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## Global Climate Change:
## Carbon Reporting Initiative

# The AFOLU Carbon Calculator

# AFOLU CARBON CALCULATOR

## THE AGROFORESTRY TOOL: UNDERLYING DATA AND METHODS

Winrock International

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# 1. SCOPE

This document describes the underlying data sources and calculation methods employed in the Agroforestry Tool of the AFOLU Carbon Calculator (http://afolucarbon.org/). The Agroforestry Tool is designed for project activities that aim at sequestering atmospheric carbon by planting combination of trees and crops, or trees and livestock in the same land, promoting the establishment of agroforestry systems (AFS).

# 2. APPLICABILITY

This Agroforestry is applicable to afforestation or reforestation activities that combine trees with crops and/or livestock in the same lands, thus promoting sequestration and storage of atmospheric carbon. These activities can be of subsistence and/or commercial nature, and must associate the establishment of trees in non-forest (e.g. agricultural or grazing) productive systems.

# 3. APPROACH TO THE AGROFORESTRY TOOL

Based on discussions with two experts in the field of agroforestry acting as consultants (Dr. F. Montagnini, and Dr. P.K. Nair), a stratification of the various possible agroforestry types into five main classes was recommended:

- **Multistrata:**
  - Homegardens (including mixed fruit and spice tree gardens): Intimate multistory combinations of several trees – especially fruit- and nut-producing species – and crops in homesteads; livestock may or may not be present; the size of the garden is small (< 1 ha) and the garden is managed intensively usually by family labor.
  - Shaded perennials: Growing shade-tolerant species such as cacao (*Theobroma cacao* L.) and coffee (*Coffea* sp.) under or in between overstory shade-, timber-, or other commercial tree crops.
- **Tree Intercropping:**
  - Alleycropping: Fast-growing, preferably leguminous, woody species grown in crop fields as a hedgerow with close (~ 0.5 m) in-row spacing and wide (4 m or more) between-row spacing; the woody species pruned periodically at low height (<1.0 m) to reduce shading of crops; the prunings applied as mulch into the alleys as a source of organic matter and nutrients, or used as animal fodder.
  - Multipurpose trees on farmlands: Fruit-, fodder -, fuelwood-, and timber trees scattered or planted in some systematic arrangements in crop- or animal-production fields.
- **Silvopastoral:**
  - Grazing under scattered or planted trees
  - Tree-fodder systems: Fodder banks

- **Protective Systems:**
    - Boundary planting, Windbreaks, Shelterbelts, Soil Conservation hedges: Use of trees to protect fields from wind damage, sea encroachment, floods, etc.
- **Agroforestry Woodlots:** Block planting of preferred tree species for specific purposes such as reclamation of salt-affected lands, eroded lands, acid soils, waterlogged soils, etc.

Data from published and unpublished literature were compiled and used to develop the yearly accumulation rates and growth curves for each of the agroforestry classes mentioned above. The approach employed in the Agroforestry Tool varies based on the geographic location in which the project activity is taking place: For Latin American activities, sufficient data were compiled to allow the development of agroforestry type-specific growth curves based on the Chapman-Richards equation (Richards 1959; Pienaar and Turnbull 1973); for African and/or Asian activities, an agroforestry type-specific average annual rate of biomass accumulation derived from the literature, compiled in each of the continents, is applied overtime.

## 4. DATA SOURCES

The data used for deriving carbon sequestration rates of various AFS by the Agroforestry Tool are based on extensive literature search. More than 1,000 literature sources were reviewed for information on AFS and C sequestration. Criteria for selecting sources included reliability of the data and its quality, and the presentation of estimates (or ranges) of AFS growth and/or biomass production (e.g. biomass accumulation overtime, or biomass stocks at a known age). A comprehensive list of the resource material consulted can be found in Annex I; however, these are, by no means, exhaustive.

