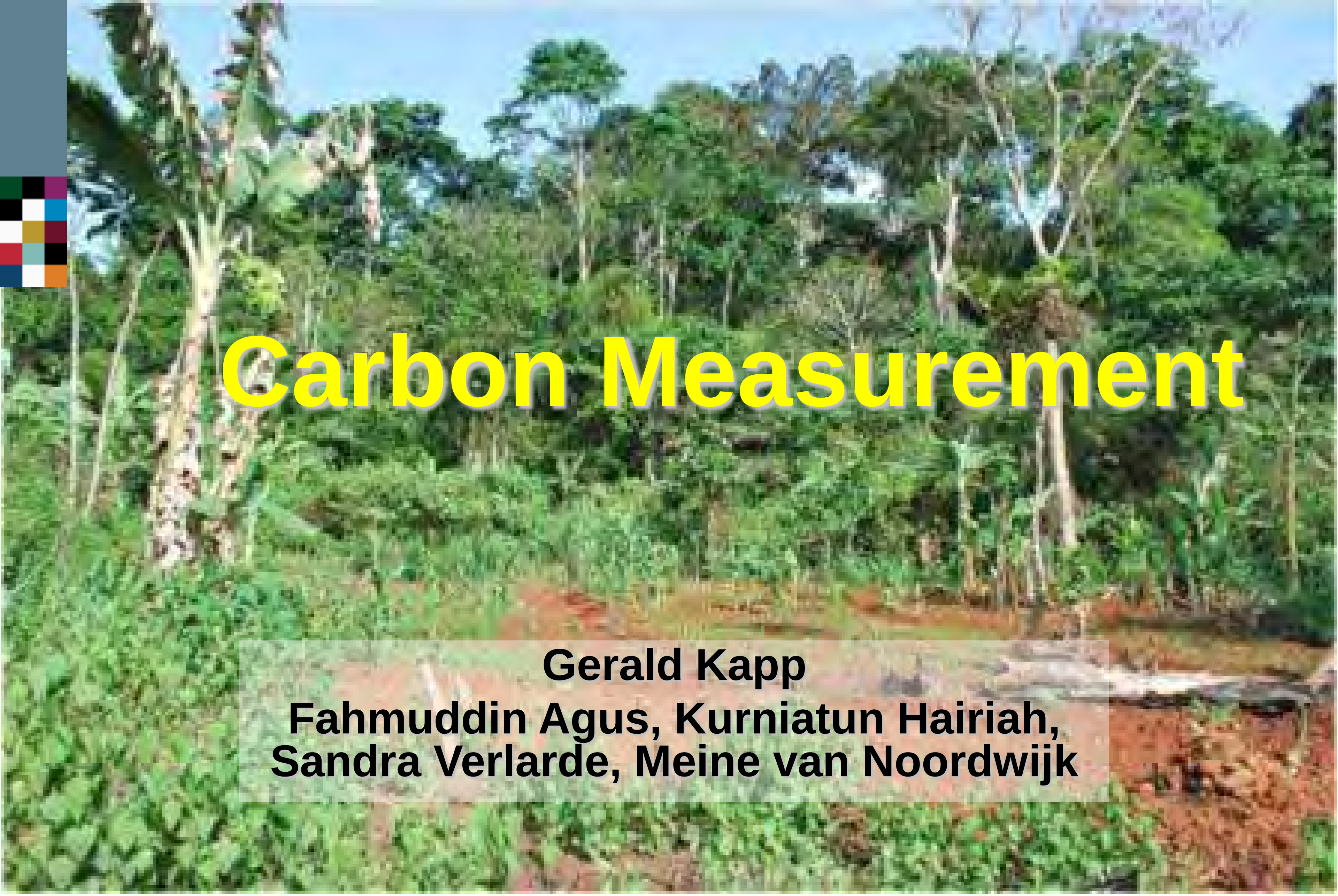

# Carbon Measurement

**Gerald Kapp**

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FOREST CARBON PARTNERSHIP

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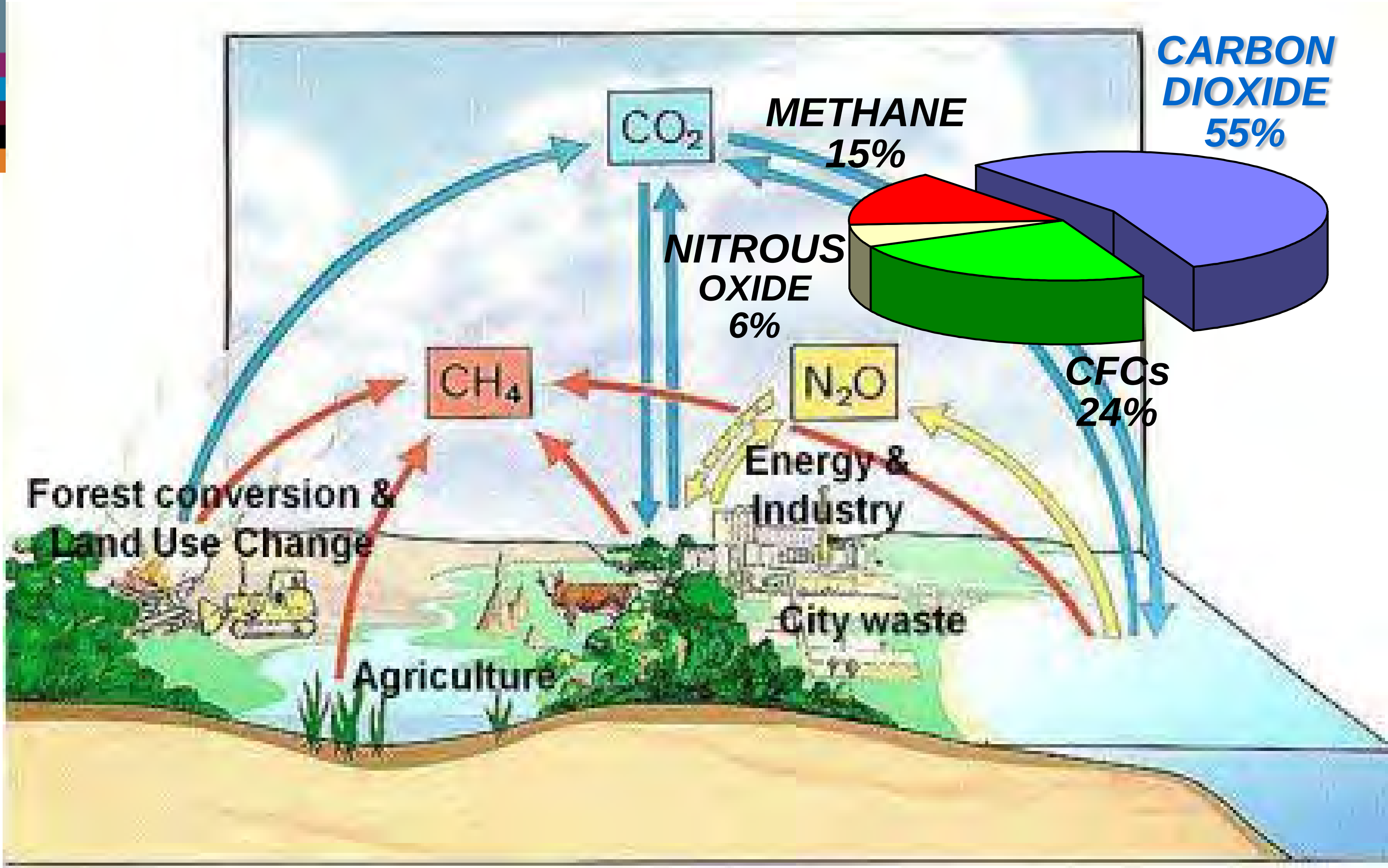
ASB Partnership for the Tropical Forest Margins

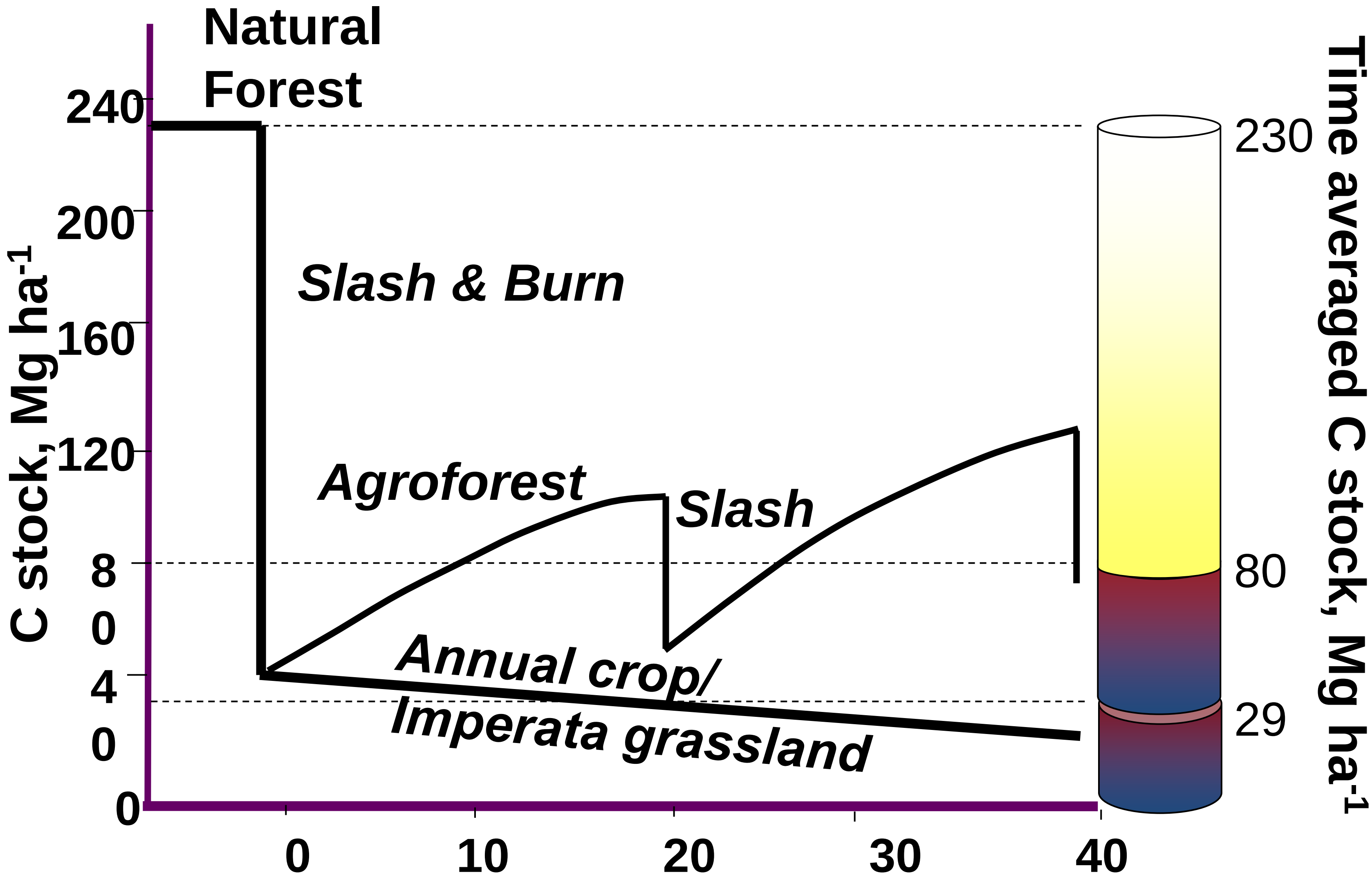
# Why should we measure C and how?

