Process-Based and Landscape-Level Measures of Soil Organic Carbon Sequestration and Fluxes in Southern New England Forests

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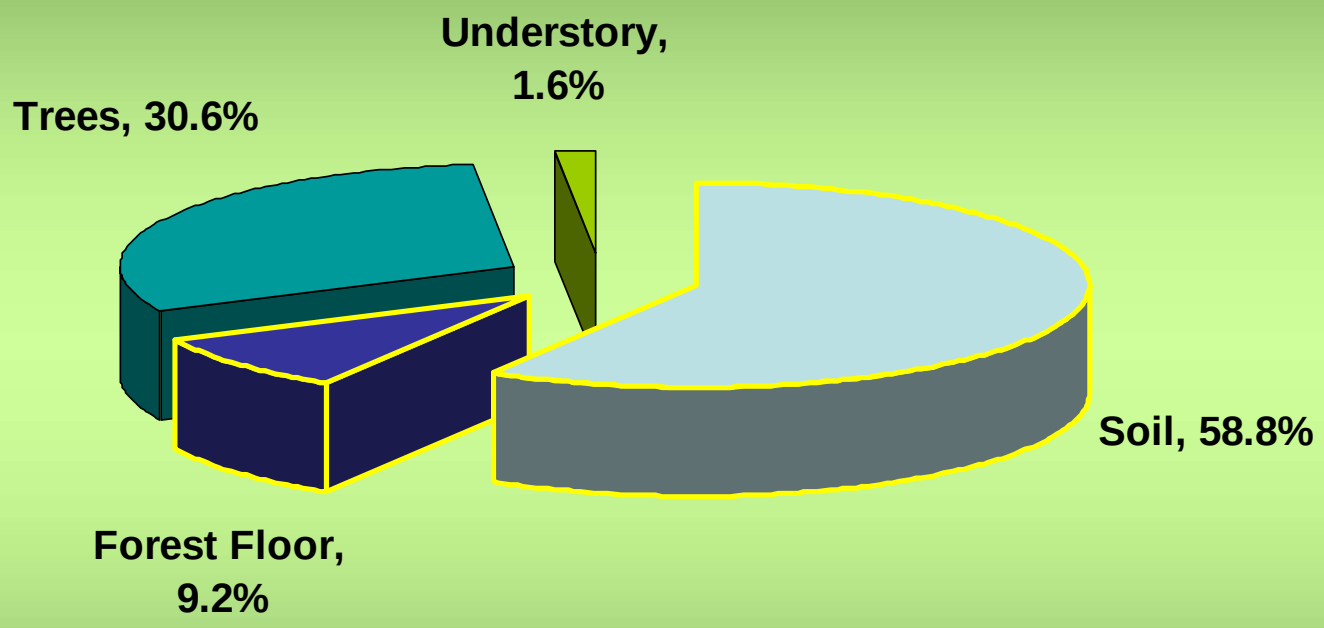
Forest Ecosystem Carbon Pools



In mature forests of temperate regions, soils comprise over 65% of the total carbon

Land-Use and Carbon

- Land-use changes from agriculture clearing and plowing over past 200 years have resulted in the release of significant amounts of carbon to the atmosphere.
- In late 1800's 30% of New England was forested, now over 70% is forested.
- As these areas are reforested, carbon accumulates (until levels prior to disturbance are reached).

