary field measurements, and estimation of the marginal cost of carbon sequestration.*
Estimating soil organic carbon controlling parameters:	*information productivity that will be used as input into models such as tillage practices, productivity, amount of crop residue, etc. should be generated. These parameters are fed into biogeochemical models to predict soil carbon sequestration.*
Spatially explicit biogeochemical modeling:	*Models are used to determine soil carbon changes over large areas. They are useful for understanding soil properties-land management interactions and for predicting soil carbon sequestration. They can simulate full ecosystem-level carbon balance, multiple land uses, or several land management practices.*
Scaling-up the results to the entire project area:	*Scaling-up to larger areas requires integration from a variety of sources including field measurements, existing databases, models, geographical information systems, and remote sensing.*

III. STEPS FOR THE INDIRECT SOIL CARBON ASSESSMENT METHOD

3.1 Overview of Soil Carbon

Cropland management modifies soil C stocks to varying degrees depending on how specific practices influence C input and output from the soil system. The main management practices that affect soil C stocks in croplands are the type of residue management, tillage management, fertilizer management (both mineral fertilizers and organic amendments), choice of crop and intensity of cropping management (e.g., continuous cropping versus cropping rotations with periods of bare fallow), irrigation management, and mixed systems with cropping and pasture or hay in rotating sequences. In addition, drainage and cultivation of organic soils reduces soil C stocks.

The total change in soil C stocks for Cropland is estimated using Equation 2.24.

EQUATION 2.24: ANNUAL CHANGE IN CARBON STOCKS IN SOILS

$$\Delta C_{soils} = \Delta C_{\text{mineral}} - L_{\text{organic}} + \Delta C_{\text{Inorganic}} \text{ -- (eq. 24).}$$

Where:

ΔC Soils = annual change in carbon stocks in soils, tonnes C yr-1

ΔC Mineral = annual change in organic carbon stocks in mineral soils, tonnes C yr-1

L Organic = annual loss of carbon from drained organic soils, tonnes C yr-1

ΔC Inorganic = annual change in inorganic carbon stocks from soils, tonnes C yr-1 (assumed to be 0 unless using a Tier 3 approach)

For Tier 1 and 2 methods, soil organic C stocks for mineral soils are computed to a default ***depth of 30 cm.***

3.2 Mineral Soils

3.2.1Choice of Methods

For mineral soils, the estimation method is based on changes in soil organic C stocks over a finite period following changes in management that impact soil organic C. Equation 2.25 is used to estimate change in soil organic C stocks in mineral soils.

Soil organic C stocks (SOC) are estimated for the beginning and end of the inventory time period using default reference carbon stocks (SOCref) and default stock change factors (FLU, FMG, FI).

EQUATION 2.25
ANNUAL CHANGE IN ORGANIC CARBON STOCKS IN MINERAL SOILS

$$\Delta C_{Mineral} = \frac{(SOC_0 - SOC_{(0-T)})}{D}$$

$$SOC = \sum_{c,s,i} \left(SOC_{REF_{c,s,i}} \bullet F_{LU_{c,s,i}} \bullet F_{MG_{c,s,i}} \bullet F_{I_{c,s,i}} \bullet A_{c,s,i} \right)$$

(Note: T is used in place of D in this equation if T is ≥ 20 years, see note below)

Where:

$\Delta C_{Mineral}$= annual change in carbon stocks in mineral soils, tonnes C yr^{-1}

SOC_0 = soilorganic carbon stock in the last year of an inventory time period,tonnes C ha^{-1}

$SOC_{(0-T)}$= soil organic carbon stock at the beginning of the inventory time period, tonnes C ha^{-1}

SOC_0 and $SOC_{(0-T)}$ are calculated using the SOC equation in the box where the reference carbon stocks and stock change factors are assigned according to the land-use and management activities and corresponding areas at each of the points in time (time = 0 and time = 0-T)

T = number of years over a single inventory time period, yr.

D = Time dependence of stock change factors which is the default time period for transition between equilibrium SOC values, yr. Commonly ***20 years***, but depends on assumptions made in computing the factors FLU, FMG and FI. If T exceeds D, use the value for T to obtain an annual rate of change over the inventory time period (0-T years).

c= represents the climate zones, ***s***the soil types, and ***i***the set of management systems that are present in a country.

SOC_{REF} = the reference carbon stock, tonnes C ha^{-1} (Table 2.3)

F_{LU} = stock change factor for land-use systems or sub-system for a particular land-use, dimensionless

[Note: F_{ND} is substituted for F_{LU} in forest soil C calculation to estimate the influence of natural disturbance regimes.]

F_{MG} = stock change factor for management regime, dimensionless

F_I = stock change factor for input of organic matter, dimensionless

A = land area of the stratum being estimated, ha.

N.B: All land in the stratum should have common biophysical conditions (i.e., climate and soil type) and management history over the inventory time period to be treated together for analytical purposes.

3.2.2 Emission Factors

Table 5.5 provides Tier 1 approach default stock change factors for land use (FLU), input (FI) and management (FMG). The method and studies that were used to derive the default stock change factors are provided in Annex 5A.1 and References. The default time period for stock changes (D) is 20 years and management practice is assumed to influence stocks to a depth of 30 cm, which is also the depth for the reference soil C stocks in Table 2.3.

Table 5.5 Relative stock change factors (F_{LU}, F_{MG}, and F_I) (over 20 years) for different management activities on cropland						
Factor value type	**Level**	**Temper-ature regime**	**Moist-ure regime**[1]	**IPCC defaults**	**Error**[2,3]	**Description**
Land use (F_{LU})	Long-term culti-vated	Tem-perate/ Boreal	Dry	0.80	± 9%	Represents area that has been continuously managed for >20 yrs, to predominantly annual crops. Input and tillage factors are also applied to estimate carbon stock changes. Land-use factor was estimated relative to use of full tillage and nominal ('medium") carbon input levels.
			Moist	0.69	± 12%	
		Tropical	Dry	0.58	± 61%	
			Moist/ Wet	0.48	± 46%	
		Tropical montane[4]	n/a	0.64	± 50%	
Land use (F_{LU})	Paddy rice	All	Dry and Moist/ Wet	1.10	± 50%	Long-term (> 20 year) annual cropping of wetlands (paddy rice). Can include double-cropping with non-flooded crops. For paddy rice, tillage and input factors are not used.
Land use (F_{LU})	Peren-nial/ Tree Crop	All	Dry and Moist/ Wet	1.00	± 50%	Long-term perennial tree crops such as fruit and nut trees, coffee and cacao.
Land use (F_{LU})	Set aside (< 20 yrs)	Tempe-rate/ Boreal and Tropical	Dry	0.93	± 11%	Represents temporary set aside of annually cropland (e.g., conservation reserves) or other idle cropland that has been revegetated with perennial grasses.
			Moist/ Wet	0.82	± 17%	
		Tropical montane[4]	n/a	0.88	± 50%	
Tillage (F_{MG})	Full	All	Dry and Moist/ Wet	1.00	NA	Substantial soil disturbance with full inversion and/or frequent (within year) tillage operations. At planting time, little (e.g., <30%) of the surface is covered by residues.
Tillage (F_{MG})	Re-duced	Tem-perate/ Boreal	Dry	1.02	± 6%	Primary and/or secondary tillage but with reduced soil disturbance (usually shallow and without full soil inversion). Normally leaves surface with >30% coverage by residues at planting.
			Moist	1.08	± 5%	
		Tropical	Dry	1.09	± 9%	
			Moist/ Wet	1.15	± 8%	
		Tropical montane[4]	n/a	1.09	± 50%	
Tillage (F_{MG})	No-till	Temperat e/ Boreal	Dry	1.10	± 5%	Direct seeding without primary tillage, with only minimal soil disturbance in the seeding zone. Herbicides are typically used for weed control.
			Moist	1.15	± 4%	
		Tropical	Dry	1.17	± 8%	
			Moist/ Wet	1.22	± 7%	
		Tropical montane[4]	n/a	1.16	± 50%	

