Forest Landscape Studies

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CSiTE Science Review

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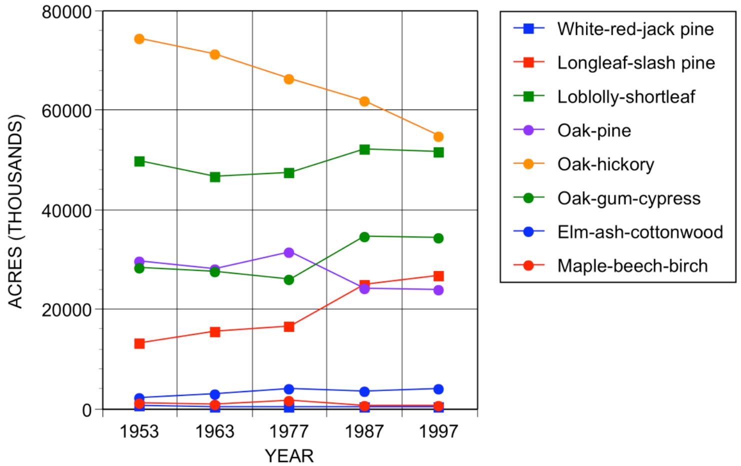
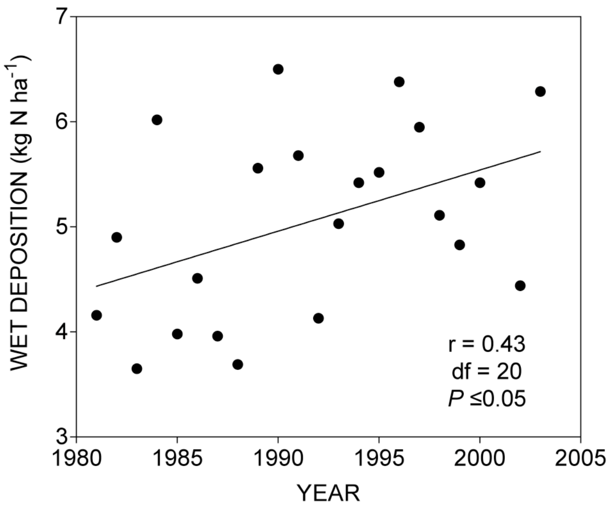
Research Question

- Research task is based on rationale that land cover can be an important determinant of soil C storage and dynamics
- Landscape features (elevation, slope, aspect) are important to biogeochemical processes but, practically speaking, can not be changed
- Land cover management has been suggested as a relatively inexpensive, practical means to promote both above- and belowground C sequestration
- One cornerstone of CSiTE
- Research question: how can land cover be "managed" to promote belowground C sequestration?

Focus Primarily on Forests

- Most (83%) forest land in the southeastern USA is "natural" or unmanaged forest (mirrors national trend)
- Forest composition is changing and will continue to change through time
- Changes could have subtle but important effects on biogeochemical cycling and soil C storage
- Greater N availability may increase soil C storage but has potentially adverse effects on water quality
- How will changes occurring in forests affect soil C sequestration?
  - Increasing atmospheric CO_2
  - Increasing temperatures
  - Increasing atmospheric N deposition





Increasing trends in N deposition on WBW

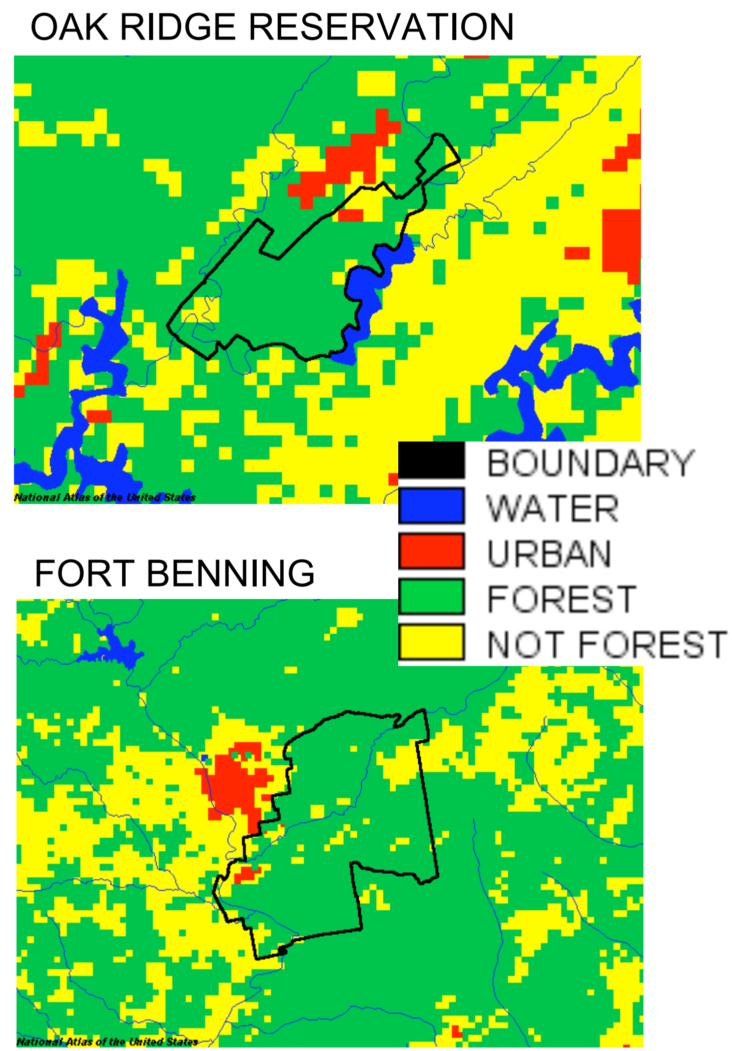
Literature Review

- Land cover is a significant determinant of net soil N mineralization and nitrification and may also affect soil N content and soil C:N ratios
- Litter quality differences can exert a strong control on N availability in forests
- Meta-analyses indicate that greater soil N availability generally promotes soil C sequestration – but results appear to be mixed

