Storage and Turnover of C in Soil Physical Fractions Following Woody Plant Invasion of Grassland

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Global Significance of Grasslands, Savannas, Woodlands

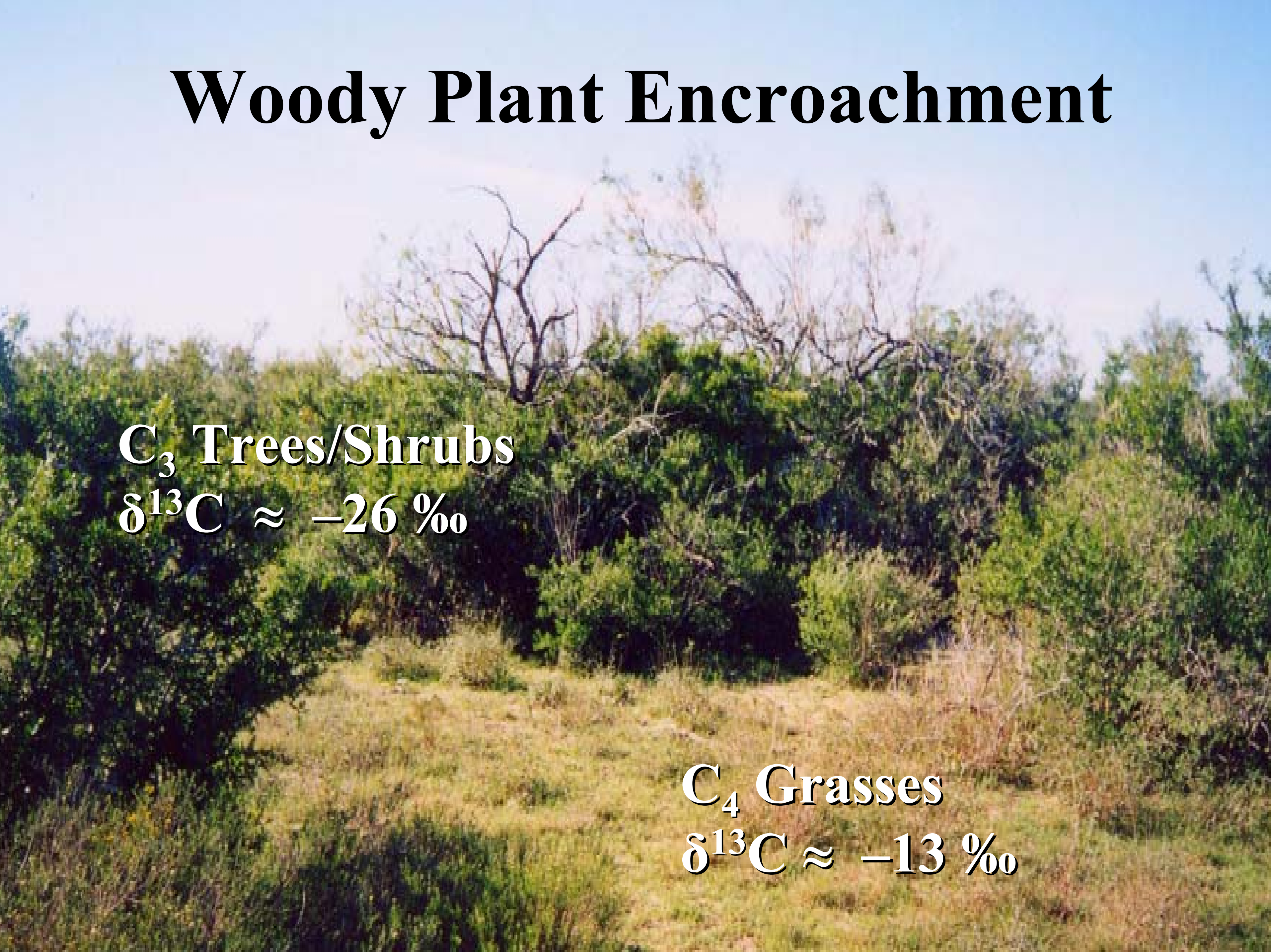
- Cover 40% of the terrestrial surface
- Account for 35-50% of terrestrial NPP
- Store 15-20% of terrestrial biomass carbon
- Store 30% of global soil organic carbon

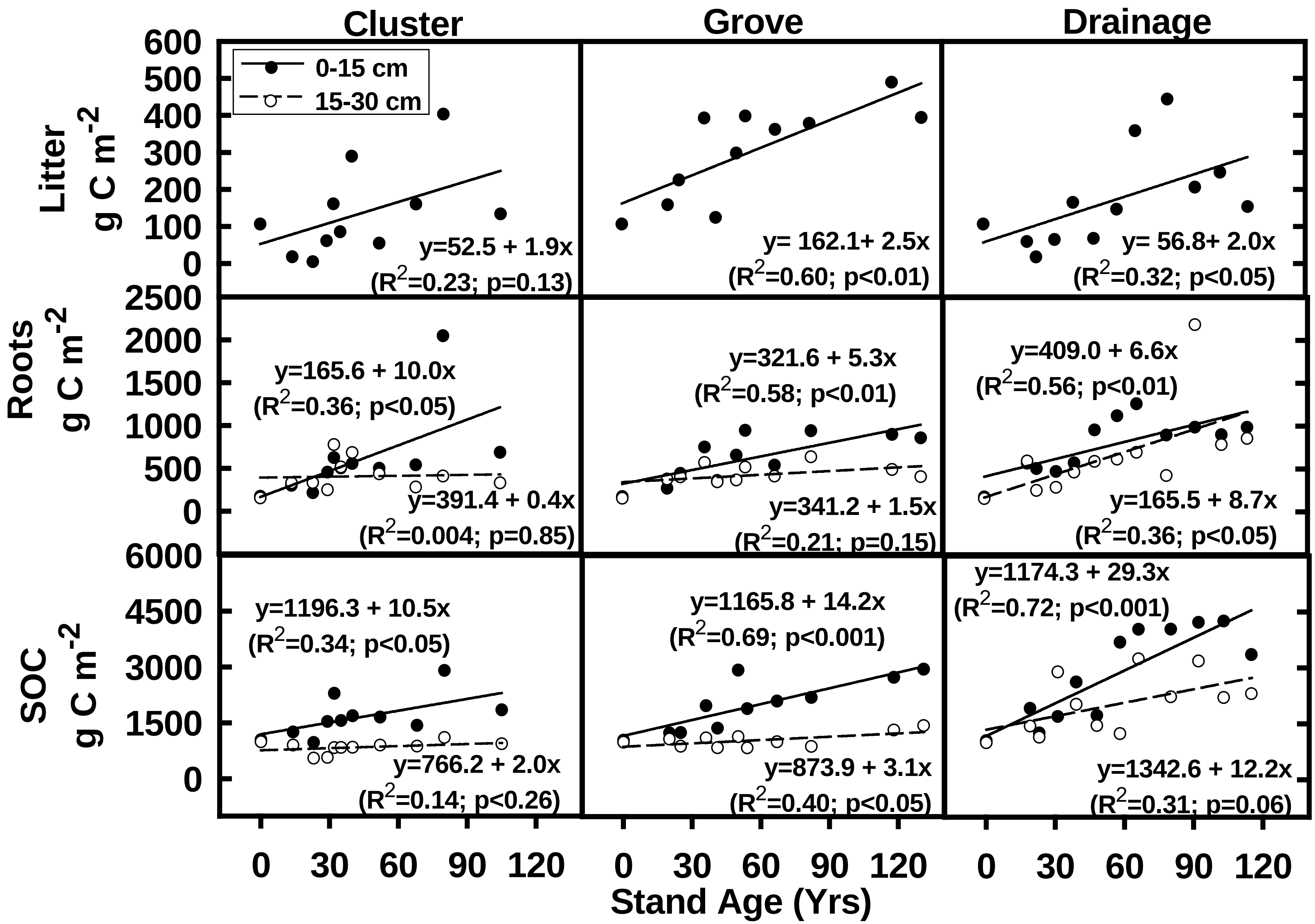
(From: Schlesinger 1997, Scurlock and Hall 1998, Olson et al. 1985)