The literature on AFS is extensive, complex, and growing. Most reports are qualitative descriptions seldom following uniform reporting pattern, and many of them use local names of plants and practices (personal communications with Dr. Montagnini and Dr. Nair). The efforts in presenting a somewhat uniform compilation of the various systems around the tropics were the earlier-mentioned Agroforestry Systems inventory by ICRAF, a substantial output of which is a Nair (1989) - edited book: *Agroforestry Systems in the Tropics*. However, this publication does not contain many quantitative aspects of the data that have been assembled for the AFOLU C Calculator (Nair, 2012; unpublished report).

There were varied levels of details and quality in the data consulted and ultimately compiled for developing biomass accumulation rates. Data quality varied based on the sources: data obtained from scientific articles most often referred to experimental AFS, and had a greater level of detail, when compared to data sourced from books, reports or reviews. As well, data reported for some of the agroforestry types, such as multistrata have been more extensively reported in the literature, and therefore has more data compiled than other types. Nonetheless, the number of data points reported by agroforestry type cannot be assumed to be an indicative of the widespread type of agroforestry implemented worldwide, but rather a more widely studied system.

## 4.1 LATIN AMERICA AND THE CARIBBEAN

Dr. Montagnini led data compilation effort for Latin America and the Caribbean. Approximately 400 sources were consulted, using the internet, personal library, and soliciting information by communicating by email with colleagues in the academic or project areas in LAC (personal communications with Dr. Montagnini).

Of all the sources consulted, 97 data sources were deemed effective for the purpose of developing carbon accumulation rates for the Agroforestry Tool (Figure 1). *Agroforestry woodlot* systems have no data compiled for Latin America and the Caribbean.

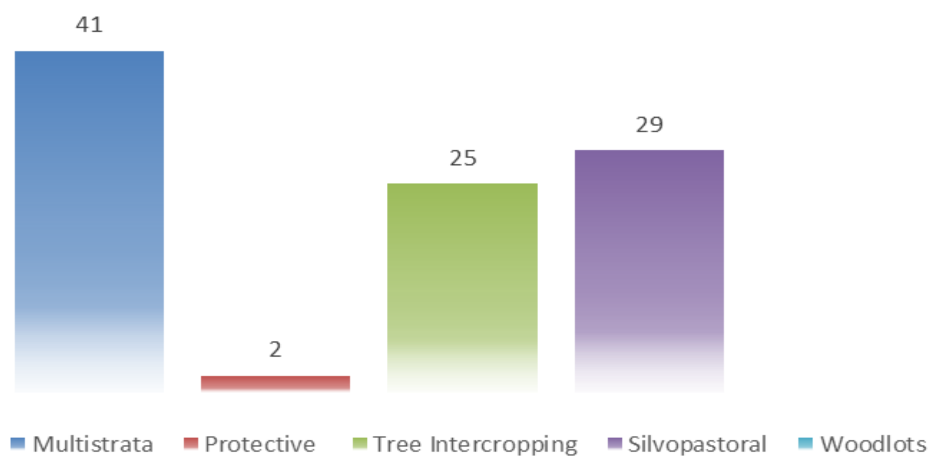


**Figure 1: Number of data sources per agroforestry system type compiled for Latin America and the Caribbean**

## 4.2 AFRICA

Dr. Nair led the data compilation effort for Africa. Forty-eight data sources were compiled across the five different agroforestry types for this continent (Figure 2), with predominance of data reported for *tree intercropping* systems.