Reference	Significant effect of land cover type on:		
	Soil N mineralization or nitrification	Soil N stocks	Soil C stocks
Zak et al. (1986); Zak and Pregitzer (1990)	YES		
Wood et al. (1992)	YES	YES	NO
Reich et al. (1997)	NO		
Compton et al. (1998)	YES	NO	NO
Finzi et al. (1998)	YES	YES	YES
Knoepp and Swank (1998)	YES		
Compton and Boone (2000)	YES	YES	NO
Jobbagy and Jackson (2000)			YES
Garten and Ashwood (2002)	YES	YES	YES

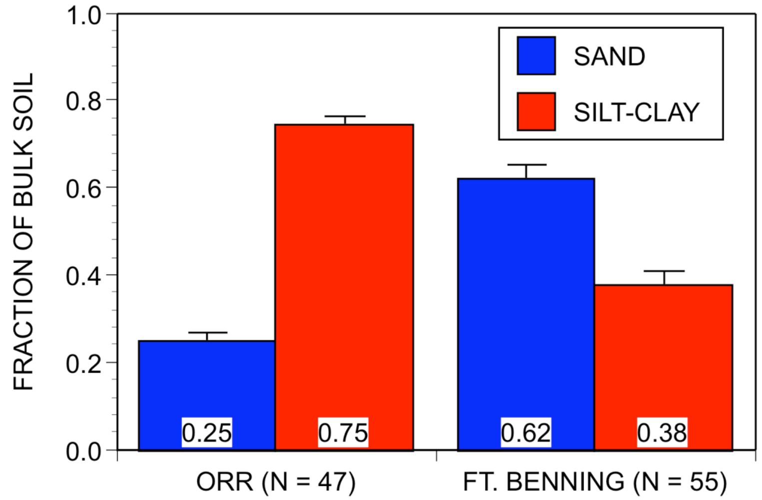
Tale of Two Studies

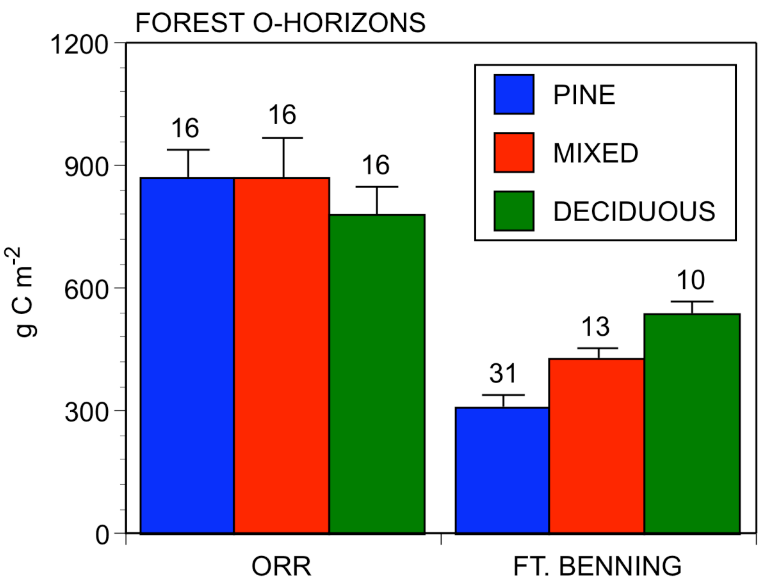
- Studies of soil C and N at different scales
- Oak Ridge Reservation, TN
  - 14,000 ha
  - 73 sampling locations (47 forest sites)
  - Considered both land cover and topography
  - Forests are 30% deciduous, 26% mixed, 8% evergreen
  - Funded by CSiTE
  - Published *Global Biogeochemical Cycles*
- Fort Benning, GA
  - 76,000 ha
  - 109 sampling locations (55 forest sites)
  - Forests are 49% mixed, 25% deciduous, 7% evergreen
  - Study of soil quality thresholds to ecosystem recovery funded by DOD SERDP-SEMP
  - In press *Ecological Engineering*
- Are there consistent patterns in soil C storage with land cover type?



Site Characterization

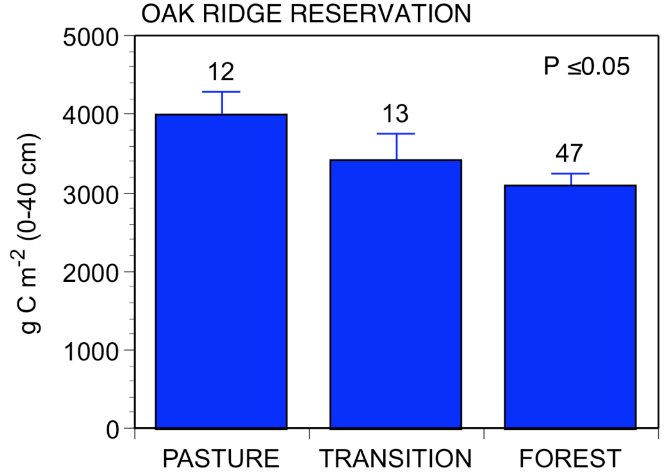
- Climate differences
  - Oak Ridge Reservation
    - Mean temperature 14 °C
    - Mean precipitaiton 137 cm yr^{-1}
    - Wet N deposition 0.6 g N m^{-2} yr^{-1}
  - Fort Benning
    - Mean temperature 18°C
    - Mean precipitation 130 cm yr^{-1}
    - Wet N deposition 0.3 g N m^{-2} yr^{-1}
- Ultisols and inceptisols at both sites but big differences in soil texture
- Also differences in forest floor C
- Only mineral soil C stocks are considered in the following analyses of land cover differences at each site