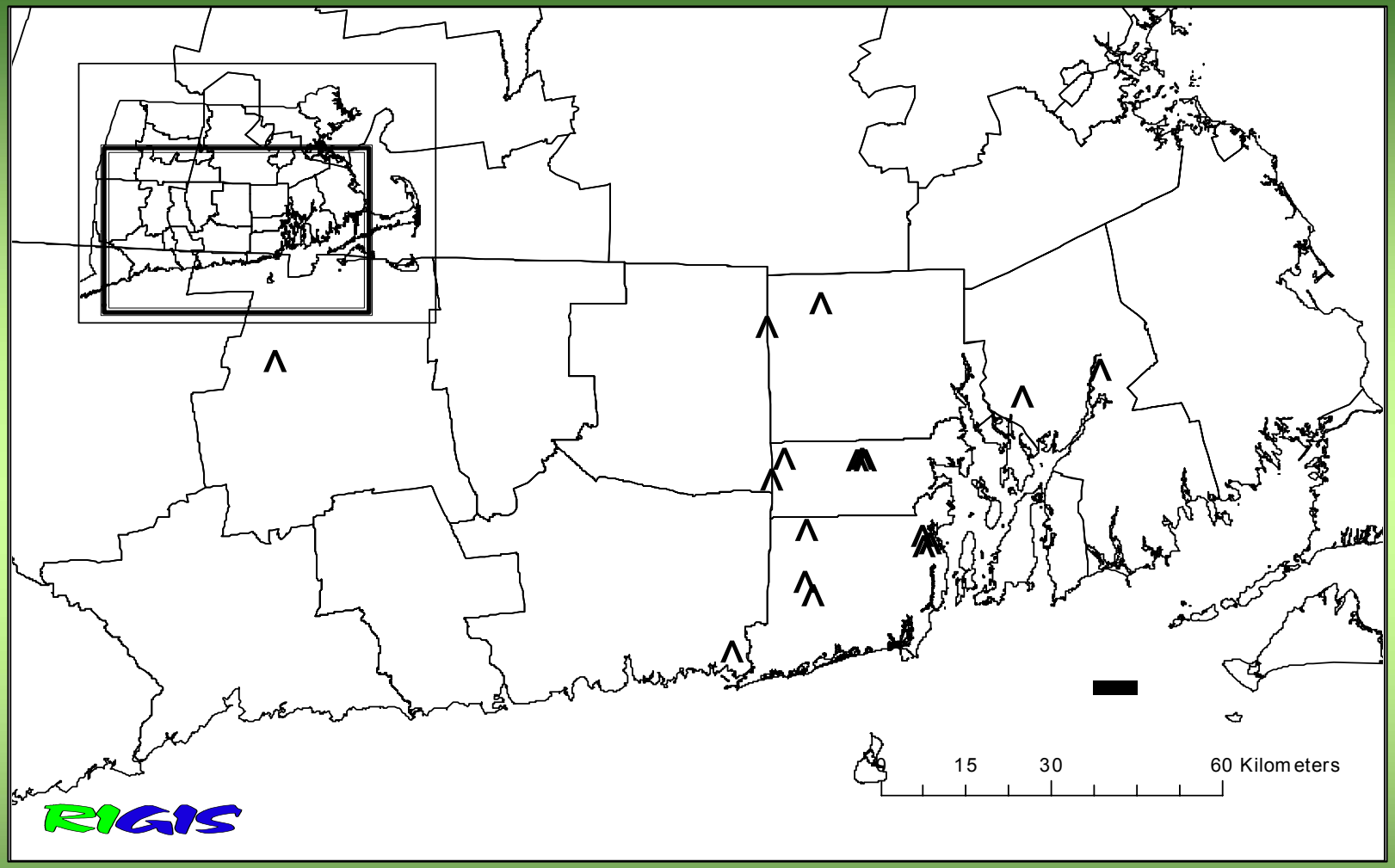
Land-Use and Carbon

- How long do these aggrading forests in New England sequester significant carbon?
- Can forests be managed to accumulate carbon?
- Does land-use history affect accumulation rates?

Objectives (I)

- Measure soil organic carbon (SOC) pools and sequestration rates in aggrading southern New England forests
- Test the effects of forest type and soil type on SOC sequestration
- Compare results from two different approaches (paired site and chronosquence) to measure SOC sequestration

Site Locations



17 sites, ranging in age from 25 to 86 years.

Soil Sampling

- Sampled to a depth of 1 m using split-core sampler
- Collected samples based on breaks in master horizons (A, B, and C)
- O horizons were sampled by cutting a 15 x 15 cm section of the forest floor

Analyses

Bulk Density

- Determined based on weight and volume of samples.

Carbon Content

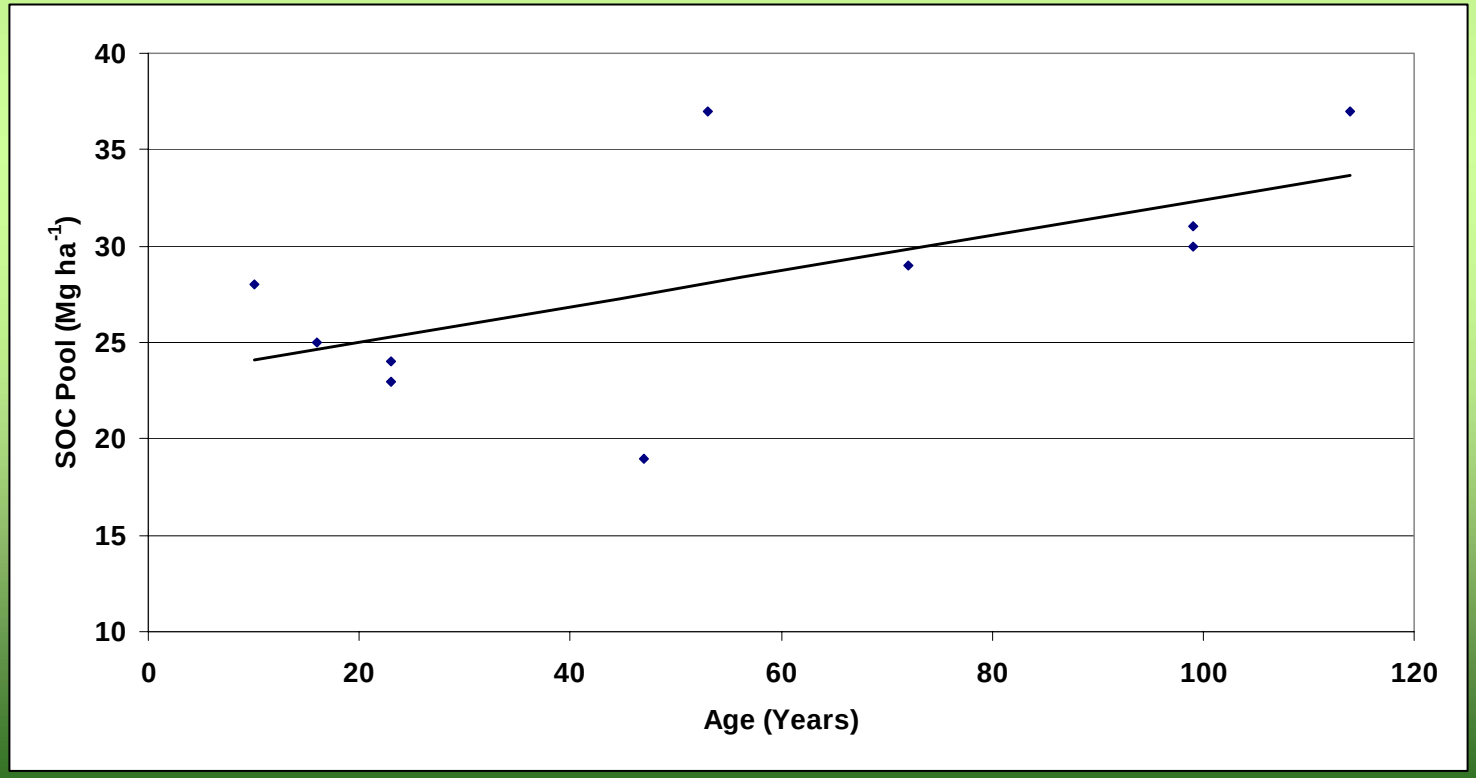
- Used C:N analyzer to determine percent carbon of each soil sample collected.