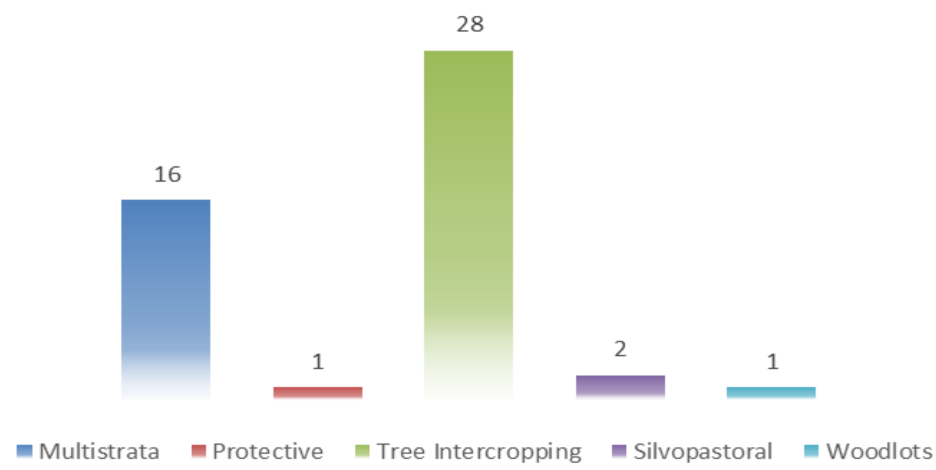


**Figure 2: Number of data sources per agroforestry system type compiled for Africa**

### 4.3 ASIA

Dr. Nair led the data compilation effort for Asia. A total of 75 data sources were compiled for the five different agroforestry types (Figure 3). In Asia, data sources were well distributed across agroforestry types, with predominance of data reported for *multistrata* systems.

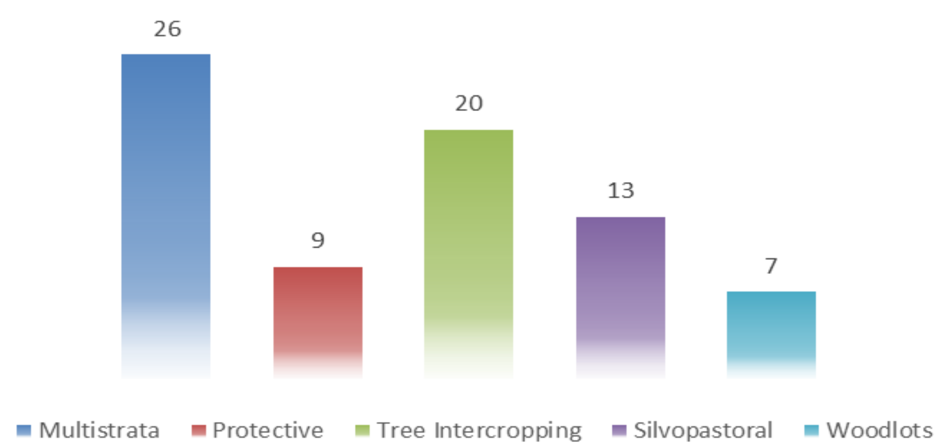


**Figure 3: Number of data sources per agroforestry system type compiled for Asia**

## 5. UNCERTAINTY OF ESTIMATES

Uncertainty is a property of a parameter estimate and reflects the degree of lack of knowledge of the true parameter value because of factors such as bias, random error, quality and quantity of data, state of knowledge of the analyst, and knowledge of underlying processes. Uncertainty can be expressed as the size of the half width of a specified confidence interval as a percentage of the mean value. For example, if the area of forest land converted to cropland (mean value) is 100 ha, with a 95% confidence interval ranging from 90 to 110 ha, we can say that the uncertainty in the area estimate is ±10% of the mean (from GOFC-GOLD 2013).

Uncertainty is an unavoidable attribute of practically any type of data including land area and estimates of carbon stocks and many other parameters used in the estimation of the AFOLU carbon benefits from activities on the land. Identification of the sources and quantification of the magnitude of uncertainty will help to better understand the contribution of each source to the overall accuracy and precision of the final estimate.

The proper manner of dealing with uncertainty is fundamental in the IPCC and UNFCCC contexts. The IPCC defines estimates that are consistent with good practice as those which contain neither over- nor underestimates so far as can be judged, and in which uncertainties are reduced as far as practicable. The first step in an uncertainty analysis is to identify the potential sources of uncertainty. Many sources are possible including measurement errors due to human errors or errors in calibration; measurement errors in the predictor variables; modelling errors due to inability of the model to fully describe the phenomenon; parameter uncertainty, and residual uncertainty; erroneous definitions or classifications that lead to double-counting or non-counting; unrepresentative samples; and variability resulting from the use of samples rather than censuses. In this section, the potential sources of uncertainty are identified and an assessment of their likely range of uncertainties used in the calculation of the carbon benefit in this Tool is presented (Table 1). A brief primer of the steps involved in assessing total uncertainties for each carbon benefit estimate is provided with a couple of simple examples to demonstrate the process. These analyses are not provided in the Tools.