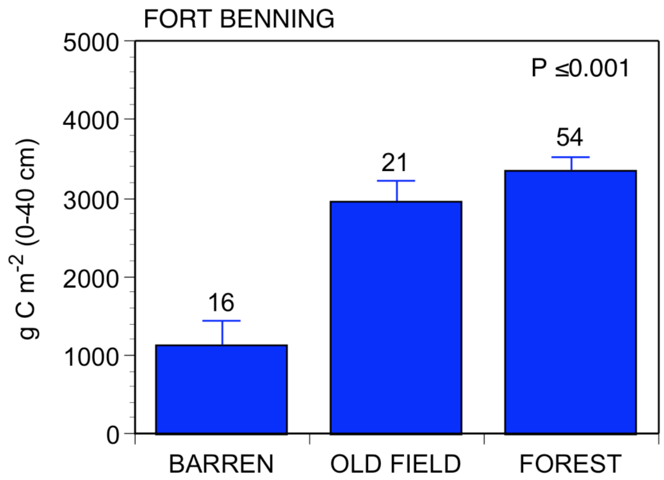




Land Cover Differences in Soil C

- Significant differences in soil C and N between broad land cover types at each study site
- Oak Ridge Reservation
  - Pastures had greater soil C stocks and a greater proportion of soil C in the silt+clay fraction (mineral-associated organic matter) than did forests
  - Soil N stocks and N availability was greater under pastures than under forests
  - Effects of topography were secondary to those of land cover
- Fort Benning
  - Soil C stocks beneath forests and old fields were similar and greater than those in barren soils
  - Calculations and field data indicate that it takes about 60 years to restore soil C stocks under barren land to current day levels under forest ecosystems
  - Barren soils are an opportunity for soil C sequestration but are a small part (<10%) of the total landscape





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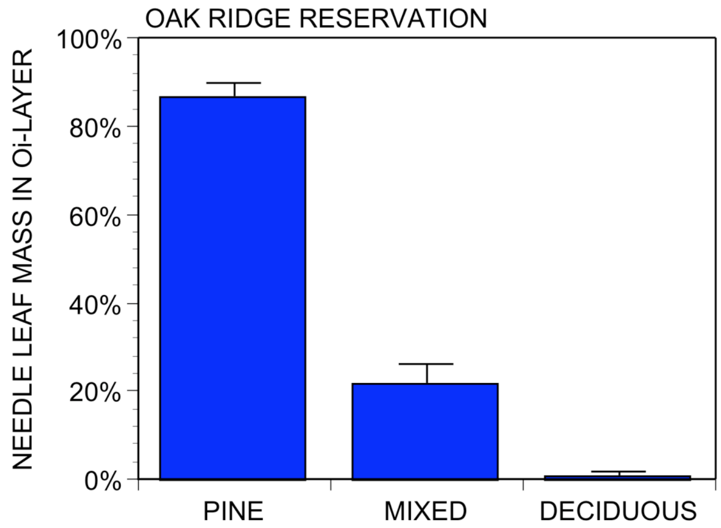
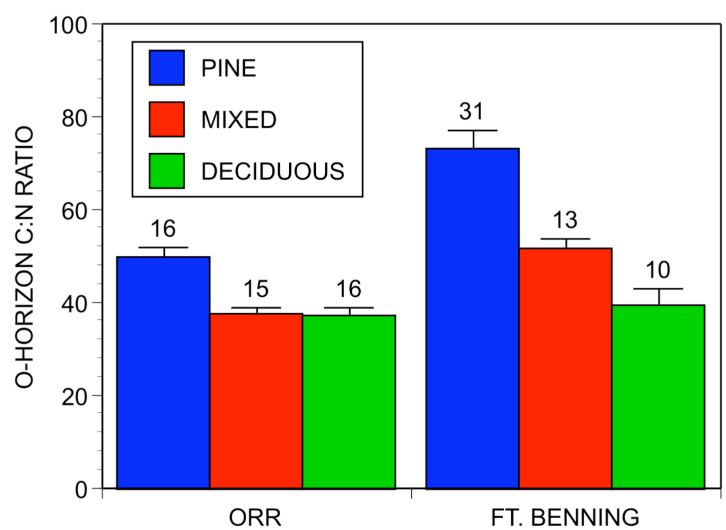
Forest Cover Types

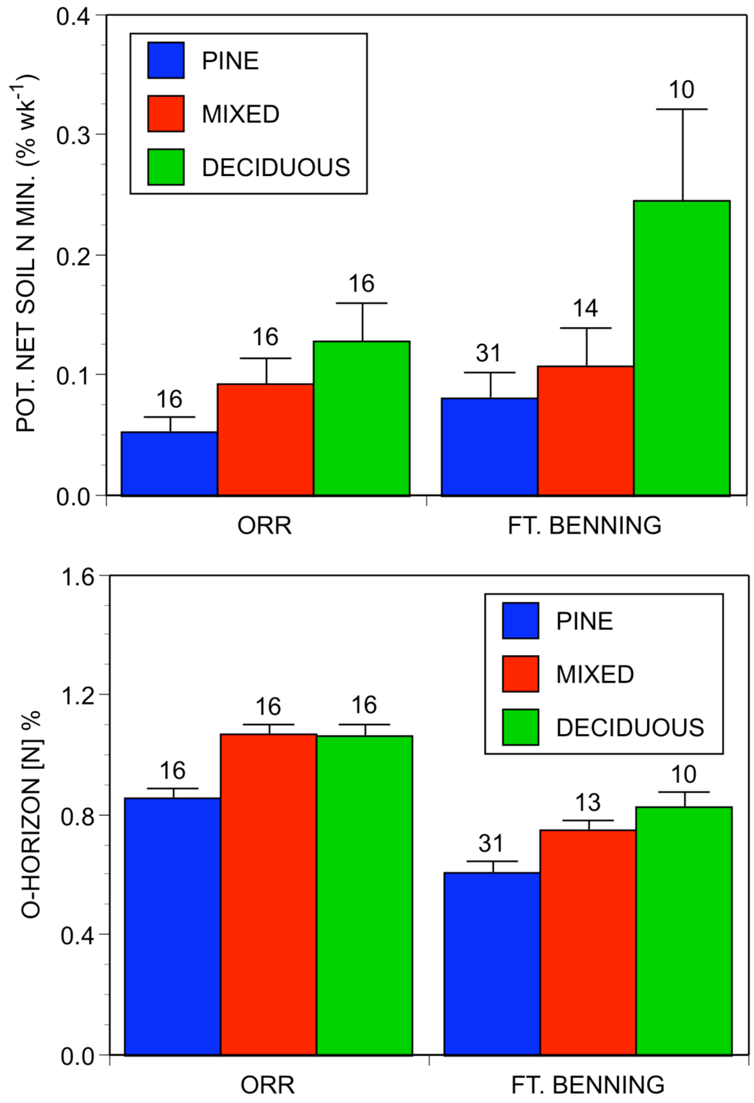
- At both sites, forests were binned into one of three broad categories
  - Pine forest – primarily needle leaf trees; sometimes with deciduous understory species
  - Mixed forest – a combination of both pine and hardwood in the overstory
  - Deciduous forest – primarily broadleaf trees; pine almost always absent
- O-horizon C:N ratios reflected trends in forest litter quality – significantly ($P \leq 0.05$) higher C:N ratios for leaf litter inputs in pine forests
- How are these differences in litter chemistry related to soil N and C?





