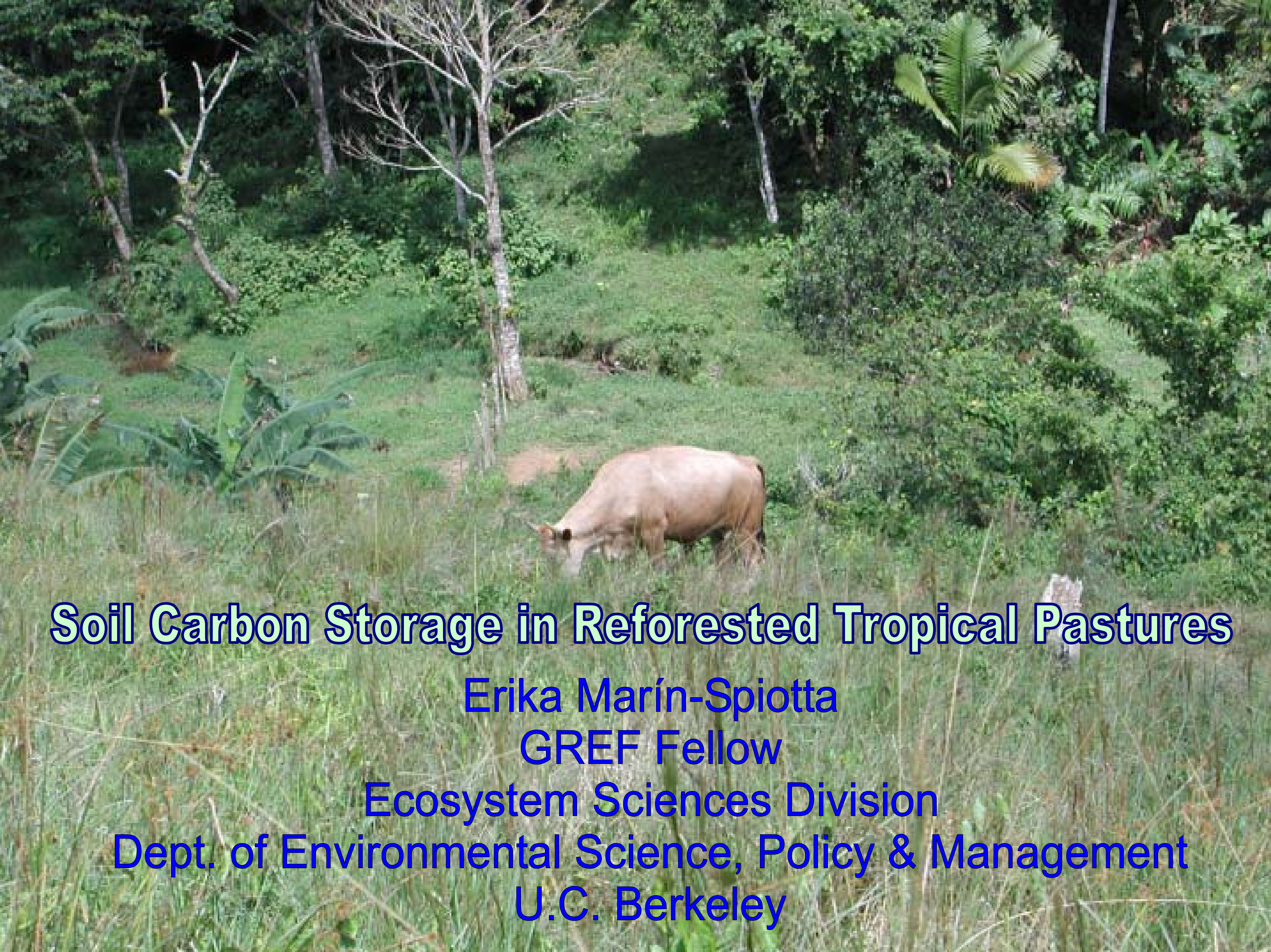


Soil Carbon Storage in Reforested Tropical Pastures

Erika Marín-Spiotta
GREF Fellow
Ecosystem Sciences Division
Dept. of Environmental Science, Policy & Management
U.C. Berkeley

View From Below: Soils can be sexy, too (and why you should care)

- Need a better understanding of factors controlling soil C dynamics and its effect on atmospheric CO_2
- Scientific and political interest in C sequestration in soils
- Rehabilitation degraded soils: agricultural and natural
- SOM as fertility source
- Bioremediation

Land Use Change: Large-Scale Field Experiments

LUC affects factors controlling soil C storage:

Physical: occlusion, barriers to decomposers; moisture, temperature, O2
Chemical: litter quality, sorption,
Biological: decomposer community

Interactions of all of the above to slow down organic matter decomposition.

Reforested Tropical Pastures

- Differences in quantity and quality of above and belowground litter inputs.
- Differences in ^{13}C / ^{12}C of tropical forage grasses (**C_4** photosynthesis) and woody vegetation (**C_3**).

C_4 plants
(average ∂ ^{13}C = -12‰)

C_3 plants
(average ∂ ^{13}C = -25‰)

Secondary forests dominate tropical (and temperate!) landscape.

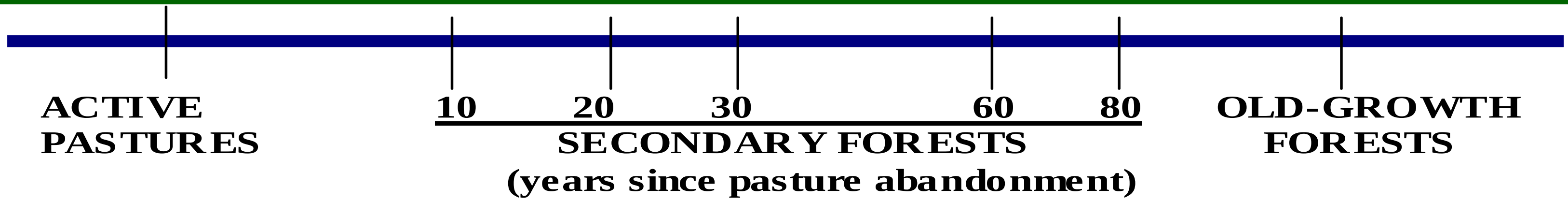
- Deforestation main land use studied in tropics
- Puerto Rico is at opposite end of land conversion: reforestation important process
- Reforestation important ecologically and economically

Research Objectives:

- To examine mechanisms that lead to soil C storage in tropical soils
- To describe general pattern in soil C accumulation or loss with reforestation of tropical pastures


PUERTO RICO
ATLANTIC OCEAN
0 20 km
0 12 mi
Isabela
Arecibo
Manatí
San Juan
Aquadilla
Bayamón
Luquillo
Fajardo
Rincón
Río
Camuy
Cave Park
Arecibo
Observatory
Ciales
El Yunque
To Culebra
Caguas
Mayagüez
Puerto Rico
Cordillera Central
Humacao
Cayey
San Germán
Vieques
Boquerón
Ponce
Patillas
Arroyo
Guánica
Dry Forest
Caribbean Sea
© Lonely Planet

CHRONOSEQUENCE APPROACH






- Wet subtropical forest (400-600 masl).
- 7 age classes, 3 site replicates per age for a total of 21 sites

Field Sampling
Summers 2001, 2002, 2003

- Collect soils every 10 cm to a 1 m depth, 3 soil pits per site
- Collect roots, forest floor
- Litterfall (biweekly)
- Tree basal area measurements and species identification