1. What is the role of carbon in climate change?
2. How land use influences C stocks?
3. What is the relation to emission reductions i.e. “carbon credits”?
4. Where does this fit into the Opp. Costs of REDD+?
5. What are techniques to measure carbon?

# 1. Contribution of different Greenhouse Gases to Global Warming – the role of C

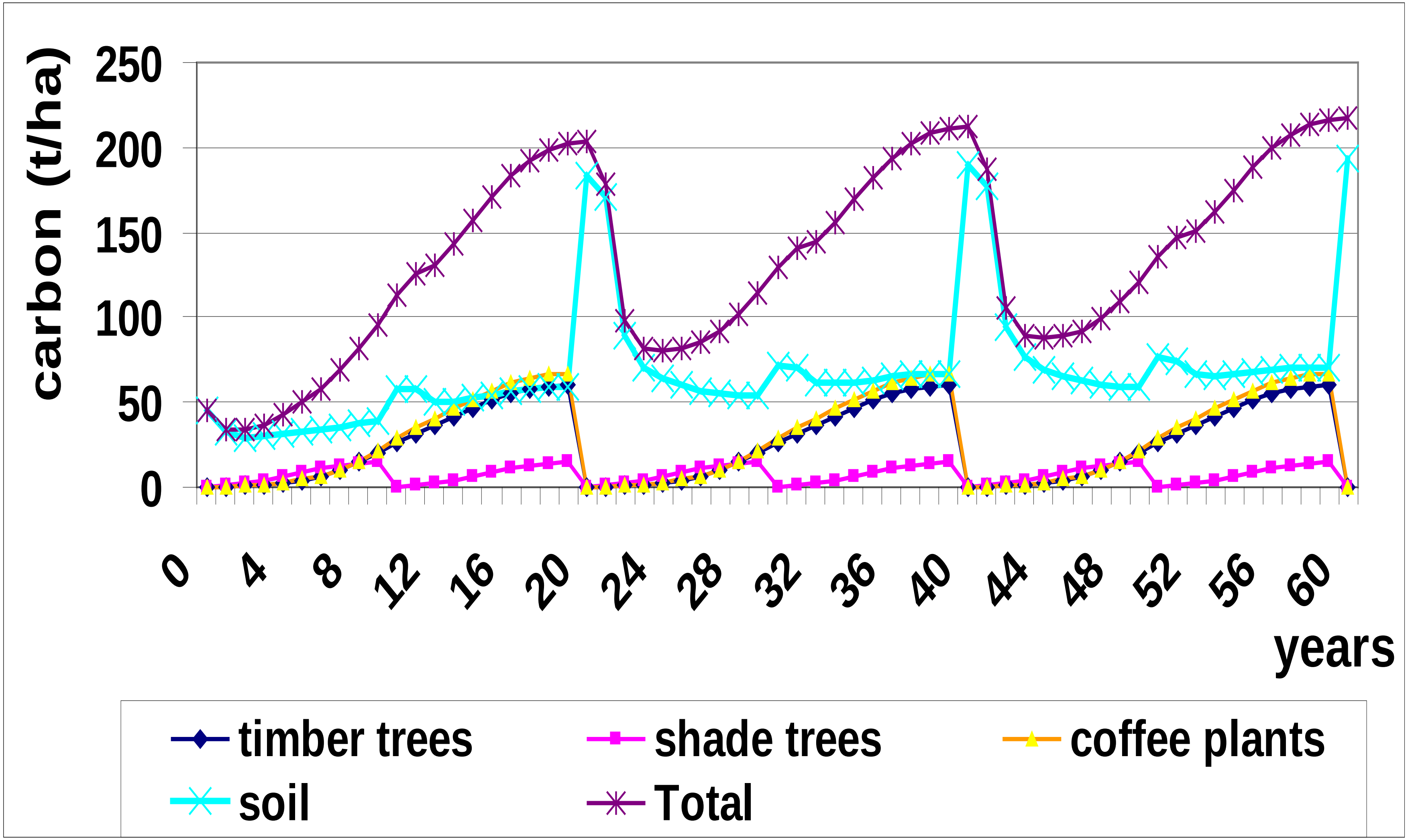


# 2. How Land-Use influences C Stocks




(IPCC, 2001, page 209)

# Carbon Stock Distribution inside a LUS




CO2Fix Model (2005)

# 3. What is the relation to emission reductions “carbon credits”?

## Carbon accounting = ATM

**Actual Carbon Stock**

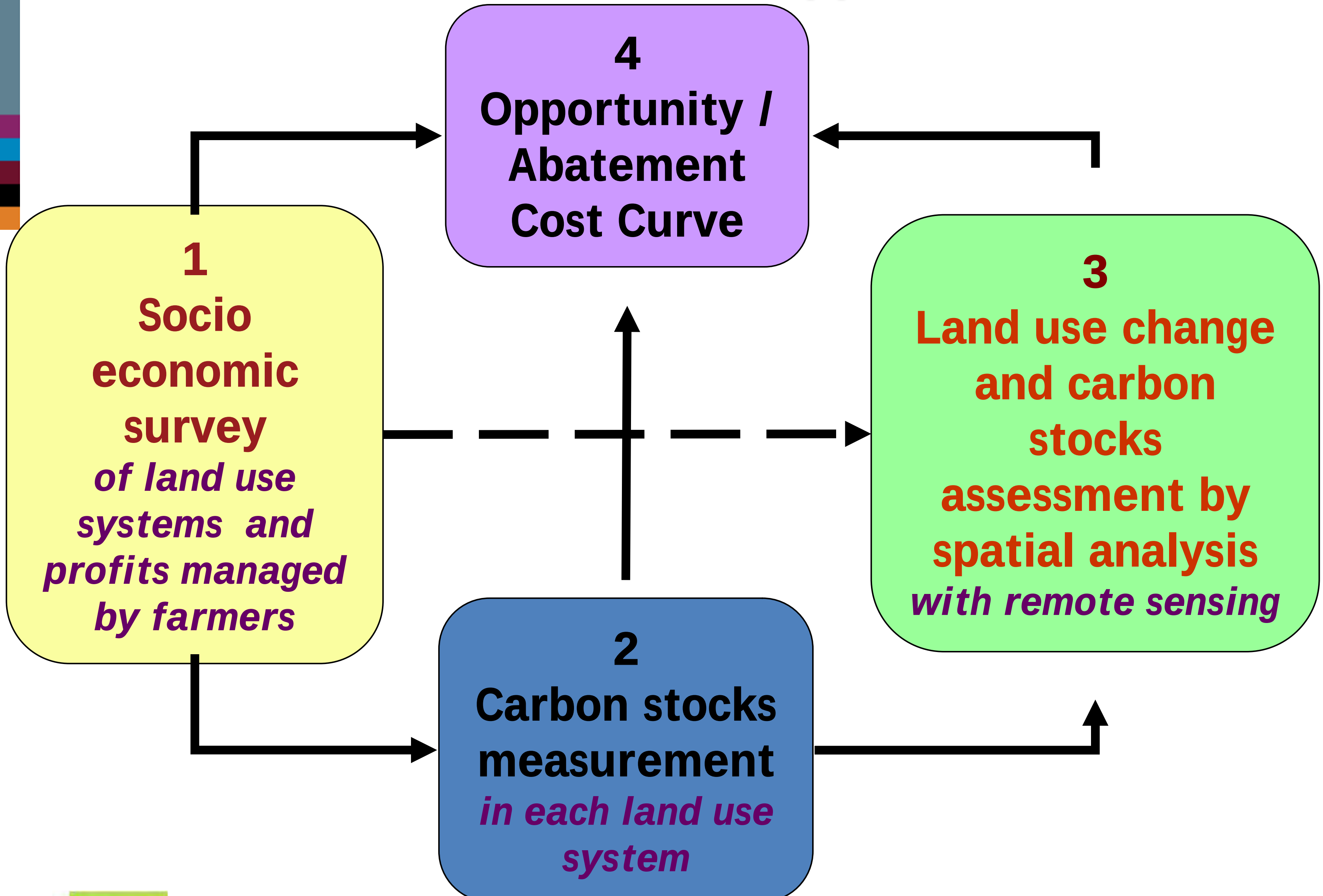
**minus**

**Reference Scenario Carbon Stock**

↓

**$$$$$$$$$$$$$$$$$$$$**

# 4. Where does this fit into the Opp. Costs of REDD+?



# How can we measure carbon in different land use systems?

1. Decide on a classification system for land uses
2. Measure the C stock densities of the land use systems
3. Measure the changes in area fraction
4. Integrating the data to a landscape level C balance

# Priority and Costs of Measuring Carbon in different Types of Land Uses and Pools

| C pool | *Method* | Land use | | | | | |
|---|---|---|---|---|---|---|---|
| | | Forest | | Perennial | | Annual Crop | |
| | | Cost | Priority | Cost | Priority | Cost | Priority |
| Tree biomass | *DBH and allometric equations* | 2 | 4 | 2 | 4 | | |
| Understorey biomass | *Destructive samples* | 4 | 2 | 4 | 1 | | |

*Note: The highest values (shaded green) indicate greater priority or higher cost. Example from Indonesia.*