TABLE 5.5 (CONTINUED)
RELATIVE STOCK CHANGE FACTORS (F_{LU}, F_{MG}, AND F_I) (OVER 20 YEARS) FOR DIFFERENT MANAGEMENT ACTIVITIES ON CROPLAND

Factor value type	Level	Temper-ature regime	Moist-ure regime[1]	IPCC defaults	Error[2,3]	Description
Input (F_I)	Low	Tem-perate/ Boreal	Dry	0.95	± 13%	Low residue return occurs when there is due to removal of residues (via collection or burning), frequent bare-fallowing, production of crops yielding low residues (e.g., vegetables, tobacco, cotton), no mineral fertilization or N-fixing crops.
			Moist	0.92	± 14%	
		Tropical	Dry	0.95	± 13%	
			Moist/ Wet	0.92	± 14%	
		Tropical montane[4]	n/a	0.94	± 50%	
Input (F_I)	Med-ium	All	Dry and Moist/ Wet	1.00	NA	Representative for annual cropping with cereals where all crop residues are returned to the field. If residues are removed then supplemental organic matter (e.g., manure) is added. Also requires mineral fertilization or N-fixing crop in rotation.
Input (F_I)	High with-out manure	Tem-perate/ Boreal and Tropical	Dry	1.04	± 13%	Represents significantly greater crop residue inputs over medium C input cropping systems due to additional practices, such as production of high residue yielding crops, use of green manures, cover crops, improved vegetated fallows, irrigation, frequent use of perennial grasses in annual crop rotations, but without manure applied (see row below).
			Moist/ Wet	1.11	± 10%	
		Tropical montane[4]	n/a	1.08	± 50%	
Input (F_I)	High – with manure	Tem-perate/ Boreal and Tropical	Dry	1.37	± 12%	Represents significantly higher C input over medium C input cropping systems due to an additional practice of regular addition of animal manure.
			Moist/ Wet	1.44	± 13%	
		Tropical montane[4]	n/a	1.41	± 50%	

[1] Where data were sufficient, separate values were determined for temperate and tropical temperature regimes; and dry, moist, and wet moisture regimes. Temperate and tropical zones correspond to those defined in Chapter 3; wet moisture regime corresponds to the combined moist and wet zones in the tropics and moist zone in temperate regions.

[2] ± two standard deviations, expressed as a percent of the mean; where sufficient studies were not available for a statistical analysis to derive a default, uncertainty was assumed to be ± 50% based on expert opinion. NA denotes 'Not Applicable', where factor values constitute defined reference values, and the uncertainties are reflected in the reference C stocks and stock change factors for land use.

[3] This error range does not include potential systematic error due to small sample sizes that may not be representative of the true impact for all regions of the world.

[4] There were not enough studies to estimate stock change factors for mineral soils in the tropical montane climate region. As an approximation, the average stock change between the temperate and tropical regions was used to approximate the stock change for the tropical montane climate.

Note: See Annex 5A.1 for the estimation of default stock change factors for mineral soil C emissions/removals for Cropland.

TABLE 2.3 DEFAULT REFERENCE (UNDER NATIVE VEGETATION) SOIL ORGANIC C STOCKS (SOC_{REF}) FOR MINERAL SOILS (TONNES C HA^{-1} IN 0-30 CM DEPTH)						
Climate Region	**HAC soils[1]**	**LAC soils[2]**	**Sandy soils[3]**	**Spodic soils[4]**	**Volcanic soils[5]**	**Wetland soils[6]**
Boreal	68	NA	10#	117	20#	146
Cold temperate, dry	50	33	34	NA	20#	87
Cold temperate, moist	95	85	71	115	130	
Warm temperate, dry	38	24	19	NA	70#	88
Warm temperate, moist	88	63	34	NA	80	
Tropical, dry	38	35	31	NA	50#	86
Tropical, moist	65	47	39	NA	70#	
Tropical, wet	44	60	66	NA	130#	
Tropical montane	88*	63*	34*	NA	80*	

Note: Data are derived from soil databases described by Jobbagy and Jackson (2000) and Bernoux *et al.* (2002). Mean stocks are shown. A nominal error estimate of ±90% (expressed as 2x standard deviations as percent of the mean) are assumed for soil-climate types. NA denotes 'not applicable' because these soils do not normally occur in some climate zones.

# indicates where no data were available and default values from 1996 *IPCC Guidelines* were retained.

* Data were not available to directly estimate reference C stocks for these soil types in the tropical montane climate so the stocks were based on estimates derived for the warm temperate, moist region, which has similar mean annual temperatures and precipitation.

[1] Soils with high activity clay (HAC) minerals are lightly to moderately weathered soils, which are dominated by 2:1 silicate clay minerals (in the World Reference Base for Soil Resources (WRB) classification these include Leptosols, Vertisols, Kastanozems, Chernozems, Phaeozems, Luvisols, Alisols, Albeluvisols, Solonetz, Calcisols, Gypsisols, Umbrisols, Cambisols, Regosols; in USDA classification includes Mollisols, Vertisols, high-base status Alfisols, Aridisols, Inceptisols).

[2] Soils with low activity clay (LAC) minerals are highly weathered soils, dominated by 1:1 clay minerals and amorphous iron and aluminium oxides (in WRB classification includes Acrisols, Lixisols, Nitisols, Ferralsols, Durisols; in USDA classification includes Ultisols, Oxisols, acidic Alfisols).

[3] Includes all soils (regardless of taxonomic classification) having > 70% sand and < 8% clay, based on standard textural analyses (in WRB classification includes Arenosols; in USDA classification includes Psamments).