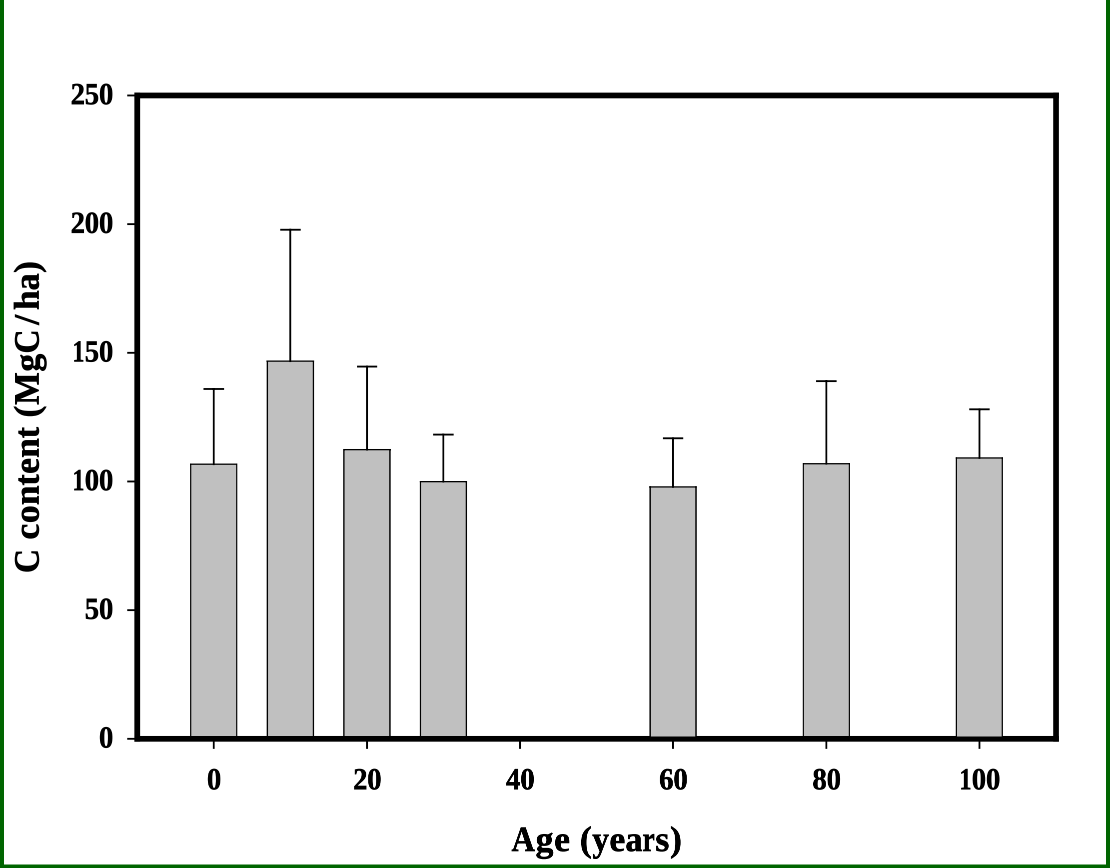




- **Objective 1 : Changes in soil C with forest succession**

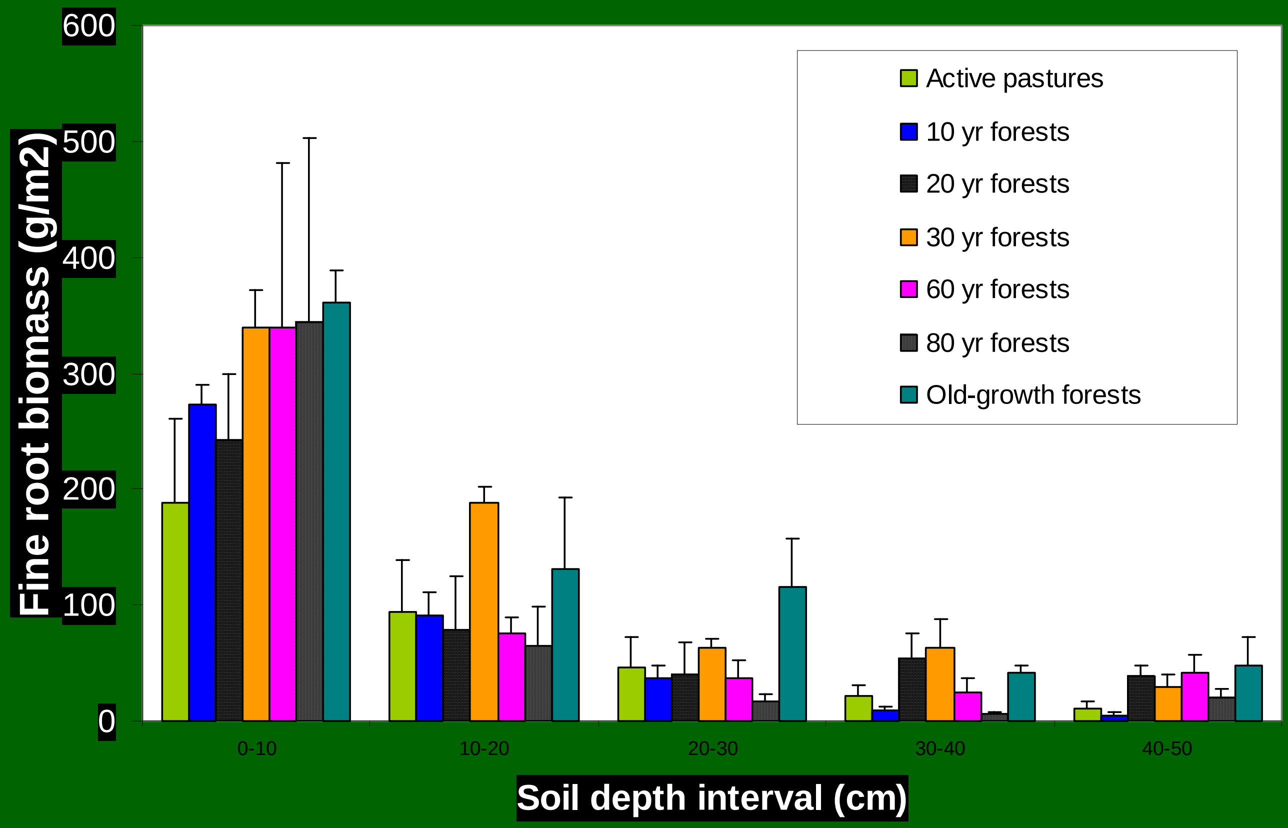
- **Deforestation usually results in initial loss of soil organic matter (C and nutrients)**
- **Reforestation and afforestation as policy actions for increasing C sequestration in tree biomass and soils**
- **Reforestation: both net changes in soil C stocks and no changes have been measured**
- **Land use type (agriculture vs. pasture), intensity and duration matter**

Age or land use did not have a significant effect on total C content in the top 1 m of soil (or top 30 cm- data not shown).

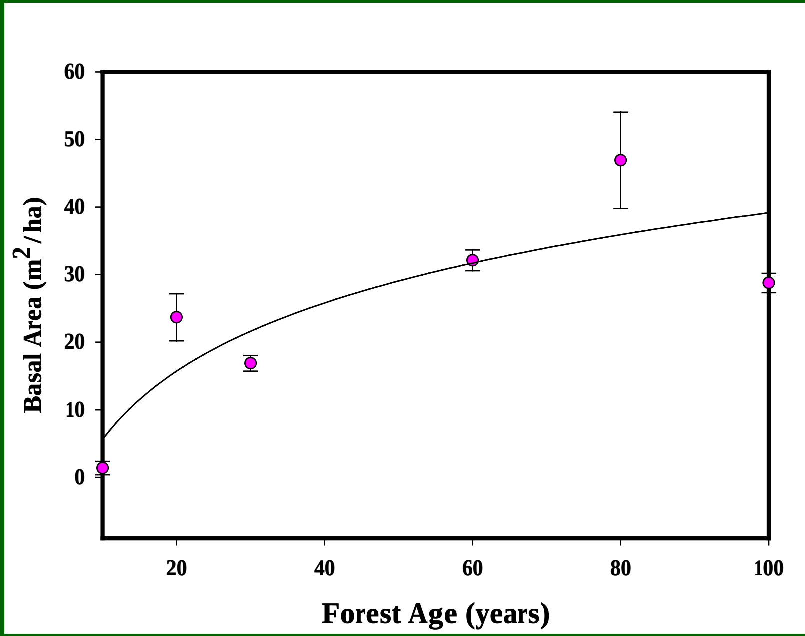


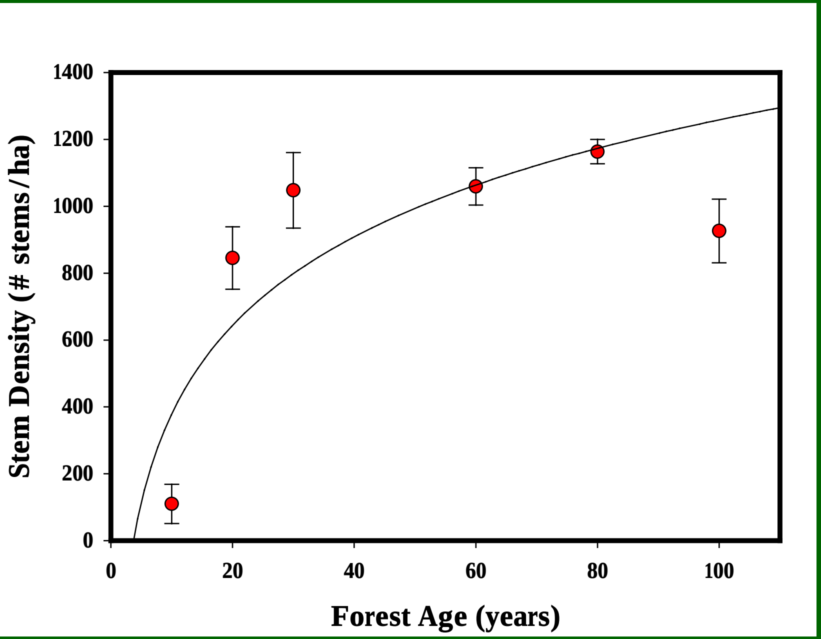
3 pits per site, n= 3 sites

Pastures did not have greater fine root biomass than forests at any depth.