Woody Plant Encroachment into Grass Dominated Ecosystems

- Geographically extensive (North and South America, Africa, Australia, Asia).
- Attributable to livestock grazing and fire suppression.
- Most evident where grasslands meet forests or other woody - dominated systems.
- May represent 20 to 40 % of U.S. carbon sink.

Woody Plant Encroachment

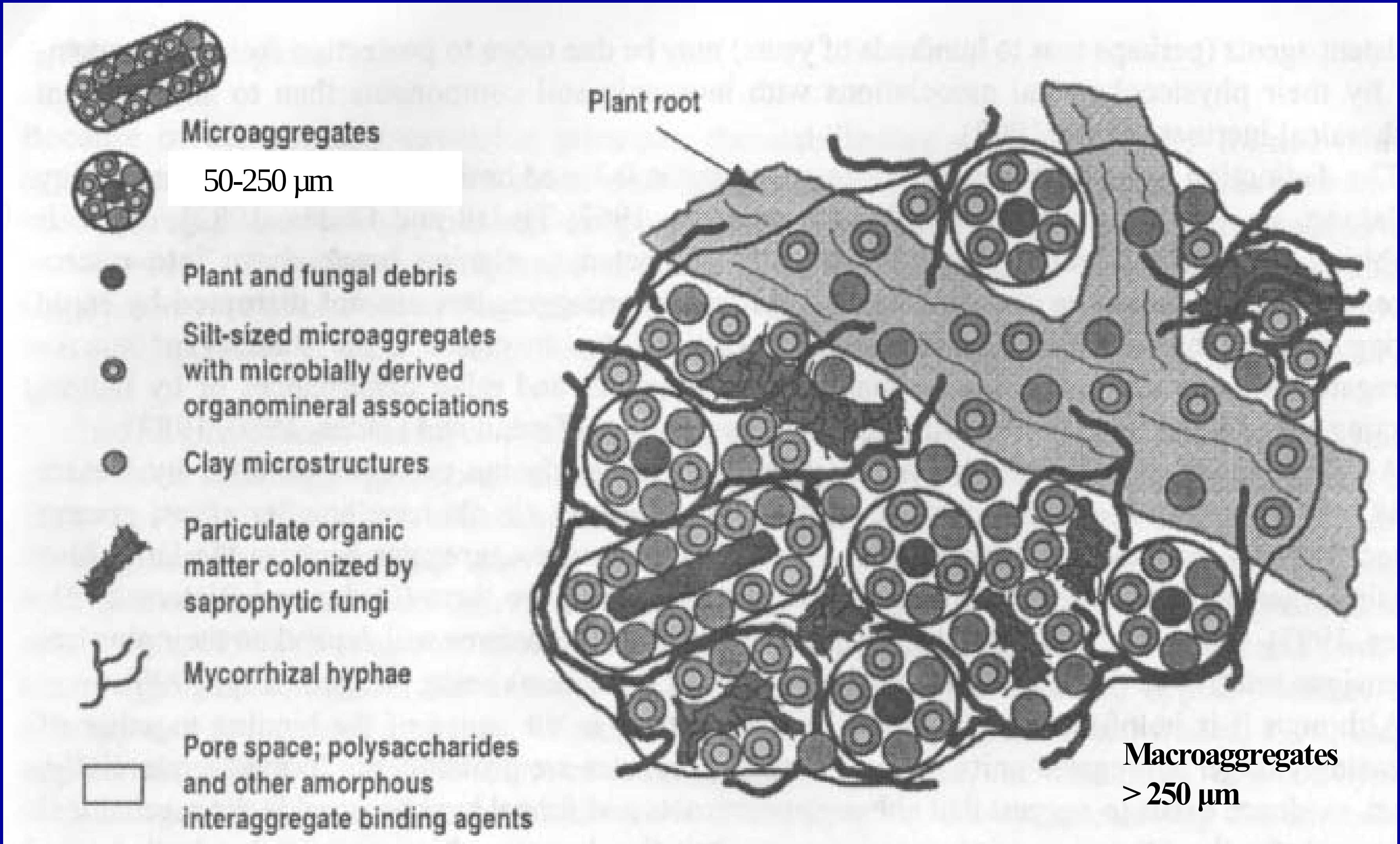




Cluster
Grove
Drainage
Litter g C m-2
Roots g C m-2
SOC g C m-2
0-15 cm
15-30 cm
y=52.5 + 1.9x
(R2=0.23; p=0.13)
y= 162.1+ 2.5x
(R2=0.60; p<0.01)
y= 56.8+ 2.0x
(R2=0.32; p<0.05)
y=165.6 + 10.0x
(R2=0.36; p<0.05)
y=391.4 + 0.4x
(R2=0.004; p=0.85)
y=321.6 + 5.3x
(R2=0.58; p<0.01)
y=341.2 + 1.5x
(R2=0.21; p=0.15)
y=409.0 + 6.6x
(R2=0.56; p<0.01)
y=165.5 + 8.7x
(R2=0.36; p<0.05)
y=1196.3 + 10.5x
(R2=0.34; p<0.05)
y=766.2 + 2.0x
(R2=0.14; p<0.26)
y=1165.8 + 14.2x
(R2=0.69; p<0.001)
y=873.9 + 3.1x
(R2=0.40; p<0.05)
y=1174.3 + 29.3x
(R2=0.72; p<0.001)
y=1342.6 + 12.2x
(R2=0.31; p=0.06)
Stand Age (Yrs)

