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USAID Forest Carbon Calculator: Data and Equations for the Agroforestry Tool

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1.0 INTRODUCTION

In cooperation with USAID's Global Climate Change team, Winrock International has developed a set of simple, user-friendly, web-based calculation tools titled the 'Forest Carbon Calculator'. The calculation tools are meant to give USAID Missions and partners an easy way to comply with USAID's policy of mainstreaming CO_2 as an Agency-wide results indicator. The calculator is not meant to provide the level of accuracy needed for carbon financing, but rather to provide an indication of areas which have potential for such financing. The tools produce estimates of sequestration or avoided emissions of carbon dioxide and carbon dioxide equivalents using sound and transparent science.

There are currently four calculator tools: *forest protection* (project activities include reducing or stopping deforestation, illegal logging, and/or fires), *forest management* (activities include reduced impact logging or stop logging), *afforestation/reforestation* (including forest restoration), and *agroforestry*. To our knowledge, this is the first and only web-based calculator that contains default values with nearly global coverage, but also allows users to override these values with more specific data.

This report outlines the data and equations used to develop the **agroforestry** tool.

2.0 INTERACTING WITH THE TOOL'S INTERFACE

2.1 Selecting the project location

After logging in, a user is required in Step 1 to enter a **project identification number ("project ID")** and the fiscal year for which the project is active, along with an optional brief description of the project. Although there is no set format for the project ID, a user should enter the USAID contract or agreement number or contact USAID for more guidance. **Note: The calculator will not move on to Step 2 unless a project ID has been entered**.

An important concept regarding the function of the calculator is that the tools are designed to function at the level of **administrative units** (referred to as "admin units"), i.e., nationally recognized states, provinces, etc. Each administrative unit has a unique profile of default values for each tool. It is important to understand the scale at which the calculator tools function to ensure that the tools are applied in the proper context. All default parameters in the calculator are the area-weighted average of the default value for each administrative unit and should not be misinterpreted to represent a value for a given point on the Earth's surface.

This approach was adopted because the carbon benefit of projects identical in size and scope will be different depending on where the project takes place. By tying the calculators to a given region of the world, we've attempted to reflect these variables at a level of organization that allows for a great deal of granularity while using commonly recognized organizational units, which are generally small enough to be meaningful but large enough to be practical.

Before any tools are selected, a user is prompted to enter information about the project's location. In this case, the project location is the administrative unit(s) in which the project is operational.

There are three options for selecting the project's administrative unit(s): by **latitude/longitude** coordinates, from **dropdown menus** of region/country/administrative units, or by clicking on an **interactive map**. The three options were chosen to allow flexibility for users who are operating under a myriad of circumstances. For example, some USAID missions may operate in places where internet connections are slow or unreliable, and therefore the interactive map is loaded only if a user selects this option. This ensures rapid webpage display. As another example, a user may not know the specific name of the administrative unit, but can identify it on a map of the country.

After an administrative unit is selected by the user, it is added to the Project Cart. If a project spans multiple administrative units or countries, a user can select additional administrative units until all of the project area is accounted for.

2.2 Selecting the project type

In Step 2, a user then selects the individual tools appropriate for the project in question. Tools are chosen for each individual administrative unit that the project encompasses. One or several project types can be selected for a given administrative unit depending on a project's ongoing activities.

2.3 Input data

In Step 3, the area of the project that falls within each administrative unit must be entered. The calculator was designed so that the only information required to be entered by the user is the project area; all other parameters rely on default values developed for the administrative unit selected. We refer to this as "Level A" data input. If a user has more specific project information on a given parameter, default values are displayed in "Level B" and can be changed by the user as needed. These values will override default values and will be used in subsequent calculation of CO2 benefits.

For the agroforestry tool, the data inputs required for each Level are described below.

Level A

Level A is designed to provide broad information about carbon sequestration resulting from agroforestry systems in cases where little to no technical information is available. In this case, default data are used in the tools and the annual carbon accumulation rates are fixed (as derived from an assumed linear accumulation of carbon over the first five years of tree growth). Therefore, the only data required for calculations under Level A are:

- Area associated with the agroforestry activity
- Effectiveness of agroforestry activity

The effectiveness rating is meant to provide an indication of project maturity and success. The user must select an effectiveness rating based on a qualitative rating system outlined in the 'what's this?' pop-up box to the right of the input box:

100% Effective: All trees in the project area have been planted and survival is between 75% and 100%.

75% Effective: All trees in the project area have been planted and survival is between 50% and 75%.