# Priority and Costs of Measuring Carbon in different Types of Pools and Land Uses

| C pool | Method | Land use | | | | | |
|---|---|---|---|---|---|---|---|
| | | Forest | | Perennial | | Annual Crop | |
| | | Cost | Priority | Cost | Priority | Cost | Priority |
| Tree biomass | *DBH and allometric equations* | 2 | 4 | 2 | 4 | | |
| Understorey biomass | *Destructive samples* | 4 | 2 | 4 | 1 | | |
| Crop | *Literature, secondary data* | | | | | 2 | 3 |
| Dead biomass | *Non destructive* | 2 | 2 | 2 | 1 | | |
| Litter | *Destructive* | 3 | 2 | 2 | 1 | | |
| Soil C | *Destructive: density and C content* | 4 | 3 | 4 | 3 | 4 | 3 |

*Note: The highest values (shaded green) indicate greater priority or higher cost. Example from Indonesia.*

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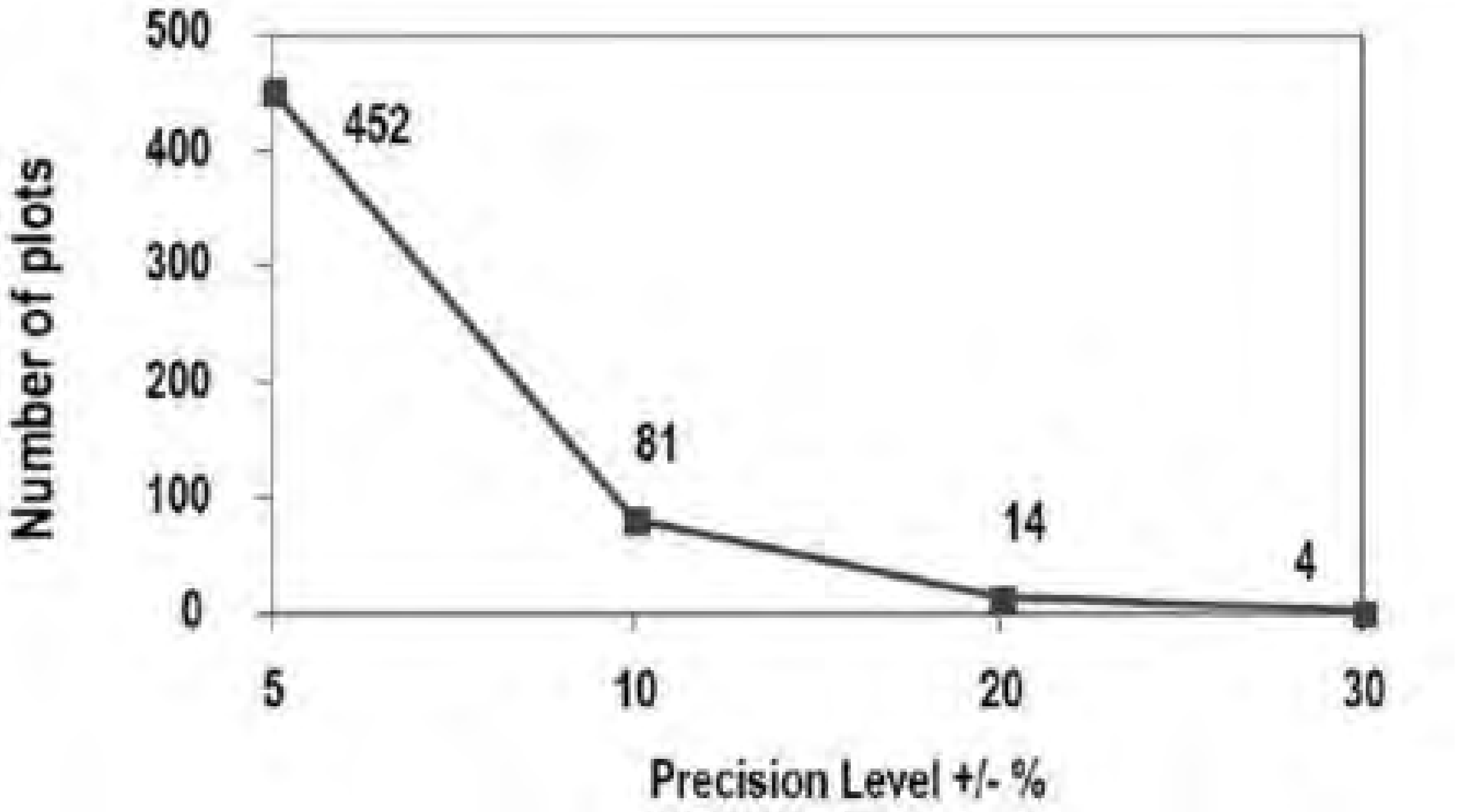
# Data Requirements according to the IPCC Good Practice Guidance

- ***Representative*: Capable of representing land-use systems/land cover categories to their proportions**
- ***Time consistent*: Capable of representing land-use systems/land cover categories consistently over time**
- ***Complete*: All lands within a country should be included, so that trade-offs are visible**
- ***Transparent*: Data sources, definitions, methodologies and assumptions clearly described**

# Decide on precision levels

- *Tier 1:* Global scale data
  - remote sensing imagery
  - global / regional equations & parameters
- *Tier 2:* National scale data
  - forest inventory data, usually focused on timber volumes of commercially-attractive timber species
  - primary data that can be converted to total biomass estimates
- *Tier 3:* Plot/watershed data
  - bio-economic models of biomass production under different management regimes, calibrated on plot-level biomass data (main crops and timber species)
  - ecological data of long-term forest plots

# Cost-benefit implications of a higher precision level




*Source: IPCC 2003, chapter 4-3

# Determine Number of Plots

1. Identify the desired precision level, e.g. =/- 10% of the mean value
2. Identify area where to collect preliminary data for each stratum. About 6-10 plots, plot size determined adequately
3. Estimate carbon stock average and standard deviation from preliminary data
4. Calculate the required number of plots

Reference: Pearson, Walker, Brown 2005: Sourcebook for Land Use, Land-Use Change and Forestry Projects. BioCF, Winrock International

# Equation Elements

$$\bar{x} = \frac{x_1 + x_2 + \ldots + x_n}{n} = \frac{\sum_{i=1}^{n} x_i}{n}$$

*Average*

$$s^2 = \frac{\sum_{i=1}^{n} (X_i - \bar{X})^2}{n-1}$$

*Variance*

$$s = \sqrt{s^2}$$

*Std. deviation*

t : Sample statistic from the probability t-distribution for a chosen confidence level, e.g. 95%.
Initially, for an unknown sample size: t = 2

# Example: Determine the No. of Plots

For a single-stratum project:

$$n = \frac{(N \times s)^2}{\frac{N^2 \times E^2}{t^2} + N \times s^2}$$

**Single-stratum project**

| | |
|---|---|
| Area | = 5,000 ha |
| Plot size | = 0.08 ha |
| Mean stock | = 101.6 t C/ha |
| Standard deviation | = 27.1 t C/ha |
| N **(number of possible sample units)** | = 5,000/0.08 = 62,500 |
| Desired precision | = 10 % |
| E **(allowable error)** | = 101.6 x 0.1 = 10.16 |

$$n = \frac{(62{,}500 \times 27.1)^2}{\frac{62{,}500^2 \times 10.16^2}{2^2} + 62{,}500 \times 27.1^2}$$

= 29 plots

Reference: Pearson, Walker, Brown 2005: Sourcebook for Land Use, Land-Use Change and Forestry Projects. BioCF, Winrock International

# Accounting for C-stock changes from land use sectors

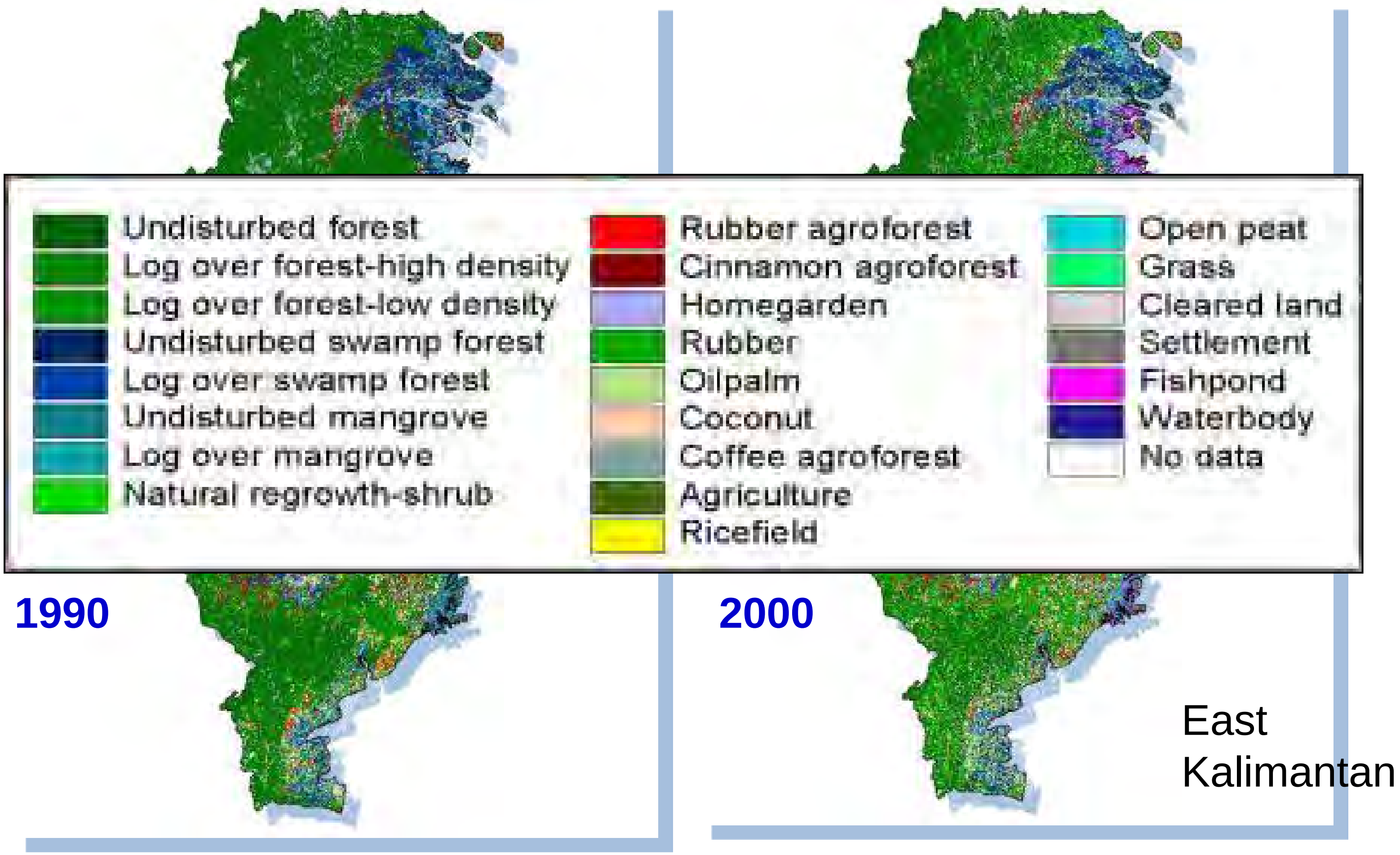
$$\Delta C = \sum_{ij} A_{ij} \left[\Delta C_{ij\ LB} + \Delta C_{ij\ DOM} + \Delta C_{ij\ SOILS}\right] / T_{ij}$$