Conceptual Model of Soil Aggregate Hierarchy

(Jastrow and Miller 1997)



Objectives

- Elucidate specific physical mechanisms of soil C sequestration by determining where organic C is stored relative to aggregate structure.
- Utilize the natural carbon isotope difference between C_4 grasses and C_3 woody plants to quantify turnover rates of SOC in specific soil fractions.

Study Area

- Texas Agricultural Experiment Station, La Copita Research Area in the eastern Rio Grande Plains,TX.

- Subtropical climate:

  MAP = 716 mm

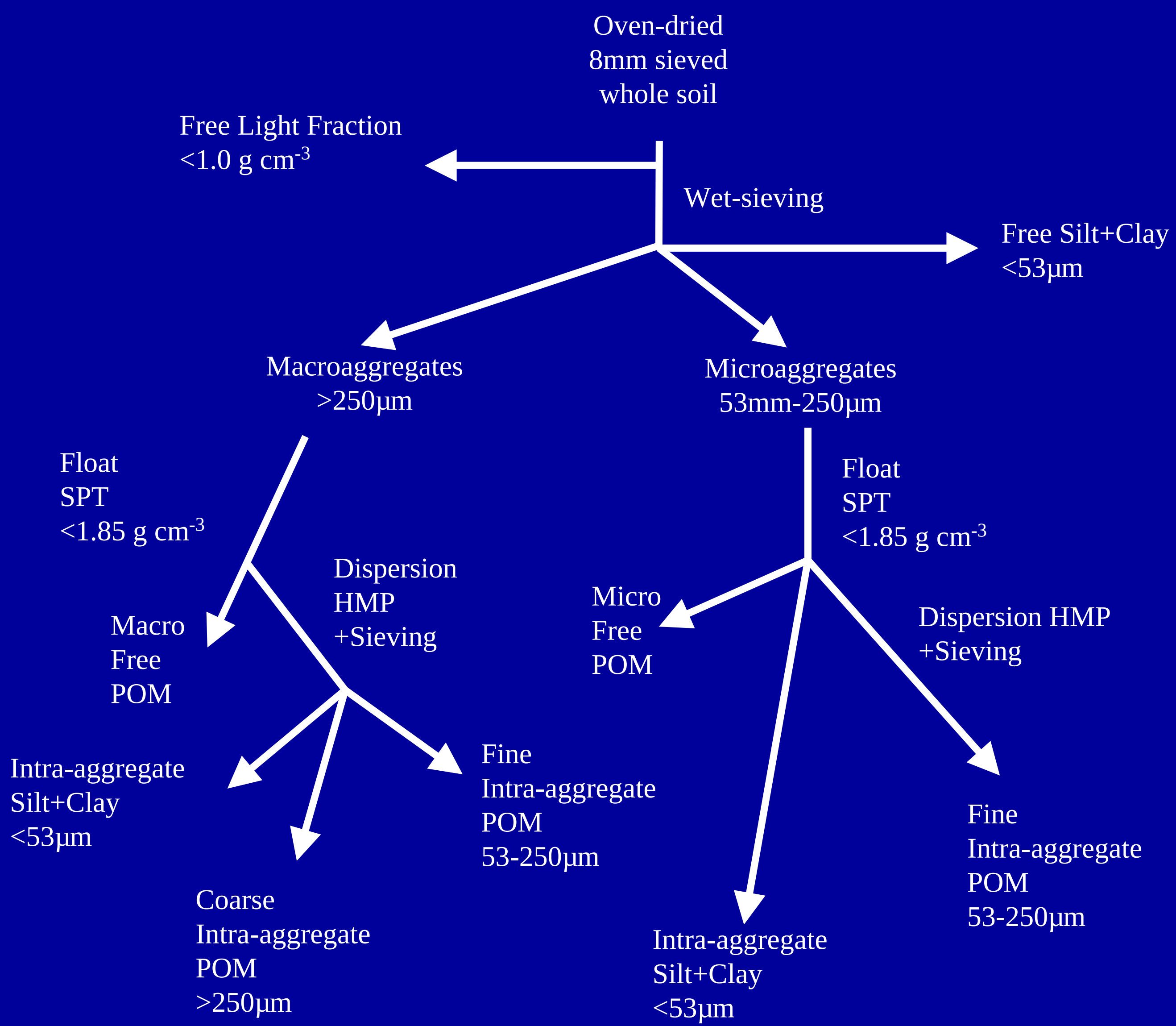
  MAT = 22.4^{o}C

- *Prosopis glandulosa*, a N-fixing tree legume, is the dominant species in all wooded landscape elements.