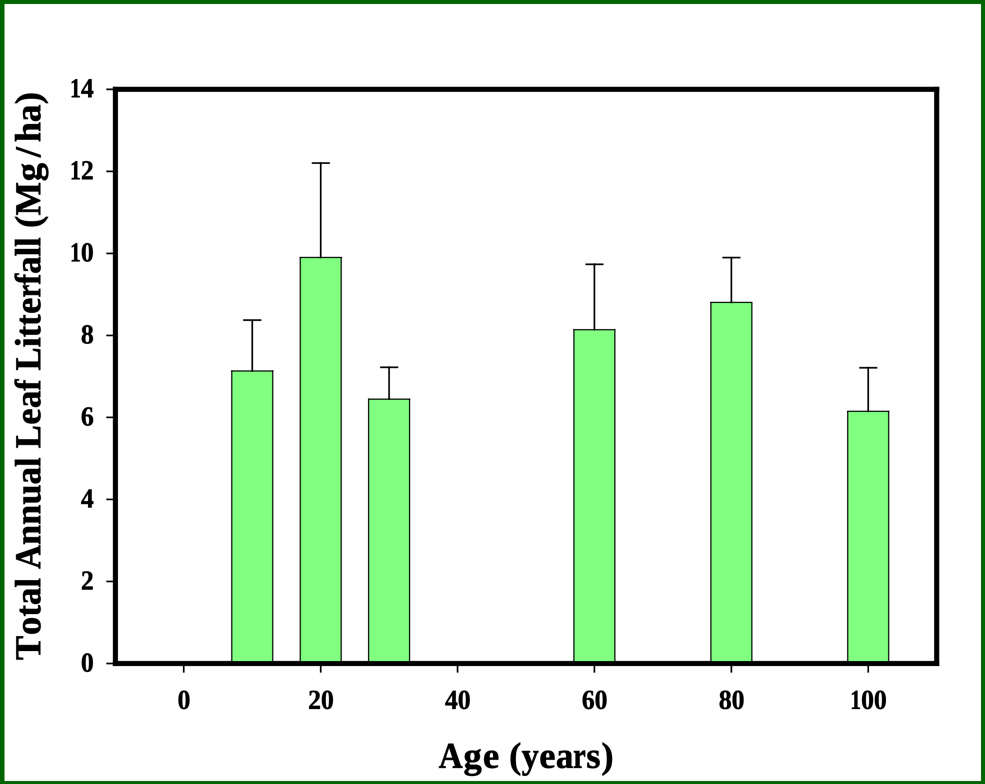
Basal Area (m2/ha) and stem density of trees with DBH >10 cm increased with forest age.





At least 27 genera in 23 families (DBH >10 cm)

Total annual leaf litterfall did not vary with forest age.



Litter collected biweekly from 5 baskets per site.

Using C Isotopes to Estimate SOM Turnover Times

- Simple mixing model to determine proportion of C4 vs. C3 derived C in SOM pool:

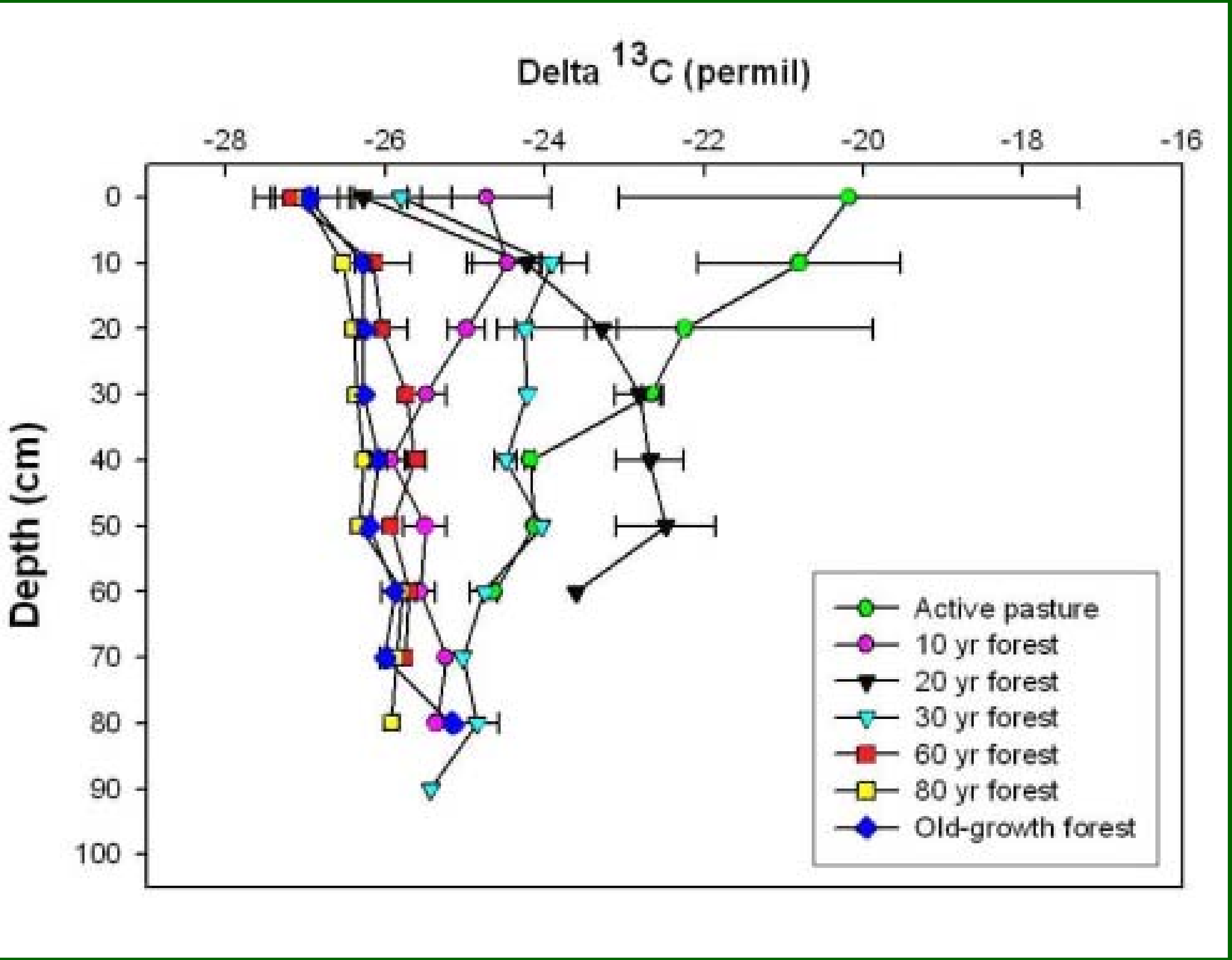
$$\%C4 = (\delta - \delta L / \delta G - \delta L) \times 100$$