LUC ⟷ Biomass ⟷ Necromass ⟷ Soil

| | |
|---|---|
| $\Delta C$ | **Annual change in C stocks in the landscape, ton C $yr^{-1}$** |
| $\sum_{ij} A_{ij}$ | **sum of areas of land use type *i* that change to *j*, ha** |
| $\Delta C_{ij}$ LB | **Change in C stocks in living biomass from changes of land use type *i* to *j* , tons C $ha^{-1}$** |
| $\Delta C_{ij}$ DOM | **Change in C stocks in dead organic matter from changes of land use type *i* to *j* , ton C $ha^{-1}$** |
| $\Delta C_{ij}$ SOILS | **Change in C stocks in soils from changes of land use type *i* to *j*, ton C $ha^{-1}$** |
| $T_{ij}$ | **Period of the transition from land use type *i* to land use type *j*, yr** |

# Accounting for C-stock changes from land use sectors

$$\Delta C = \sum_{ij} A_{ij} [\Delta C_{ij\ LB} + \Delta C_{ij\ DOM} + \Delta C_{ij\ SOILS}] / T_{ij}$$



# Accounting for C-stock changes from land use sectors

$$\Delta C = \sum_{ij} A_{ij} [\Delta C_{ij\ LB} + \Delta C_{ij\ DOM} + \Delta C_{ij\ SOILS}] / T_{ij}$$

Modelling

Plot level measurement

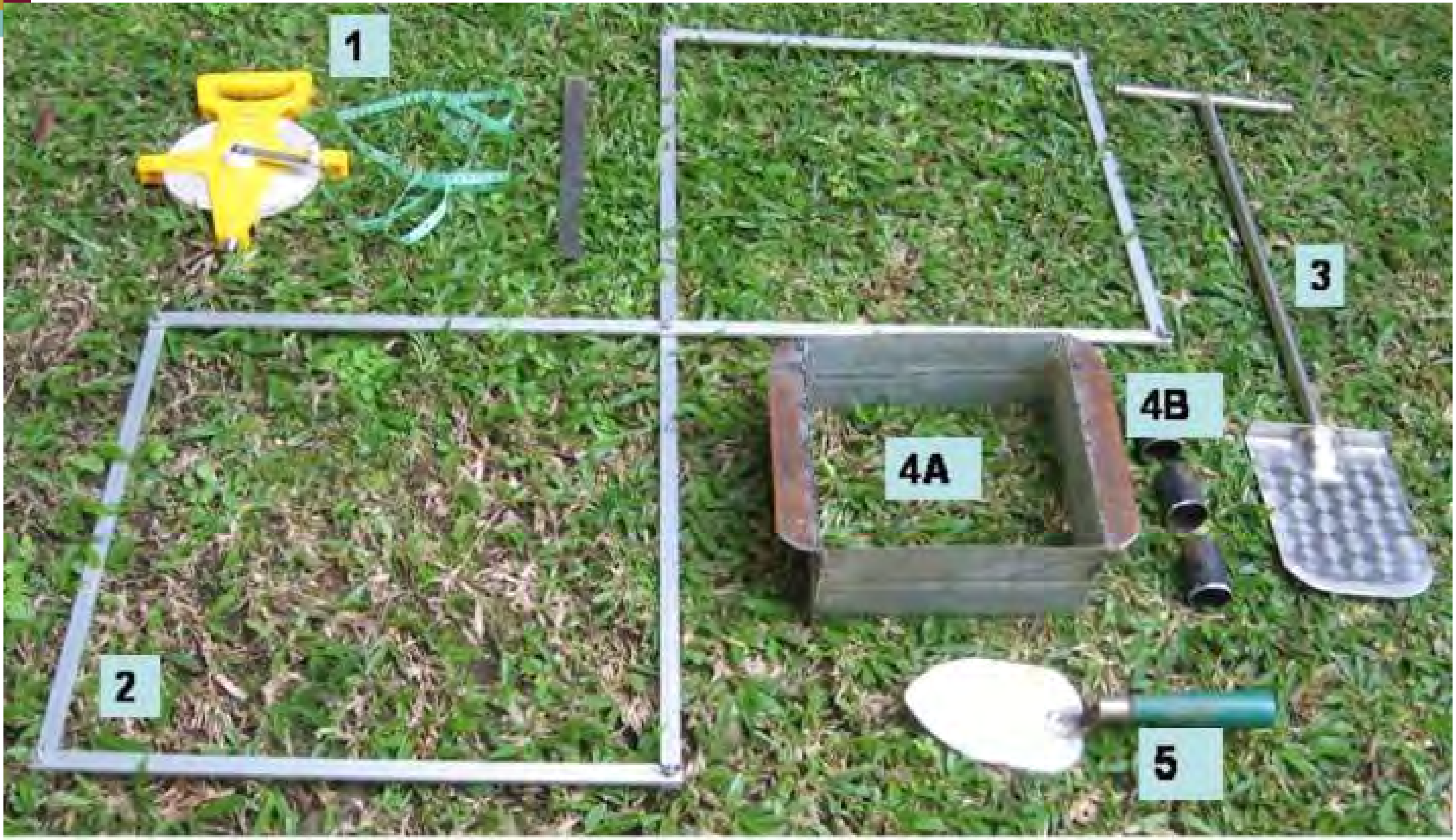
# Measurement of C stock of

**Bio-mass**


**Necro mass**

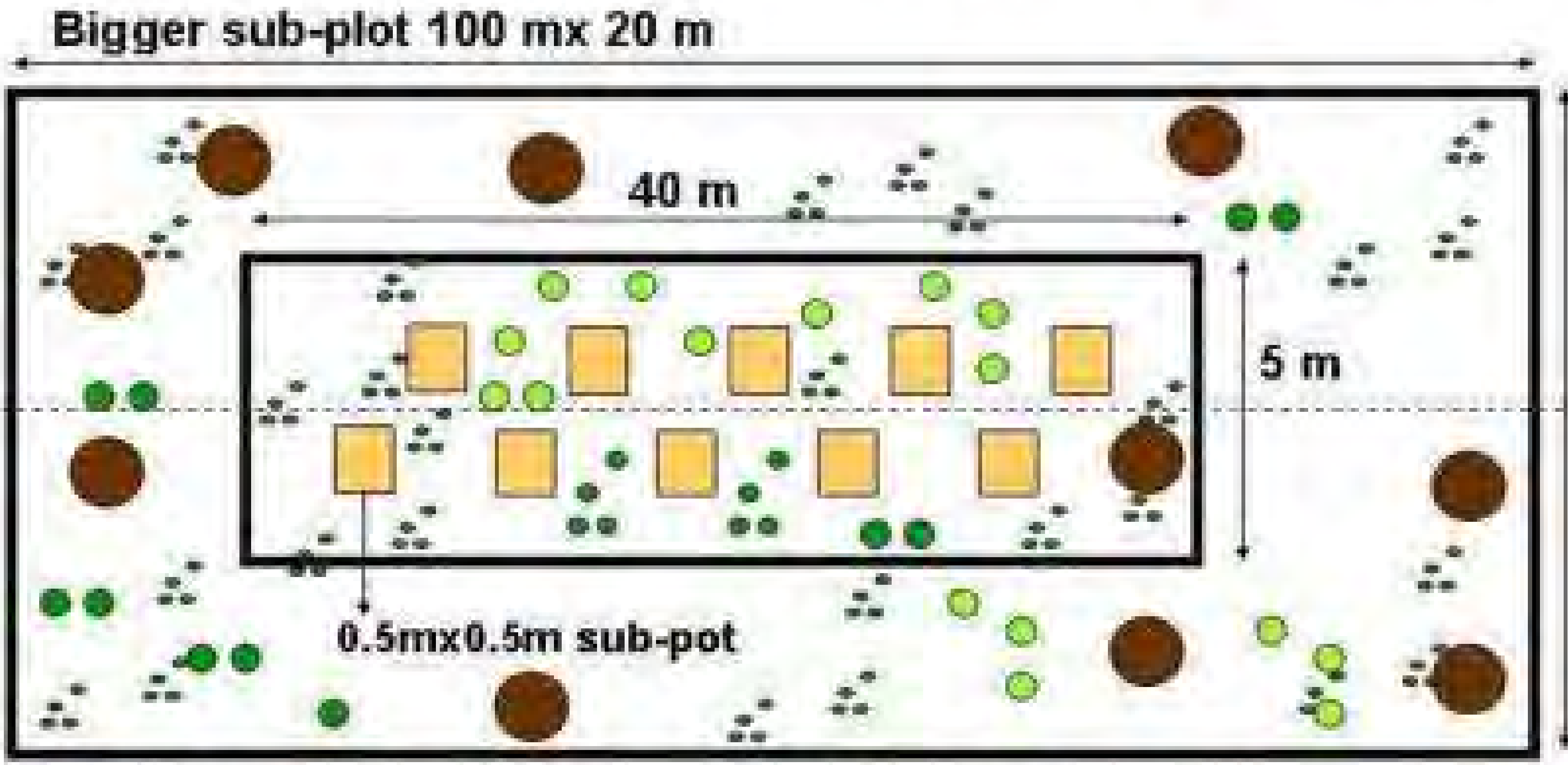
**Soil**

# Equipments needed




**To assess the performance of existing land use systems as C sinks and/or preserving C stocks: Setting up plot sampling**

