Sequestering Carbon at the Bottom of the Pyramid:

*Actionable Science for Climate Change Mitigation*

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Department of Forestry
What we know

The facts of climate change
2015 Was Hottest Year in Historical Record, Scientists Say

By JUSTIN GELLE

August Ties July for Hottest Month on Record

By KAREN WORKMAN
MAUNA LOA CARBON DIOXIDE HITS NEW HIGH IN 2015

Mauna Loa average (400.8 ppm)
global average (399.4 ppm)

NOAA Climate.gov, adapted from State of the Climate 2015
Evidence in the atmosphere
Atmospheric CO$_2$ Concentration

Year 2007
Atmospheric CO$_2$ concentration: 383 ppm
37% above pre-industrial

1970 – 1979: 1.3 ppm y$^{-1}$
1980 – 1989: 1.6 ppm y$^{-1}$
1990 – 1999: 1.5 ppm y$^{-1}$
2000 - 2007: 2.0 ppm y$^{-1}$
2007: 2.2 ppm y$^{-1}$

Data Source: Pieter Tans and Thomas Conway, NOAA/ESRL
Is Increasing CO2 Natural? NO!

1. Fossil fuel consumption rates are well known, accounts for more than enough of the Co2 increase

2. Earth’s atmosphere is naturally radioactive due to C14. It has been declining due to “dead source”. This leaves: deep ocean, volcanoes, and fossil fuels

3. The ratio of C13 to C12 is declining, due to biological sources
Trends
GISTEMP LOTI (incl. 2016 prediction)

1°C above pre-industrial

2016 prediction
Some say scientists can't agree on Earth's temperature changes.

Here's what “disagreement” looks like.
Temperature and CO₂ from Antarctic ice cores over the past 800,000 years
What’s Really Warming the World?

Skeptics of manmade climate change offer various natural causes to explain why the Earth has warmed 1.4 degrees Fahrenheit since 1880. But can these account for the planet’s rising temperature? Watch to see how much different factors, both natural and industrial, contribute to global warming, based on findings from NASA’s Goddard Institute for Space Studies.
Climate change will adversely affect crop production
Adaptation is globally uneven

Notes: Level 1 adaptation included changes in crop variety but not the crop, the planting date of less than 1 month, and the amount of water applied for areas already irrigated. Level 2 adaptation additionally included changes in the type of crop grown, changes in fertilizer use, changes in the planting of more than 1 month, and extension of irrigation to previously unirrigated areas.

Source: Climate change 1995. Impacts, adaptations and mitigation of climate change: scientific-technical analyses; contribution of working group 2 to the second assessment report of the intergovernmental panel on climate change, UNEP and WMO, Cambridge Press University, 1996.
Carbon Emissions from Land Use Change

Tropical deforestation
13 Million hectares each year

2000-2007

<table>
<thead>
<tr>
<th>Region</th>
<th>Emissions (Pg C y⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tropical Americas</td>
<td>0.6</td>
</tr>
<tr>
<td>Tropical Asia</td>
<td>0.6</td>
</tr>
<tr>
<td>Tropical Africa</td>
<td>0.3</td>
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</table>

[2007-Total Anthropogenic Emissions: 8.5 + 1.5 = 10 Pg]

1.5 Pg C y⁻¹

Canadell et al. 2007, PNAS; FAO-Global Resources Assessment 2005
Native Forest

Burned

Fire front

Slashed for logging

Active Pasture

Bare Pasture

Forest
Burned
Slashing and Burning
Pasture
Burned
Total CO$_2$ emissions from land-use and other sectors in selected countries

<table>
<thead>
<tr>
<th>Country</th>
<th>LULUCF</th>
<th>Other</th>
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<tbody>
<tr>
<td>EU 27</td>
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<td></td>
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<tr>
<td>USA</td>
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<td>Ethiopia</td>
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<td>Kenya</td>
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<td></td>
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<tr>
<td>Mozambique</td>
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<tr>
<td>Nepal</td>
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<tr>
<td>Nicaragua</td>
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<td>Tanzania</td>
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<td>Vietnam</td>
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<td>Zambia</td>
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<td></td>
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<tr>
<td><strong>Malawi</strong></td>
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<td></td>
</tr>
<tr>
<td>India</td>
<td></td>
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<td>China</td>
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<td>Indonesia</td>
<td></td>
<td></td>
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<tr>
<td>Brazil</td>
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</table>

Per cent of total
Deforestation and degradation

intact forests

non-intact forest

other land use

Deforestation

Degradation
Policy Response - REDD

What we can do about it
What is REDD+?