$$\%C3 = 100 - \%C4$$

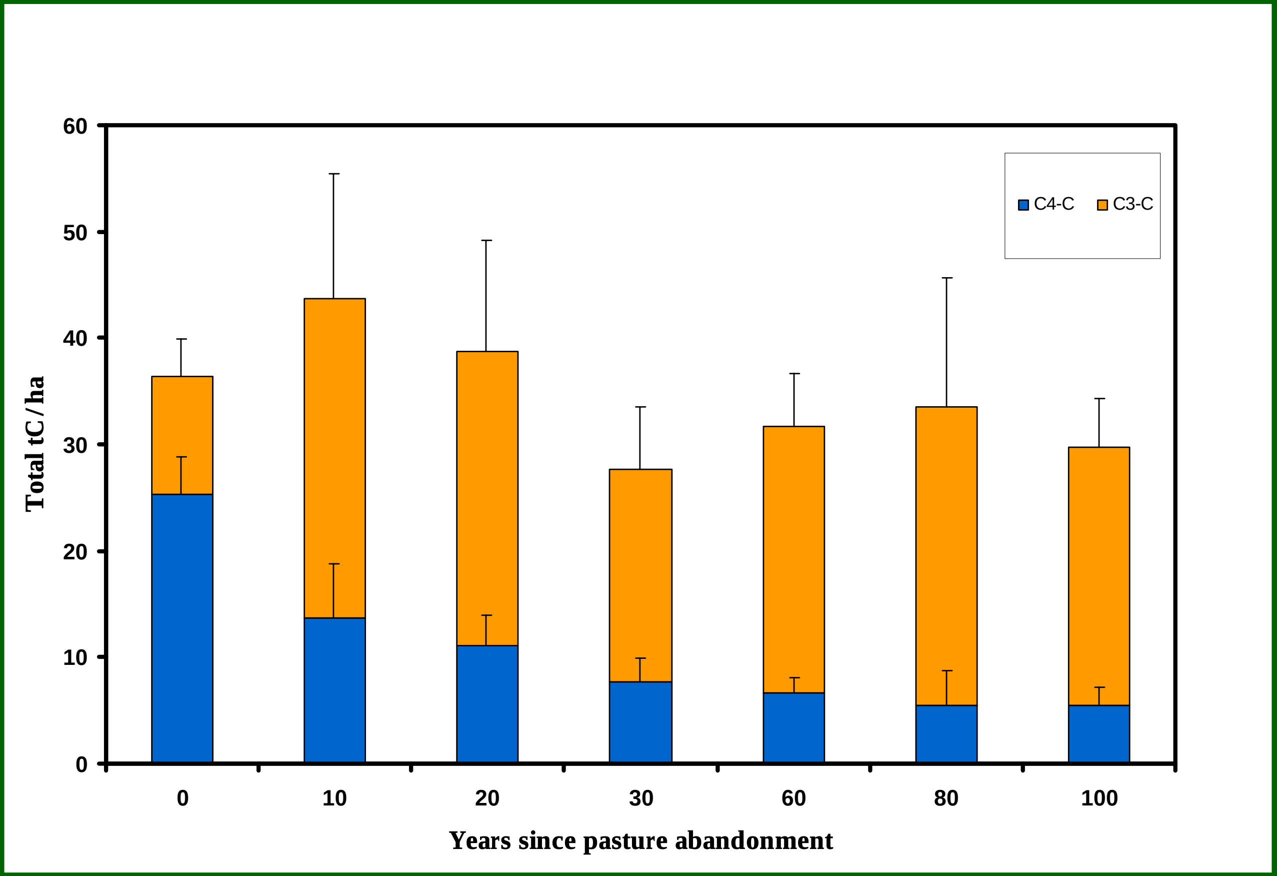
  - *where δ is the $\delta^{13}C$ of the soil sample in question, δ_L is the $\delta^{13}C$ of a composite sample of forest floor and roots (or C_3) , and δ_G is a composite sample of pasture grass tissues (C_4).*

- "Bomb" Radiocarbon (^{14}C) will be analyzed at CAMS-LLNL

Soil δ ^{13}C-C (‰) with Depth

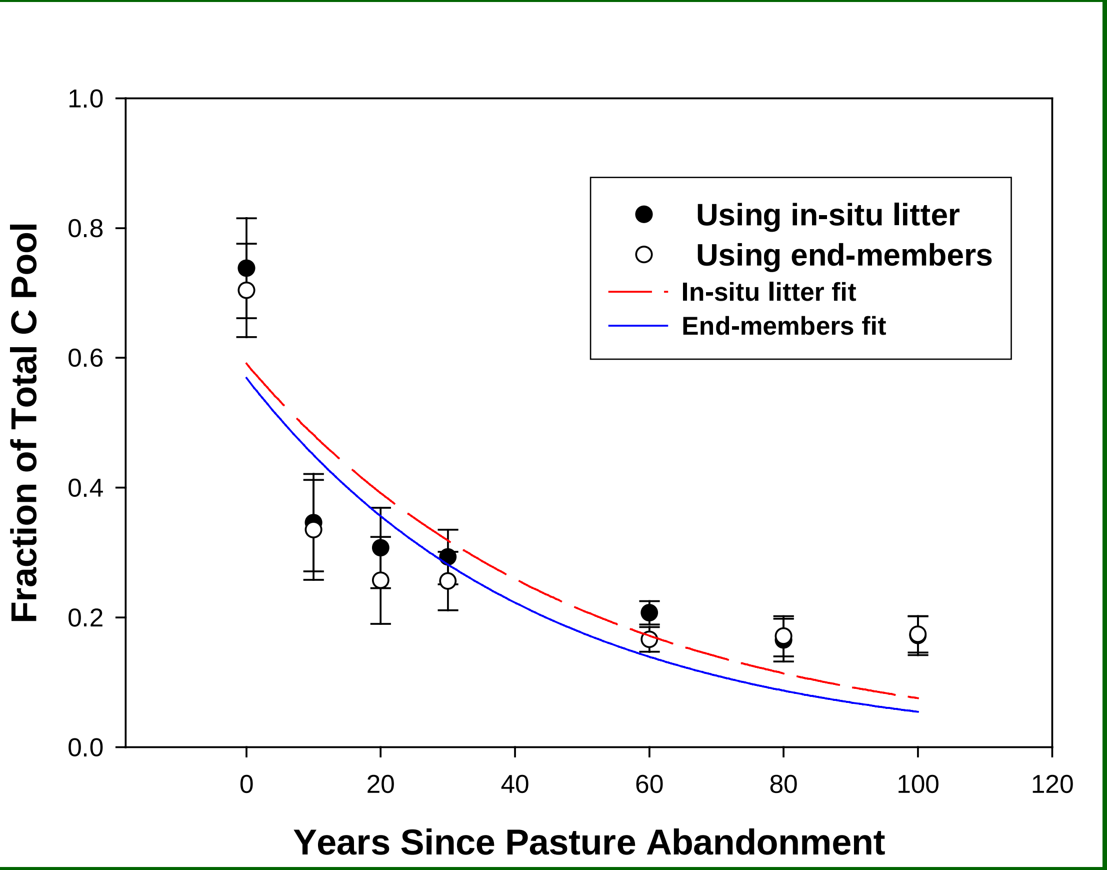


Contribution of C4-C and C3-C (in t C/ha) to total soil C pool in top 10 cm



Contribution of C4-C to total soil C pool (0- 10 cm)

Fraction C_4-C in-situ = 0.59 -0.021 (age) (r^2 = 0.74, p = 0.01)
Fraction C_4-C end-members = 0.57 -0.024 (age) (r^2 = 0.70, p = 0.02)



Average C_4-C value of -15.02 ‰ and C_3-C value of -29.52 ‰

C Fractionation

- Experimental and modeling studies suggest that the total C pool is composed of different components, or “fractions”, with different residence times in the soil
- Attempts to separate total C pool into “fractions”, ie. stages of decomposition
- Common methods: particle size, density, aggregate-size, solubility, isotopes
- Operationally defined

Density Fractionation

- Physical separation of soil organic matter:
  - Free Light Fraction (f LF): identifiable leaf, root fragments, unattached organic debris (youngest)
  - Occluded Light Fraction (o LF): OM released after disruption of aggregates (older)
  - Heavy Fraction (HF): mineral associated OM (oldest)

Objective 2 : Mechanisms of soil C storage

- Examine effect of changes in soil physical structure and plant litter chemistry on the formation of stable SOM.

Hypotheses:

1.) The primary mechanism for soil C storage during reforestation will be the development of an aggregate hierarchy.

2.) The hydrophobic content of plant litter will be more important than traditional measures of litter quality in the formation of stable soil C.

H2: ***The hydrophobic content of plant litter will be more important than traditional measures of litter quality in the formation of stable soil C.***

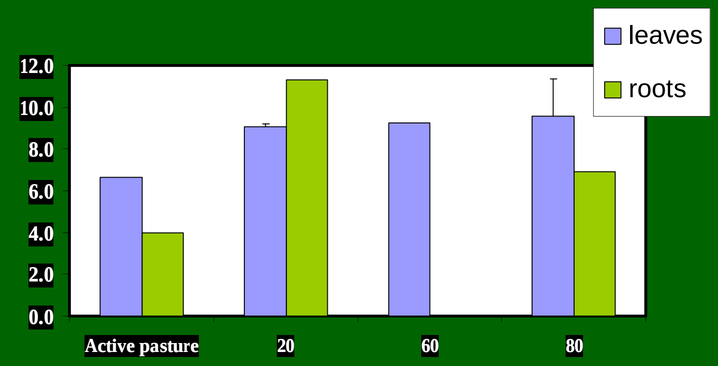
- Litter C:N, lignin:N and lignin content as measure of decomposability
- But lignin degraded in soils
- Evidence of accumulation of nonpolar C in older soil C fractions
- Recent attention to plant and soil lipids as precursors to most stable SOM

- Soil lipids: plant and microbially derived
- Plant lipids: secondary compounds, waxes, suberin, terpenoids.
- Theories of plant herbivory suggest production of these secondary plant compounds increases with forest succession