The reader is referred to the GOFC-GOLD 2013 sourcebook for more details on all sources of uncertainty and how to reduce them. In general, with the use of current medium to high resolution remote sensing data, the suite of algorithms for interpreting the imagery, and the standard methods for accuracy assessment of the products, data on land cover and land cover change are likely to be relatively accurate for forest to non-forest, but less so for forest type of percent tree cover. Assessing uncertainties in the estimates of C stocks, and consequently of C stock changes (i.e. the emission factors), can be more challenging than estimating uncertainties of the area and area changes. This is particularly true for agroforestry systems that are often characterized by a high degree of spatial variability and therefore require additional resources to acquire samples that are adequate to produce accurate and precise estimates of the C stocks in a given pool.

In addition to the uncertainties associated with each parameter, when parameters are combined as in e.g. estimating emissions from combining area planted and carbon accumulation rates that vary by age, then overall error of the product will change. Uncertainties in individual parameter estimates can be combined using either (1) error propagation (IPCC Tier 1) or (2) Monte Carlo simulation (IPCC Tier 2). Tier 1 method is based on simple error propagation, and cannot therefore handle all kinds of uncertainty estimates. The key assumptions of Tier 1 method are (from GOFC-GOLD 2013):

- estimation of carbon emissions and removals is based on addition, subtraction and multiplication
- there are no correlations across parameters (or if there is, they can be aggregated in a manner that the correlations become unimportant)
- none of the parameter estimates has an uncertainty greater than about ±60%
- uncertainties are symmetric and follow normal distributions

However, even in the case that not all of the conditions are satisfied, the method can be used to obtain approximate results. In the case of asymmetric distributions, the uncertainty bound with the greater absolute value should be used in the calculation. The Tier 2 method is based on Monte Carlo simulation, which is able to deal with any kind of models, correlations and distribution. However, application of Tier 2 methods requires more resources than that of Tier 1.

The key parameters are low to medium uncertainty, with high certainty associated with younger forests and tropical native dry forests.  The low uncertainty for tropical rain and moist forests is due to the relatively large data base for these forest types, whereas for tropical dry forests the data based is small. The other parameter used in the calculations is area planted—it is assumed that this will be well known with an uncertainty of about 5% or less.

**Table 1 Key parameters used to estimate the carbon benefits of agroforestry activities and an assessment of their uncertainties.**

| Component | Parameter | Uncertainty | | | Comment |
|---|---|---|---|---|---|
| | | Low (<20%) | Medium (20-60%) | High (>60%) | |
| **LAC - Multistrata** | Carbon accumulation rate | | X | | Chapman Richards using data from literature review |
| **LAC - Protective** | Carbon accumulation rate | | | X | Carbon accumulation rates derived from 2 points |
| **LAC – Tree intercropping** | Carbon accumulation rate | | X | | Chapman Richards using data from literature review |
| **LAC –Silvopastoral** | Carbon accumulation rate | | X | | Chapman Richards using data from literature review |
| **LAC - Woodlots** | Carbon accumulation rate | N.A. | N.A. | N.A. | No data points compiled from literature |
| **Africa - Multistrata** | Carbon accumulation rate | | X | | C accumulation rates derived from 16 data points |
| **Africa – Protective** | Carbon accumulation rate | | | X | C accumulation rates derived from only 1 data point |
| **Africa – Tree intercropping** | Carbon accumulation rate | | X | | C accumulation rates derived from 28 data points |
| **Africa – Silvopastoral** | Carbon accumulation rate | | | X | C accumulation rates derived from 2 data points |
| **Africa – Woodlots** | Carbon accumulation rate | | | X | C accumulation rates derived from 1 data point |
| **Asia - Multistrata** | Carbon accumulation rate | | X | | C accumulation rates derived from 26 data points |
| **Asia – Protective** | Carbon accumulation rate | | X | | C accumulation rates derived from 9 data points |
| **Asia – Tree intercropping** | Carbon accumulation rate | | X | | C accumulation rates derived from 20 data points |
| **Asia – Silvopastoral** | Carbon accumulation rate | | X | | C accumulation rates derived from 13 data points |
| **Asia – Woodlots** | Carbon accumulation rate | | X | | Carbon accumulation rates derived from 7 data points |