[4] Soils exhibiting strong podzolization (in WRB classification includes Podzols; in USDA classification Spodosols)

[5] Soils derived from volcanic ash with allophanic mineralogy (in WRB classification Andosols; in USDA classification Andisols)

[6] Soils with restricted drainage leading to periodic flooding and anaerobic conditions (in WRB classification Gleysols; in USDA classification Aquic suborders).

3.2.3 Activity Data

Cropland systems are classified by practices that influence soil C storage. The default management classification system is provided in Figure 5.1. Inventory compilers should use this classification to categorize management systems in a manner consistent with the default Tier 1 stock change factors. In general, practices that are known to increase C storage, such as irrigation, mineral fertilization, organic amendments, cover crops and high residue yielding crops, have higher inputs, while practices that decrease C storage, such as residue burning/removal, bare fallow, and low residue crop varieties, have lower inputs. These practices are used to categorize management systems and then estimate the change in soil organic C stocks.

Practices should not be considered that are used in less than 1/3 of a given cropping sequence (i.e., crop rotation), which is consistent with the classification of experimental data used to estimate the default stock change factors. Rice production, perennial croplands, and set-aside lands (i.e., lands removed from production) are considered unique management systems (see below).

Each of the annual cropping systems (low input, medium input, high input, and high input w/organic amendment) are further subdivided based on tillage management. Tillage practices are divided into no-till (direct seeding without primary tillage and only minimal soil disturbance in the seeding zone; herbicides are typically used for weed control), reduced tillage (primary and/or secondary tillage but with reduced soil disturbance that is usually shallow and without full soil inversion; normally leaves surface with >30% coverage by residues at planting) and full tillage (substantial soil disturbance with full inversion and/or frequent, within year tillage operations, while leaving <30% of the surface covered by residues at the time of planting). It is *good practice* only to consider reduced and no-till if they are used continuously (every year) because even an occasional pass with a full tillage implement will significantly reduce the soil organic C storage expected under the reduced or no-till regimes.

The main types of land-use activity data are: i) aggregate statistics (Approach 1), ii) data with explicit information on land-use conversions but without specific geo-referencing (Approach 2), or iii) data with explicit information on land-use conversions and geo-referencing (Approach 3), such as land-use and management inventories making up a statistically-based sample of a country's land area (see Chapter 3 for discussion of approaches). At a minimum, globally available land-use and crop production statistics, such as FAO databases(http://faostat.fao.org/), provide annual compilations of total land area by major land-uses, select management data (e.g., irrigated vs. non-irrigated cropland), land area in 'perennial' crops (i.e., vineyards, perennial herbaceous crops, and tree-based crops such as orchards) and annual crops (e.g., wheat, rice, maize, sorghum, etc.). FAO databases would be an example of aggregate data (Approach 1).

Management activity data supplement the land-use data, providing information to classify management systems, such as crop types and rotations, tillage practices, irrigation, manure application, residue management, etc.

These data can also be aggregate statistics (Approach 1) or information on explicit management changes

(Approach 2 or 3). Where possible, it is *good practice* to determine the specific management practices for land areas associated with cropping systems (e.g., rotations and tillage practice), rather than only area by crop.

Remote sensing data are a valuable resource for land-use and management activity data, and potentially, expert knowledge is another source of information for cropping practices. It is *good practice* to elicit expert knowledge using methods provided in Volume 1, Chapter 2 (eliciting expert knowledge).

National land-use and resource inventories, based on repeated surveys of the same locations, constitute activity data gathered using Approach 2 or 3, and have some advantages over aggregated land-use and cropland management data (Approach 1). Time series data can be more readily associated with a particular cropping system (i.e., combination of crop type and management over a series of years), and the soil type can be determined by sampling or by referencing the location to a suitable soil map. Inventory points that are selected based on an appropriate statistical design also enable estimates of the variability associated with activity data, which can be used as part of a formal uncertainty analysis. An example of a survey using Approach 3 is theNational Resource Inventory in the U.S.

Activity data require additional in-country information to stratify areas by climate and soil types. If such information has not already been compiled, an initial approach would be to overlay available land cover/land-use maps (of national origin or from global datasets such as IGBP_DIS) with soil and climate maps of national origin or global sources, such as the FAO Soils Map of the World and climate data from the United Nations Environmental Program. A detailed description of the default climate and soil classification schemes is provided in Chapter 3, Annex 3A.5. The soil classification is based on soil taxonomic description and textural data, while climate regions are based on mean annual temperatures and precipitation, elevation, occurrence of frost, and potential evapotranspiration.

3.2.4 Calculation Steps

The steps for estimating SOC0 and SOC (0-T) and net soil C stock change per ha for *Cropland Remaining Cropland* on mineral soils are as follows:

Step 1: Organize data into inventory time periods based on the years in which activity data were collected (e.g., 1990 to 1995, 1995 to 2000, etc.)

Step 2: Determine the amount *Cropland Remaining Cropland* by mineral soil types and climate regions in the country at the beginning of the first inventory time period. The first year of the inventory time period will depend on the time step of the activity data (0-T; e.g., 5, 10 or 20 years ago).

Step 3: Classify each Cropland into the appropriate management system using Figure 5.1.

Step 4: Assign a native reference C stock values (SOCREF) from Table 2.3 based on climate and soil type.

Step 5: Assign a land-use factor (FLU), management factor (FMG) and C input levels (FI) to each Cropland based on the management classification (Step 2). Values for FLU, FMG and FI are given in Table 5.5.

Step 6: Multiply the factors (FLU, FMG, FI) by the reference soil C stock (SOCREF) to estimate an 'initial' soil organic C stock (SOC (0-T)) for the inventory time period.

Step 7: Estimate the final soil organic C stock (SOC0) by repeating Steps 1 to 5 using the same native reference C stock (SOCREF), but with land-use, management and input factors that represent conditions for each cropland in the last (year 0) inventory year.

Step 8: Estimate the average annual change in soil organic C stocks for *Cropland Remaining Cropland* (ΔC Mineral) by subtracting the 'initial' soil organic C stock (SOC (0-T)) from the final soil organic C stock (SOC0), and then dividing by the time dependence of the stock change factors (i.e., 20 years using the default factors). If an inventory time period is greater than 20 years, then divide by the difference in the initial and final year of the time period.

Step 9: Repeat steps 2 to 8 if there are additional inventory time periods (e.g., 1990 to 2000, 2001 to 2010, etc.). A numerical example is given below for *Cropland Remaining Cropland* on mineral soils, using Equation 2.25 and default reference C stocks (Table 2.3) and stock change factors (Table 5.5).

3.3 Organic Soils

3.3.1Choice of Methods

Equation 2.26 is used to estimate C stock change in organic soils (e.g., peat-derived, Histosols). The basic methodology is to stratify cultivated organic soils by climate region and assign a climate-specific annual C loss rate. Land areas are multiplied by the emission factor and then summed up to estimate annual C emissions.