- Reducing Emissions from Deforestation and Forest Degradation (REDD) is an effort to create a financial value for the carbon stored in forests, offering incentives for developing countries to reduce emissions from forested lands and invest in low-carbon paths to sustainable development.

- "REDD+" goes beyond deforestation and forest degradation, and includes the role of conservation, sustainable management of forests and enhancement of forest carbon stocks.

- The key idea is results-based payments to be derived from verified carbon emission reductions or removals.
IPCC definitions

$\text{tC ha}^{-1}$

Deforestation

Forest Land

Non-Forest Land

"temporarily unstocked"

Forest Land

Forest definition

Intact Forest

Forest Management

Forest Degradation

Devegetation

Revegetation

Afforestation

Forestation

Cropland

Wetland

Settlement

Grassland

Other Land

time
REDD+ using IPCC definitions

Conservation

Forest management

Enhancement of forest carbon stocks
WEF potential: Actions in forests

Figure 5.1: Terrestrial carbon component of total required abatement by 2020

- Reduced emissions of methane and other gases from agriculture: 1.3 Gt
- Abatement through agriculture: 1.9 Gt
- Afforestation: 1.5 Gt
- Reduced deforestation: 4.3 Gt

Source: ClimateWorks’s Project Catalyst analysis
Potential Actions, Land Cover Actions

These Options make economic sense even without the benefit of carbon finance


Note: The curve presents an estimate of the maximum potential of all technical GHG abatement measures below €60 per tCO₂e if each lever was pursued aggressively. It is not a forecast of what role different abatement measures and technologies will play.

Source: Global GHG Abatement Cost Curve v2.0
The scope of REDD+ was agreed in Cancun. Developing countries are encouraged to contribute to mitigation actions in the forest sector by undertaking the following activities:

I. Reducing emissions from deforestation
II. Reducing emissions from forest degradation
III. Conservation of forest carbon stocks
IV. Sustainable management of forests
V. Enhancement of forest carbon stocks
The four REDD+ “design” elements

Decision 1/CP.16, para. 71, requests countries to have the following elements in place for REDD+ implementation and to access results-based payments/results-based finance:

- National Strategy (NS) or Action Plan (AP)
- NFMS including MRV
- Safeguard Information system (SIS)
- FREL / FRL

Overview of the four design elements and where the respective methodological guidance can be found in the UNFCCC decisions.
Two functions of a National Forest Monitoring System for REDD+

**OUTPUT**

**NATIONAL FOREST MONITORING SYSTEM**

**MONITORING**
- Satellite Land Monitoring System
- Web Interface
- Community Monitoring
- Other Forest-Related Monitoring Systems

**MRV**
- National Forest Inventory
- GHG Inventory

**OUTPUT**
- Forest area change
- Forest carbon stocks
- Forest-related GHG emissions and removals

To monitor outcomes of REDD+
Data sharing, transparency
Local knowledge, data and validation
Integrate with existing systems
National Forest Monitoring System

- National Forest Inventory
  - Emission Factors
  - Field sample plots
  - Allometry for carbon

- Satellite Forest Cover Monitoring
  - Activity Data
  - Deforestation, Degradation mapping
  - Forest carbon mapping

- GHG Inventory & Reporting
  - Emissions, Removals Estimation
  - Reporting using standard IPCC
  - Tools for computation, data management
Rural poverty: the other great development issue
The Rural Poverty Threat:

A billion people live in extreme poverty surviving on less than $1 per day as subsistence farmers.
Response: a single intervention:

Greener agriculture and forestry by enhancing carbon stocks and sequestration...
Conserving and Replanting Forests
Using Trees for Livelihoods in Agro-Forestry
One landscape in East Africa:
- Annual maize farming system
- High soil erosion, low productivity
Eddie,
An entrepreneur
Agro-Forestry and Carbon

- Some estimates from international organizations suggest there is a large amount of carbon sequestration already occurring in these managed landscapes (Verchot and Singh 2009).