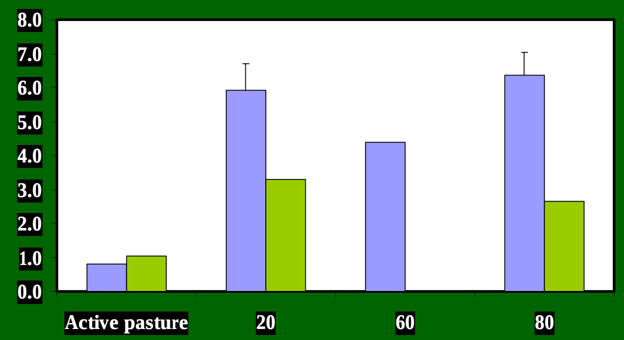
Preliminary Litter Chemistry Results

- **On average, forest tissues had higher hydrophobic (NPE) and tannin concentrations than pasture tissues ($p<0.05$).**
- **Leaves had higher NPE than roots across land use ($p<0.05$).**
- **Aboveground pasture tissues had significantly lower levels of NPE than the 20 year old forest leaves ($p<0.05$).**

Nonpolar extractables (% dw)

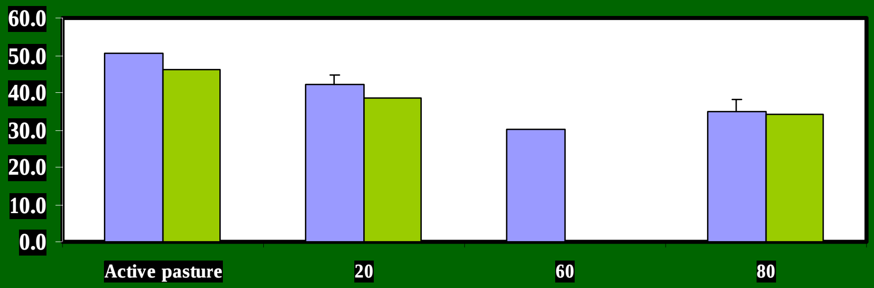


Tannins (% dw)

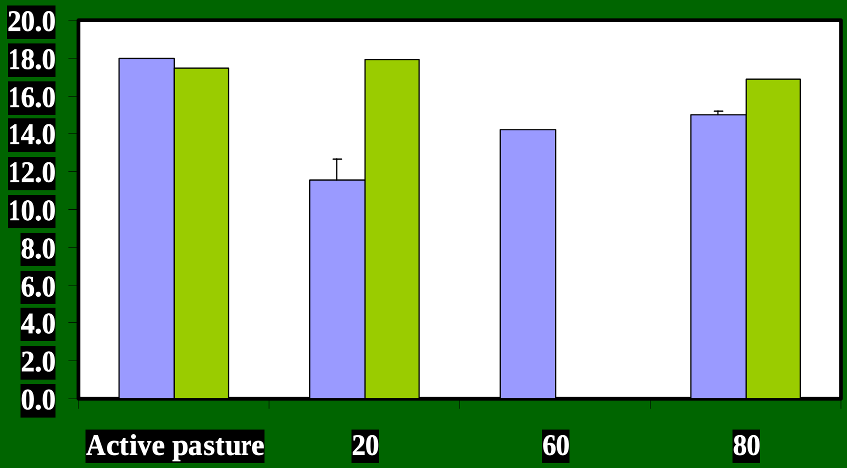


- **There were no patterns in C:N and lignin:N across land use or over time.**

C:N

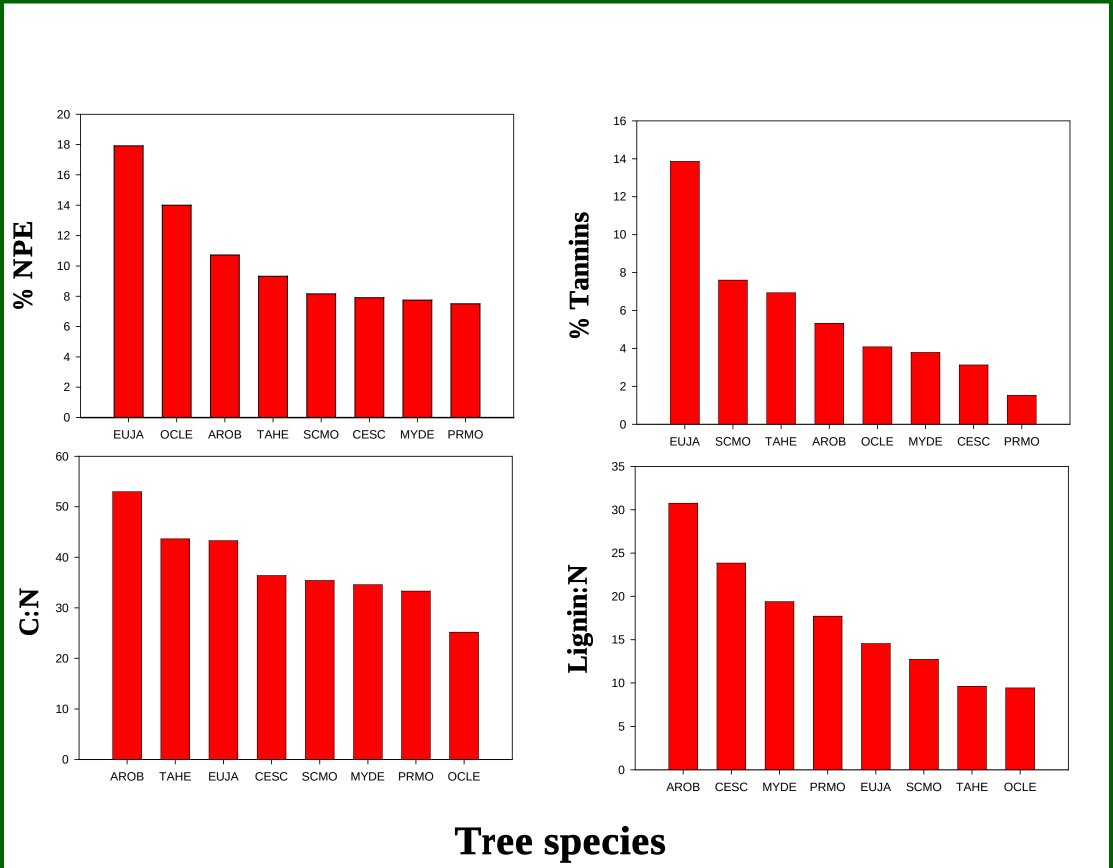


Lignin:N



Leaves (blue) and roots (green) (0-10 cm)

Species differences in leaf tissue chemistry



Syzigium jambos **(EUJA), a common invader in secondary forests, had the highest tannin and NPE concentrations; while** ***Prestoea montana*** **(PRMO), more important in old-growth forests had the lowest values for tannin and NPE.**

Litter quality variables for grab samples of leaves collected at the same site from common tree species.
Species codes: SCMO, Schefflera morototoni; PRMO, Prestoea montana; TAHE, Tabebuia heterophylla; EUJA, Syzigium jambos; OCLE, Ocotea leucoxylon; MYDE, Myrcia

deflexa; CESC, Cecropia schreberiana.

Hydrophobic C: protected by chemical recalcitrance or physical protection? Interaction?

- Are the C fractions with slowest turnover rates hydrophobic?
- *Approach*

1. Characterize and quantify hydrophobicity of SOM and litter inputs: nonpolar organic extractions, lipid analysis (GC-MS and ^{13}C-NMR)
2. Characterize nonpolarity C in light fraction *(using XAD-8 resins)* and sorbed to minerals (^{13}C-NMR); correlate with turnover rates of fractions

3. Test for correlations between chemistry plant inputs and SOM pools, SOM turnover rates, litter decomposition rates
4. How does chemical composition of SOM/DOM affect physical protection?