EQUATION 2.26
ANNUAL CARBON LOSS FROM DRAINED ORGANIC SOILS (CO_2)

$$L_{Organic} = \sum_{c} (A \bullet EF)_c$$

Where:

$L_{Organic}$ = annual carbon loss from drained organic soils, tonnes C yr-1

A = land area of drained organic soils in climate type *c,* ha

Note: A is the same area (Fos) used to estimate N_2O emissions in Chapter 11, Equations 11.1 and 11.2

EF = emission factor for climate type *c*, tonnes C ha-1 yr-1

TABLE 5.6
ANNUAL EMISSION FACTORS (EF) FOR CULTIVATED ORGANIC SOILS

Climatic temperature regime[1]	IPCC default (tonnes C ha^{-1} yr^{-1})	Error [2]
Boreal/Cool Temperate	5.0	± 90%
Warm Temperate	10.0	± 90%
Tropical/Sub-Tropical	20.0	± 90%

[1] Climate classification is provided in Chapter 3.

[2] Represents a nominal estimate of error, equivalent to two times standard deviation, as a percentage of the mean. Estimates are based on Glenn *et al*., 1993; Kasimir-Klemedtsson *et al*., 1997; Freibauer and Kaltschmitt, 2001; Leifeld *et al*., 2005; Augustin *et al*., 1996; Nykänen *et al*., 1995; Maljanen *et al*., 2001, 2004; Lohila *et al*., 2004; Ogle *et al*., 2003; Armentano and Menges, 1986.

3.3.2 Emission Factors

Default emission factors are provided in Table 5.6 for cultivated organic soils. Assignment of emission factors for perennial tree systems, such as fruit trees that are classified as Cropland, may be based on the factors for cultivated organic soils in Table 5.6 or forest management of organic soils (see Chapter 4). Shallower drainage will lead to emissions more similar to forest management, while deeper drainage of perennial tree systems will generate emissions more similar to annual cropping systems.

3.3.3 Activity Data

In contrast to the mineral soil method, croplands on organic soils are not classified into management systems under the assumption that drainage associated with all types of management for crops stimulates oxidation of organic matter previously built up under a largely anoxic environment. However, in order to apply the method described in Section 2.3.3.1 (Chapter 2), croplands do need to be stratified by climate region and soil type (see Chapter 3, Annex 3A.5 for guidance on soil and climate classifications).

Similar databases and approaches as those outlined for *Mineral Soils* in the Tier 1 discussion can be used for deriving area estimates. The land area with organic soils that are managed for Cropland can be determined using an overlay of a land-use map on climate and soils maps. Country-specific data on drainage projects combined with land-use surveys can be used to obtain a more refined estimate of the relevant areas.

3.3.4 Calculation Steps

The steps for estimating the loss of soil C from drained organic soils are as follows:

Step 1: Organize data into inventory time periods based on the years in which activity data were collected (e.g., 1990 to 1995, 1995 to 2000, etc.)

Step 2: Determine the amount of *Cropland Remaining Cropland* on organic soils for the last year of each inventory time period.

Step 3: Assign the appropriate emission factor (EF) for annual losses of CO2 based on climate (from Table 5.6).

Step 4: Estimate total emissions by summing the product of area (A) multiplied by the emission factor (EF) for all climate zones.

Step 5: Repeat for additional inventory time periods. A numerical example is given below for *Cropland Remaining Cropland* on drained organic soils, using Equation 2.26 and default emission factors (Table 5.6).

IV. STEPS FOR THE DIRECT SOIL CARBON ASSESSMENT METHOD

Carbon stocks and greenhouse gas emissions should be measured and reported in compliance with the UNFCCC reporting principles of transparency, consistency, comparability, completeness, and accuracy. The majority of the non-Annex I Parties uses the IPCC default assumption that there are no changes in soil carbon. Given that soil carbon is a significant carbon pool, it is critical to estimate stocks and changes, using higher tier methods in line with IPCC GPG for LULUCF. The use of a higher tier method improves estimates of carbon emissions and removals compared with the default method. Several steps are required to estimate changes in soil organic carbon stocks within a project area over time. A hybrid approach (Tier-3) involving a combination of approaches (e.g., combining modeling with on-site sampling and independent verification) is preferable in terms of improved accuracy of carbon stock estimation. The on-site soil carbon stock assessment involves the following key steps:

IV.1 DEFINE AND BOUND THE MEASUREMENT SITE/PROJECT AREA

Given the inherent high spatial variability of soil organic carbon, an accurate quantification and monitoring of SOC stocks and stock changes is a complex task even in relatively homogeneous ecosystems. Such feature is further exacerbated in the case of smallholder environments by the existence of multiple land use activities occurring at various management intensities. Moreover, sources of uncertainty and suitable levels of precision and accuracy differ when working at the landscape scale as opposed to the farm scale for the reason that biogeochemical processes affecting SOC dynamics operate and interact at different spatial scales.

The measurement sites are typically large enough to capture variation in conditions at the landscape scale (e.g. valley bottoms, slopes, ridge-tops) and can be replicated at different scales, within projects, watersheds, administrative boundaries, countries, or even continents.

Before proceeding to the next steps of carbon stock assessment, it is important to delineate the project boundary, with active participation of relevant stakeholders including communities living in and around the project area. This process is important to know the actual size of the project and is crucial for the sustainability of the carbon stock. When the boundary is agreed among stakeholders, coordinates should be recorded using Global Positioning System (GPS). The GPS data will be later transferred into computer in order to draw the base map of the project and estimate the area. The

Arc GIS software would be used to distribute and locate sample plots on the base map. The software also generates coordinates of each sample plot, which is later used to locate the plots on the ground during the actual carbon stock assessment.

IV.2 STRATIFY THE AREA/LANDSCAPE

Stratification refers to the division of any heterogeneous landscape into distinct sub-sections (strata) based on some common grouping factor. In order to facilitate fieldwork and increase the accuracy and precision of measuring and estimating carbon, it is useful to divide the project area into sub-populations or "strata" that form relatively homogenous units. If stratification leads to no, or minimal, change in costs, then it should not be undertaken.

Stratification of the landscape/watershed into more or less homogenous clusters or land use systems should be on the basis of parameters such as climate (rainfall, temperature), topography, land use, land management, land cover, soil type, availability of data, etc. Stratifying on too many variables can rapidly become un-manageable in terms of the number of strata produced and in practice it is often adequate to stratify on at most several major ecological zones. The initial stratification should be conducted in a hierarchical order whereby the factor that exerts the strongest influence on SOC stocks is ranked first, and other factors with less influence on SOC are subsequently assigned (e.g. a classical ranking approach might be climate, soil texture, land cover and land use management, etc.).

In Ethiopia context, Agro-ecological zones are considered suitable for stratification as they create homogenous stratum in terms of bio-physical conditions, including climate, terrain, soil, vegetation. On this basis, there are five AEZs, namely; *Tepid to cool sub-humid mid highlands, Hot to warm humid lowlands, Tepid to cool humid mid highlands, Tepid to cool moist mid highlands, and Tepid to cool sub-moist mid highlands*. A description of the characteristics of the AEZs is presented as annex 1.