Methods

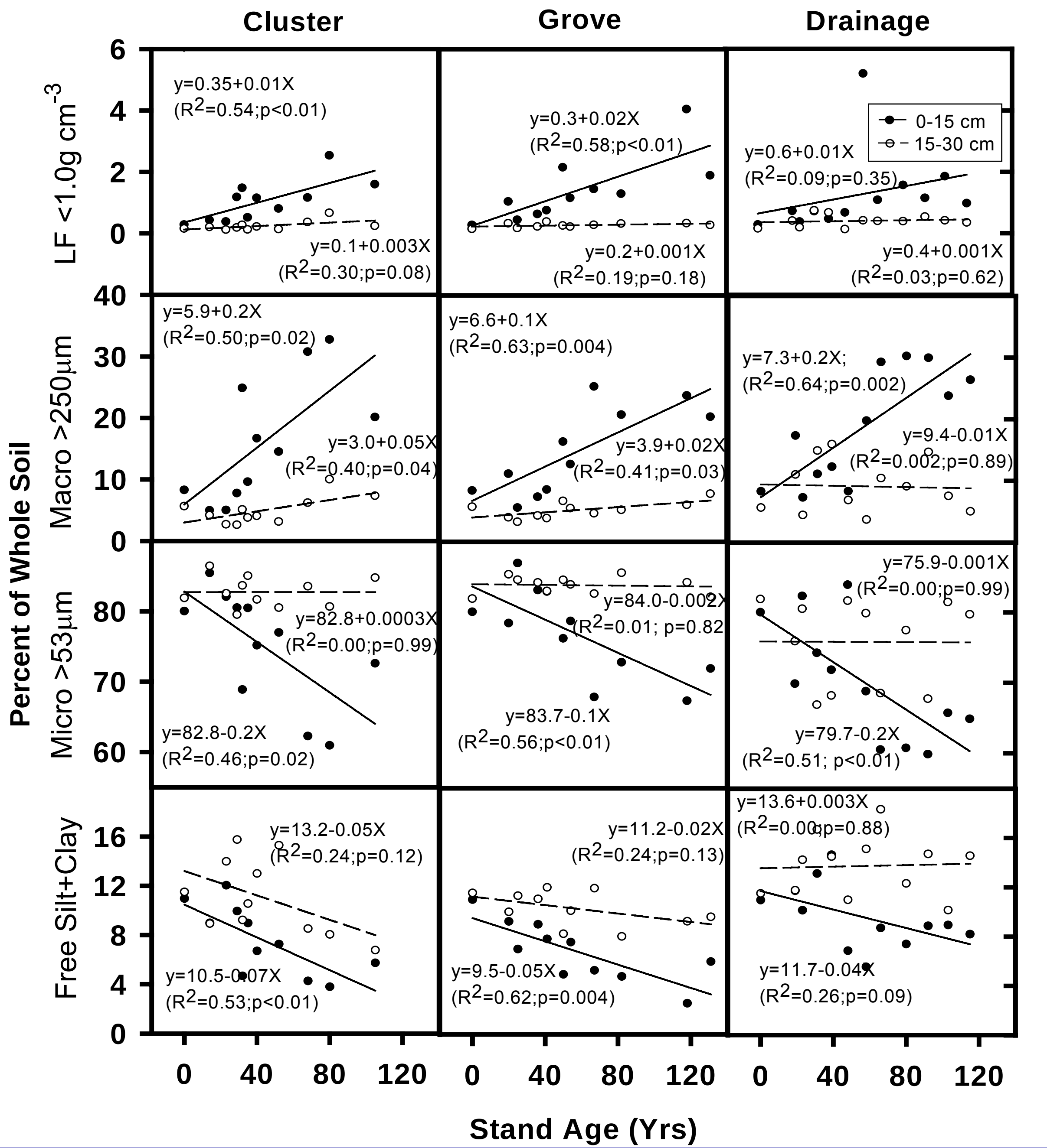
- Chronosequence approach utilized: grasslands represent Time 0, and woodlands range in age from 10-130 years.
- Four soil cores (0-30cm) collected from each of 10 sites in grassland, cluster, grove, & drainage woodland landscape elements.
- Cores sectioned into 0-15 and 15-30cm depth increments and pooled.

Soil Fractionation Scheme

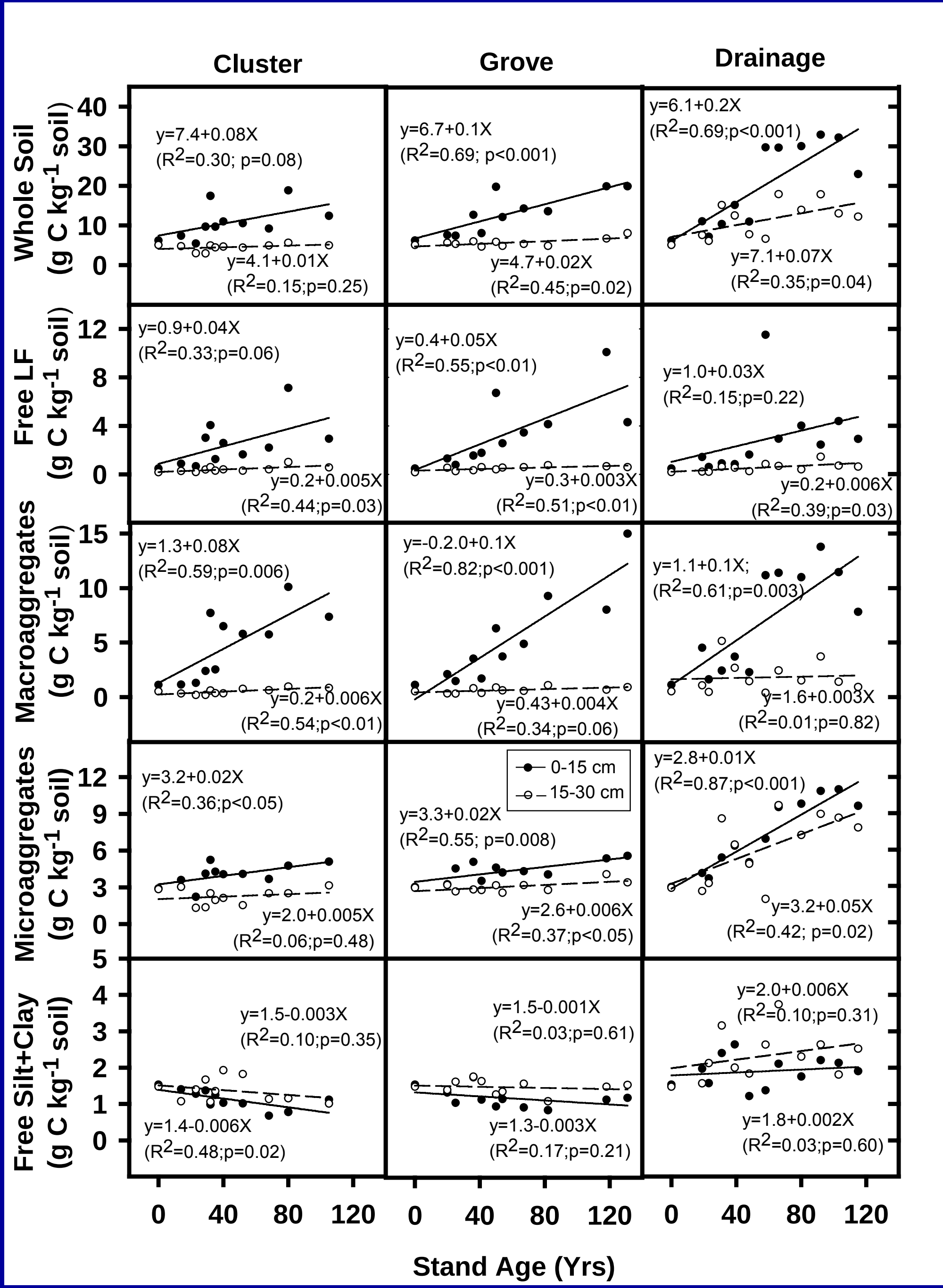


Methods

- Soil fractions were pulverized and analyzed for $\delta^{13}C$ and %C by continuous flow/isotope ratio mass spectrometry.