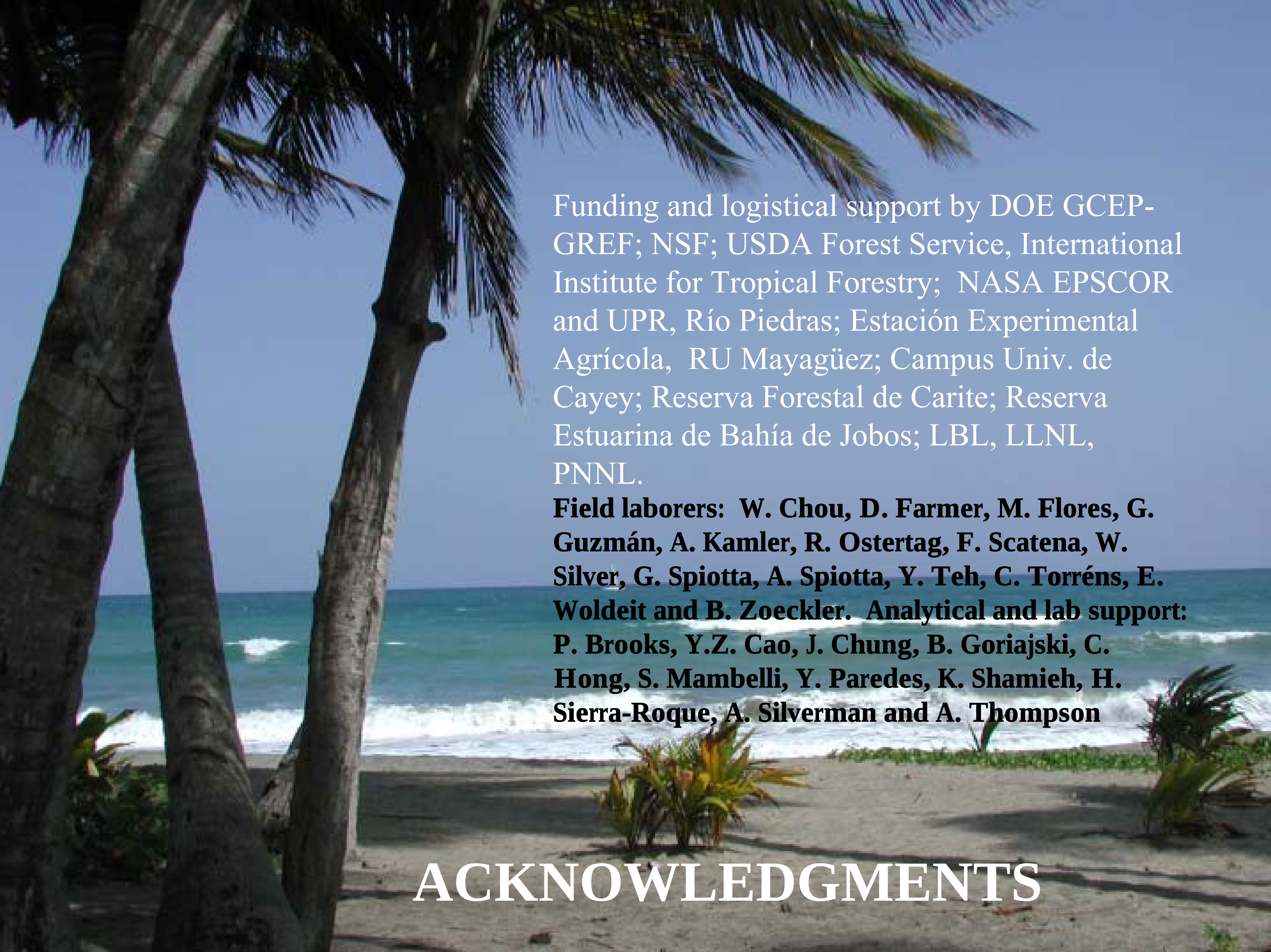
- Quantify sorptive capacity of soils at my sites
- Perform adsorption experiments with “native” and “transplant” DOM and SOM and litter extracts

Summary

- Patterns in soil C gain and loss over time using 13C and 14C
- Correlations between litter quality (hydrophobicity) and soil turnover rates

Collaborators

- ***Dr. Whendee Silver*** (U.C. Berkeley): soil respiration and other trace gas production
- ***Dr. Rebecca Ostertag*** (U. of Hawaii): foliar and root litter decomposition experiments (litter vs. site quality transplant)
- ***Dr. Margaret Torn*** (LBNL & GREF mentor): ^{13}C-CO_2 soil respiration and ^{14}C modeling
- ***Dr. Chris Swanston*** (CAMS, LLNL): density fractionation and ^{14}C analyses
- ***Dr. Sarah Burton*** (EMSL, PNNL): ^{13}C-NMR facility and data interpretation
- ***Mario Flores:*** textural analyses and particle-size fractionation



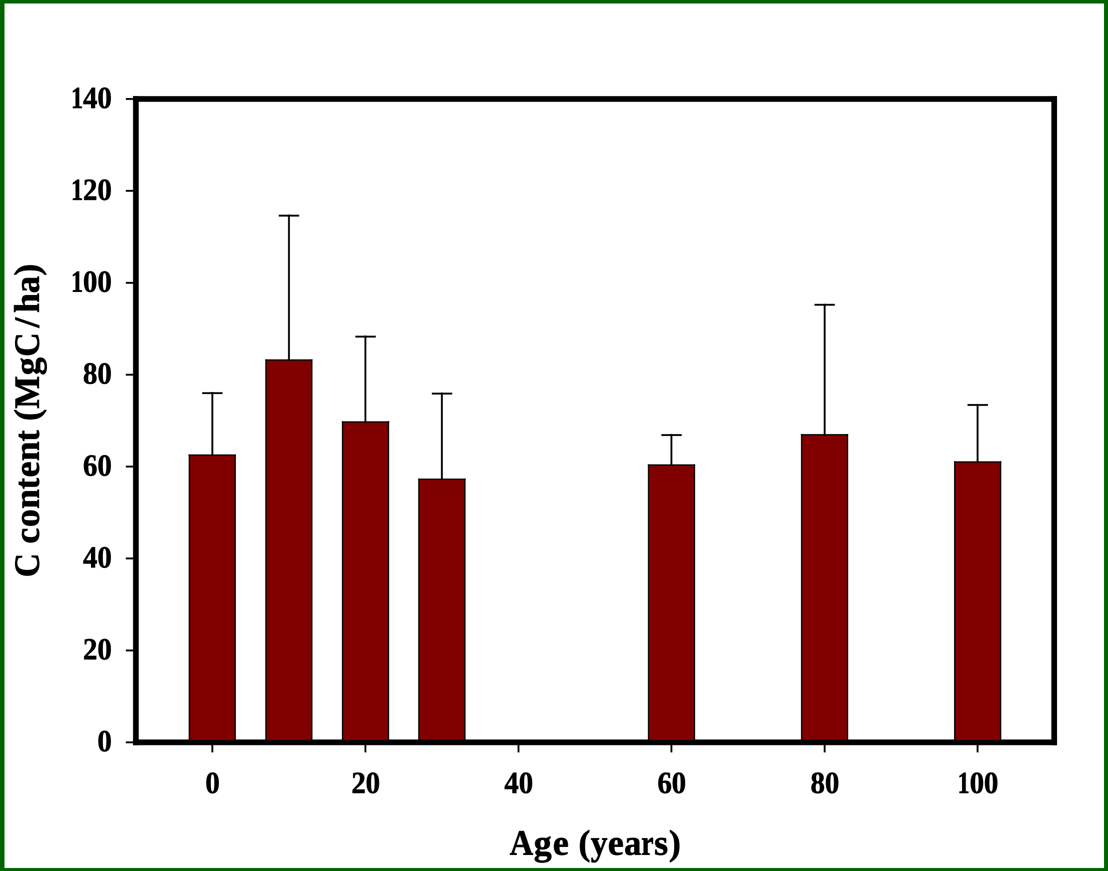
Funding and logistical support by DOE GCEP-GREF; NSF; USDA Forest Service, International Institute for Tropical Forestry; NASA EPSCOR and UPR, Río Piedras; Estación Experimental Agrícola, RU Mayagüez; Campus Univ. de Cayey; Reserva Forestal de Carite; Reserva Estuarina de Bahía de Jobos; LBL, LLNL, PNNL.

Field laborers: W. Chou, D. Farmer, M. Flores, G. Guzmán, A. Kamler, R. Ostertag, F. Scatena, W. Silver, G. Spiotta, A. Spiotta, Y. Teh, C. Torréns, E. Woldeit and B. Zoeckler. Analytical and lab support: P. Brooks, Y.Z. Cao, J. Chung, B. Goriajski, C. Hong, S. Mambelli, Y. Paredes, K. Shamieh, H. Sierra-Roque, A. Silverman and A. Thompson