Forest Age

- Tree cores - dyed to enhance rings and counted to determine forest ages.

Chronosequence Approach

Chronosequence – uses SOC pools from different aged forests to calculate a single sequestration rate.



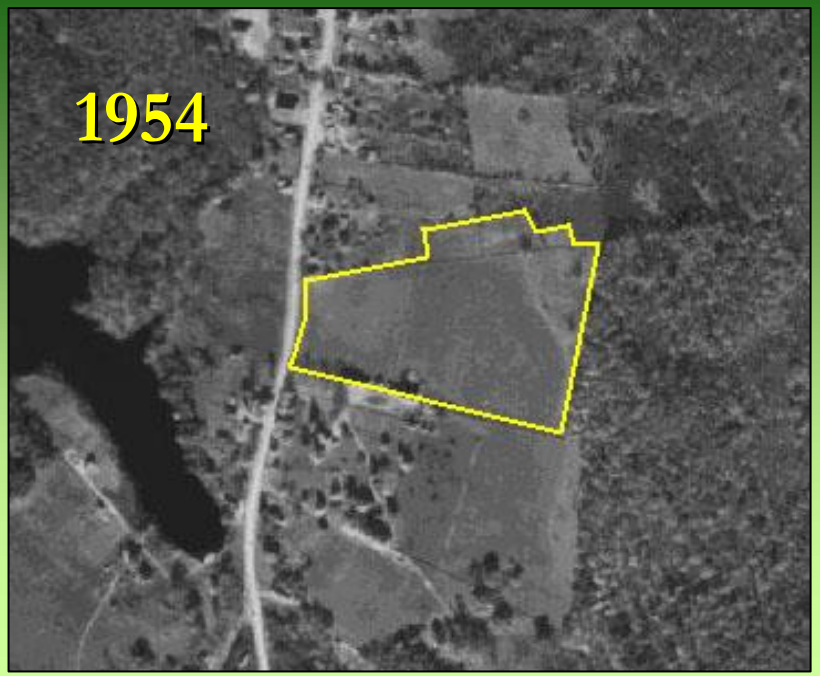
Paired Sites:

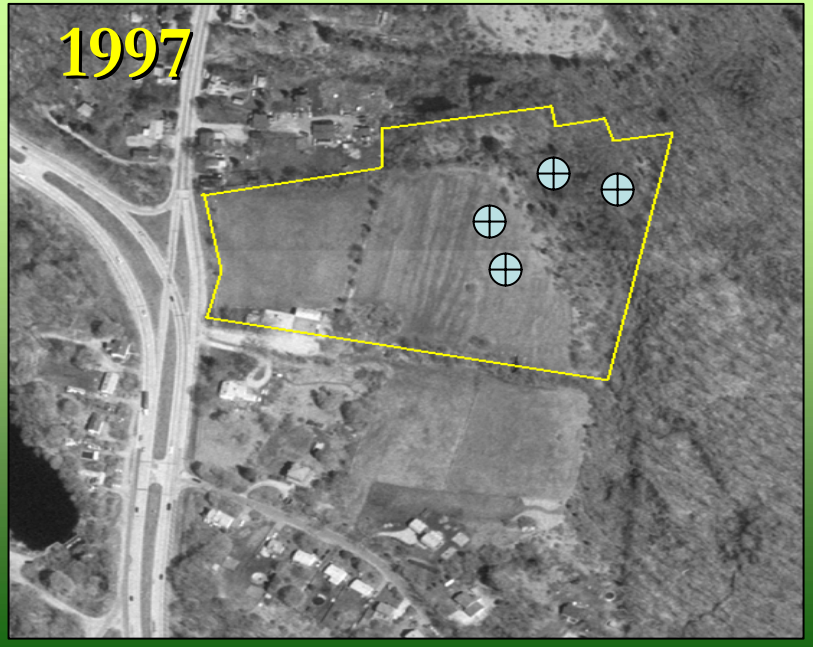
- Field and forest having same soil type comprise paired site