Cluster
Grove
Drainage
Percent of Whole Soil
LF <1.0g cm-3
Macro >250µm
Micro >53µm
Free Silt+Clay
Stand Age (Yrs)
0-15 cm
15-30 cm
y=0.35+0.01X
(R2=0.54;p<0.01)
y=0.1+0.003X
(R2=0.30;p=0.08)
y=0.3+0.02X
(R2=0.58;p<0.01)
y=0.2+0.001X
(R2=0.19;p=0.18)
y=0.6+0.01X
(R2=0.09;p=0.35)
y=0.4+0.001X
(R2=0.03;p=0.62)
y=5.9+0.2X
(R2=0.50;p=0.02)
y=3.0+0.05X
(R2=0.40;p=0.04)
y=6.6+0.1X
(R2=0.63;p=0.004)
y=3.9+0.02X
(R2=0.41;p=0.03)
y=7.3+0.2X;
(R2=0.64;p=0.002)
y=9.4-0.01X
(R2=0.002;p=0.89)
y=82.8+0.0003X
(R2=0.00;p=0.99)
y=82.8-0.2X
(R2=0.46;p=0.02)
y=84.0-0.002X
(R2=0.01; p=0.82
y=83.7-0.1X
(R2=0.56;p<0.01)
y=75.9-0.001X
(R2=0.00;p=0.99)
y=79.7-0.2X
(R2=0.51; p<0.01)
y=13.2-0.05X
(R2=0.24;p=0.12)
y=10.5-0.07X
(R2=0.53;p<0.01)
y=11.2-0.02X
(R2=0.24;p=0.13)
y=9.5-0.05X
(R2=0.62;p=0.004)
y=13.6+0.003X
(R2=0.00;p=0.88)
y=11.7-0.04X
(R2=0.26;p=0.09)



Cluster
Grove
Drainage
Whole Soil (g C kg-1 soil)
y=7.4+0.08X
(R2=0.30; p=0.08)
y=4.1+0.01X
(R2=0.15;p=0.25)
y=6.7+0.1X
(R2=0.69; p<0.001)
y=4.7+0.02X
(R2=0.45;p=0.02)
y=6.1+0.2X
(R2=0.69;p<0.001)
y=7.1+0.07X
(R2=0.35;p=0.04)
Free LF (g C kg-1 soil)
y=0.9+0.04X
(R2=0.33;p=0.06)
y=0.2+0.005X
(R2=0.44;p=0.03)
y=0.4+0.05X
(R2=0.55;p<0.01)
y=0.3+0.003X
(R2=0.51;p<0.01)
y=1.0+0.03X
(R2=0.15;p=0.22)
y=0.2+0.006X
(R2=0.39;p=0.03)
Macroaggregates (g C kg-1 soil)
y=1.3+0.08X
(R2=0.59;p=0.006)
y=0.2+0.006X
(R2=0.54;p<0.01)
y=-0.2.0+0.1X
(R2=0.82;p<0.001)
y=0.43+0.004X
(R2=0.34;p=0.06)
y=1.1+0.1X;
(R2=0.61;p=0.003)
y=1.6+0.003X
(R2=0.01;p=0.82)
Microaggregates (g C kg-1 soil)
y=3.2+0.02X
(R2=0.36;p<0.05)
y=2.0+0.005X
(R2=0.06;p=0.48)
0-15 cm
15-30 cm
y=3.3+0.02X
(R2=0.55; p=0.008)
y=2.6+0.006X
(R2=0.37;p<0.05)
y=2.8+0.01X
(R2=0.87;p<0.001)
y=3.2+0.05X
(R2=0.42; p=0.02)
Free Silt+Clay (g C kg-1 soil)
y=1.5-0.003X
(R2=0.10;p=0.35)
y=1.4-0.006X
(R2=0.48;p=0.02)
y=1.5-0.001X
(R2=0.03;p=0.61)
y=1.3-0.003X
(R2=0.17;p=0.21)
y=2.0+0.006X
(R2=0.10;p=0.31)
y=1.8+0.002X
(R2=0.03;p=0.60)
Stand Age (Yrs)