50% Effective: All trees in the project area have been planted but survival is lower than 50%.

25% Effective: More than 50% of the trees to be planted are already in the ground.

0% Effective: Less than 50% of the trees to be planted are currently in the ground.

Level B

Under Level B, the user is given an option to change default parameters (used in Level A) by entering project-specific data. The following are the optional inputs for Level B under the Agroforestry tool:

- Growth habit (fast, medium, slow).

- Stand density (dense, medium, low)
- Site quality (good, fair, poor)
- Annual aboveground biomass accumulation
- Root to shoot ratio

Users are not obligated to provide information for all optional Level B parameters; the calculation is performed by applying user input of known parameters and default values for the other parameters. If a user has specific information about the aboveground biomass accumulation of the trees planted, the calculation will override the more generic Level B parameters of growth habit, stand density and site quality and use the more specific value of biomass accumulation. Based on the information supplied on aboveground biomass accumulation, the tool will automatically add in the belowground biomass using a default root to shoot ratio. However, if the user also has a more specific root to shoot ratio, the default value will be overridden by the user-defined value.

If a user does not have information on aboveground biomass accumulation of the trees planted in the project area, Level B parameters of growth habit, stand density and site quality can be adjusted from the default selections chosen under Level A (medium growth habit, medium stand density, poor site quality). Not all default values need to be adjusted; for example, if only stand density and site quality are known, the calculation will use default “medium” for growth habit.

3.0 DATABASE DEVELOPMENT

To develop the default values used for calculating CO2 benefits from agroforestry activities, we performed an extensive review of literature about biomass accumulation in agroforestry systems within tropical and subtropical areas of the world. More than 150 references were consulted and entered into a database provided each reference met the following conditions:

- The report stated clearly the carbon pools considered and the units in which the different pools were expressed;
- Carbon stocks or growth rates were reported based on tree or system age

The following information was extracted from each reference and compiled as separate entries in the database:

- Type of agroforestry system: homegarden, multicrop, shade, others (not specified)
- Region
- Country/province
- Dominant species
- Climatic zone
- Pools reported
- Age (yr)

- Above ground biomass carbon[1] - AGC (t C ha^{-1})
- Below ground biomass carbon[1] - BGC (t C ha^{-1})
- Root to shoot ratio
- Total tree carbon (t C ha^{-1})
- Growth rate (t C ha^{-1} yr^{-1})
- Stocking (trees ha^{-1})
- Source
- Notes

Several studies reported carbon stocks or growth rates, but failed to specify which carbon pools were included. (The litter pool was not considered in the carbon accumulation modeling to keep the estimations conservative.) Other studies reported carbon stocks in specific pools, but did not provide the information necessary to calculate growth rates (i.e., age of trees for a given carbon stock value). These studies were discarded. A few data points were also discarded because they were outliers, i.e., they fell well beyond the range of other reported values. In total, our database contained 63 entries distributed among different three continents (Figure 1) covering a broad range of ages and carbon values (Table 1). In addition to the 63 data points, some references provided forest growth equations that were also included in the database.

For those cases where belowground carbon was not provided in the reference, the belowground carbon pool was calculated from aboveground biomass based on the following (Mokany et al., 2006):

$$BGC\ (t\ C\ ha^{-1}) = 0.205\ AGC$$

This relationship is valid in cases where aboveground biomass of trees is less than 62.5 t C ha^{-1}, as was the case for all the values obtained from the literature (Table 1).

[1] Units of biomass were converted to units of carbon by applying the commonly used factor of 50%, i.e. 1 unit of biomass = 0.5 units of carbon.