- Sample multiple locations within field and forest

- Core trees to determine age

- Difference between field and forest used to calculate rate





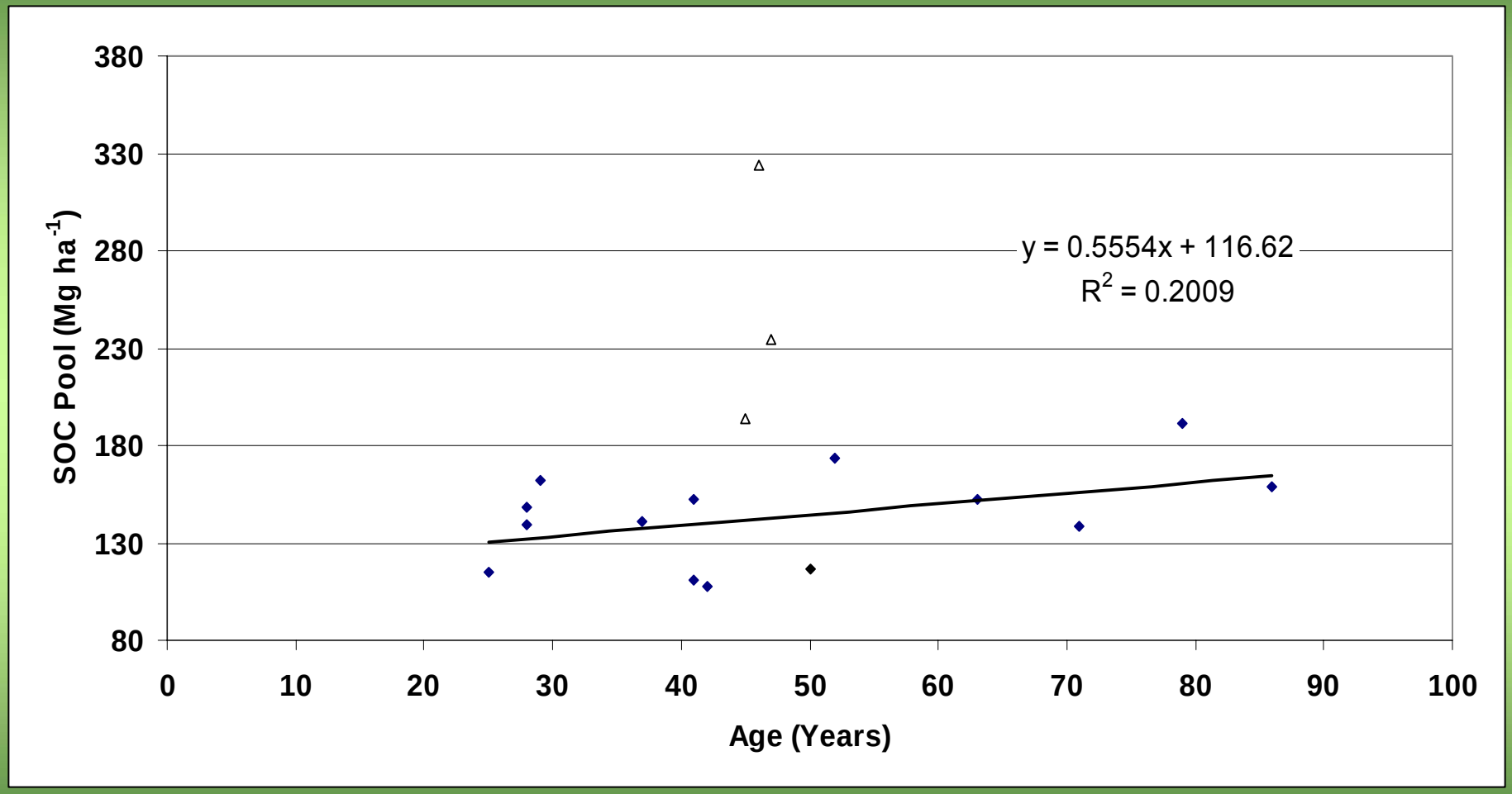
Results – Site Ages and SOC Pools

Soil or Vegetation Type	n	Mean Field Pool Size* (Mg C ha^{-1})**	CV (%)	Mean Forest Pool Size* (Mg C ha^{-1})**	CV (%)
Merrimac	7	102^{a}	31	150^{a}	23
Sudbury	9	118^{a}	27	154^{a}	24
Coniferous	9	110^{a}	34	160^{a}	22
Deciduous	7	113^{a}	21	142^{a}	22
Total	16	$111^{\dagger}$	28	$152^{\dagger}$	22

** Means with different letters are significantly different based on a t-test at the $\alpha = 0.05$ level within field and forest types.

- Mean forest pools were significantly higher than mean field pools ($p<0.01$)

Results – Chronosequence Method



Sequestration rate = 0.56 Mg C ha^{-1} yr^{-1}

Results – Paired Site Method

Site	Age (Years)	Forest Type	Difference Between Field and Forest Pools (%)	Whole Soil SOC Sequestration Rate (Mg C ha^{-1} yr^{-1})
St6	25	Coniferous	31	1.42
SR1	28	Coniferous	19	0.92
SNK2	28	Deciduous	12	0.61
S3	29	Deciduous	34	1.91
MC3	37	Coniferous	10	0.39
SBurr1	41	Deciduous	8	0.22
SC2	41	Deciduous	30	1.10
Me1-MA	42	Deciduous	13	0.34
MNK2	45	Deciduous	18	0.79
SG1	46	Deciduous	7	0.49
SR2	47	Coniferous	18	0.90
MNK10	50	Deciduous	22	0.52
SWG1	52	Coniferous	27	0.90
SC2-II	63	Coniferous	29	0.71
ME1	71	Coniferous	34	0.66
MHC1	79	Coniferous	54	1.31
MC2	86	Coniferous	60	1.11

- Mean sequestration rate = 0.84 Mg C $ha^{-1}yr^{-1}$.
- No significant differences among soil or forest type
- (but 8 of the 10 highest rates were for coniferous forests)

Results – Comparison of Approaches

SOC Pool	Chronosequence Rate ($Mg\ C\ ha^{-1}\ yr^{-1}$)	Paired Sites Rate ($Mg\ C\ ha^{-1}\ yr^{-1}$)
Total Soil	0.56	0.84
Mineral soil	0.36	0.23
O Horizon	0.19	0.61
A horizon	0.34	-0.02
Subsoil	0.02	0.16

Chronosequence Method:

- **Lower rate**
- **Majority of sequestration occurring in mineral soil**
- **O horizon rate relatively low**
- **Subsoil rate negligible**

Paired Site Method:

- **Higher rate (50%)**
- **Majority of sequestration occurring in O horizon**
- **A horizon not sequestering SOC**
- **Subsoil rate more significant**

Effects of Land-Use History

Site	Forest Age (years)	Field Vegetation	Forest Vegetation	Soil Type	Field Pool (Mg C ha^{-1})	Forest Pool (Mg C ha^{-1})
SG1	46	Hay	Deciduous	Sudbury	301	324
				Mean	111	152