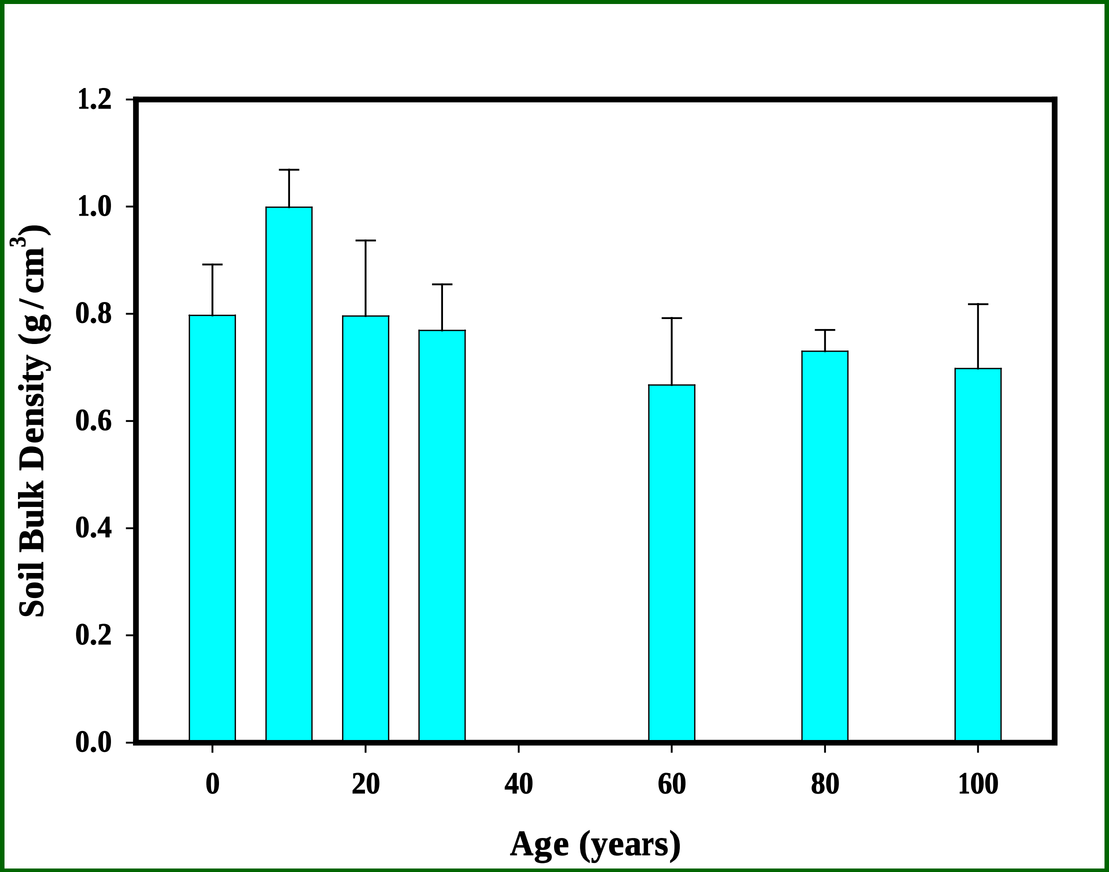
ACKNOWLEDGMENTS

The Plant Ecologists' Café

Pastures did not differ from forests in C content in top 30 cm of soil profile.



Bulk density in the 0-10 cm depth did not differ significantly. Two of the three old-growth forest sites are visited by cattle; the third site with no evidence of cattle had the lowest bulk density value recorded: 0.49 g/cm3.



Assuming a δ_L of -17‰ and a δ_G of -26‰, at our 20 year old sites:

Soil depth (cm)	$\%C_3$	$\%C_4$	C_3/C_4
0-10	100	0	
10-20	76	24	3.10
20-30	67	33	2.06
30-40	74	26	2.79
40-50	55	45	1.21
50-60	50	50	1.01

Table 1. Example of proportion of C_3 and C_4 derived C for 20 year old sites.

Pasture
60 t C/ha
100% C_4

→ 10 years

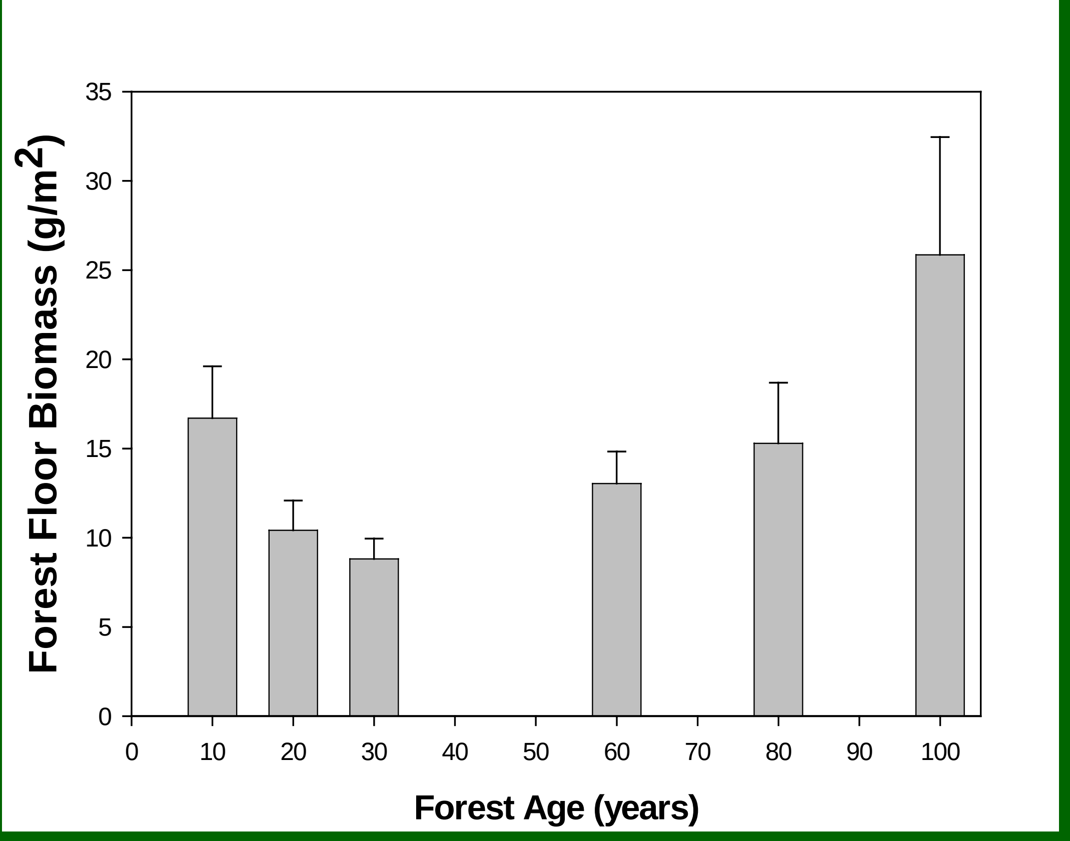
Secondary Forest
80 tC/ha
54.5% C_4 = 43.6 t C/ha
45.5% C_3 = 36.4 t C/ha

- After 10 years forest regrowth, 20 tC/ha gained, but 16.4 t C/ha of pasture-derived C was lost.

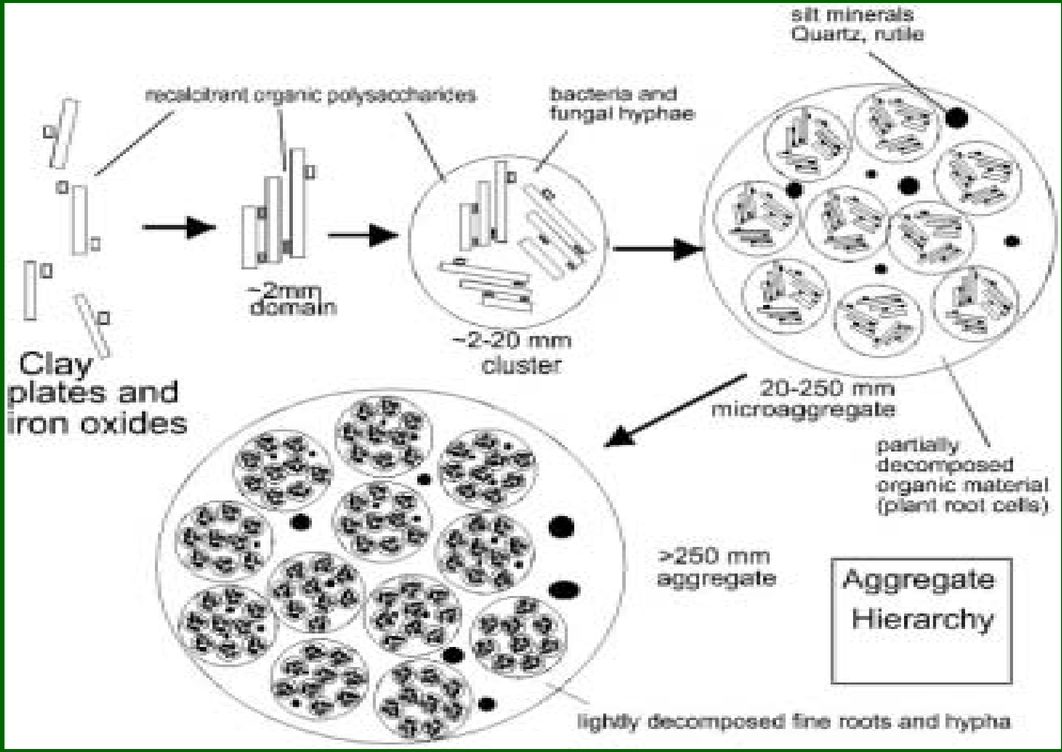
- Challenges using ^{13}C method:
  - unable to distinguish between residual "primary" forest C and new secondary forest C (both C_3)
  - uncertainties in $\delta^{13}C$ of end points, ages, turnover rates, land use history
  - assumptions inherent in "chronosequence" studies
  - simple mixing model (will try to improve)

I will also use ^{14}C and bomb carbon models to "date" soil C fractions and resolve uncertainties in turnover rates.