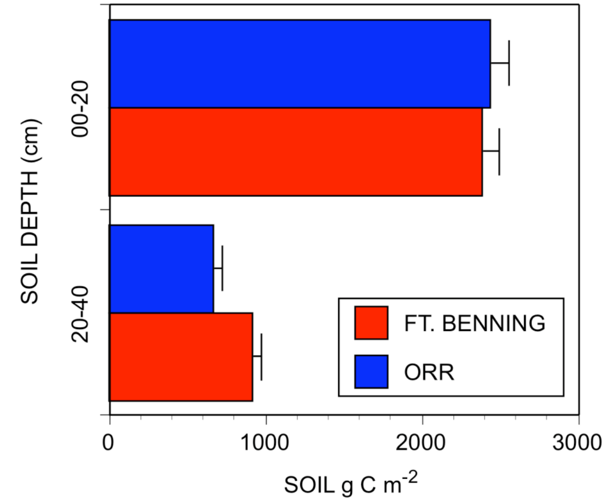
Forest Cover and Soil Nitrogen

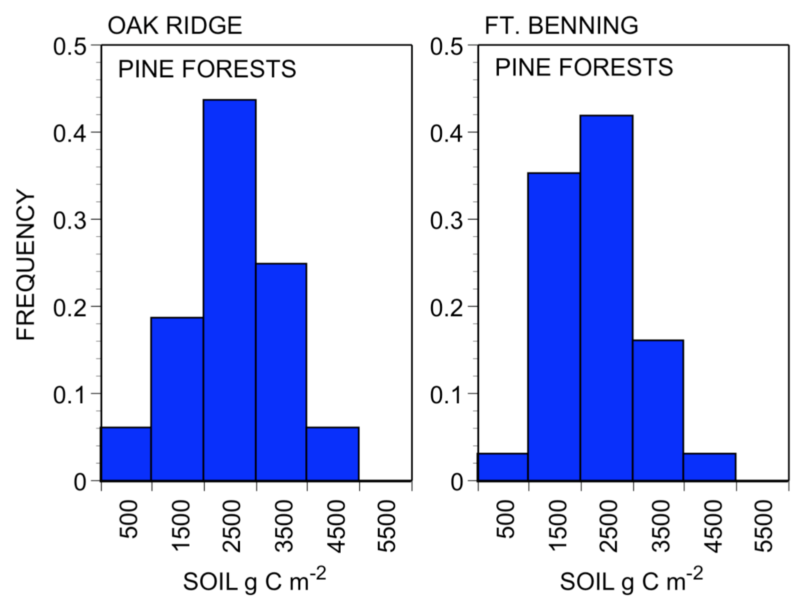
- There were no significant differences between forest categories for surface (0-20 cm) mineral soil N stocks at either site
    - ORR: 144 ±8.1 g N m^{-2} (n = 47)
    - Ft. Benning: 105 ±6.9 g N m^{-2} (n = 55)
- However, normalized potential net soil N mineralization rate was significantly different between forest categories at both sites
- Deciduous forests had the highest potential rates and pine forests had the lowest
- Differences between forest categories in soil N availability are reflected in forest floor N
- Is there a feedback from leaf litter chemistry differences to soil C stocks?



Forest Cover and Soil C

- No significant differences in soil C stocks beneath different forest categories at either Oak Ridge or Fort Benning
- Despite apparent differences in soil texture and litter chemistry, differences in forest soil C storage between the two sites were altogether unremarkable
  - Depth profiles were similar
  - Proportion of soil C in mineral-associated organic matter was similar (≈ 70 ±1%)
  - Similar mean surface soil C stocks
- Do mean values tell the whole story?
- Subtle differences in frequency distributions of forest soil C are in agreement with litter chemistry effects
- Detection of differences at this level requires lots of sampling – are other methods needed?





Calculated Significance

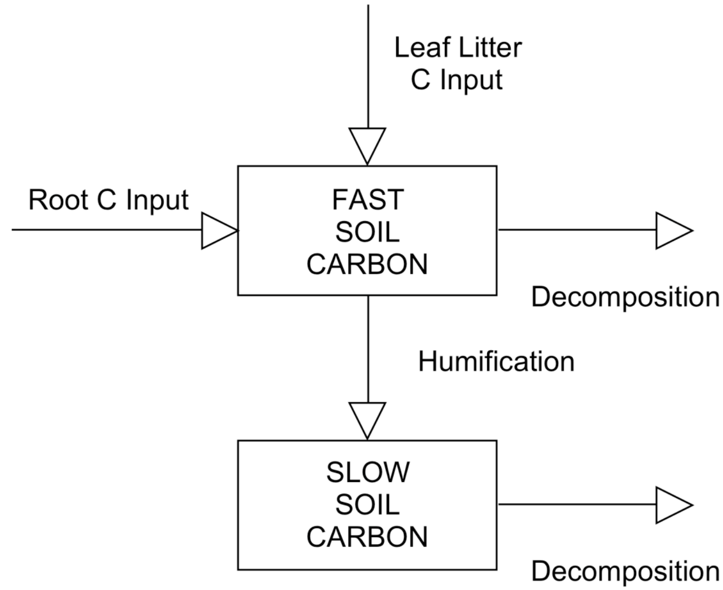
- Oak Ridge Reservation
  - 14,000 ha or 140 E+6 m^2
  - 64% forest land or 89.6 E+6 m^2
  - Mean forest soil C stock (0-40 cm) is 3112 ±142 g C m^{-2}
  - Total forest soil C on ORR is 2.8 E+5 Mt
  - An increase of ≈1 SE (5%) in forest soil C would add 14 E+3 Mt C (9,524 Corollas yr^{-1})
- Fort Benning
  - 76,000 ha or 760 E+6 m^2
  - 81% forest land or 616 E+6 m^2
  - Mean forest soil C stock (0-40 cm) is 3288 ±140 g C m^{-2}
  - Total forest soil C on Ft. Benning is 2.0 E+6 Mt
  - An increase of ≈1 SE (5%) in forest soil C would add 101 E+3 Mt C (68,710 Corollas yr^{-1})