# Nested Plot Design for Sampling




- Trees with dbh>30 cm (girth 95 cm) inside **bigger sub-plot**
- Trees with dbh in a range of 5 - 30 cm inside **5m x 40m sub-plot**
- Trees with dbh < 5 cm (girth < 15cm) **inside 0.5 x 0.5 m sub-plot**
- Understorey and litter layer sample plot

# Important parameters for aboveground tree biomass

1. Tree trunk diameter
2. Wood specific gravity
3. Total height
4. Forest type (dry, moist or wet)

Very Important

Less Important

$$AGB = \rho D^2 H \text{ ....... kg/tree}$$

Chave *et al.* (2005)

# Estimation of tree biomass

(Chave et al., 2005)

- **Branching pattern**
- **Diameter at breast height (dbh at 1.3 m)**
- **Wood density**

- **Light (< 0.6 Mg $m^{-3}$)**
- **Medium (0.6 - 0.75 Mg $m^{-3}$),**
- **Heavy (0.75 - 0.9 Mg $m^{-3}$ )**
- **Very heavy (> 0.9 Mg $m^{-3}$)**

**(*Anonymous, 1981*)**

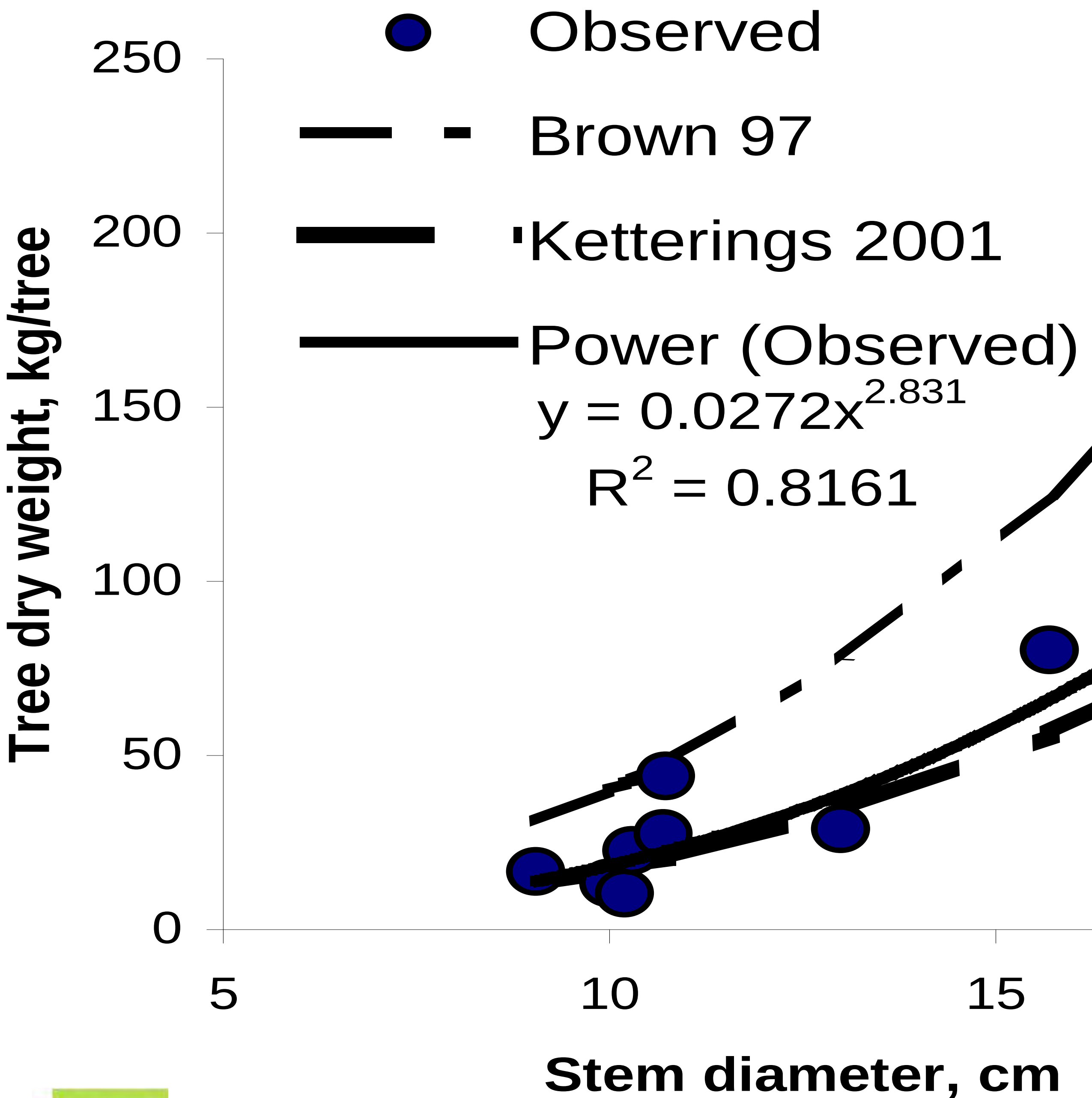
***http:\\www.icraf.cgiar.org***

# Relation of tree size to carbon stocks

| Stem diameter DBH (cm) | Biomass DM per tree (Mg) | No. of tree per hectare | Carbon per ha (Mg/ha) | Carbon (%) |
|---|---|---|---|---|
| 10 | 0.13 | 900 | 53 | 19 |
| 30 | 2.25 | 70 | 71 | 24 |
| 50 | 8.50 | 20 | 76 | 26 |
| 70 | 20 | 10 | 90 | 31 |
| Total | - | 1,000 | 290 | 100 |

| Rainfall, mm/yr | Allometric | Diameter, cm | No tree | $R^2$ |
|---|---|---|---|---|
| Dry (<1500) | **$W = 0.139\ D^{2.32}$** *(Brown, 1997)* | 5-40 | 28 | 0.89 |
| Moist (1500-4000) | **$W = 0.118\ D^{2.53}$** *(Brown, 1997)*<br>**$W = 0.049\ D^2\ H$** *(Brown et al., 1995)*<br>**$W = 0.11\ \rho\ D^{2+c}$** (c=0.62) *(Ketterings et al., 2001)* | 5-148 | 170 | 0.90 |
| Wet (>4000) | **$W = 0.037\ D^{1.89}\ H$** (Brown, 1997) | 4-112 | 160 | 0.90 |
| W = Tree Biomass, kg/tree; D=dbh, cm; $\rho$ = wood density, g $cm^{-3}$ | | | | |

# Paraserianthes N .Lampung




**Wood density = 0.375 g cm$^{-3}$**

# Estimation of tree biomass in agroforestry systems

$W = 0.11\ \rho\ D^{2+0.62}$ *(Ketterings et al., 2001)*

**W = Biomass; D = dbh; ρ = wood density**

**Total Carbon = 46%**



Are we going to use this allometric equation?