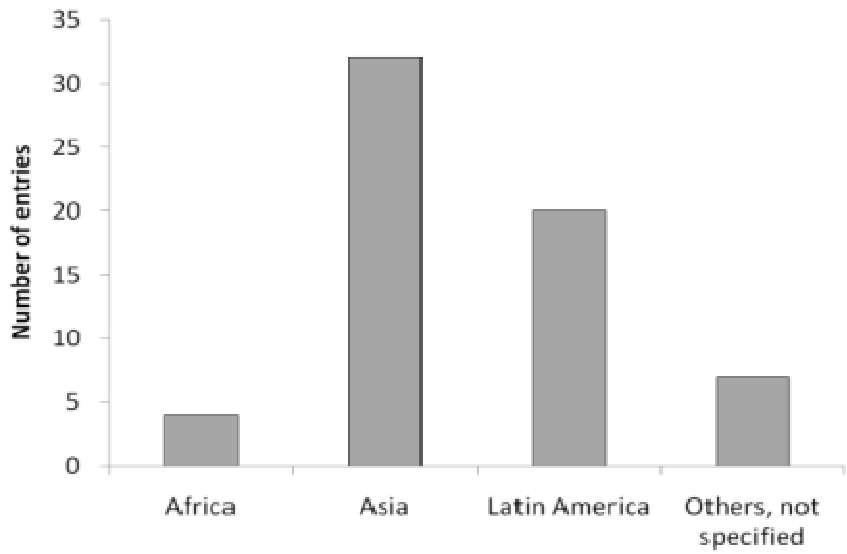

Figure 1. Distribution of data among different tropical regions.

Table 1. Range of ages and carbon values included in the agroforestry database.

Agroforests	Age (Yr)	Tree carbon (t C ha^{-1})
Min	2	1.6
Max	30	105.0
Average	10	39.5

4.0 FOREST GROWTH MODELING AND PARAMETERIZATION

Climate has a definite role on both carbon storage capacity and growth (Lugo *et al.*, 1988). Reports on potential carbon storage and growth rates for agroforests are commonly expressed for different precipitation regimes (Schroeder, 1994, Winjum and Schroeder, 1997). Due to this decisive role of climate, we generated two families of curves to represent carbon dynamics of agroforestry systems growing under dry and humid conditions. However few reports of agroforestry systems in dry climatic conditions were identified in the literature, perhaps due to restriction of agroforestry implementation in these areas imposed by the lack of precipitation. Therefore, an assumption that the maximum carbon accumulation rate in dry areas correspond to 70% of the rate in humid areas was made[2]. The user does not need to define climate condition; this information is set automatically in Step 1 when the administrative units for the project location are selected.

Other factors influencing the productivity of agroforestry systems are species, soil conditions and management (Lugo *et al.*, 1988; Roshetko et al.,2007). These elements are included in Level B as growth habit, site quality, and stand density, respectively. Poor site quality was set as the default to calculate carbon growth under Level A in order to keep the estimations conservative. Growth habit at level A was assumed to be medium due to the

[2] Accumulation rate based on interpretation of limited data-base coupled with experts opinions and other lessons learned with other forest systems around the world.

high heterogeneity of species, ages and arrangements under the agroforest systems reviewed in the literature. Overall, growth rates under humid and dry climatic regimes were two thirds of the rates reported by Schroeder (1994) for similar range of ages.

Although there are other management practices that could affect forest growth (fertilization, weeding, thinning, pruning, etc.) these activities are not considered to maintain the tool's user friendliness while allowing sound estimations with limited information about agroforest management data. In this context, differences in growth habit, site quality and stand density are considered as the main factors that define different growth patterns under dry or humid climatic conditions.

Carbon accumulation in agroforestry systems under different growth habit, site quality and management conditions was estimated by fitting a Chapman Richards equation (Zeide, 1993) to the ranges of data values compiled in the database:

$$Y = a(1 - e^{-bt})^c$$

Where:

Y = Carbon stock (t C ha^{-1})

a: is the maximum carbon accumulation capacity per agroforest type.

b: parameter influencing growth rate

c: parameter influencing the inflection point of the growth curve.

t: time since establishment in years.

The carbon accumulation modeling included only the aboveground and belowground tree carbon pools to keep the estimations conservative. According to (Zeide, 1993), the Chapman-Richards equation "is valued for its accuracy and is used more than any other function in studies of tree and stand growth". The Chapman-Richards equation was parameterized to reflect the influence of climate, site quality and stand density on forest growth. The procedure used in the parameterization is described below.

Table 2 illustrates the parameters used in the forest growth curves for humid and dry conditions in agroforestry systems. Figure 2 shows the shape of the different curves in relation to the data points compiled for different agroforestry systems of the world using the regression models that were considered the best fit for the data reported in the literature. The different curves[3] were developed to reflect the variation in the range of values found in the literature and assume that variation is resulting from differences in climatic regimes, biophysical conditions and management practices. Carbon accumulation rates and resulting carbon stocks after 5 and 20 years for each carbon potential curve are given in Table 3.

[3] The maximum and minimum asymptotes were set based on the range of values reported for adult agroforestry system.

Table 2. Parameters of a Chapman-Richards growth model assigned for each of the curves that define different carbon growth and storage potentials for agroforestry systems. Parameter a is associated with maximum carbon accumulation capacity, parameter b influences the initial growth rate, and parameter c influences the inflection point of the growth curve.