- For example, remote sensing in 64 rural locations in Africa:
  - forested area declined 50%, agricultural area increased 23%, and the proportion of agricultural land under tree cover increased 22% (Place 2001).
  - Agricultural land now accounts for over double the area of forested land in Africa (FAO 2006), giving justification to the slogan that, “the future of trees is on farms.”
Agroforestry

- Establish trees over cropping and/or gardening activities as additional crop or wood suppliers
- Establish trees within grazed pastures or rangelands either for drought fodder, shelter or additional products
- Often linked with improved agricultural practice
- Usually community based
Biomass outside of dense forests

• 1) regeneration systems on managed landscapes where biomass recovery occurs as plantations, orchards, agroforestry, and widely-spaced tree complexes associated with agriculture.

• 2) open woodlands such as the cerrado and the Chaco ecosystems in South America, Miombo of East and West Africa, and other open forest ecosystems in the tropics and sub tropics,
The first challenge: The Millennium Development Goals (MDGs) establish two interrelated objectives: poverty alleviation and environmental sustainability.

• Over 1.5 billion people of the world’s population live in extreme poverty...

• ...of which 1.0 billion live in rural areas where their livelihoods depend on the consumption and sale of natural products.

• About two-thirds of the rural poor live in ecologically vulnerable areas and marginally productive landscapes.

• A significant share of the world’s poor are small-hold farmers.
Linking carbon and development

• **A Response:** increase the amount of carbon in soil and biomass for small holder systems:

  • First, carbon sequestration takes place with the adoption of reforestation, sustainable land use, agroforestry and related livelihood activities as a *mitigation measure*;

  • Second, reforestation, sustainable land use and agroforestry are *adaptation strategies* for climate change;

  • additional co-benefits related to biodiversity conservation and other environmental concerns, livelihoods and poverty reduction (i.e., sustainable development)
organic resource depleted smallhold

Farm Carbon Pools (ton C per ha)

- maize 2880 kg
- beans 188 kg
- 70 t C per ha
- Total System C 136 ton C per ha

Carbon sequestration results from the restoration of organic resources in smallhold farming systems
Two Value Chains: Shea Nut Over Cassava

Butyrospermum parkii

Manihot esculenta
Payments for Carbon Services

Innovative socio-economic policy for improving environmental performance

Payment for Ecosystem Services
Simplified Traditional West African Farming System

• Cereal crops (millet; sorghum; maize; upland rice);

• Agroforestry associations with Shea Trees (V. paradoxa) at 40 trees/ha;

• Jatropha (J. curcas) hedges along field boundaries (300 M hedge/ha)

• Neem tree (Azadirachta indica) associations at 5 trees/ha
Simplified Traditional West African Farming System (cont.)

- Total system income:

<table>
<thead>
<tr>
<th>Product</th>
<th>Income (USD/ha/yr)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cereal</td>
<td>240</td>
<td></td>
</tr>
<tr>
<td>Shea Oil</td>
<td>36</td>
<td></td>
</tr>
<tr>
<td>Jatropha Oil</td>
<td>24</td>
<td></td>
</tr>
<tr>
<td>Neem Oil</td>
<td>350</td>
<td></td>
</tr>
<tr>
<td>Carbon</td>
<td>78</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>728</td>
<td></td>
</tr>
</tbody>
</table>

x 2.4 ha (per capita average) = 1747 USD

Nearly double the average annual income for those living at the “ethical poverty” level of $2.40/day
Carbon payments can fill the 'gap' until other income streams come on-line.
What is TOF