Carbon Sequestration in Size/Density Fractions

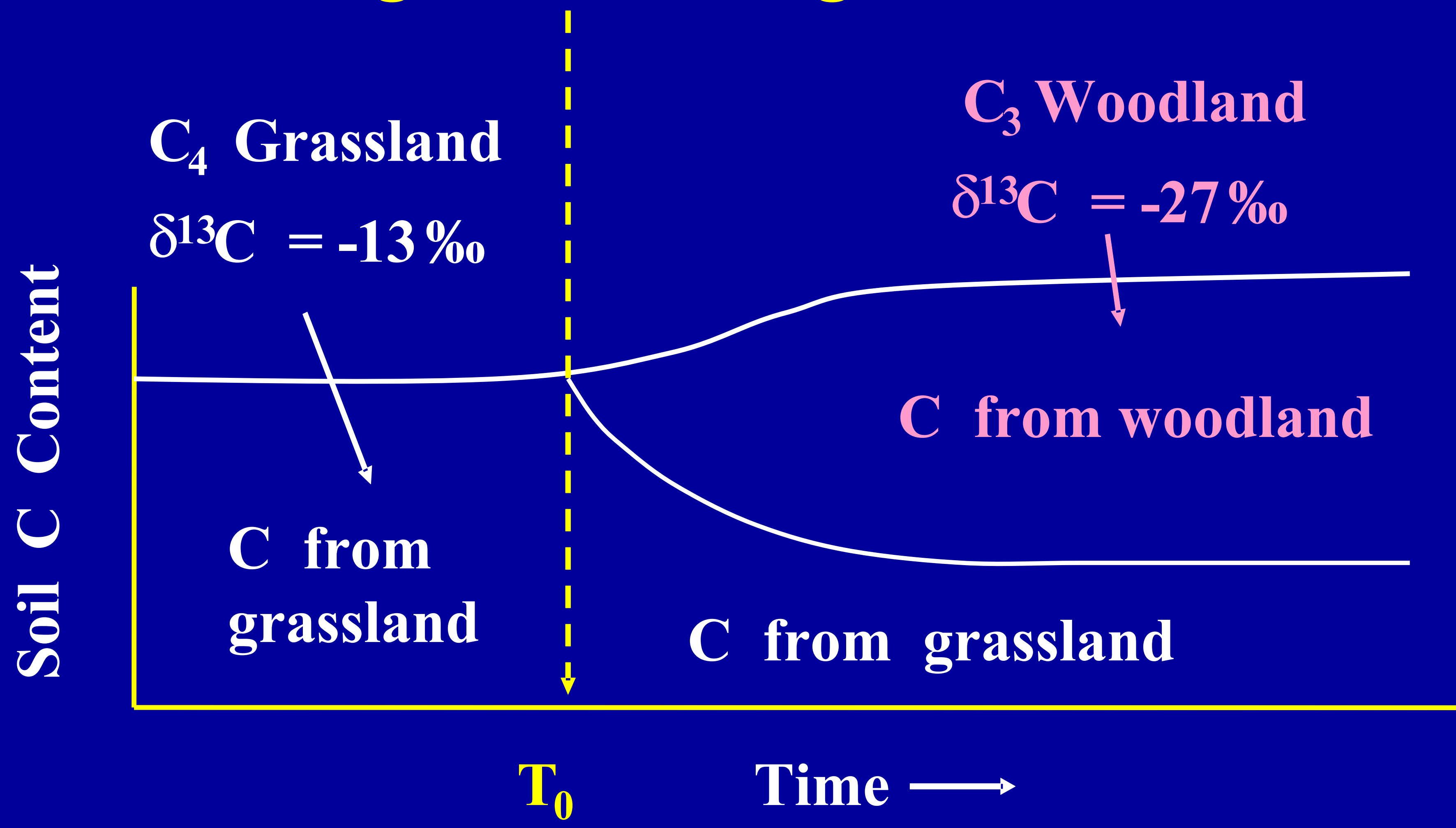
	g C m^{-2} yr^{-1}					
	Cluster		Grove		Drainage	
	0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm
Whole Soil	10.5 (4.9)	2.0 (1.6)	14.2 (3.2)	3.1 (1.3)	29.3 (5.7)	12.2 (5.8)
Free Light Fraction	5.5 (2.5)	1.0 (0.4)	7.4 (2.2)	0.6 (0.2)	4.0 (3.0)	1.1 (0.4)
Macroaggregate	11.8 (3.0)	1.2 (0.4)	13.7 (2.4)	0.7 (0.3)	12.8 (3.1)	0.3 (2.4)
Free POM	6.5 (2.0)		3.6 (1.2)		4.9 (1.9)	
Coarse IPOM	1.5 (0.4)		0.5 (0.1)		1.1 (0.3)	
Fine IPOM	0.6 (0.1)		0.2 (0.1)		0.9 (0.1)	
Silt+Clay	1.5 (0.4)		0.6 (0.1)		4.5 (1.0)	
Microaggregate	2.1 (0.9)	1.0 (1.3)	1.5 (0.7)	1.3 (0.7)	8.7 (1.2)	8.6 (3.4)
Free POM	0.7 (0.4)		1.1 (0.2)		2.2 (0.4)	
IPOM	0.2 (0.3)		-0.1 (0.2)		0.7 (0.4)	
Silt+Clay	0.3 (0.4)		-0.03 (0.4)		6.0 (1.3)	
Free Silt+Clay	-1.2 (0.4)	-0.6 (0.7)	-0.7 (0.3)	-0.1 (0.3)	-0.5 (0.7)	0.8 (1.1)

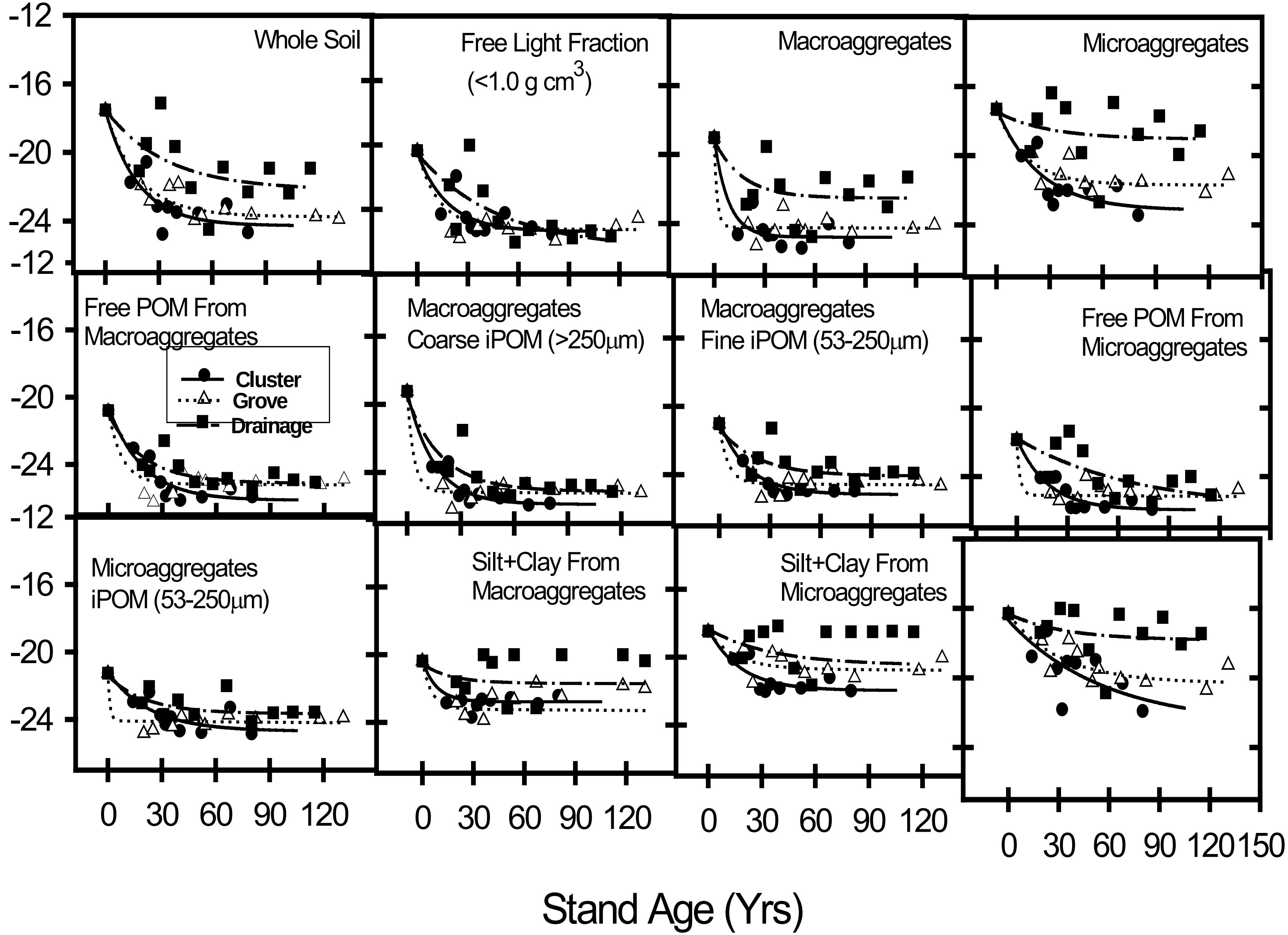
Table 5.5 Accumulation of Soil Organic Matter in Abandoned Agricultural Soils and in Other Disturbed Sites, Which are Allowed to Return to Native Vegetation