IV.3 DETERMINE THE NUMBER OF SAMPLE PLOTS

Once the strata's are identified and agreed on, the number of sample plots required in each stratum must be determined. The decision on the number of plots depends on the required level of accuracy, logistics, manpower, cost and the length of the monitoring interval. Due to the heterogeneity of SOC distribution, the number of samples required to accurately assess SOC stocks at scales suitable for carbon trading is high. When designing sampling campaigns, taking into account the factors influencing SOC distribution, such as soil type, land-use, climate, and vegetation will help to optimize sampling depths and numbers, ensuring that samples accurately reflect the distribution of SOC at the site.

Optimal size does not necessarily guarantee the desired precision of carbon estimate unless it is complemented with a proper unbiased sampling design. The number of plots depends on the variation in soil carbon levels, the required level of accuracy and the length of the monitoring interval. The number of plots required to measure carbon stocks is often within a precision level of ±10% of the mean SOC stocks at 95% confidence level. In addition to the precision level, the sampling calculator and the equation require data on average carbon stock of each stratum, estimate of standard deviation and variance. The following equation can be used to calculate the number of sample plots. Furthermore, it is possible to use the "*Winrock Terrestrial Sampling Calculator"* tool to find the number of sample plots in each stratum. A section of this web-based tool is presented as presented annex 5. The number of samples to be measured in each stratum should be determined as a proportion of the area and the variance observed for that particular stratum. It is assumed that the above parameters are known from the project set up, pre-project estimates (e.g. results from a pilot-study) or literature data. A training exercise for technicians can generate these data.

$$N = \frac{A}{AP}; \qquad N_{i=\frac{A_i}{AP}}$$

Where:

N=Number of sample plots in the project area
Ni=Number of sample plots in stratum i
A=the total project area in ha
Ai= size of each stratum i; ha
AP_i=sample plot size (constant for all strata); ha

$$n = \frac{\left[\sum_{i=1}^{L} N_i * \ st_i\right]^2}{\left(N * {E_1}/{Z_{\frac{\alpha}{2}}}\right) + \sum_{i=1}^{L} N_i * (st_i)^2}$$

$$n_i = \frac{\sum_{i=1}^{L} N_i * \ st_i}{\left(N * {E_1}/{Z_{\frac{\alpha}{2}}}\right) + \sum_{i=1}^{L} N_i * (st_i)^2} * N_i * st_i$$

$$E_1 = Q_1 * P$$

Where:

- n = *sample size (total number of sample plots required) in the project area*
- i = *1, 2, 3, … L project strata*
- st_i = *standard deviation for each stratum i; dimensionless*
- E_1 = *allowable error of the estimated quantity Q*
- Q_1 = *approximate average value of the estimated quantity Q, (e.g. aboveground wood volume per hectare); e.g.* $m^3\ ha^{-1}$
- p = *desired level of precision (e.g. 10%); dimensionless*
- α = *1-α is probability that the estimate of the mean is within the error bound E*
- $z_{\alpha/2}$ = *value of the statistic z (embedded in Excel as: inverse of standard normal probability cumulative distribution), for e.g. 1-α = 0.05 (implying a 95% confidence level)* $z_{\alpha/2}$ *=1.9599*

It is possible to reasonably modify (e.g. increase or decrease) the sample size after the pre-sampling or first monitoring event based on the actual variation of the carbon stock changes determined from taking the initial samples.

IV.4 RANDOMIZE/LOCATE THE MEASUREMENT PLOTS WITHIN THE TARGET AREA AND STRATA

After the quantity of sample plots are identified, a sampling grid could be used to systematically layout the sample plots on the map (aerial photos or topographic map) of the project. This is important to provide unbiased estimates of carbon stocks and other parameters such as yield, organic and inorganic fertilizers application, livestock type and number, residue management, etc. The distance between grids depends on the number of sample plots and each sample point on the grid represents an area corresponding to the size of the grid cell of the sample layout. For example, if the distance between square grids is 1km, each sample point represents an area of 1km x 1km= 10ha. Thus, if 15 plots fall within a stratum, the interest of the area estimate will be 15 x 10ha= 150ha.

The number of plots to be characterized per strata depends on the level of variability within strata in the target area, the size of the stratum, required levels of precision and resource availability. Viewing the site on satellite images or using Google Earth can provide information on terrain and vegetation type, road access, population center, etc. To avoid subjective choice of plot locations (plot centers, plot reference points, movement of plot centers to more "convenient" positions), the permanent sample plots must be located randomly or systematically with a random start within each identified stratum. Random location of plots can be accomplished in one of two ways:

- *Locate plots systematically with a random start. In this case the plots are located using a systematic method-usually on a grid, with the location of the first points on the grid determined randomly. This must be undertaken prior to field work, with the plot locations specified on a map or aerial photos, and locations specified either as distance and direction from a known point or as a GPS coordinate.*
- *Locate individual plots randomly, using a randomization procedure in a GIS to specify the coordinates of each plot.*

If the stratum consists of sites that are geographically separated, then the plots to be allocated to each site should be in proportion of the site area to the total stratum area with rounding of the fractions. For example, if one stratum consists of three geographically separated sites, then it is proposed to:

- *Divide the total stratum area by the number of plots, resulting in the average area represented by each plot*
- *Divide the area of each site by this average area per plot, and assign the integer part of the result to this site, e.g., if the division results in 6.3 plots, then 6 plots are assigned to this site, and 0.3 plots are carried over to the next site, and so on.*

Once the randomization is completed, the GPS coordinate, administrative location, and stratum of each plot must be recorded and archived.

In addition to random location of the plots, it is critical that plot sampling is undertaken at the same time of year each time repeat sampling at permanent sample plots is undertaken. The goal is to sample the plots under, to the greatest degree possible, the same ecological and treatment conditions with each repeat sampling. Thus the day and month of establishment of permanent sample plots, and the ecological conditions existing at that time, must be recorded. Future samples at these plots should be established within 15 days of the same day and month in the year in which the plots are resampled, unless significantly changed ecological or treatment conditions (for instance a very late spring, late tillage, etc.) mandate a greater gap between the initial sampling date and a specific later repeat sampling date.

IV.5 DECIDE ON THE SHAPE AND SIZE OF THE SAMPLE PLOT

The size and shape of the sample plots is a trade-off between accuracy, precision, time and cost for measurement. It is however important to bear in mind the IPCC Good Practice of Comparability of methods. Nested plots, containing smaller sub-units of equal size, are a practical design for measuring soil organic carbon in the field. The measurement plots can take the form of nested circles, square or rectangles. Decision regarding the size and shape of plots to be laid on the ground should coincide with recommended practice in the ecological literature and represent a compromise between recommended practice, accuracy and practical considerations of time and effort. Once decided, the dimension and number of the nested plots including sampling depth, collection and analytical parameters and methods should be consistent across the different sampling events and sample plots in the strata. For agricultural lands, circular nested plots fits natural patch sizes in the field better than square or rectangular or linear plot shapes. The plot size also depends on resource availability, objectives of the carbon assessment, etc. For soil carbon stock assessment in agricultural lands, a principal circular plot of 2500 meter square[1] (i.e. r=28.2m) will be laid. Nested circular plots of 16 m^2 (r=2.26) will be laid at four corners and the center within the principal sample plot (see figure 1).