• TOF includes agroforestry, plantations, and individual trees
• Agroforestry is the inclusion of trees within farming systems (ICRAF working definition)
• Found on more that 43% of all agricultural land globally, where 30% of rural populations live (Zomer et al 2014)
• Represents over 1 billion hectares of land and more than 900 million people. (Zomer et al. 2014)
• Agricultural land = over double the area of forested land in Africa (FAO 2006), giving justification to the slogan that, “the future of trees is on farms.”
• Globally, the amount of tree cover on agricultural land increased substantially between 2000 and 2010, with the area of >10% tree cover increasing 3%, or more than 828 000 km²
Trees in banana plantation (Guinea): Hubert de Foresta, IRD (Fap, 2013)

Large big tree (*Celtis integrifolia*)
Obstacles to implementation:
- Going to scale
- Lowering transaction costs
- Validation
Actionable Science: Measurements
Landsat and GeoEye data
Landsat – 30m pixel resolution

Scale 1:9755
GeoEye – sub-meter resolution

Scale 1:9755
Land Cover Map, Landsat, **Fine**, 30 m

Landsat-5 TM image of 15 June 2005: 20 km x 20 km extract
Concept of NDVI:

\[ \text{NDVI} = \frac{\text{NIR} - \text{RED}}{\text{NIR} + \text{RED}} \]
Concept of Vegetation Index

\[
\frac{(0.50 - 0.08)}{(0.50 + 0.08)} = 0.72
\]

\[
\frac{(0.4 - 0.30)}{(0.4 + 0.30)} = 0.14
\]
Principle of End Member Pixel Unmixing
Computation of $f_C$

$$f_C = \frac{\text{NDVI} - \text{NDVI}_{\text{open}}}{\text{NDVI}_{\text{canopy}} - \text{NDVI}_{\text{open}}} \times 100$$
Example from Thailand – Mae Chaem Watershed
Class Maps vs. Continuous Fields

Forest Type
- Tropical Hill Evergreen
- Mixed Deciduous
- Dry Dipterocarps
- Agriculture

Fractional Cover (Adjusted)
- 60 - 70%
- 71 - 80%
- 81 - 90%
- 91 - 100%
- Non-forest
False Color IR Mosaics
fC Mosaics
New 2013-2015 fC Mosaic
New 2013-2015 fC Mosaic
Ntchisi fC Change Intensity
Perekezi fC Change Intensity
Opportunities

• New technologies are emerging that allow very high spatial resolution earth observations
  • 10 years ago: 1-2 meter
  • Today: 50 centimeters

• This may create opportunities for monitoring landscapes in which tree cover is sparse or widely spaced
  • Where individual trees, as objects, can be detected

• If methods exist, remote sensing allows for large area monitoring – at the landscape scale
  • Reduction in costs of field sampling based methods in highly patchy woodland and TOF landscapes
  • Increase in opportunity for small holders and communities of small holders to be engaged in carbon mitigation projects.
Measurement of Trees Outside of Forests and Open Woodlands

- Identify and measure individual trees in non-forest land cover including trees on farms, trees outside forest, grasslands, settlements, etc.

- Requires fine resolution (<1m) satellite imagery (Quickbird, Worldview, etc)

- Requires modified allometry to relate crown attributes (crown projection area, crown diameter) to stem DBH or directly to AGB

- Map carbon in all trees within area of interest

(0.6 m PAN Quickbird image of Western Kenya)
High resolution satellite monitoring of projects

New plantings

Older trees
MSU and ICRAF combined field efforts
New Allometric Equations Developed for CBP

(n=85, Data collected by ICRAF in Yala Watershed)

AGLB = 0.08*DBH^{2.45}
R^2 = 0.98

BGLB = 0.02*DBH^{2.46}
R^2 = 0.94
Relationship between DBH and crown diameter in Rukinga Ranch in eastern Kenya.
Similar $R^2$ for trees in western Kenya
New Allometric Equations Developed for CBP