### 5.1 COMBINING UNCERTAINTIES FOR MULTIPLICATION

The simple error propagation method is based on two equations: one for multiplication and one for addition and subtraction of uncertainties. The equation to be used in case of multiplication is:

$$U_{total} = \sqrt{U_1^2 + U_2^2 + .... + U_n^2}$$

Where:

$U_i$ = percentage uncertainty associated with each of the parameters

$U_{total}$ = the percentage uncertainty in the product of the parameters

An example of combining uncertainties in estimating the carbon benefits from planting multistrata agroforestry systems in Asia using the Tier I method is shown below:

| | Mean value | Uncertainty (% of mean) |
|---|---|---|
| Area planted (ha) | 1,000 | 5 |
| Above and below ground C stock at age 10 yr (t C/ha) | 82 | 45 |

Thus the carbon emissions are:

1,000 ha *82 t C/ha = 82,000 t C

And the uncertainty = $\sqrt{5^2 + 45^2} = \pm 45\%$

**5.2 COMBINING UNCERTAINTIES FOR ADDITION AND SUBTRACTION**

In the case of addition and subtraction, for example when carbon emissions are summed up, the following equation will be applied:

$$U_{total} = \frac{\sqrt{(U_1 * x_1)^2 + (U_2 * x_2)^2 ...(U_n * x_n)^2}}{|x_1 + x_2 ... + x_n|}$$

Where:

$U_i$ = percentage uncertainty associated with each of the parameters

$x_i$ = the value of the parameter

$U_{total}$ = the percentage uncertainty in the sum of the parameters

An example of this application is in the combination of carbon stock estimates (addition) shown below:

| | Mean | 95 % CI |
|---|---|---|
| | t (C/ha) | |
| Living Trees | 113 | 11 |
| Down Dead Wood | 18 | 3 |
| Litter | 7 | 2 |

Therefore the total stock is 138 t C/ha and the uncertainty =

$$\frac{\sqrt{(11\%*113)^2+(3\%*18)^2+(2\%*7)^2}}{|113+18+7|} = \pm 9\%$$

Using this simple error propagation method is applicable to the calculations used in this AR Tool. The Monte Carlo type analysis is more complicated to apply, but gives more reliable results particularly where uncertainties are large, distributions are non-normal, or correlations exist. Furthermore, Tier 2 method can be applied to models or equations, which are not based only on addition, subtraction and multiplication. (The reader is referred to Chapter 5 of IPCC GPG LULUCF for more details on how to implement the Monte Carlo analysis).

# 6. CALCULATION METHODS

Calculation methods employed by the Agroforestry Tool to estimate annual rates of carbon sequestered by each of the five AFS types varied according to data availability and quality.

Data availability dictated the type of statistics that could be derived from compiled data (basic statistics such as mean, and standard deviation, can only be derived from at least 3 data points). For agroforestry types with less than 3 data points compiled, the reported value is applied as the mean accumulation rate. However, users are strongly encouraged to override defaults provided in such cases (e.g. *woodlot systems* for LAC, and *protective* and *woodlot systems* for Africa) for more accurate estimates.

Data quality in this context relates to the perceived representativeness of the data compiled. In other words, a detailed assessment of each data point and its likelihood of being representative of a given AFS type at the indicated age was conducted.