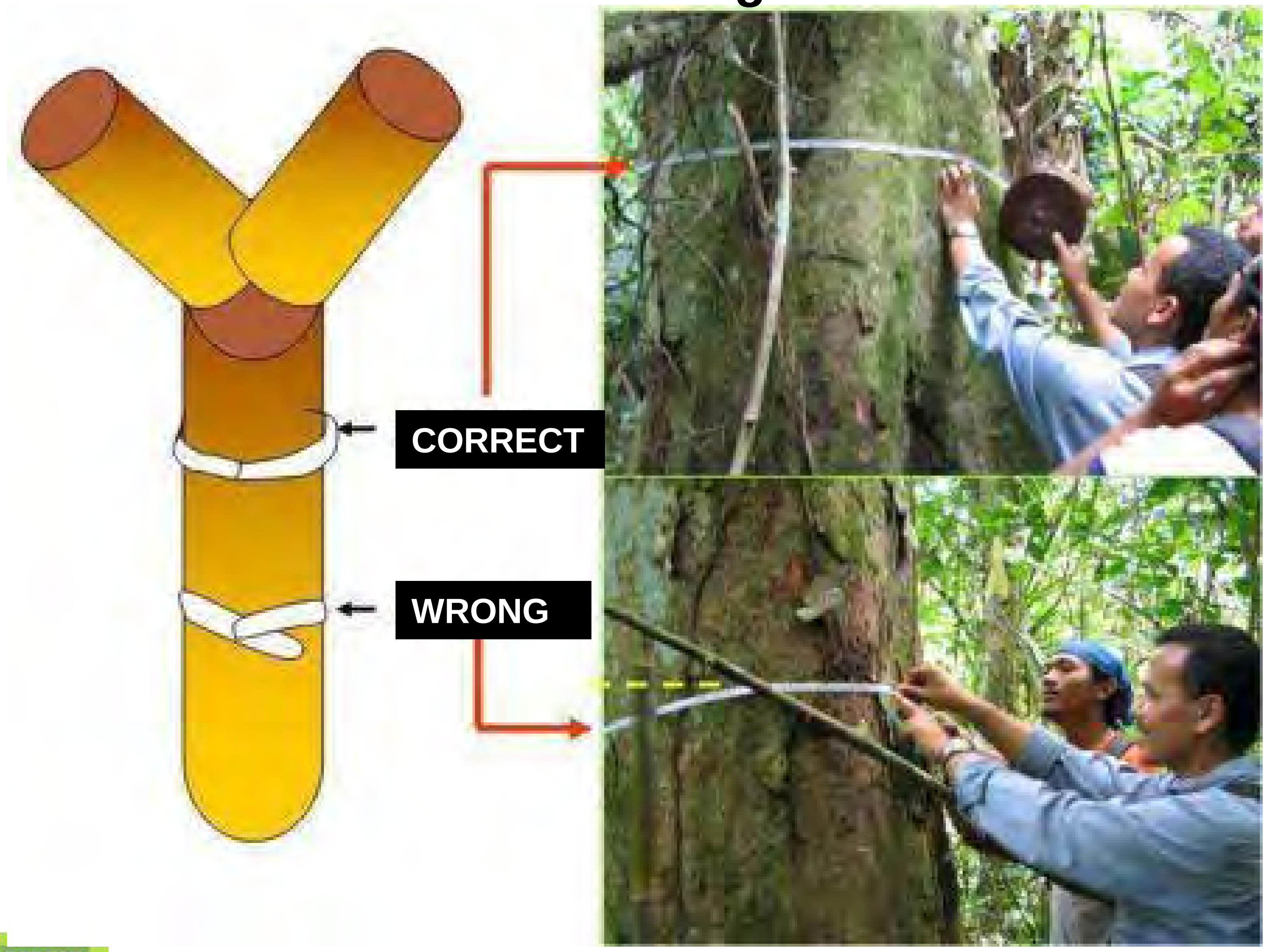
$$W = 0.118\ D^{2.53}$$

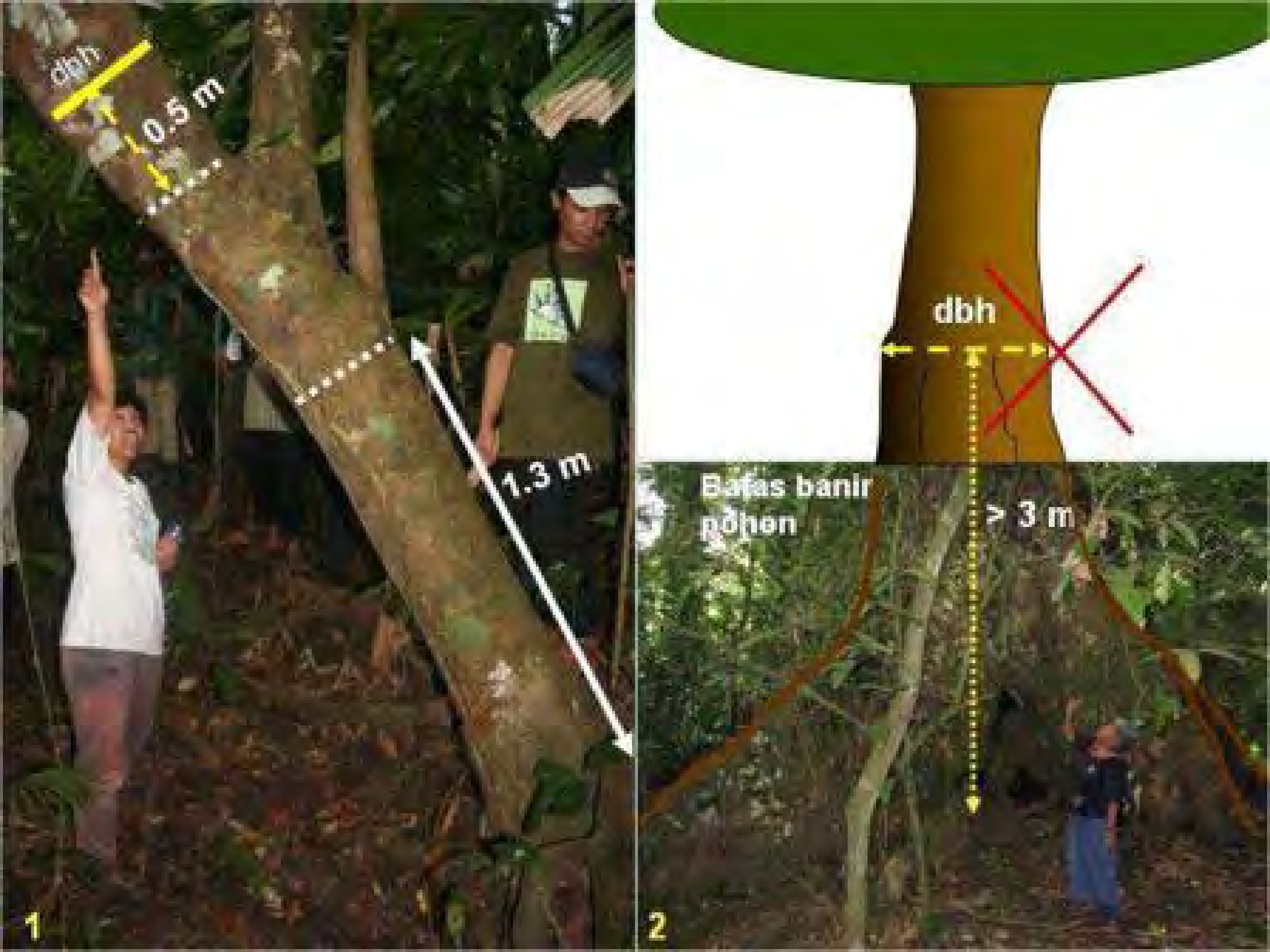
*(Brown, 1997)*

# Biomass equations for 'woody' species

| Vegetation | Equations | $R^2$ |
|---|---|---|
| Coffee (Arifin, 2001) | $W = 0.2811\ D^{2.0635}$ | 0.9455 |
| Banana (Arifin, 2001) | $W = 0.0303\ D^{2.1345}$ | 0.9887 |
| Bamboo (Priyadarsini,1998) | $W = 0.1312\ D^{2.2784}$ | 0.9541 |
| Paraserianthes (Sugiarto, 2001) | $W = 0.0272\ D^{2.831}$ | 0.8161 |
| Tea (*Camelia sinensis*) (Hariyadi, 2005) | $W = 0.1594\ D^{1.1517}$ | |
| Pinus (Waterloo, 1995) | $W = 0.0417\ D^{2.6576}$ | 0.9085 |