System x climates	Carbon potential	Parameters		
		a	b	c
Agroforests	High	70	0.20	3
dry	Medium	50	0.20	4
	Low	30	0.16	3
Agroforests	High	100	0.25	3
humid	Medium	80	0.23	4
	Low	60	0.20	4

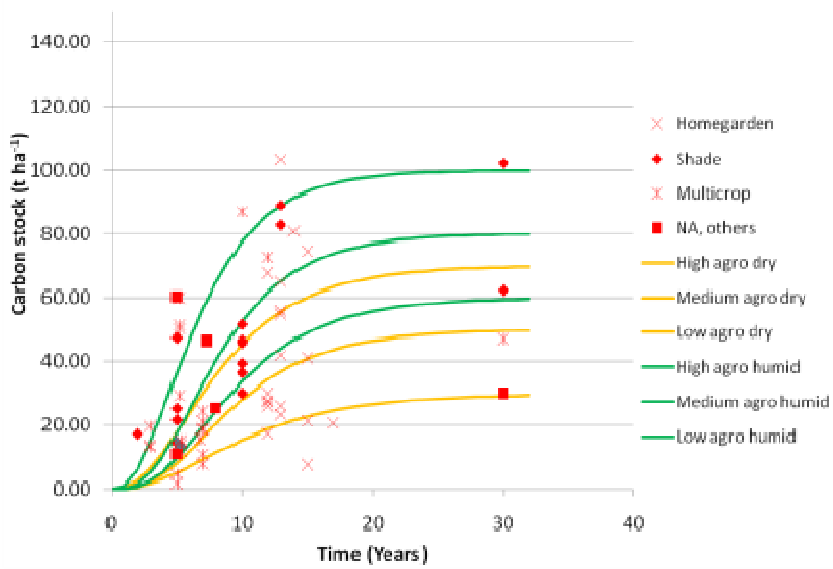

Figure 2. Fitted growth models for agroforestry systems growing in two different climate regimes: dry (yellow lines) and humid (green lines) climates. The data points used to parameterize the growth models are shown in red. The three curves in each climate type represent high, medium and low carbon accumulation potential and were developed based on the range (scatter) of carbon values available in the database.

Table 3. Estimated rate of carbon accumulation and total carbon stocks in agroforestry systems over 5 and 20 years under different growth scenarios[4].

Agroforestry Systems	Age = 5		Age = 20	
	MAI[5] t C ha^{-1} yr^{-1}	Stock t C ha^{-1}	MAI t C ha^{-1} yr^{-1}	Stock t C ha^{-1}
Agroforests dry				
High	3.54	17.68	3.31	66.22
Medium	1.60	7.98	2.32	46.44
Low	1.00	5.01	1.32	26.48
Agroforests humid				
High	7.26	36.32	4.90	97.99
Medium	3.49	17.45	3.84	76.83
Low	1.92	9.58	2.79	55.72

5.0 CALCULATIONS OF CARBON BENEFITS

Carbon benefits associated with agroforestry activities are calculated based on information entered by the user on growth habit, stand density and site quality. Three carbon accumulation rates – low, medium or high, as in Figure 4 above – are assigned, one for each parameter (growth habit, stand density, site quality) (Table 4).

Table 4. Carbon potentials associated with the parameters included under Level B. Default selections are shown in bold.

Growth factors	Carbon potential curve		
	High	Medium	Low
Growth habit	fast	**medium**	slow
Stand density	dense	**medium**	low
(trees ha^{-1})	>400	**200-400**	<200
Site quality	good	fair	**poor**

The final carbon benefit (in t CO_2) is then calculated as the sum of weighted carbon accumulation rates, with the assumption that weights assigned evenly across the three parameters. In equation terms, this becomes:

$$\textbf{Benefit (t } CO_2\textbf{)} = \{\text{Area} * (44/12) * [(0.33 * \text{GH}) + (0.33 * \text{SD}) + (0.33 * \text{SQ})]\} * \%\text{effective} \qquad (1)$$

[4] Estimates based on the application of the models (Figure 2).
[5] Mean annual increment (MAI)is the average growth of a forest stand (or a tree) per year to a specified age.

Where:

GH	= carbon accumulation rate according to growth habit
SD	= carbon accumulation rate according to stand density
SQ	= carbon accumulation rate according to site quality
Area	= project area (user-defined)
% effective	= effectiveness rating of the agroforestry project (user-defined)
44/12	= conversion factor to convert carbon to carbon dioxide

The parameters highlighted in **red** (area of project and % effectiveness) represent data that a user **must enter** under Level A. Variables highlighted in **blue** represent parameters that are stored in an underlying default database but that can be changed by the user under Level B if desired.