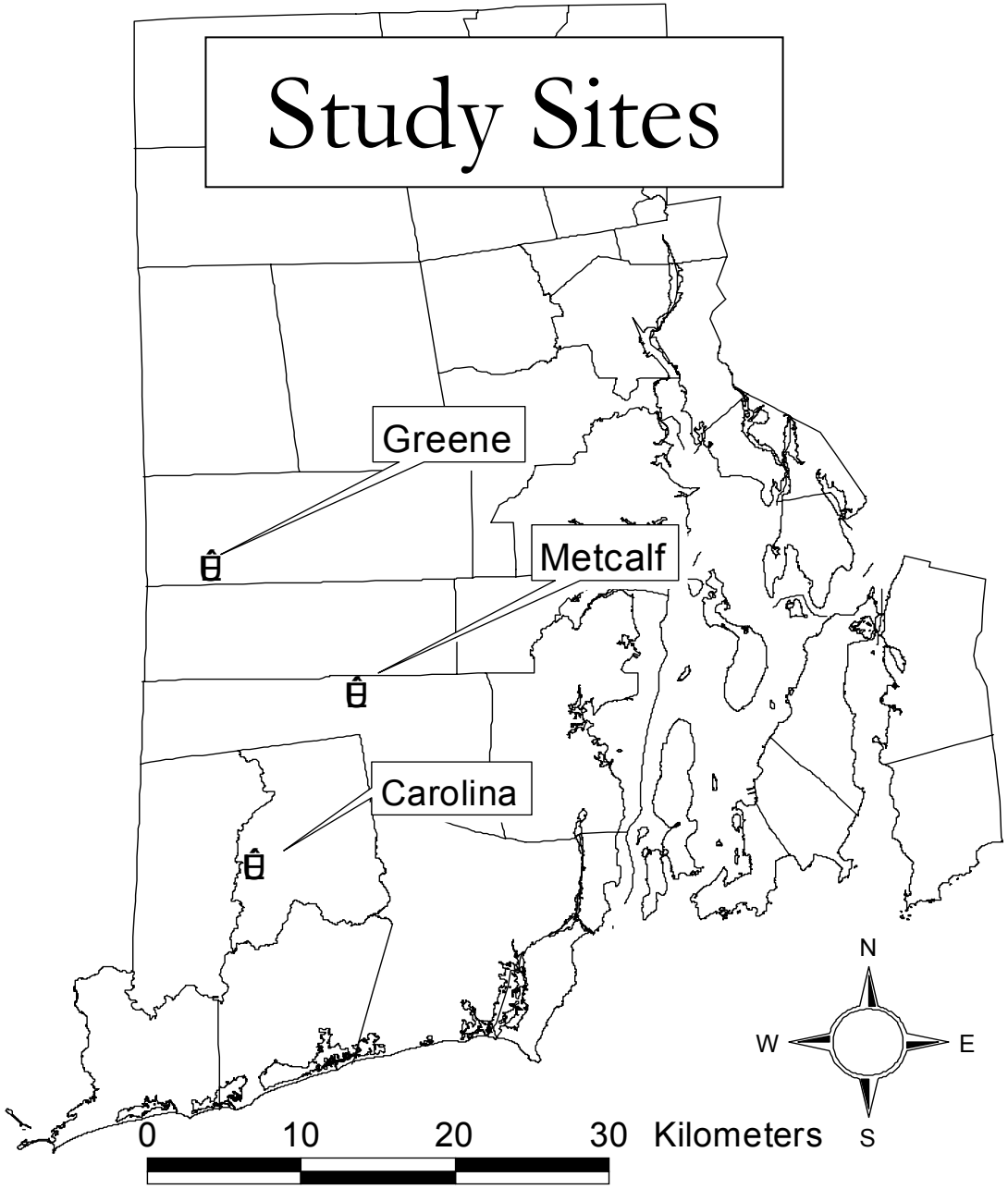
- Much higher SOC pools could be due to previous land-use practices.
- In the chronosequence method, this site was considered an outlier.
- The paired site method showed a 7% difference between field and forest SOC pools. Rate = 0.49 Mg C $ha^{-1}yr^{-1}$.
- Data suggest paired site method is more effective at accounting for land-use history affects.

Summary (I)

- SOC pools and sequestration did not differ significantly by soil or forest type
- Chronosequence method likely underestimating SOC sequestration
- Paired site method accounts for variability among sites due to land-use history

Objectives (II)

- Document SOC additions and losses in three forested watersheds
- Use these process-based measurements of SOC flux to develop annual SOC budgets
- Compare annual process-based fluxes to paired site sequestration rates


Study Sites
Greene
Metcalf
Carolina
N
W
E
S
0
10
20
30
Kilometers

Watershed Characteristics

Site	Size (ha)	Deciduous (%)	Coniferous (%)	Stream Type	Mean Daily Discharge (m^3 day^{-1})
Carolina	32	81	19	Seasonal	467
Greene	83	59	41	Seasonal	623
Metcalf	142	91	9	Perennial	900