# Measuring tree diameter at plot level for estimating C stock

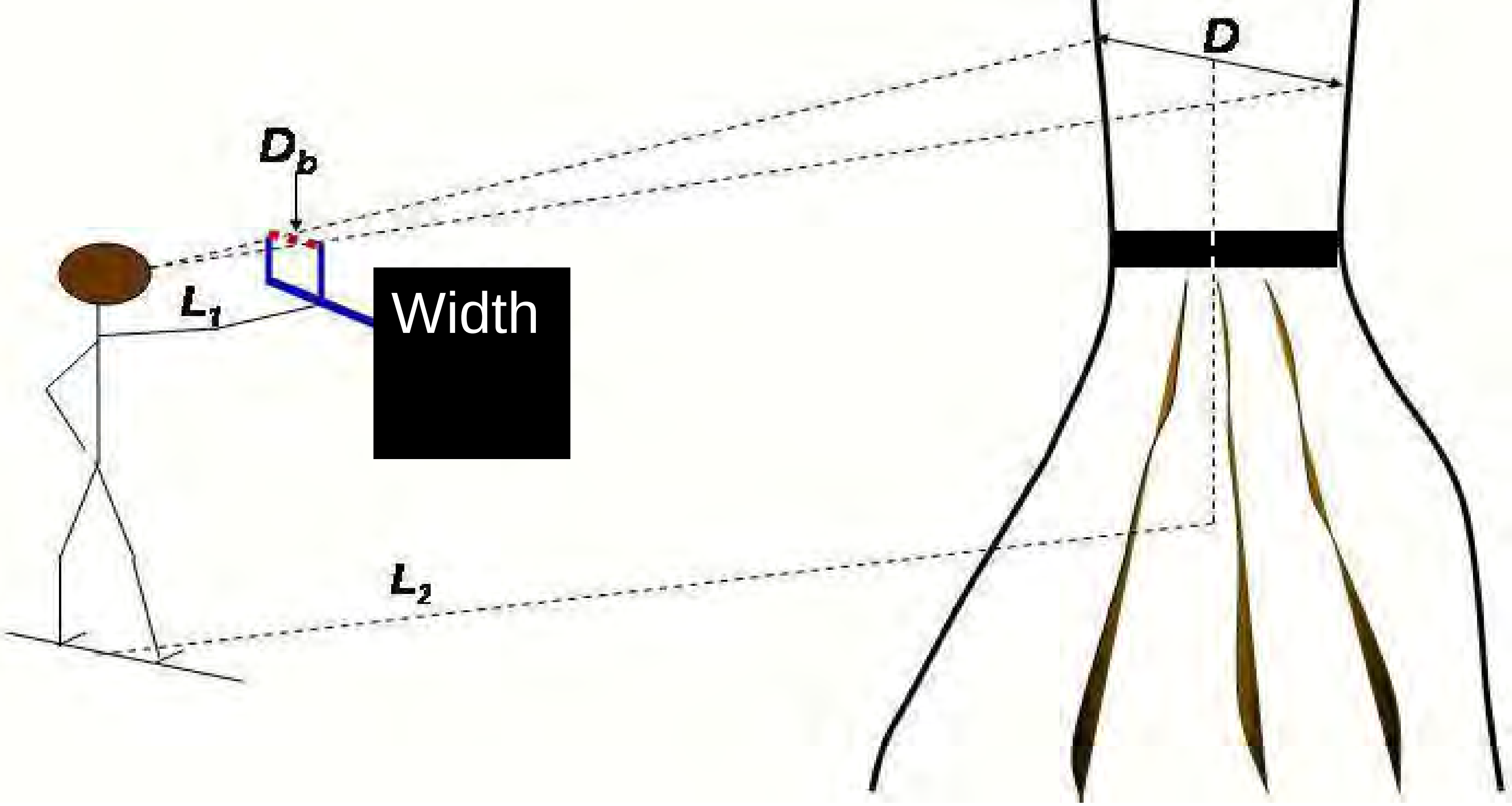



dbh
0.5 m
1.3 m
1
dbh
Batas banir pohon
> 3 m
2

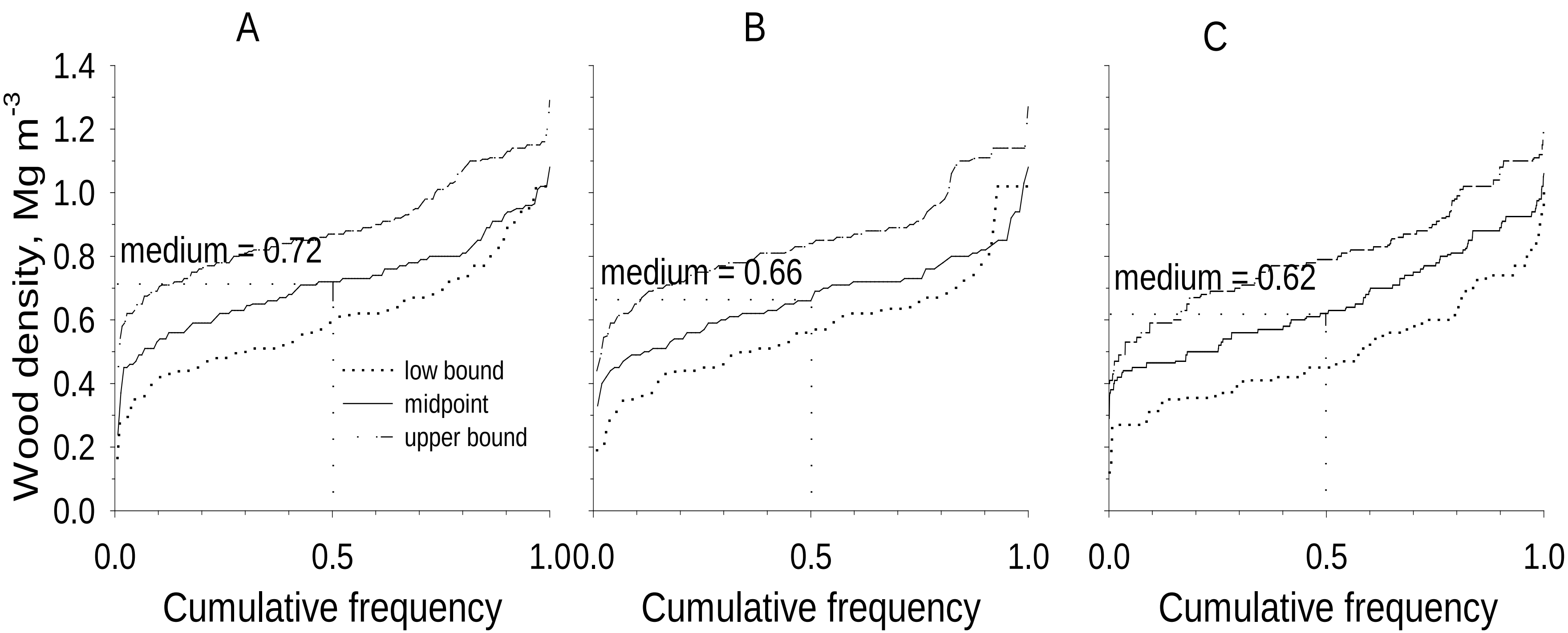
# Measuring tree diameter as basis for allometric biomass estimate

$$D(m) = \frac{Db(cm) x L_2(m)}{L_1(cm)}$$

Tree with high plank roots



# Wood Density




Natural forest | Disturbed forest | Rubber agroforest

**H**igh, **M**edium, **L**ow (0.6, 0.4, 0.2 g $cm^{-3}$)

http://www.worldagroforestry.org/sea/Products/AFDbases/AF/index.asp

# Table for total biomass of trees > 5 cm DBH

| No | Local/Scien tific name | Branched? Y/N | G | D | H | ρ*) | Biomass, kg/tree**) | Note |
|---|---|---|---|---|---|---|---|---|
| 1 | | | | | | | ……… | |
| 2 | | | | | | | ……… | |
| 3 | | | | | | | ……… | |
| 4 | | | | | | | ……… | |
| … | | | | | | | ……… | |
| 100 | | | | | | | ……… | |
| | TOTAL TREE BIOMASS | | | | | | …………. | |

***Note***:
G=girth, cm, D = dbh= G/π, cm where π =3.14 ; H= tree height, cm, ρ = Wood density, g $cm^{-3}$

*)Estimated wood density: **H**igh, **M**edium, **L**ow (0.6, 0.4, 0.2 g $cm^{-3}$)

***** *) Estimate AGB using specific allometric equation for tree growing in the tropical forest, and for trees growing in the agroforestry and plantation system

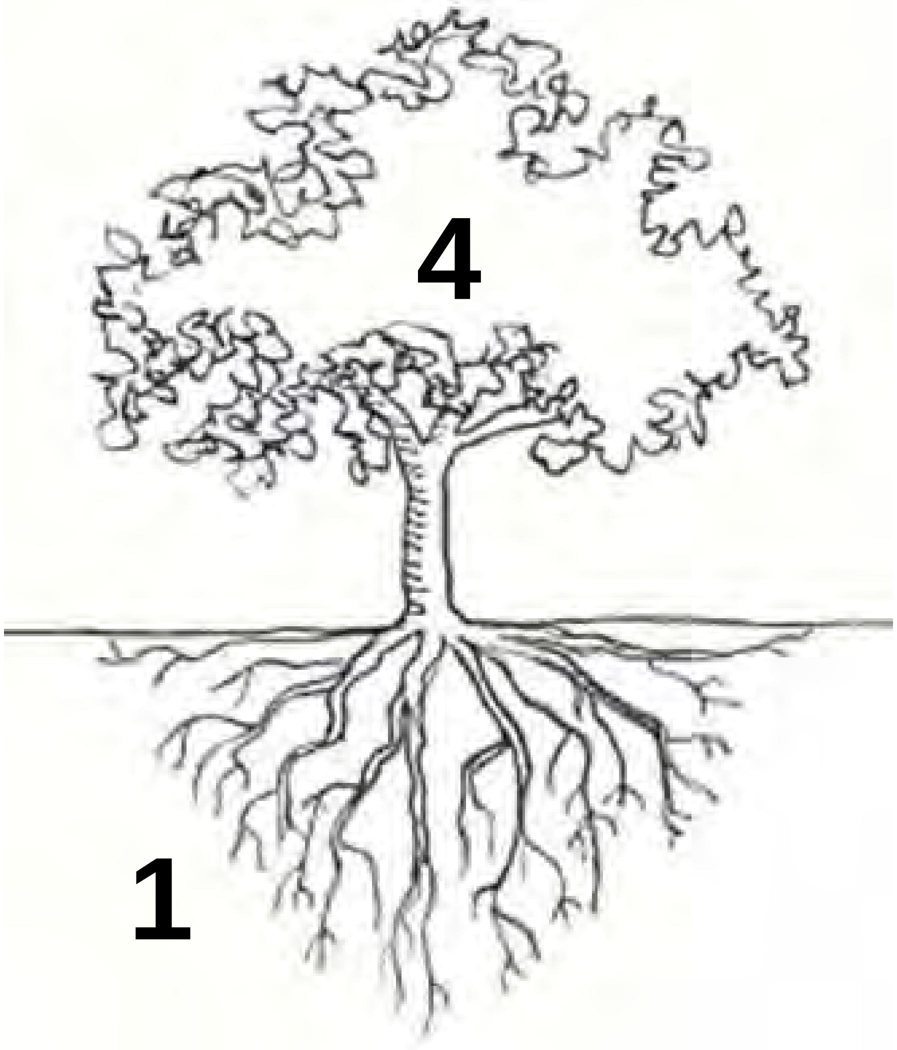
# Table for total biomass of understorey

**C stock = DW (kg) x total C (0.46)**

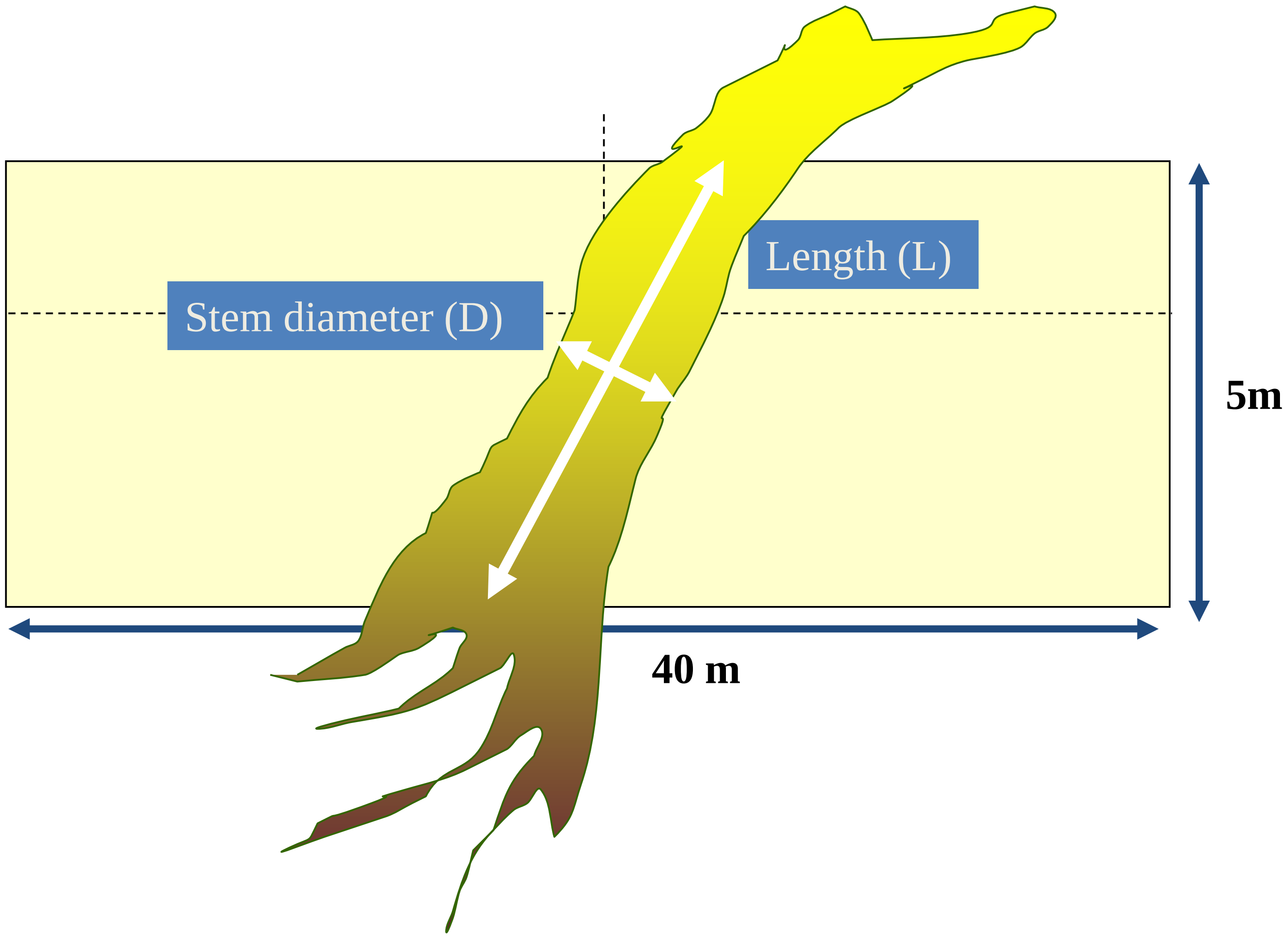
| No. | Total FW (kg) | Sub-sample FW (g) | Sub-sample DW (g) | Total DW fine litter | | Total C, % | Total C-stock, ton/ha |
|---|---|---|---|---|---|---|---|
| | | | | kg/0.25 $m^2$ | kg/$m^2$ | | |
| 1 | | | | | | | |
| 2 | | | | | | | |
| 3 | | | | | | | |
| 4 | | | | | | | |
| 5 | | | | | | | |
| 6 | | | | | | | |
| | | | | Total DW | …… | | |
| | | | | Avg. DW | …… | | |