If a user is managing an agroforestry project and project activities include specific, plot-based measurements of aboveground biomass accumulation over time in the trees planted, this information can also be entered in Level B. If chosen, the aboveground biomass accumulation rate entered will be used to estimate belowground biomass using a default root-to-shoot ratio (which can also be defined by the user if known, otherwise a default value is given) and to calculate a more precise estimate of CO_2 benefits. Under this scenario, the selections made under Level B for growth habit, stand density and site quality will be overridden and replaced with more specific, user-defined information. If this information is entered, the equation becomes:

$$\textbf{Benefit (t } CO_2\textbf{)} = \{\textbf{Area} * (44/12) * [(\textbf{AGBAR} * 0.5) + (\textbf{AGBAR} * 0.5 * \textbf{RSR})]\} * \textbf{\%effective} \qquad (2)$$

Where:

Area	= project area (user-defined)
AGBAR	= aboveground biomass accumulation rate of trees planted in the agroforestry system; t ha^{-1} yr^{-1}
0.5	= conversion factor to convert dry biomass to carbon
RSR	= root to shoot ratio
% effective	= effectiveness rating of the agroforestry project (user-defined)
44/12	= conversion factor to convert carbon to carbon dioxide

6.0 EXAMPLE CALCULATIONS

6.1 Level A

Under Level A, carbon benefits are estimated by applying the carbon accumulation rates associated with the default selections of medium growth habit, medium stand density (200-400 stems ha^{-1}) and low site quality. Climate – which defines which set of growth curves are used – is defined automatically when the user selects the project location (part of the unique profile for the admin unit).

For example, an agroforestry project developed over an area of 1,000 ha in a humid region in Brazil in which all trees were planted and survivorship of the trees was high, would result in the following benefits per year, as calculated from Equation 1 above:

Benefits = {1000 * (44/12) * [(0.33 * 3.49) + (0.33 * 3.49) + (0.33 * 1.92)]} * 1

Benefits = **10,769 t CO_2e**

An agroforest project developed over the same area (1000 ha) with the same project effectiveness (100%) in a dry region of Brazil would result in the following benefits, as calculated using Equation 1 above:

Benefits = {1000 * (44/12) * [(0.33 * 1.60) + (0.33 * 1.60) + (0.33 * 1.00)]} * 1

Benefits = **5,082 t CO_2e**

6.2 Level B

For level B calculations, growth habit, stand density and site quality are determined by the user (Table 4). The respective values (low, medium and high – Table 3) are then used in Equation 1.

Using the 100% effective humid agroforestry project example above, if more detailed information under Level B is entered (fast growth habit, medium stand density, poor site quality):

Benefits = {1000 * (44/12) * [(0.33 * 7.26) + (0.33 * 3.49) + (0.33 * 1.92)]} * 1

Benefits = **15,330 t CO_2e**

For the same project, if a user has conducted plot-level measurements of the trees that have been planted and knows that the rate of biomass accumulation is 10 tons ha^{-1} yr^{-1}, this information would be entered into Level B and the CO_2 benefits would be calculated using Equation 2 above:

Benefit (t CO_2) = {1000 * (44/12) * [(10* 0.5) + (10* 0.5 *0.20)]} * 1

Benefits = **22,000 t CO_2e**

Projects with diversified technicalities

Not all projects are equal. Some projects might have 75% of the site is planted with trees because 25% is committed to annual/seasonal agriculture production; others might only decide to plant 60% of the total area due to financial restraints; or even some project area might have different planting densities according to the soil productivity and/or landscape factors within the project area. All this scenarios and many others are possible. However to keep the tool simple and user-friendly, users must group similar technicalities in their area into one “project activity”, and enter each project activity separately. Results must be added, subtracted, multiplied and/or divided at the end according to the relationship of the project activities entered.

6.0 GENERATING OUTPUT

After a user enters the area of the project that falls within each administrative unit and changes Level B defaults if desired, a summary page will be generated in Step 4 that displays the total carbon benefits of the project (in tonnes of CO_2 equivalent) across all administrative units and all project activities.

The summary table reports CO_2 benefits by activity type, by administrative unit and by project. All values used in the calculations are also summarized. At this point, a user has the option to modify the data to make any corrections or to go back to the home page to begin entering another project.

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