IV.5 DETERMINING MEASUREMENT FREQUENCY

It is recommended that for carbon accumulation, the frequency of measurements should be defined in accordance with the rate of change of the carbon stock. Measurements of initial stocks employed in the baseline must take place within $\pm$ 5 years of the project start date, for simplicity referred to

[1] The size of the sampling unit is consistent with the average land holding of a subsistence farming household in Ethiopia, which is estimated to be 0.25ha

here as stocks at t = 0. The estimates are valid in the baseline for 10 years, after which they must be re-estimated from new field measurements. The re-measured estimate should be within 90% confidence interval of the t = 0 estimate (baseline), the t = 0 stock estimate takes precedence and is re-employed, and where the re-measured estimate is outside (i.e. greater than or less than) the 90% confidence interval of the t = 0 estimate, the new stock estimate takes precedence and is used for the subsequent period.

IV.6 FIELD MEASUREMENT OF SOC

Carbon stock assessment is a very intensive and time taking task and it is therefore important to get prepared well in advance in terms of tools and equipment, Logistics, transports, clothing, boots, first aid kit, camping equipment, etc. It is important to be appropriately dressed in full attire and safety boots. Below are the general steps to be followed to conduct soil carbon stock assessment in the field.

i. *Prepare tools and equipment*

The quantity of tools and equipment should be adequate enough to the number of team to be deployed for the fieldwork. The following are some of the tools and equipment required for the fieldwork.

Equipment	
▪ Core Samplers ▪ Auger ▪ Backpack ▪ Batteries (AA&9-volt) ▪ Stakes and machete ▪ First aid kit ▪ Nylon ropes	▪ Compass (Suunto challenger MCA-D) ▪ Cotton rags (for cleaning equipment) ▪ Measuring tape ▪ Flagging tape or ribbons ▪ GPS (Garmin Oregon 550) ▪ Sheet holder/clip boards ▪ Data sheets ▪ Stapler with pins

ii. Locating plots in the field

Once the permanent sample plots are randomized on the map of the project area/landscape, the locations of plots must be marked and the geo-references or coordinates of the sample plots must be recorded. In addition, the administrative location, and stratum of each plot must be recorded and archived. During navigation to the field, there is a possibility that a sample plot fall in area, which is not accessible or suitable for measurement and not representative of the area. For instance, the plot may fall in an area of exposed rock, an impermeable man made materials such as road, river, etc. During such anomalous circumstance, where less than 5% of the stratum area is composed of areas of this type, the entire plot may be systematically relocated by moving the plot to a randomly located point. In general, laying out the principal circular plot and the nests in the field may be undertaken using the following steps:

- *Mark the center point (also record the GPS reading)*
- *From the center point, measure 28.2 m radius to direct north (360^0), south (180^0), east (90^0) and west (270^0) directions*
- *Repeat the same to northeast (45^0), southwest (225^0), northwest (315^0) to southeast (135^0) directions*
- *Use compass and a pre-cut and graduated tape or rope and mark the end points using pegs*
- *Then connect the end points and establish the principal plot*
- *Record the GPS reading at each end point*
- *Once the principal plot is layed, locate 4 sample points inside the principal plot at East, West, North and South corners along the line connecting the two opposite corners*
- *Locate one additional soil core at the center of the plot for bulk density measurement*
- *After laying the principal plot and the nests, start the measurements.*

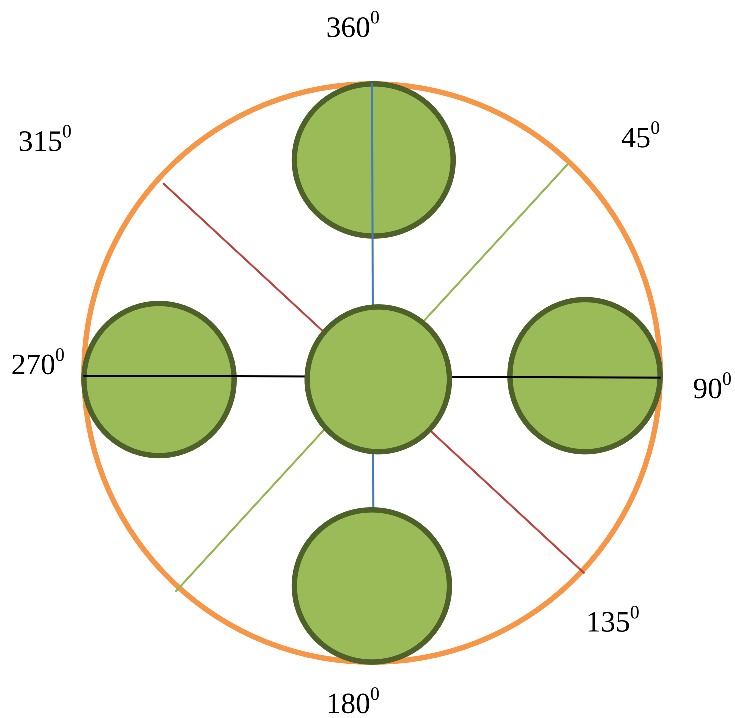


Figure 1 Nested plot design for soil carbon stock assessment

iii. Conduct SOC Stock Accounting

Carbon stock accounting is important to determine the carbon stock in the project baseline, to develop project idea note (PIN) and project design document (PDD), to validate, register and implement emission reduction measures. The IPCC recommends monitoring soil organic carbon in the top 30cm of the mineral soil. Sampling must therefore occur to a minimum depth of 30cm. The depth of the sample must be the same within the Carbon Estimation Area. The following are key steps to conduct soil carbon stock assessment after the assessment team arrives in the site and finds the location of the measurement plot on the ground.

General Note:

- If the sample plot location falls in an area of exposed bedrock or impermeable parent material (for instance compacted till) or an impermeable man made material (for instance a road surface), the entire sample plot may be systematically relocated by moving the plot to a randomly located point
- Take GPS measurement at the center of the principal plot as points sampled in the field may be different than the a-priori randomly selected sample points
- Record information regarding agriculture management practices such as crop rotation, tillage practices, fertilization, and irrigation and crop yields, etc. should be recorded using the data recording sheet in annex .
- Use either a soil corer of 30 cm in length or hand-dug pits of 30 cm in depth
- Sampling methods must remain consistent from one measurement round to the next.