Ecosystem type	Previous land use	Period of abandonment (yr)	Rate of accumulation (g C m^{-2} yr^{-1})	Reference
Subtropical forest	Cultivation	40	30-50	Lugo et al. (1986)
Temperate deciduous forest	Cultivation	100	45	Jenkinson (1990)
Temperate coniferous forest	Cultivation	50	21-26	Schiffman and Johnson (1989)
Temperate coniferous forest	Diked soils	100	26	Beke (1990)
Temperate deciduous forest	Mine spoils	50	55	Leisman (1957)
Temperate grassland	Mine spoils	28-40	28	Anderson (1977)
Tropical forest	Cultivation	100	41	Silver et al. (2000)

(From: Schlesinger 1997; Silver et al. 2000)

Vegetation Change





Whole Soil
Free Light Fraction (<1.0 g cm^3)
Macroaggregates
Microaggregates
Free POM From Macroaggregates
Cluster
Grove
Drainage
Macroaggregates Coarse iPOM (>250µm)
Macroaggregates Fine iPOM (53-250µm)
Free POM From Microaggregates
Microaggregates iPOM (53-250µm)
Silt+Clay From Macroaggregates
Silt+Clay From Microaggregates
$\delta^{13}C_{V\text{-}PDB}$
-12
-16
-20
-24
0 30 60 90 120
0 30 60 90 120 150
Stand Age (Yrs)

Computing the Fraction of Carbon Derived from Grassland

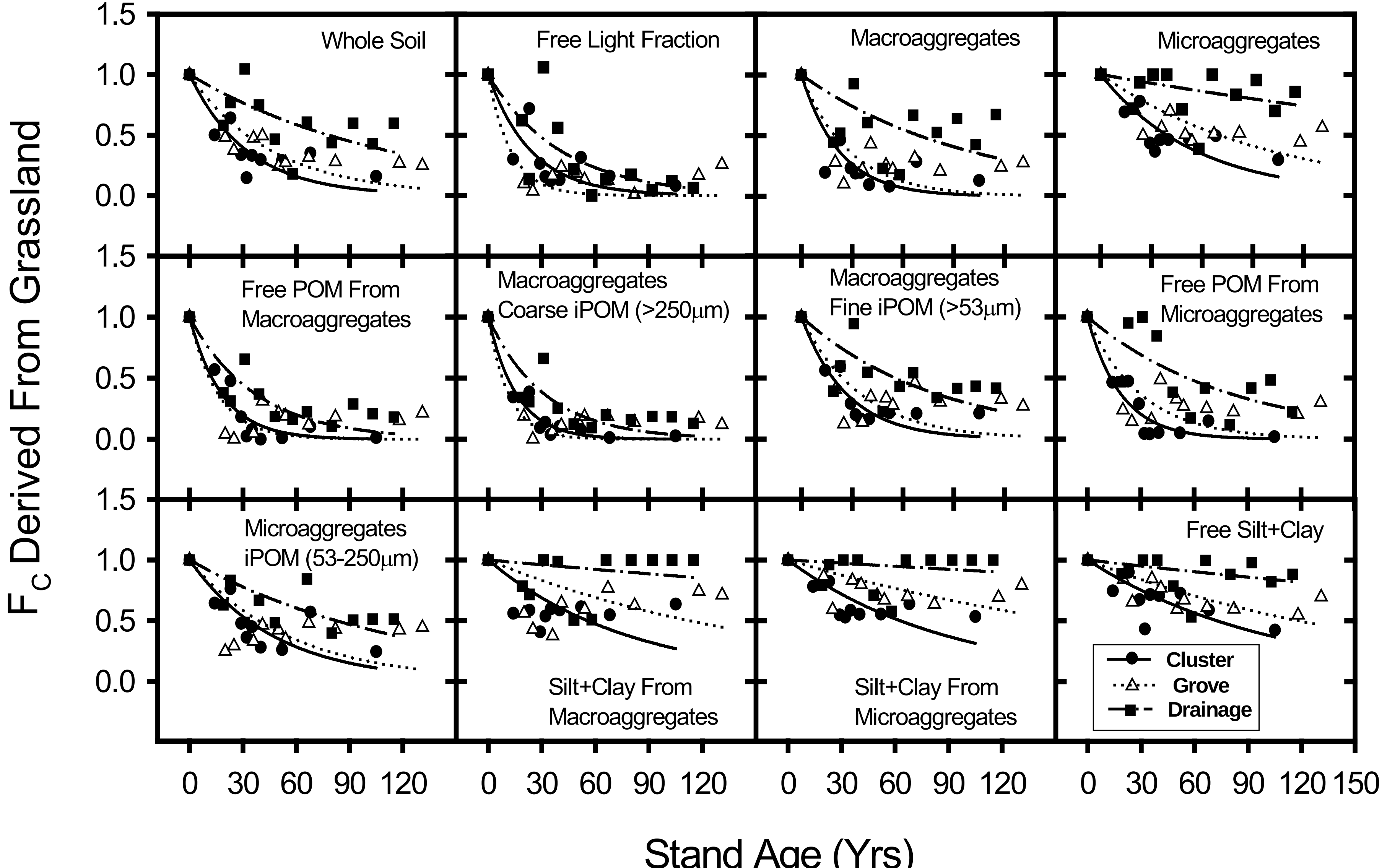
$$F_C = \frac{\delta_{WS} - \delta_{WI}}{\delta_{GS} - \delta_{WI}}$$