Litter Manipulation Experiment

- Results from landscape level studies prompted a litter manipulation experiment on the ORR
- Purpose is to determine effects of changing leaf litter amounts and chemistry on soil processes important to C sequestration
- Similar experiments at other locations indicate a variety of potential changes associated with litter manipulation:
  - Light- and heavy-fraction organic matter
  - Fungal and bacterial communities
  - C and N leaching
  - Soil C and N mineralization rates
- Recent relevant hypotheses:
  - Increased soil C inputs accelerate OM decomposition (i.e., priming efffect)
  - Changes in N availability may stabilize HF-OM
  - Disconnect between aboveground C inputs and soil C stocks

Experimental Design

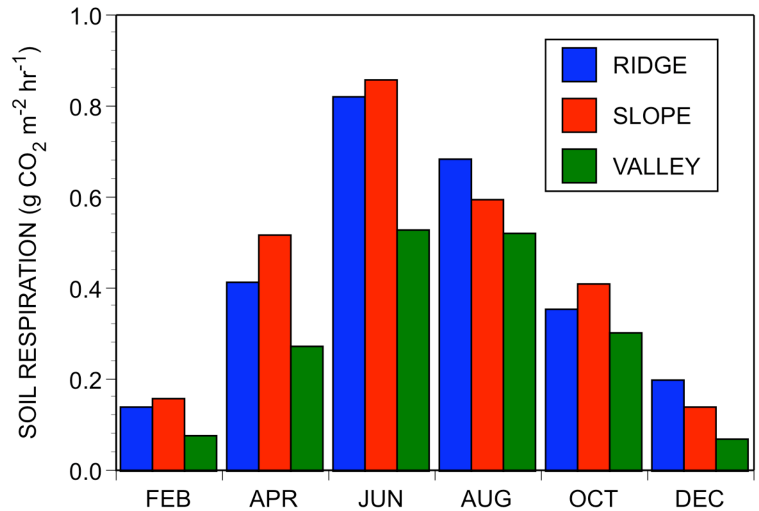
- Started experiment in late 2001
- Litter treatments on 3 x 3 m plots at a ridge, slope, and valley study site
  - Control (450 g dry mass m^{-2} yr^{-1})
  - Leaf litter exclusion
  - Supplemental leaf litter (3X control)
  - Litter replacement (pine needles)
- Three replicate plots per treatment
- Repeated measures ANOVA
- Annual capture of leaf fall on exclusion and replacement plots and transfer to supplemental litter plot
- Pine litter C:N ratios are ≈140 while deciduous litter C:N ratios are ≈70 at the ridge and slope site and ≈40 in the valley
- No trenching

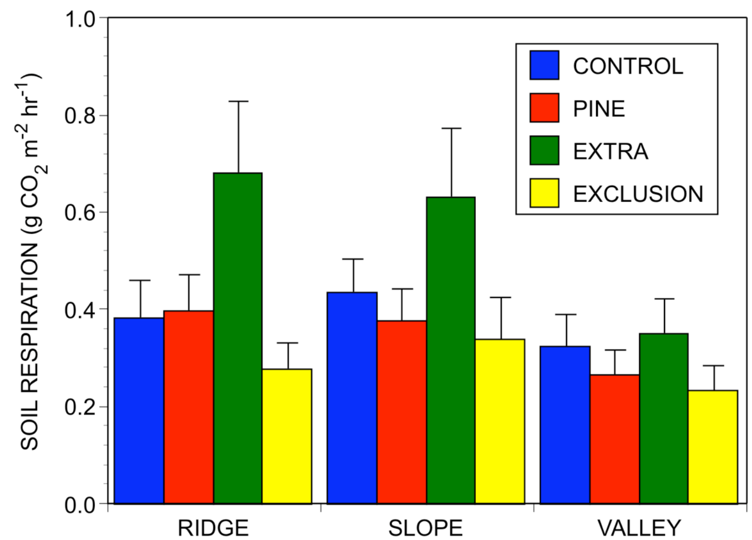


Measurement	*Frequency*
Soil temperature	*2 hours (first 2 years)*
Soil respiration	*Every other month (first 2 years)*
Mineral soil C and N stocks	*1,2, …, 5 yr interval*
Soil C in POM and MOM	*1,2, …, 5 yr interval*
Potential net soil N mineralization	*1,2, …, 5 yr interval*
Litter fall amount and chemistry	*1,2, …, 5 yr interval*
Root biomass	*End of experiment*

Effects on Soil Respiration

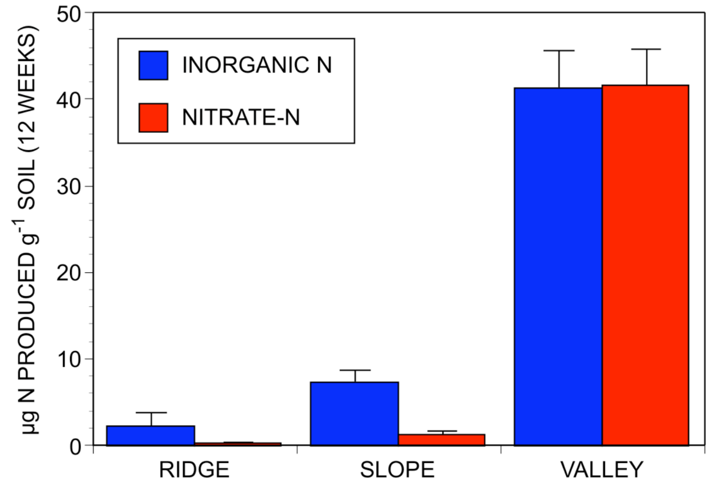
- Baseline soil respiration measurements were made over 24 months (n = 4 per plot)
- O-horizon was removed prior to each measurement and then replaced
- Repeated measures ANOVA indicated statistically significant litter treatment effects at the ridge ($P \leq 0.001$), slope ($P \leq 0.10$), and valley ($P \leq 0.05$) site
- Plots receiving supplemental litter had highest soil CO_2 efflux – litter exclusion plots had the lowest
- Supplemental litter disappeared quickly in the valley (there are apparent strong between site differences in leaf litter decomposition rates)