## 6.1 LATIN AMERICA AND THE CARIBBEAN

Total carbon stocks (in Mg C $ha^{-1}$) along with the respective age (in years) of each of the AFS were fitted into a Chapman-Richards logistic growth equation (Richards 1959; Pienaar and Turnbull 1973), a popular sigmoid-shaped biological growth model. These data were used to derive the parameters in the equation below, ultimately determining the shape and steepness of the curve, and therefore the rate of biomass carbon accumulation over time.

**Total Benefit (t $CO_2$)** = Area* (MAX* [1–EXP(-k* Age)]^[1/(1-m)]) *(44/12) * Effectiveness

Where:

| | |
|---|---|
| Area | = area of AFS project activity; hectares, ha |
| MAX | = asymptote maximum peak biomass yield; tons dry mass per hectare, or t d.m. $ha^{-1}$ |
| k | = parameter used in modeling tree growth; dimensionless |
| Age: | = age of forest; years (user-defined) |
| m | = parameter used in modeling tree growth; dimensionless |
| 44/12 | = conversion factor from carbon to carbon dioxide equivalent |
| Effectiveness | = management effectiveness rating (%) |

Parameters in blue can be entered by the user, while parameters in red have default values offered by the Agroforestry Tool. Parameters in black are fixed within the calculations. The age of the forest is optional and can be entered under Advanced Inputs of the Tool, but if not specified by the users, it will default to one year initially.

A different carbon accumulation curve based on the Chapman-Richards equation was developed for three of the five agroforestry types (Table 2), with the exception of *protective* and *woodlot systems*, given the little or no data compiled for these AFS type in LAC.

**Table 2: Parameters for the carbon accumulation model based on the Chapman-Richards equation for each agroforestry type**

| Agroforestry type | n | MAX | k | m | $r^2$ |
|---|---|---|---|---|---|
| Multistrata systems | 41 | 65 | 0.114 | 0.1 | 0.128 |
| Silvopastoral systems | 30 | 60 | 0.171 | 0.7 | 0.534 |
| Tree intercropping systems | 26 | 100 | 0.081 | 0.10 | 0.098 |

#### 6.1.1 MULTISTRATA

The carbon accumulation model for *multistrata* agroforestry systems in LAC was developed based on 41 data points. The biomass accumulation curve for this type of AFS approaches a maximum of 65 t C $ha^{-1}$.

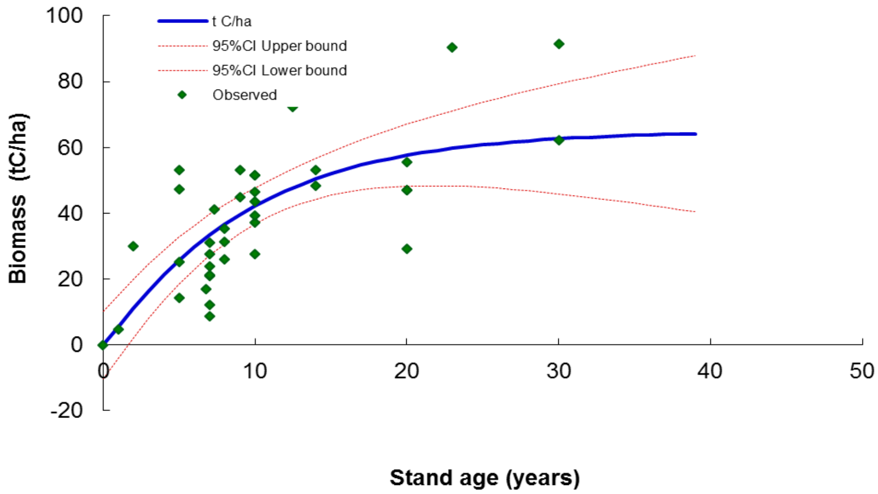


**Figure 4: Aboveground carbon accumulation curve for Multistrata, fitted using 41 data points. Upper and lower curves represent upper and lower bounds of 95% CI.**

#### 6.1.2 TREE INTERCROPPING

The carbon accumulation model for *tree intercropping* systems in LAC was developed based on 25 data points. The biomass accumulation curve for this type of AFS approaches a maximum of 90 t C ha$^{-1}$.