\( n=85, \text{ Data collected by ICRAF in Yala Watershed} \)

- Above Ground
  \[ \text{AGLB} = 0.08 \times (\text{DBH})^{2.45} \]
  \[ R^2 = 0.98 \]

- Below Ground
  \[ \text{BGLB} = 0.02 \times (\text{DBH})^{2.46} \]
  \[ R^2 = 0.94 \]
Object detection analysis of individual tree crowns (0.6 m PAN Quickbird image)
Tons of Carbon

155 ha
1418.83 tC
9.15 tC/ha
25 January 2011 Worldview 2 Satellite Image (water tank is 10 m diameter)
Tons of Carbon
25 ha
3.16 tC/ha
27 ha
221.75 tC
8.21 tC/ha
Wildlife Works Rukinga Ranch REDD Project

<table>
<thead>
<tr>
<th>WW Plot ID</th>
<th>MSU Plot ID</th>
<th>AGB t C/ha</th>
<th>Total tCO2e/ha</th>
<th>Average DBH (cm)</th>
<th>Trees &gt;10cm / plot</th>
<th>Canopy Cover (leaf OFF)</th>
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</thead>
<tbody>
<tr>
<td>T17</td>
<td>222</td>
<td>18.5</td>
<td>95.0</td>
<td>21.6</td>
<td>31</td>
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<tr>
<td>T16</td>
<td>223</td>
<td>4.4</td>
<td>22.5</td>
<td>13.8</td>
<td>22</td>
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<tr>
<td>T14</td>
<td>224</td>
<td>1.5</td>
<td>7.9</td>
<td>12.2</td>
<td>11</td>
<td>5%</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>8.2</td>
<td>17.3</td>
<td>64</td>
<td>18%</td>
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<table>
<thead>
<tr>
<th>Stratum</th>
<th>n</th>
<th>Area (ha)</th>
<th>Trees Carbon Mean (tCO2e / ha)</th>
<th>Shrubs Carbon Mean (tCO2e / ha)</th>
<th>Herbaceous Carbon Mean (tCO2e / ha)</th>
<th>Total Strata Mean (tCO2e / ha)</th>
<th>Total Strata Carbon Stock (t C02-e)</th>
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<tbody>
<tr>
<td>ag active</td>
<td>12</td>
<td>713.7</td>
<td>67.98</td>
<td>23.08</td>
<td>2.88</td>
<td>172.24</td>
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<td>26</td>
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<td>8.48</td>
<td>1.41</td>
<td>91.42</td>
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<td>5651.1</td>
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<td>0.99</td>
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<td>dryland forest strata 5</td>
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<td>8133.4</td>
<td>46.23</td>
<td>2.30</td>
<td>2.14</td>
<td>92.89</td>
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<td>dryland forest strata 6</td>
<td>23</td>
<td>4345.5</td>
<td>35.87</td>
<td>7.26</td>
<td>2.36</td>
<td>83.39</td>
<td>362,368.4</td>
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<td>grassland</td>
<td>4</td>
<td>1610.9</td>
<td>3.05</td>
<td>1.40</td>
<td>4.85</td>
<td>17.06</td>
<td>27,474.3</td>
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<td>montane forest</td>
<td>3</td>
<td>57.1</td>
<td>45.56</td>
<td>33.45</td>
<td>0.00</td>
<td>144.86</td>
<td>8,265.6</td>
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<tr>
<td>Total:</td>
<td>30</td>
<td>30,168.66</td>
<td>30,168.66</td>
<td>30,168.66</td>
<td>30,168.66</td>
<td>2,624,568.9</td>
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</table>

Table 11. Total carbon stocks for trees, shrubs and herbaceous material for Rukinga Ranch.
Locations of MSU Biomass Sampling

Western:
- Kakamega
- Mau
- Lambwe

Central:
- Aberdares
- Mt Kenya

Eastern:
- Arabuko-Sokoke
- Tsavo

GIS Data – World Resources Institute
- Closed Forest (>65%)
- Open forest (40-65%)
- Very Open Forest (15-40%)
Above Ground Biomass in Natural Forests (MSU data only – t C/ha)