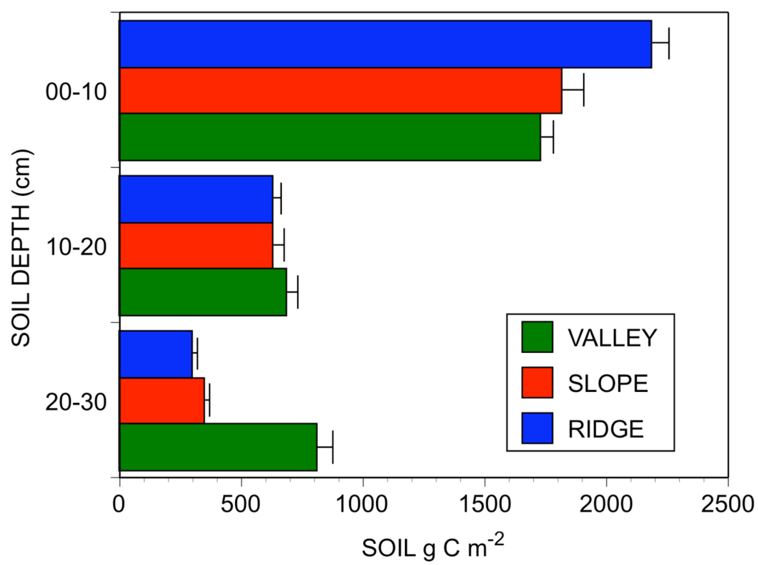




Effects on Soil N and C

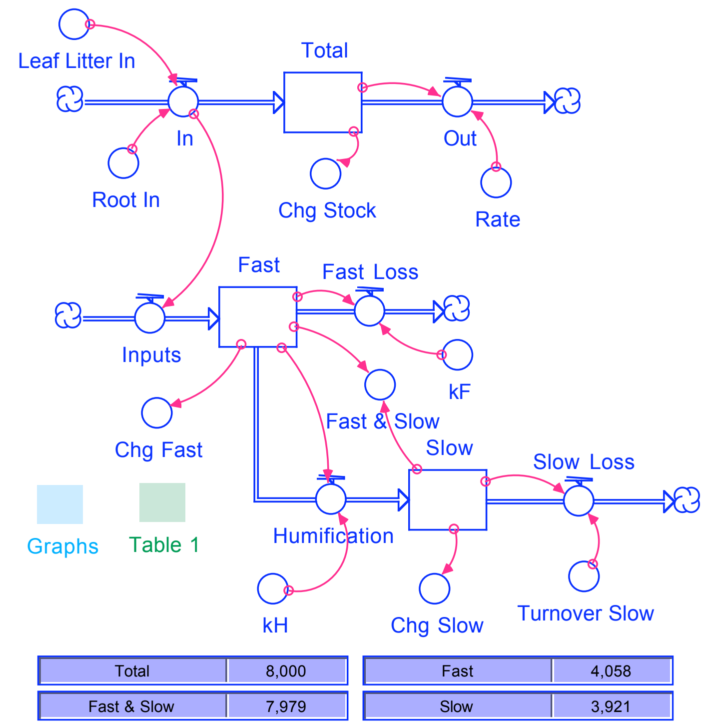
- Soil N Mineralization
  - No significant effect of litter manipulation on laboratory measures of net soil N mineralization in spring 2002 and 2003
  - Significant site differences soil N availability and high levels of nitrification in valley soils
- Surface (0-10 cm) soil C and N stocks
  - No significant effect of litter manipulation on surface soil C and N concentrations or stocks in 2002 and 2003
- Significant Site Differences
  - Surface soil N concentrations and stocks are significantly greater in valley
  - Surface soil C concentrations and stocks are significantly greater on the ridge
  - Fraction of surface soil C in POM is significantly less at the valley site
  - Valley subsoils (>10 cm deep) have higher C binding capacities





Modeling Treatment Effects

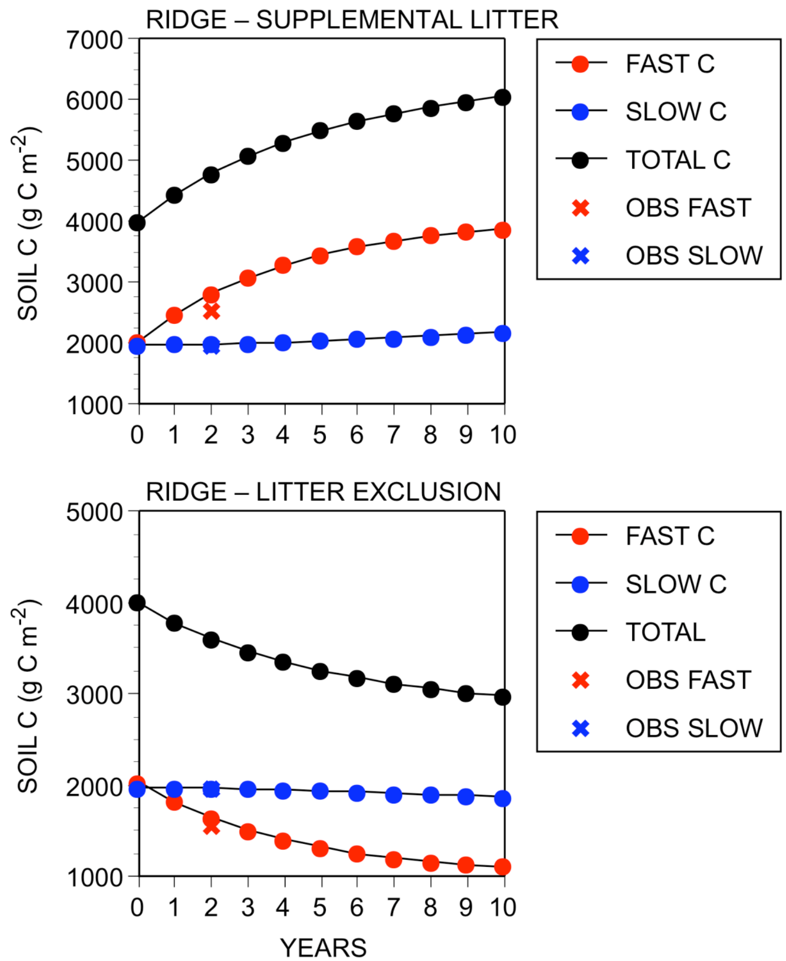
- Litter treatment effects after 2 years were limited to the O-horizon
- How long must treatments persist to change soil C storage?
- Predicted answers from a 2-pool model of forest soil C
  - Fast pool = O-horizons + POM
  - Slow pool = mineral-associated OM
- Used data from control plots to parameterize the model
- Predicted changes under litter exclusion and supplemental litter additions
- Uncertainties
  - Root C inputs = leaf litter C input
  - Turnover time of the slow pool