# C stocks of Tree Root System

- Default values for the shoot/root ratio (SR-ratio) are **4:1** for humid tropical forest on normal upland soils
- up to **10:1** on continuously wet sites
- around **1:1** at very low soil fertility, long dry seasons



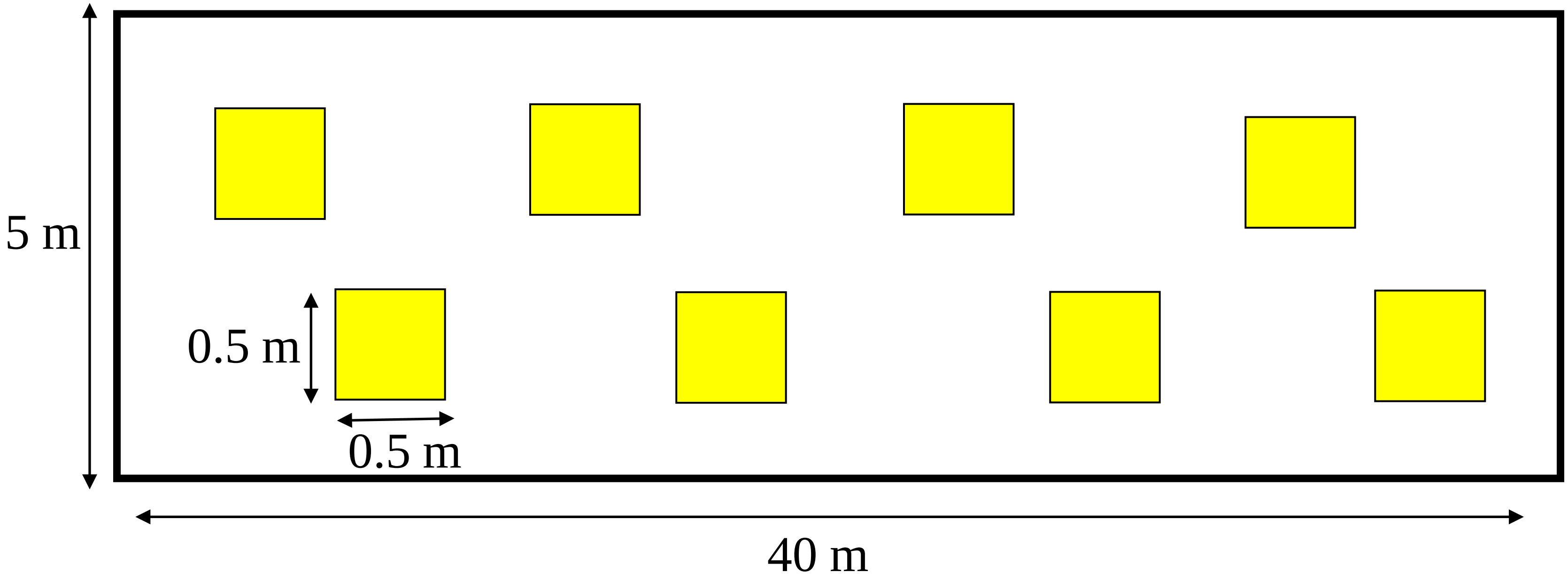
# Estimation of Necromass: Laying trees




$$DW = \pi/4 \times D^2\,[cm^2] \times \text{length}\,[cm] \times \text{wood density}\,[g\,cm^{-3}]$$

# NECROMASS: Undisturbed sampling

# Destructive sampling: understorey and litter




# Sample handling: Separating roots and soil

# Soil sampling ➔ Soil bulk density

## Bulk Density = Weight / Vol. (g $cm^{-3}$)


Metal frame: 20x20x10 cm

# Estimation of total C stock in soil

**Example**

**How much C stock (ton/ha) in soil layer of 10 cm, if soil bulk density 1.0 $kg/dm^3$ or 1.0 $ton/m^3$, and concentration of $C_{org}$ in soil is 2.0% ?**

**Soil weight per ha = 100 m x 100 m x 0.10 m x 1.0 $ton/m^3$ = 1,000 ton**

**Soil C- stock = 1,000 ton x 0.02 = 20 ton/ha**

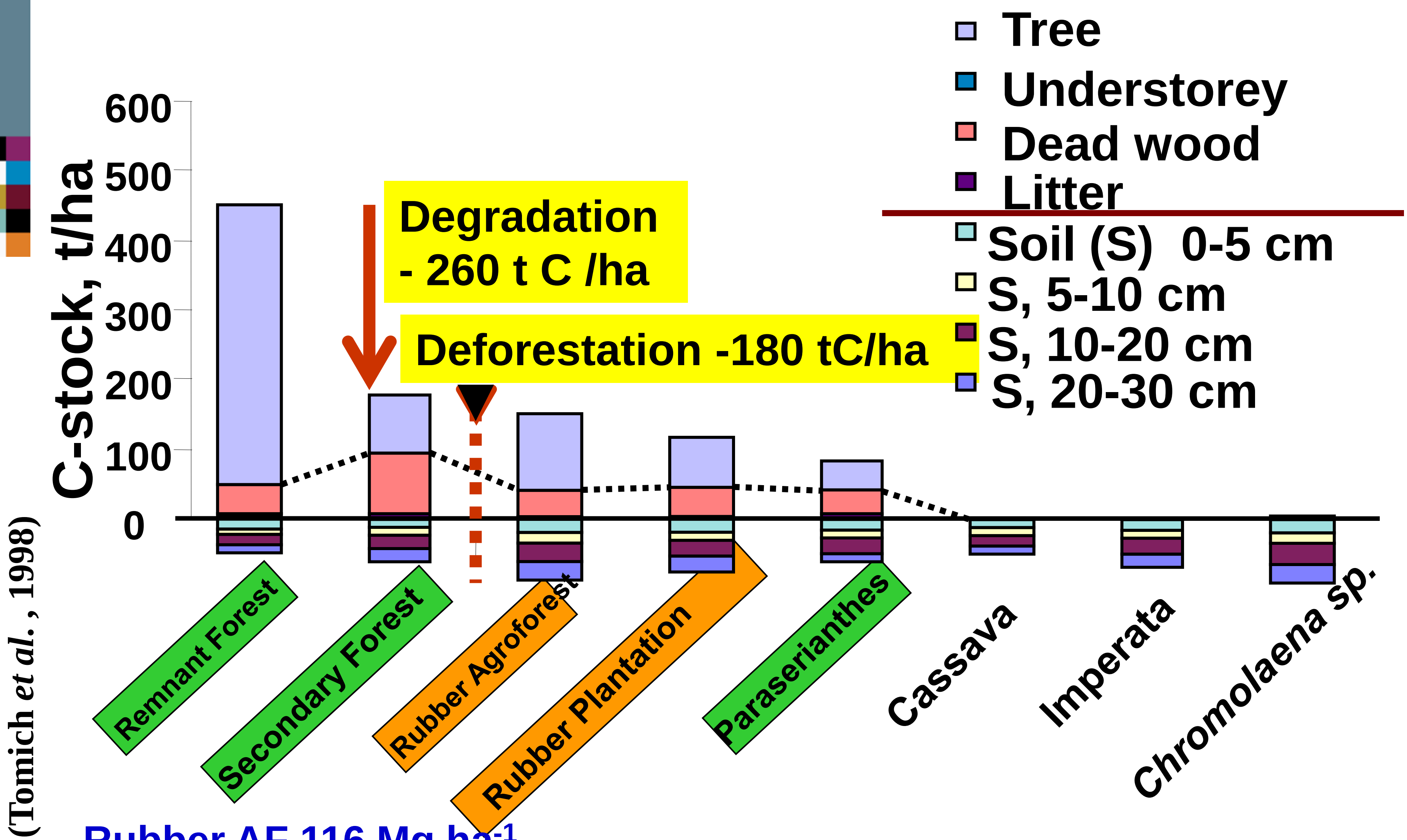
# Estimation of Total C stock per plot

| LUS | Rep | Trees ton/ha | Under-storey ton/ha | Litter ton/ha | Roots ton/ha | Soil 0-5 cm ton/ha | Soil 5-15 cm ton/ha | Total C-stock ton/ha |
|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 1+2+3+4 +5+6 |
| | 1 | | | | | | | |
| | 2 | | | | | | | |
| | 3 | | | | | | | |
| | 4 | | | | | | | |
| | 5 | | | | | | | |
| | 6 | | | | | | | |
| | | | | | | | | **Σ ….** |

# Carbon stocks in peat land

It will not be discussed here

(Photo: Fahmudin Agus)




Rubber AF 116 Mg ha$^{-1}$

C increment 3.5 Mg ha$^{-1}$ yr$^{-1}$

Rubber Life cycle 40 years

# Problems in C measurement

1. High variation of Agroforestry in the landscape (crop-fallow rotation, complex or simple agroforestry)
2. Difficulty in quantifying charcoal in the soil originating from previous slash and burning activities

# Charcoal after land burning….. How long it will stay?


From C sequestration perspective, which vegetation gives most benefit?

# Time Average Carbon stocks of different LUS

| Land use system (LUS) | C stock time-averaged (tC/ha) | $CO_2$ stock time-averaged ($tCO_2$/ha) |
|---|---|---|
| Natural forest | 250 | 918 |
| Logged forest | 200 | 734 |
| Heavily logged forest | 120 | 440 |
| Agroforest 1 | 80 | 294 |
| Agroforest 2 | 60 | 220 |
| Cocoa | 50 | 184 |
| Oil palm plantations | 41 | 150 |
| Improved pastures | 5 | 18 |
| Low-productivity pastures | 2 | 7 |
| Agriculture 8yr fallow | 15 | 55 |
| Agriculture 3yr fallow | 5 | 18 |

*Sources: Palm, et al. 2004; White, et al. 2005.*

# Will this farmer get carbon benefits?

## Would high C stock in landscape mosaic be able to maintain high biodiversity as well?

# Thanks