Carolina

Metcalf

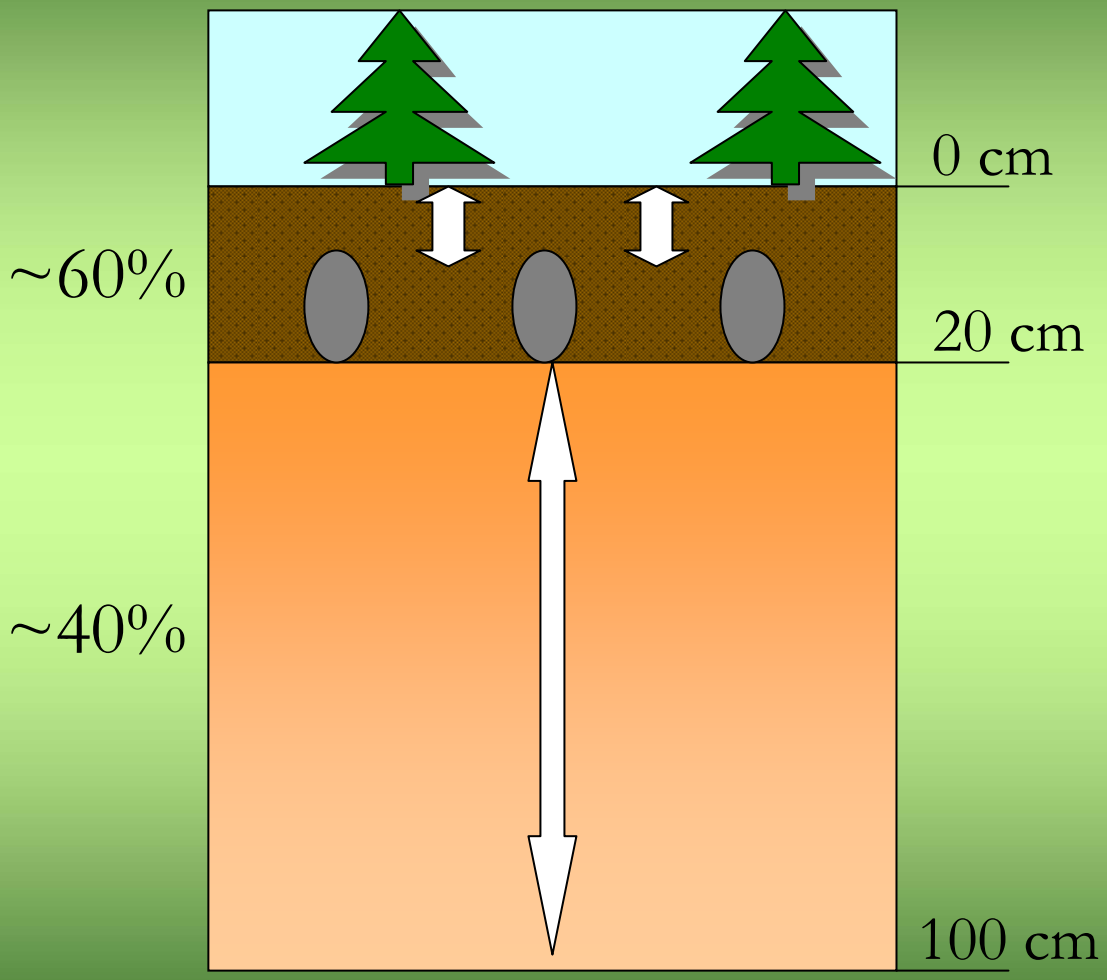
Carbon Additions

<u>Leaf Litter</u> – collected bi-weekly to bi-monthly, depending on the season.

<u>Deadfall</u> – ½ meter square plots to determine yearly inputs.

<u>Roots</u> – fine roots measured using in-growth cores. Coarse roots estimated.

Root Additions



18 cores buried in each watershed prior to the growing season.

Root data scaled up to account for:

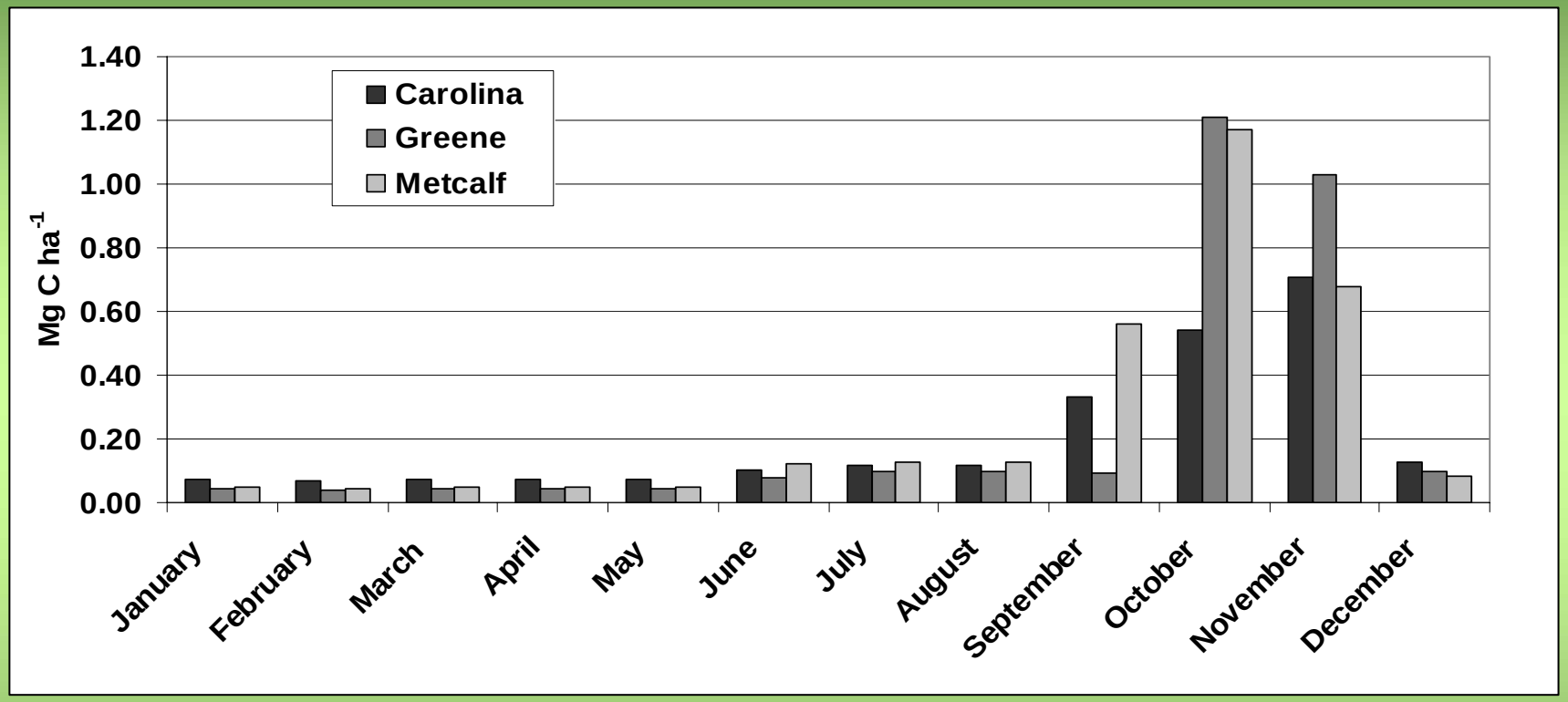
- Root growth in 0-5 cm depth
- Root growth in 20-100 cm depth

Carbon Losses

CO_2 – measured carbon lost through soil respiration. Collars in place in soil for repeated measurements from same locations

DOC – measured carbon lost through stream flow out of the watershed

Carbon Additions – Leaf Litter



Leaf litter contributed considerable C to the soils

Carbon Additions - Roots

Fine root additions averaged 2.3 Mg C ha^{-1} yr^{-1}.