Process	Ridge	Slope	Valley
C inputs ($g\ m^{-2}\ yr^{-1}$)	490	432	454
Turnover fast C (years)	4.1	5.0	1.9
Humification rate (yr^{-1})	0.017	0.014	0.042

Predicted Soil C Sequestration

- Predicted treatment effects on fast and slow soil C stocks after 2 years agree reasonably well with field measurements
- Model results indicate:
  - 2-fold faster turnover of labile soil C in the valley (a mesic site)
  - Faster humification rate at valley site
- Under increased leaf litter production:
  - Greater short-term (10-yr) potential for soil C sequestration at ridge and slope sites ($\Delta \approx 2.0$ kg C m^{-2}) than at the valley site ($\Delta \approx 1.0$ kg C m^{-2})
  - Greater short-term allocation of soil C to the slow pool at valley site (57%) than at ridge and slope site (≈34 %)
- Significant between site differences in soil N availability may impact longer-term soil C dynamics



Related Studies

- CSiTE studies of native grass plantings on the Oak Ridge Reservation
  - Efforts started in 2002 to establish C4 grasses on abandoned fescue hay pastures and loblolly stands killed by pine beetles
  - Opportunities to use changing stable C isotope ratios for studies of soil C dynamics
- CSiTE studies of soil humification reactions
  - Experiments underway at Santee Experimental Forest (PNNL, USFS, ORNL)
  - Using ^{13}C-glycine to track fate of monomer in humification under different hydrologic treatments and soil amendments
- We will continue to leverage CSiTE forest research with other related studies
  - Studies of soil C dynamics along an elevation gradient the the southern Appalachian Mountains
  - Studies of soil C dynamics on the ORR (EBIS)

Summary & Significance

- Comparison of soil N dynamics and C storage at two locations with very different soil properties show consistent differences between broad forest categories in potential net soil N availability
  - Related to quality (C:N) of litter inputs
  - Greater soil N availability is associated with lower litter C:N ratios (deciduous litter)
- Similar comparisons show no significant differences in soil C storage between locations or broad forest categories within location
- Litter manipulation experiments in forests at a local scale indicate:
  - Marked topographic differences in soil N availability (ridge and slope vs. valley)
  - No topographic differences in mineral soil C storage (also true for entire ORR)
  - Immediate effects on mineral soil CO_2 efflux measurements
- Modeling of forest litter exclusion and litter addition (3X ambient) indicates:
  - Shorter turnover of fast soil C and greater humification rates at the mesic site
  - Greater potential for soil C storage in labile (fast) pools at xeric sites
  - Greater potential for long-term soil C sequestration at a mesic site
- Differences in soil N availability between locations or forest categories do not translate to differences in soil C stocks in a way that can be easily detected using measurements of C in bulk soils, particulate- or mineral-associated OM

Backup Slides (Day 1)

C.T. Garten, Jr.