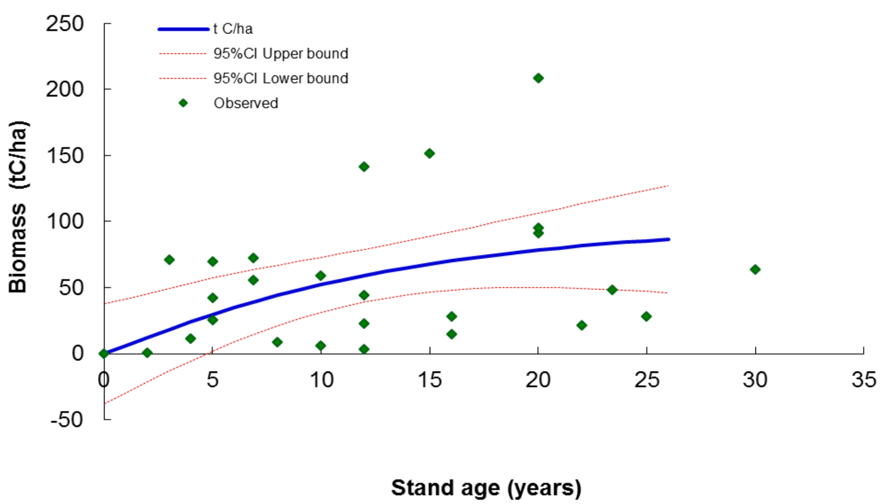


**Figure 5: Aboveground carbon accumulation curve for Tree Intercropping, fitted using 25 data points. Upper and lower curves represent upper and lower bounds of 95% CI.**

#### 6.1.3 SILVOPASTORAL

The carbon accumulation model for *silvopastoral* agroforestry systems in LAC was developed based on 29 data points. The biomass accumulation curve for this type of AFS approaches a maximum of 60 t C ha$^{-1}$.

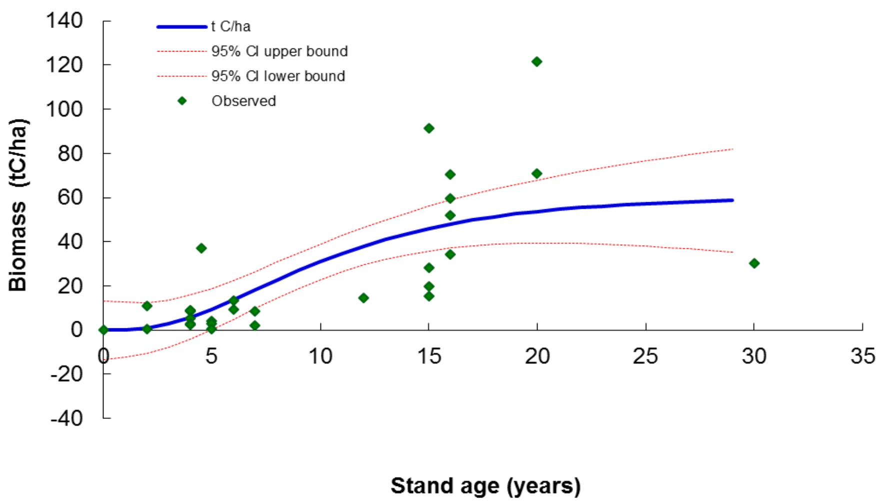


**Figure 6: Aboveground carbon accumulation curve for silvopastoral systems, fitted using 29 data points. Upper and lower curves represent upper and lower bounds of 95% CI.**

#### 6.1.4 PROTECTIVE SYSTEMS

Carbon accumulation rates for protective agroforestry systems are based on the average of two data points compiled from literature. The annual carbon accumulation rate for these systems is 4.68 t C $ha^{-1}$ $yr^{-1}$.