No significant differences among drainage classes.

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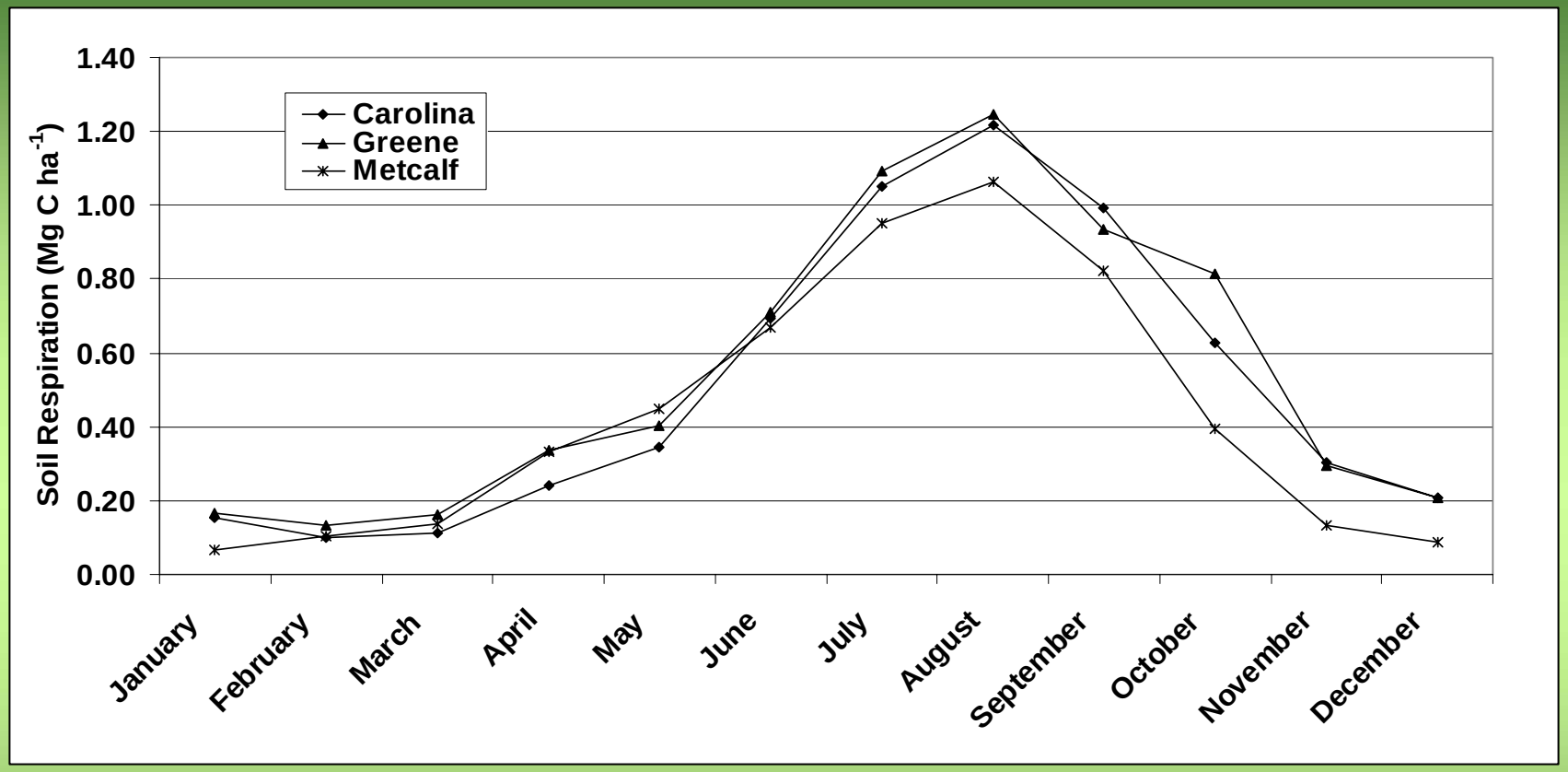
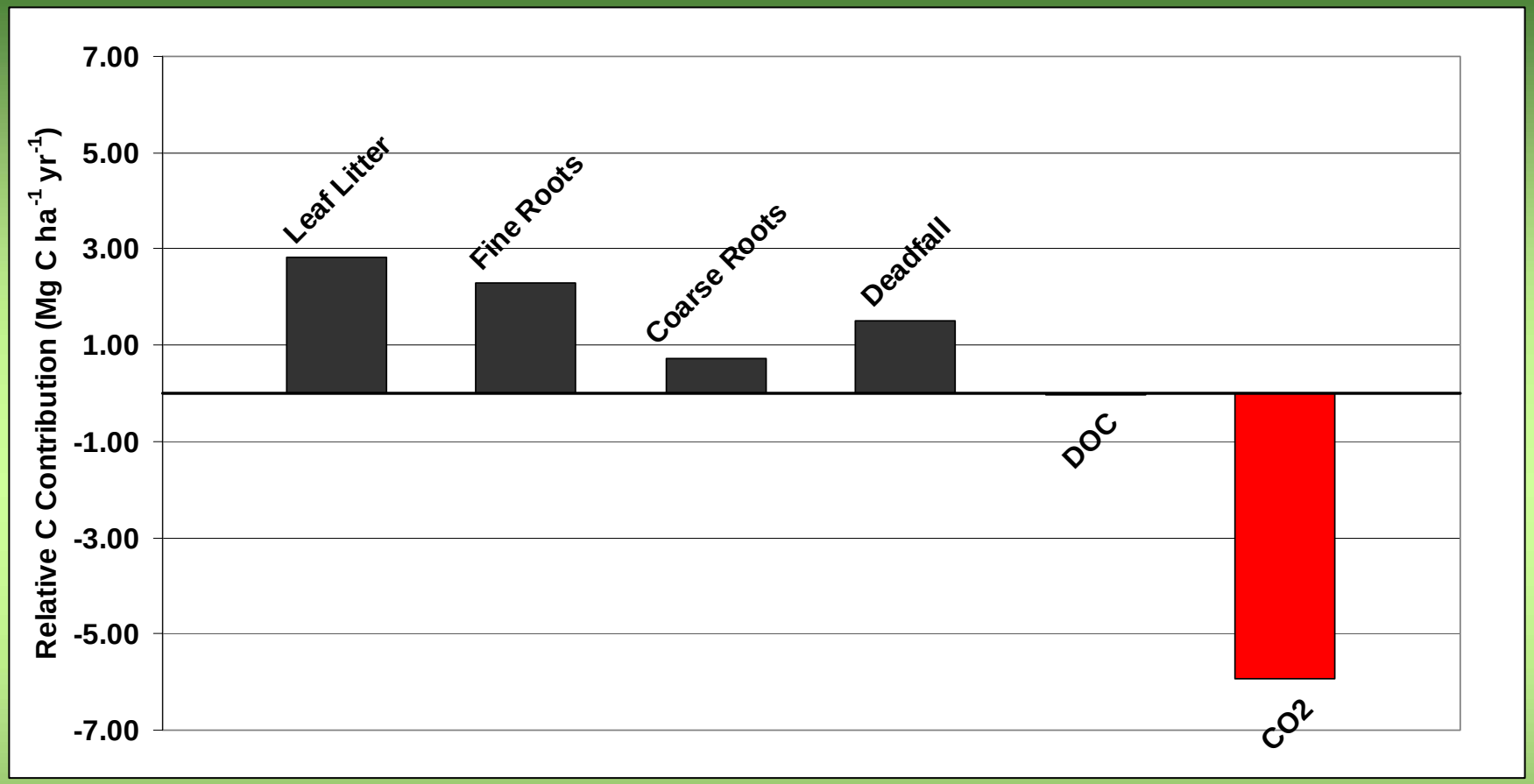
Carbon Losses