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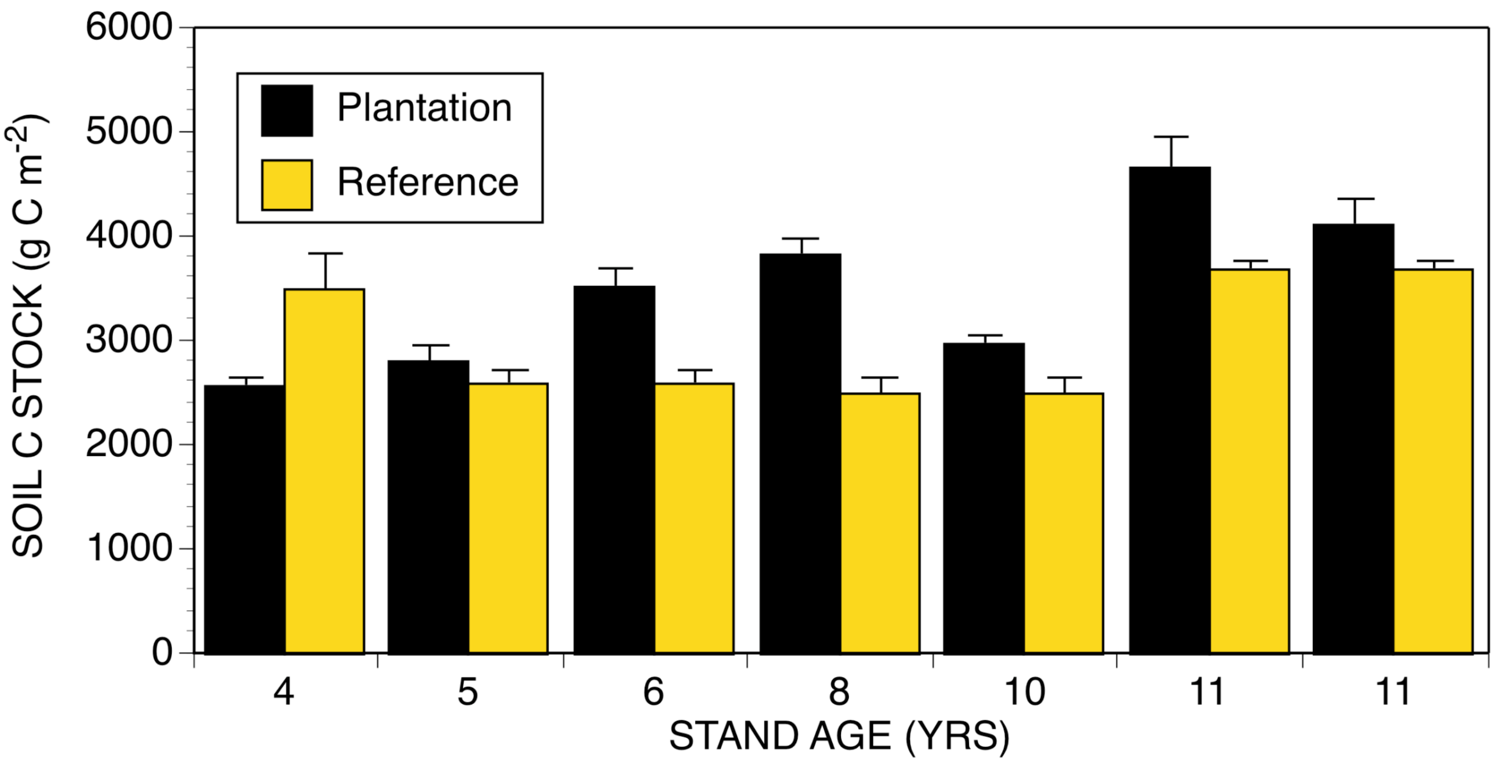
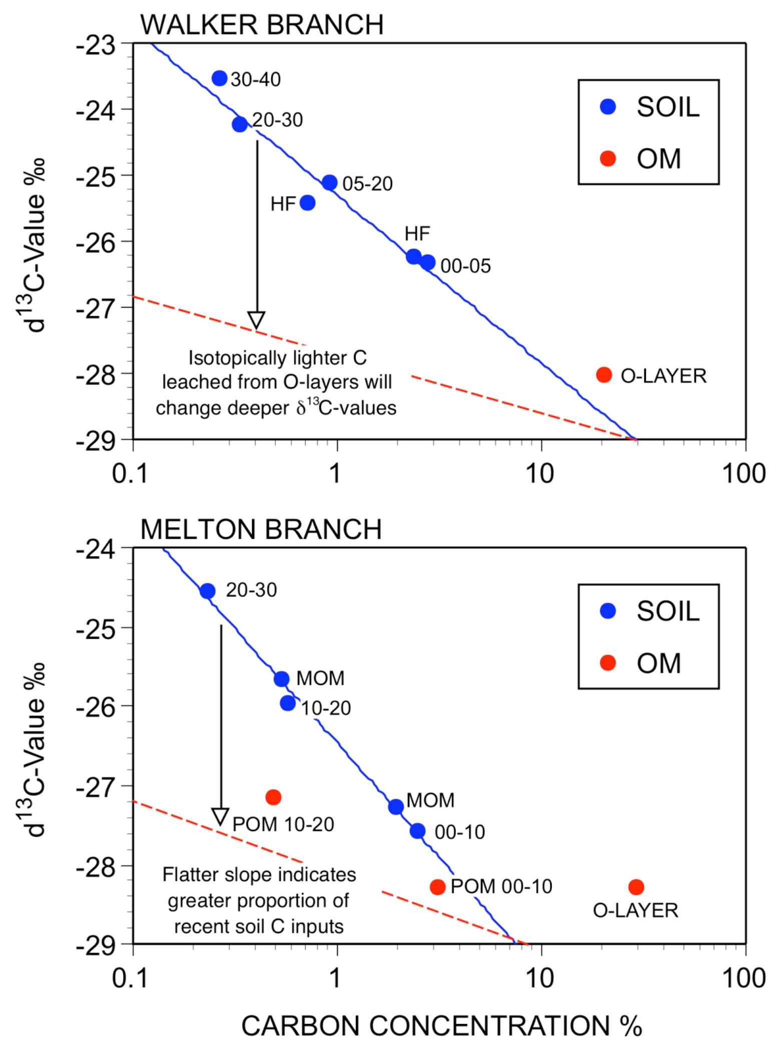
Tree Plantations

- Rates of soil (0-40 cm) C accumulation under tree plantations in TN and SC were 40 to 170 g C m^{-2} yr^{-1} during first decade following establishment
- Farm to tree plantation conversions can result in high initial rates of soil C sequestration in the southeastern US



C Isotope Applications in Soil Blocks

- Natural abundance δ^{13}C-value in the forest floor is ≈ -28 ‰ (similar to fresh C inputs)
- Labile C (free particulate OM) in surface soils (0-20 cm) is also ≈ -28 ‰
- δ^{13}C-values increase with soil depth along a continuum of organic matter decomposition
- Old soil C adsorbed to silt and clay is more enriched in ^{13}C than recently added C
- Urea applications will displace and leach recent C (-28 ‰) to deeper soil horizons
- Leaching of recent C to deeper horizons will decrease δ^{13}C-values of OM on silt and clay
- We will analyze the δ^{13}C-values of leached C (DOC) and C sorbed as organo-mineral complexes to estimate mixing of old and new C at various soil depths



Measurement Variability

- Measurements of stable C isotope ratios in bulk soils and soil fractions are always less variable than C concentrations
  - Observation at multiple forest sites
  - Paired measurements
- Coefficients of variation in concentration data are generally between 10 and 40%
- Coefficients of variation in $\delta^{13}C$ data are generally ≤ 3% for the same samples
- Small differences in C isotope ratios can be significant because there is little variation among soil samples (or the same sample type) within a study site
- Spatial variation in soil C concentrations has been a long-standing limitation to the precise calculation of change in soil C stocks – not so with $\delta^{13}C$ -values