Once the soil bulk density and carbon concentration are known, the soil carbon will be calculated using the following equation:

Soil Carbon= calculated soil bulk density* horizon thickness*C concentration

The C pool for a specific soil layer of thickness is calculated by using the following equation:

$$Mg\ C\ ha^{-1} = \frac{C}{10^3}\ BDT\ \frac{10^4 m^2}{ha}$$

Where:

C is the C concentration (kg C Mg^{-1}),

BD is the bulk density (Mg m^{-3}), and

T is the thickness (m) of the soil layer.

a) Soil Chemical Analysis

Steps

1. Take soil samples at the four corners and at the center of the big plot
2. Remove all vegetation and organic layers (litter) and take samples of the 0-10, 10-20 and 20-30 cm soil depth.
3. Take soil sample using a soil auger (the length of the soil auger is 15 cm)
4. Mix soil from each depth within in the plot separately and prepare one composite per depth. It is also possible to thoroughly mix the composite samples from the four subplots and take one sample for each depth for chemical analysis
5. Place the sub-sample in a clearly labeled plastic bag, seal it and take it to laboratory. The size of the sub-sample should be adequate enough (≥250gm) for the laboratory analysis
6. In the lab, air dry the subsample soil by placing it in a shallow try in a well-ventilated, dust and wind free area
7. Sieve the soil sample through a 2 mm sieve and grind them in a mortar in order to pass through a 60 mesh screen
8. Conduct soil chemical (carbon) analysis using the right method

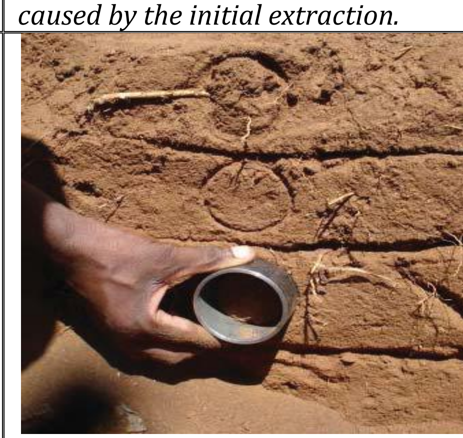
***Note**: In each pit, three samples are taken at soil depths of 1-10, 10-20 and 20-30 cm. Samples from the four pits are combined according to the three depth levels and put into one plastic bag to form a composite soil sample of the site*


b) Soil Bulk Density Analysis

Steps

1. Avoid any place with possible soil compaction due to other sampling activities.
2. Remove the coarse litter layer and dig 30 cm deep and about 40 cm wide hole **(please note that it is possible to take composite soil sample for chemical analysis from the same peat)**
3. Take samples from 0-10, 10-20 and 20-30 cm depth using a core sampler of equal size
4. Transfer all soil from the core sampler into a plastic bag
5. Level[2] the samples separately
6. Take sub sample from each layer to lab
7. Oven dry the soil sample at 105^{0}C to constant mass
8. Measure the dry weight
9. Calculate the soil organic carbon
   i.e. Soil organic carbon stock=sampling depth x SOC carbon concentration x soil bulk density

***Note**: care must be taken during core extraction to make sure that no soil is lost from the core. If soil is lost during extraction or if other factors prevent extraction of a complete core, a new sample should be taken as close as possible to the initial extraction location at a point where no disturbance was caused by the initial extraction.*



Labeling Soil sample

Name of Area: ______________________
Name of Strata: _____________________
Plot number: _______________________
GPS location: ______________________
Date of extraction: _________________
Sample depth (layer): _______________
Name of the person in charge: ________

Figure 2: The sampling cylinder is pushed into the wall with a plastic hammer. When hammering, it helps to cover the cylinder with a wooden plank

Figure 3: The core with soil sample is extracted carefully from the wall of the pit, using a trowel or a knife if necessary

Figure 2 using a sharp field knife, any excess soil over the core should be removed to ensure a volumetric soil sample

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GLOSSARY OF TERMS

Afforestation: defined under the Kyoto Protocol as the direct, human induced conversion of non-forest land to permanent forested land for a period of at least 50 years.

AFOLU: an acronym for 'agriculture, forestry and other land uses'. A term put forward by the Intergovernmental Panel on Climate Change Guidelines (2006) to cover 'land use, land use change and forestry (LULUCF), and agriculture'.

Baseline: the emission or removal of greenhouse gases that would occur without the project.

Carbon sequestration: the removal of carbon from the atmosphere to long-term storage in sinks through physical or biological processes, such as photosynthesis.

Carbon sink: a pool (reservoir) that absorbs or takes up carbon released from other components in the carbon cycle.

Carbon stock: the quantity of carbon in a given pool or pools per unit area.

Cropland: defines any land on which non-timber crops are grown. This includes both herbaceous crops and higher carbon-content systems including vineyards and orchards.

Grazing land: a very broad category that includes managed pastures, prairies, steppe and savannas. Grazing lands will often include trees, but only when the canopy-cover is less than 30%. Aquatic systems such as flooded grasslands and salt marshes are also included in this category.

Land Use: Land use describes how land is categorized. IPCC has six broad categories of land use: forest land, cropland, grassland, wetlands, settlements, and other.

Litter: fallen leaves, needles, twigs still recognizable as the parent organic material.

LULUCF: acronym for 'land use, land-use change and forestry'.

Nitrification: the aerobic microbial oxidation of ammonium to nitrate

Sequestration: the process of increasing the carbon stock in an ecosystem.

Sink: a pool or reservoir (e.g., a forest) that absorbs or takes up carbon released from other components of the carbon cycle, and that absorbs more than it releases.

Tier: the IPCC Good Practice Guidance tiers are levels of methodological complexity: Tier 1 is the most basic and uses global default values for carbon stocks; Tier 2 is intermediate and uses national values; and Tier 3 is most demanding in terms of complexity and data requirements, and uses site-specific values for carbon stocks.

ANNEX 1: KEY FEATURES OF THE AGRO-ECOLOGICAL ZONES

Agro-ecological Zone [a]	Altitude (m) [b]	Temperature (°C) [c]	Annual rainfall (mm) [d]	Dominant soil type [e]
Tepid to cool sub-humid mid highlands	1600-3200	11-21	1200	Nitisols, Cambisols, Vertisols, Fluvisols
Hot to warm humid lowlands	600-2200	21-27	1300	Nitosols, Vertisols, Cambisols
Tepid to cool humid mid high-lands	1800-3200	11-21	1100	Nitosols, Cambisols, Vertisols, Luvisols, Leptosols
Tepid to cool moist mid high-lands	1000-2100	11-21	1100	Cambisol, Leptosols
Tepid to cool sub-moist mid highlands	1100-1900	11-27	1300	Nitosols, Cambisols

Sources: [a,b,c,e,d] Ministry of Agriculture (2013); [f] Hijmans *et al*., 2005: http://www.worldclim.org;