Average forest floor biomass in secondary forests.



H1: ***The primary mechanism for soil C storage during reforestation will be the development of an aggregate hierarchy.***



- AGGREGATE HIERARCHY: model hierarchical contribution SOM to soil aggregate stabilization (Oades and Waters 1991)

From G. Vrdoljak's PhD Thesis, U.C. Berkeley

- C protected within microaggregates where accessibility to microbes is limited or anaerobic conditions may occur
- Lower C contents in cultivated soils attributed to disruption of soil aggregates
- C within aggregates is older than C on aggregate surfaces
- CO_2 lost from disturbed aggregates

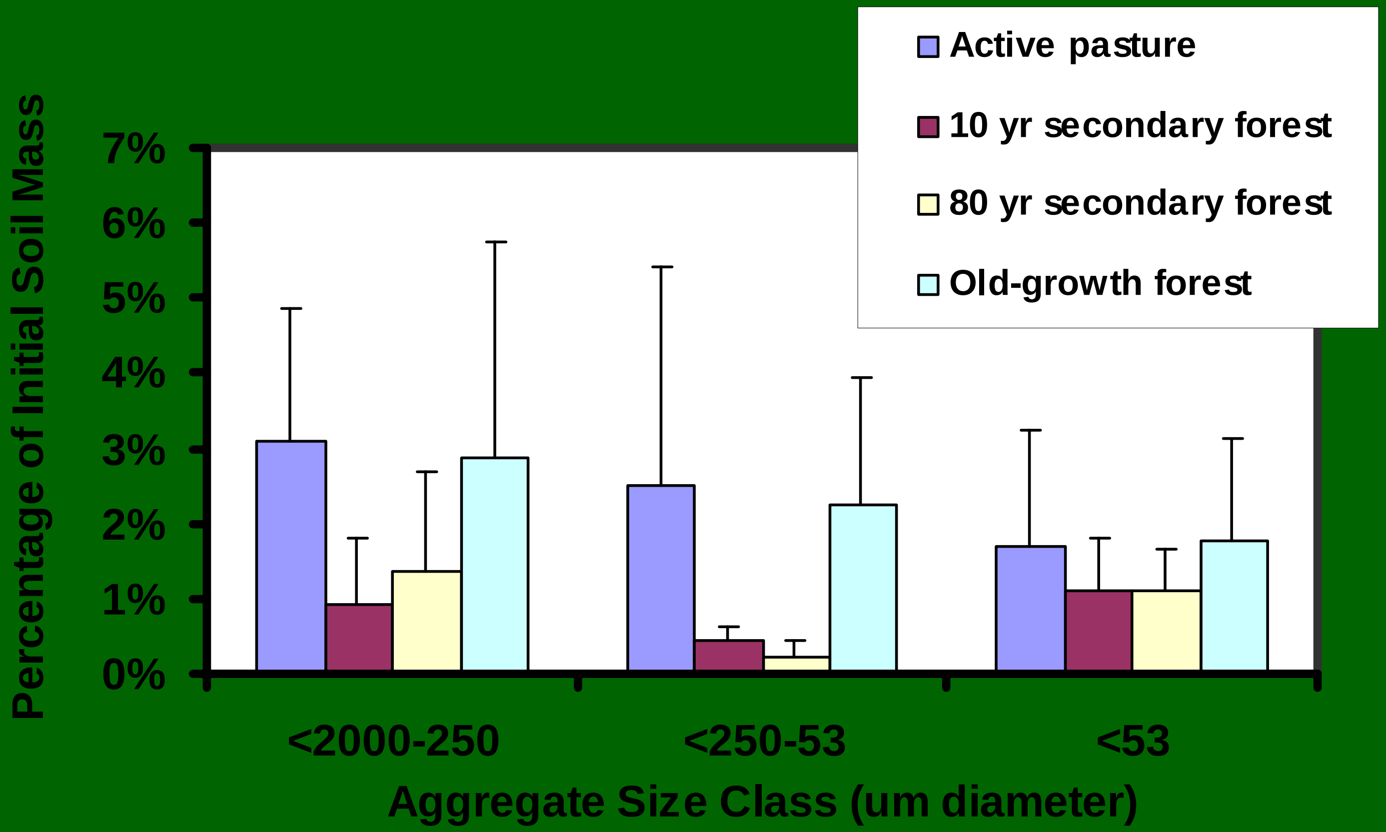
- Aggregate hierarchy thought not to be important in highly weathered tropical soils
- But recent evidence AH in Oxisols
- Recovery of aggregation post disturbance?
- Effect cattle vs pasture grasses - bulk density vs roots

- *Approach:*
- Test for differences in water-stable aggregate size distribution across sites
- Test for presence of aggregate hierarchy:
  - expect total C and N to increase with size
  - expect C:N ratio to decrease from larger to smaller

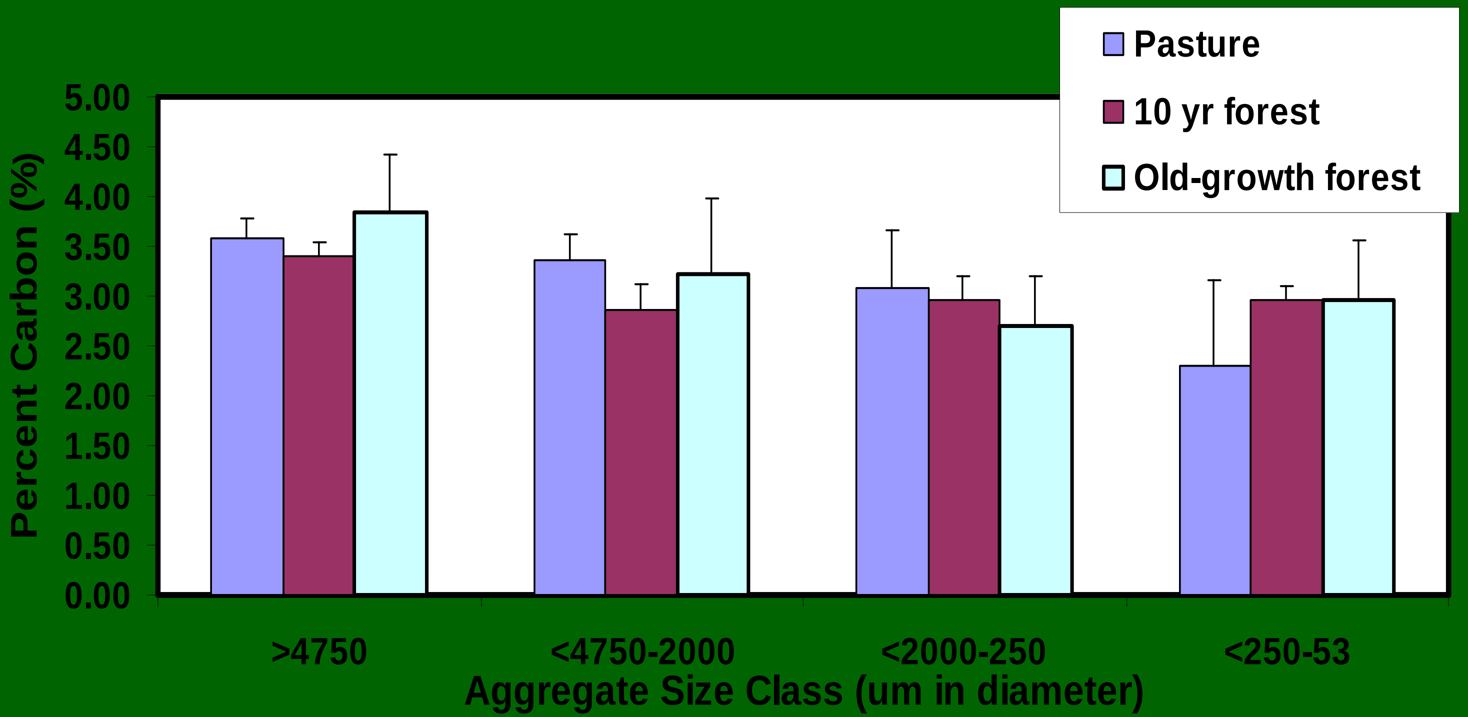
Prelimary Results:

Large macroaggregates (>4.75 mm diameter) are very stable to slaking in water for 5 min (standard method in temperate agricultural soils) so treatment did not result in differences in agg distribution and stability across sites.

Percentage of the initial mass of soil aggs > 4750 um that disassociated into smaller agg sizes and into primary particles.



C composition of different aggregate sizes



- The defining characteristics of AH are:

(1) a gradual breakdown of macroaggregates into microaggregates with increasing dispersing energy;

(2) an increase in C content with increasing aggregate size; and

(3) decrease in C turnover rates from macroaggregates to microaggregates (Six et al. 2000).