- Soil respiration varied with temperature.
- No significant differences were observed among drainage classes.

Overall Annual Fluxes



Annual fluxes ranged from 0.85 to 2.14 Mg C ha^{-1} yr^{-1}, averaging 1.39 Mg C ha^{-1} yr^{-1}.

Summary (II)

- Leaf litter and fine roots most significant additions within watersheds.
- Soil respiration accounts for nearly all losses and DOC is negligible.
- Mean annual flux higher than paired site SOC sequestration rate, but within range of reported values.

Conclusions and Implications

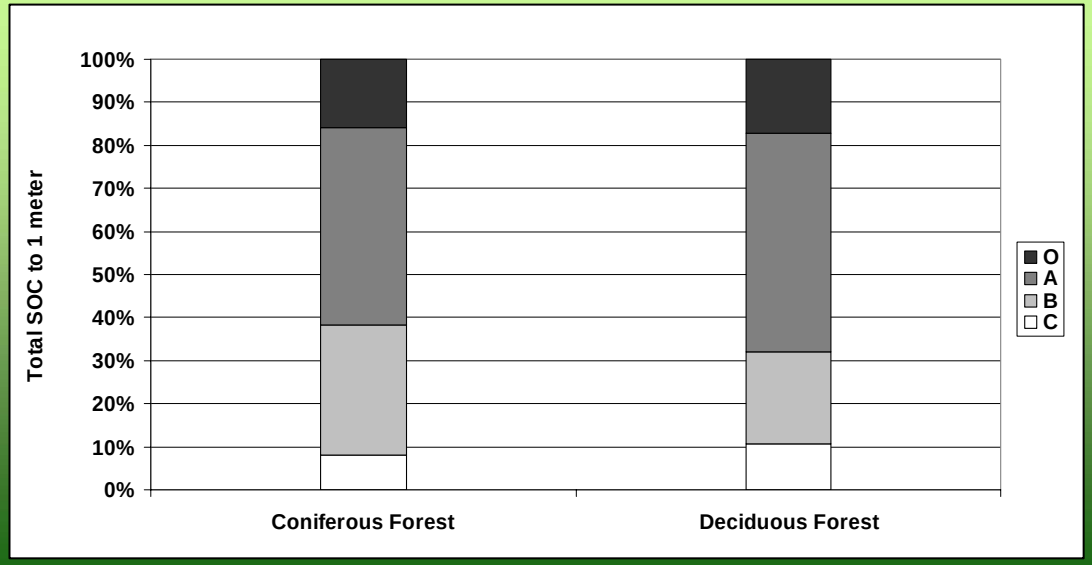
- Additional studies focusing on drainage class and CO_2 flux needed.
- Additional studies focusing on root production would help to solidify C flux budgets.
- SOC represents 35 – 40% of ecosystem C sequestration.
- Coniferous forests may be more efficient at sequestering SOC and forests could be managed to sequester C.
- Using the rates we measured, approximately 5 ha of forest sequesters enough carbon to offset the emissions of a typical person.

How Much?

- Average person emits: **5.4** tons CO_2 per year
- Metcalf forest sequesters: **133** tons CO_2 per year

Therefore, this 142 ha forest is sequestering enough carbon to offset the emissions of 25 people.

Results – SOC Pools

54 to 67% of SOC is stored in the A horizons in fields

62 to 68% of SOC is stored in the O and A horizons in forests