ANNEX 2: DEFAULT EMISSION AND PARAMETER VALUES RELEVANT TO CALCULATE N2O EMISSION

Parameters	***Values***
EF_1 for N additions from mineral fertilisers, organic amendments and crop residues, and N mineralized from mineral soil as a result of loss of soil carbon	*0.01*
EF1FR for flooded rice fields [kg N2O–N (kg N)-1]	*0.003*
EF2 CG, Temp for temperate organic crop and grassland soils (kg N2O–N ha-1)	*16*
EF2F, Trop for tropical organic forest soils (kg N2O–N ha-1)	*8*

Summary of default values of parameters

Parameters	**Values**
$F_{rac}BURN$	0.25 in developing countries; 0 in developed countries (kg N/kg crop-N)
$F_{rac}GASF$	0.1 kg NH3–N + NO*x*–N/kg of synthetic fertilizer N applied
$F_{rac}NCRBF$	0.03 kg N/kg of dry biomass
$F_{racNCR0}$	0.015 kg N/kg of dry biomass
$F_{rac}R$	0.45 kg N/kg crop-N

ANNEX 3: COMBUSTION FACTOR VALUES FOR FIRES IN A RANGE OF VEGETATION TYPES (FROM TABLE 2.6, 2006 IPCC GUIDELINES FOR NATIONAL GREENHOUSE GAS INVENTORIES)

Vegetation type	**Subcategory**	**Mean Value**
Savanna Grasslands/ Pastures (early dry season burns)	Tropical/sub-tropical grassland	0.74
	Grassland	-
All savanna grasslands (early dry season burns)		**0.74**
Savanna Grasslands/ Pastures (mid/late dry season burns)*	Tropical/sub-tropical grassland	0.92
	Tropical pasture~	0.35
	Savanna	0.86
All savanna grasslands (mid/late dry season burns)		**0.77**
Other vegetation types	Peatland	0.50
	Tropical Wetlands	0.70
Agricultural residues (Post harvest field burning)	Wheat residues	0.90
	Maize residues	0.80
	Rice residues	0.80
	Sugarcane	0.80

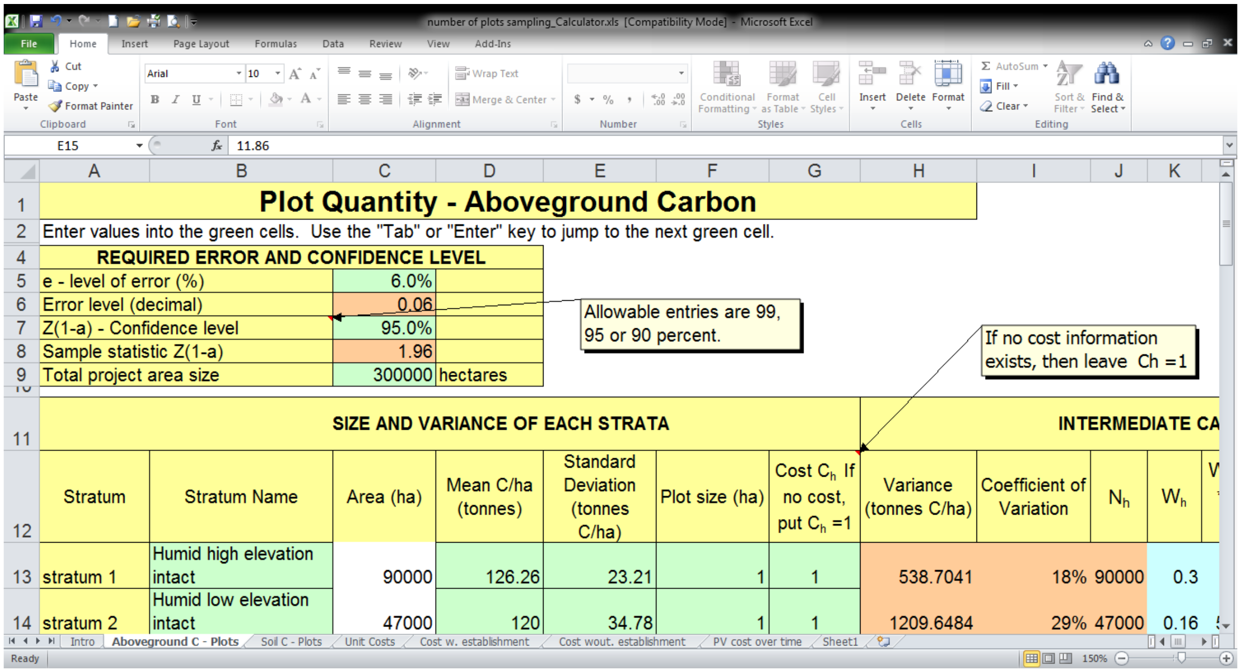
ANNEX 4: ABOVE GROUND BIOMASS FIELD INVENTORY FROM

Plot Number:	**Land use type:**
Latitude:	**Age of land use type:**
Longitude:	**Recorder:**
Nest:	**Date:**
GPS and compass reading of the Nest	

Plant ID[3]	**Species**[4]	**DBH (cm)**[5]	**H (m)**[6]	**Remark**[7]

[3] Start with 1 for each plot
[4] Species and life-from A: tree, P: palm, B: Bamboo, C: other: indicate
[5] DBH
[6] Height of tree
[7] Notes from observation (e.g. Hollow trees, etc…)

ANNEX 5: A SECTION OF THE INTERFACE OF THE ONLINE TOOL FOR ESTIMATING NUMBER OF PLOTS



ANNEX 6: DATA COLLECTION TOOL FOR EX-ACT: ANNUAL PRODUCTION SYSTEM

Annual System									
Cropping system	Crop type (major crops)	Improved agronomic practices **(Yes/No)**	Nutrient managemen t **(Yes/No)**	No Till./residue management **(Yes/No)**	Water management **(Yes/No)**	Manure application **(Yes/No)**	Residue/bi omass burning **(Yes/No)**	Yield Qt/ (Average)	Area (ha)

<u>Key (Farm land management practices)</u>

- Improved agronomic practices: Improved Variety ,Cover crop and green manure ,Multiple cropping, crop rotation , Multiple cropping, inter cropping
- Nutrient management: Mulching ,Improved fallow ,Manure management ,Composting ,Improved fertilize use efficiency
- No Till. /residue management: Reduced tillage , Reside management
- Water management: Terracing and Water harvesting structure

ANNEX 7: DATA COLLECTION TOOL FOR EX-ACT: INPUTS & INVESTMENTS USED FOR AGRICULTURAL PRODUCTION

S/N.	Name of inputs	Quantity applied (in kilograms per year)
1	**Lime application**	
	Limestone	
	Dolomite	
	Not-specified	
2	**Fertilizers**	
	Urea	
	DAP	
	Sewage	
	Compost	
	Phosphorous	
	Potassium	
3	**Pesticides**	
	Herbicides	
	Insecticides	
	Fungicides	