Western:
- Kakamega
- Mau

Eastern:
- Arabuko-Sokoke
- Tsavo

Tier 1 AGB tC/ha
- Wet: 146
- Moist: 122
- Montane: 89
- Dry: 56
- Shrub: 33

Source: Table 4.7 in Vol 4, 2006 IPCC Guidelines
WHRC Carbon Map:
Vast areas of Kenya are greater than Zero t/ha AGB
(Baccini et al. 2008. A first map of tropical Africa’s above-ground biomass derived from satellite imagery.)
Unep to take lucrative carbon farming to rural Kenya

A Plan to Cut Carbon Emissions From Deforestation

The program is well-defined in principle, but the actual numbers remain uncertain. “To the extent that you can manage something, you have to be able to measure it,” said Achim Steiner, the executive director of the United Nations Environmental Program, in a recent interview in Nairobi, Kenya. “Our challenge right now is to determine how a different land use would have either a net benefit or a net cost in terms of carbon storage capacity.”

The United Nations group hopes to solve this problem by measuring carbon-storage capacities through a recently introduced program known as the Carbon Benefits Project.

One test region is the northern Lake Victoria basin, which includes parts of Uganda and western Kenya. The rolling hills of the region are divided between old-growth forests, subsistence farms, tea fields and human settlements – each of which stores a different amount of carbon. Knowing exactly how much carbon each type of land use sequesters is crucial for the envisioned international program.

According to Eleanor Milne, a Colorado State University scientist who is coordinating the first stage of the project, the Carbon Benefits Project will use the Lake Victoria basin to “create a
Detecting and Measuring Trees Outside Forests in Senegal

Sokone, Senegal Area of Interest: Latitude is 13° 50.7’ N; Longitude is 16° 21.1’ W
Layout of sampled plots and measured trees in the Sokone site

Cashew plots

Other TOF in agricultural land
Tree Crown digitized in the Sokone site
Field measured DBH and remote sensing CPA

**Sokone**

\[ y = 0.5912x + 13.408 \]
\[ R^2 = 0.7605 \]

**Karang**

\[ y = 0.3514x + 24.613 \]
\[ R^2 = 0.7913 \]
28 October 2010 - Worldview 2 Satellite Imagery – 0.5m PAN resolution - 3.4 x 1.8 km subset
Semi-Automated Crown Detection of Individual Trees
Carbon map for block 4 & 5 in the Sokone site
Carbon map in block 1 (KAR 1) the Karang site

Legend
KAR 1
tC_tree
- 0.21 - 0.76
- 0.76 - 2.68
- 2.68 - 9.70
- 9.70 - 33.56
- 33.56 - 53.66
Pasture

201 ha
1543.2 t of C
7.7 t C per ha
Examples
South East Asia
Globally measuring, monitoring and managing carbon projects.

Carbon2Markets™ is a project of Michigan State University that focuses on combining value chains from carbon credits in the carbon financial markets and agro-forestry products for small holders in developing countries. Carbon2Markets™ provides accurate measurements of carbon sequestration from reforestation and agro-forestry land management activities using high resolution remote sensing data, web-GIS tools, and modeling. Our offset projects have repeat monitoring to ensure long-term storage of sequestered carbon. Our model of project development and monitoring enhances the ground measurements with measurements from earth observing satellites.
Vietnam Afforestation: Acacia
Thailand
Inpang Network – Carbon Training
Jay Samek  Michigan State Univ.
August 11, 2007
Natural Para Rubber Plantation on Degraded Land
Para Rubber inter-cropped with Sala fruit
Mixed natural and product species community forest
Indigo dying
Technical development
Scientific Cooperation
Engage Civil Society
Community Dialog
อันว่าฟ้าหลงที่ปิ้มณหย่อนโลกส่วน
Carbon Bank project
Training and Capacity Building
Thank You

The Carbon2Markets Project

Department of Forestry
Michigan State University