#### 6.1.5 WOODLOTS

No carbon accumulation rate is provided for agroforestry woodlots, given no data was compiled for this agroforestry type. Users are required to enter their own annual carbon accumulation rate of agroforestry woodlots in order to estimate the carbon benefits of such project activities.

### 6.2 AFRICA AND ASIA

Carbon benefits for AFS in Africa and Asia are calculated based on the linear projection of the annual accumulation rate derived from data compiled in literature. The following linear model is applied:

**Total Benefit (t CO2) =** Area * (CAR*Age) * (44/12)* Effectiveness

Where:

| | |
|---|---|
| Area | = area of AFS project activity; hectares, ha |
| CAR | = carbon accumulation rate, t C $ha^{-1}$ $yr^{-1}$ |
| Age: | = age of forest; years (user-defined) |
| 44/12 | = conversion factor from carbon to carbon dioxide equivalent |
| Effectiveness | = management effectiveness rating (%) |

Parameters in blue can be entered by the user, while parameters in red have default values offered by the Agroforestry Tool, which can be overridden by the user. Parameters in black are fixed within the calculations. The age of the forest is optional and can be entered under Advanced Inputs of the Tool, but if not specified by the users, it will default to one year initially.

Mean carbon accumulation rates along with its associated statistics for each of the five agroforestry types for Africa and Asia are shown in table 3.

**Table 3: Mean annual carbon accumulation rate (in t C ha-1 yr-1) and 95% confidence intervals for each of the five different agroforestry types for Africa and Asia**

| Africa | N | CAR ($tC.ha^{-1}.yr^{-1}$) | 95% CI |
|---|---|---|---|
| Multistrata | 16 | 5.30 | 3.0 |
| Protective | 1 | 1.35 | - |
| Tree Intercropping | 28 | 2.37 | 0.6 |
| Silvopastoral | 2 | 2.58 | - |
| Woodlots | 1 | 2.00 | - |
| **Asia** | **N** | **CAR ($tC.ha^{-1}\cdot yr^{-1}$)** | **95% CI** |
| Multistrata | 26 | 8.24 | 0.4 |
| Protective | 9 | 2.86 | 0.6 |
| Tree Intercropping | 20 | 2.73 | 0.5 |
| Silvopastoral | 13 | 2.89 | 0.7 |
| Woodlots | 7 | 2.73 | 1.0 |

## 6.3 HYPOTHETICAL EXAMPLE

A hypothetical project activity is planting 300 hectares of fruit and nut trees in Veraguas, Panama. This type of agroforestry is considered to be multistrata. After selecting the location and entering the total area the hypothetical agroforestry project activity takes place on, the user must respond to a series of multiple choice questions to estimate the effectiveness rating this multistrata agroforestry activity, which in this example is estimated at 80%. Then the benefits from this project activity are estimated as follows:

**Total Benefit (t $CO_2$)** = 300* (65* [1–EXP(-0.114* 1)]^[1/(1-0.1)]) *(44/12) * 0.8

**Total Benefit (t $CO_2$)** = 300*5.47*(44/12)* 0.8

**Total Benefit (t $CO_2$)** = 300*20.05* 0.8

**Mutistrata Agroforestry Benefits** = 4,811.4 t $CO_2$e

In this example, the multistrata agroforestry project activity that is 80% effective in planting 300 ha of fruits and nut trees in Veraguas, Panama, will result in a carbon benefit of approximately **4,811 t $CO_2$e** for the first year.

# 7. OVERRIDING DEFAULT DATA

The ability to override the Agroforestry Tool's default database is very limited. Users may change:

- The type of agroforestry system planted:
  - Multistrata
  - Protective
  - Tree intercropping
  - Silvopastoral
  - Woodlots
- The age of the planted agroforest
- The carbon accumulation rate of the planted agroforest

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# ANNEX I – RESOURCE MATERIAL

(Provided to Winrock International by Dr. P.K. Nair in 2012)


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