F_C = fraction of soil C derived from grassland

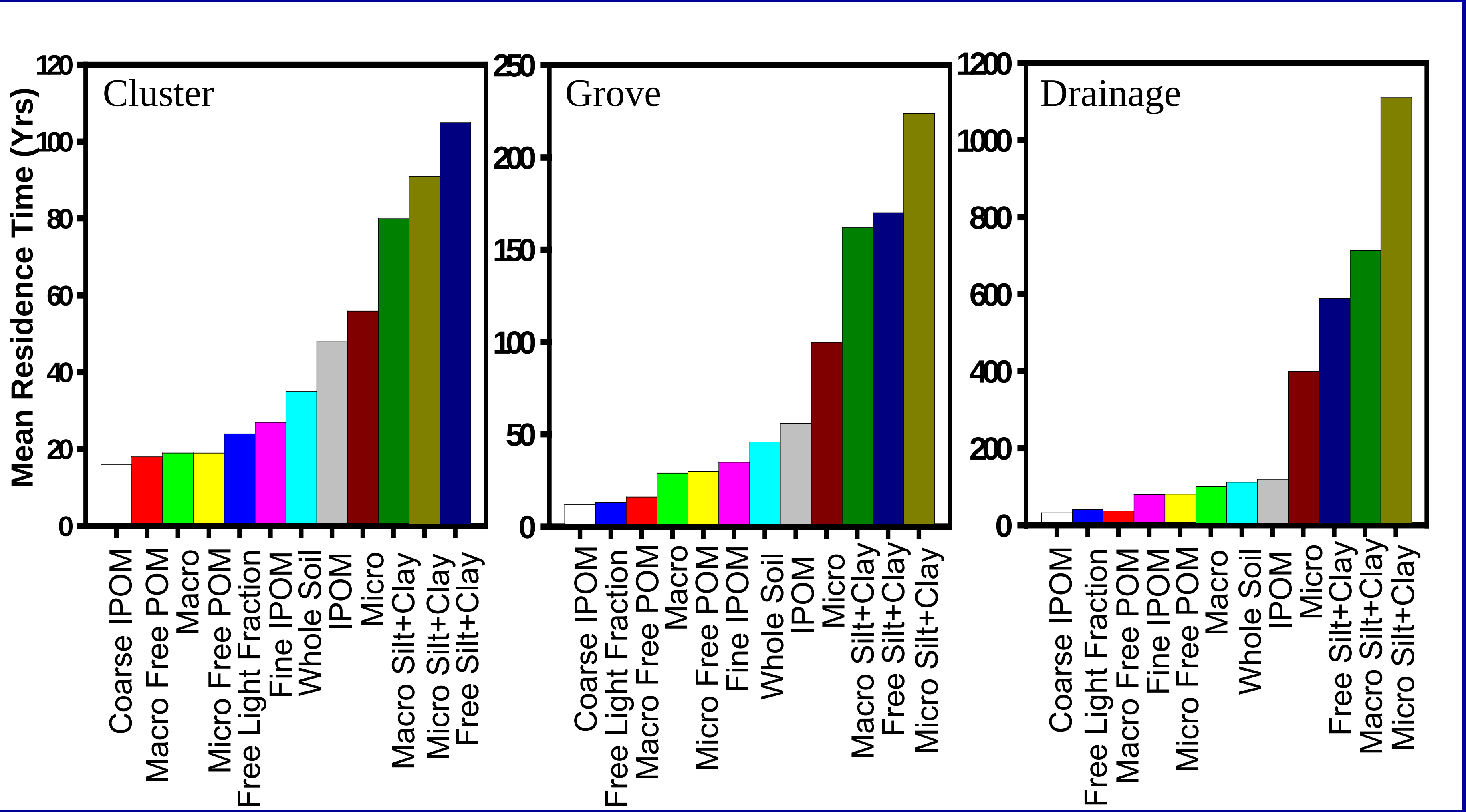
δ_{WS} = $\delta^{13}C$ of soil physical fraction in woodland

δ_{WI} = $\delta^{13}C$ of woody plant litter & roots (-26 ‰)

δ_{GS} = $\delta^{13}C$ of soil physical fraction in remnant grassland


Whole Soil
Free Light Fraction
Macroaggregates
Microaggregates
Free POM From Macroaggregates
Macroaggregates Coarse iPOM (>250μm)
Macroaggregates Fine iPOM (>53μm)
Free POM From Microaggregates
Microaggregates iPOM (53-250μm)
Silt+Clay From Macroaggregates
Silt+Clay From Microaggregates
Free Silt+Clay
Cluster
Grove
Drainage
1.5
1.0
0.5
0.0
0
30
60
90
120
150
F_C Derived From Grassland
Stand Age (Yrs)

Mean Residence Times of Soil Fractions



Conclusions

1. Relative proportions of the free light and macroaggregate fractions increased linearly with time after woody invasion; conversely, proportions of microaggregate and free silt+clay fractions decreased linearly, reflecting their incorporation into macroaggregates.

2. C concentrations (g C kg^{-1} $soil^{-1}$) in all soil fractions except free silt+clay increased with woody plant invasion and was greatest in macroaggregates.

3. Free POM associated with the macroaggregate fraction accounted for most of the C accumulation in that fraction.

4. Based on natural ^{13}C, MRTs for microaggregates (185 yrs) were substantially longer than those for macroaggregates (49 yrs), indicating that the older C associated with microaggregates is physically protected and/or biochemically recalcitrant.

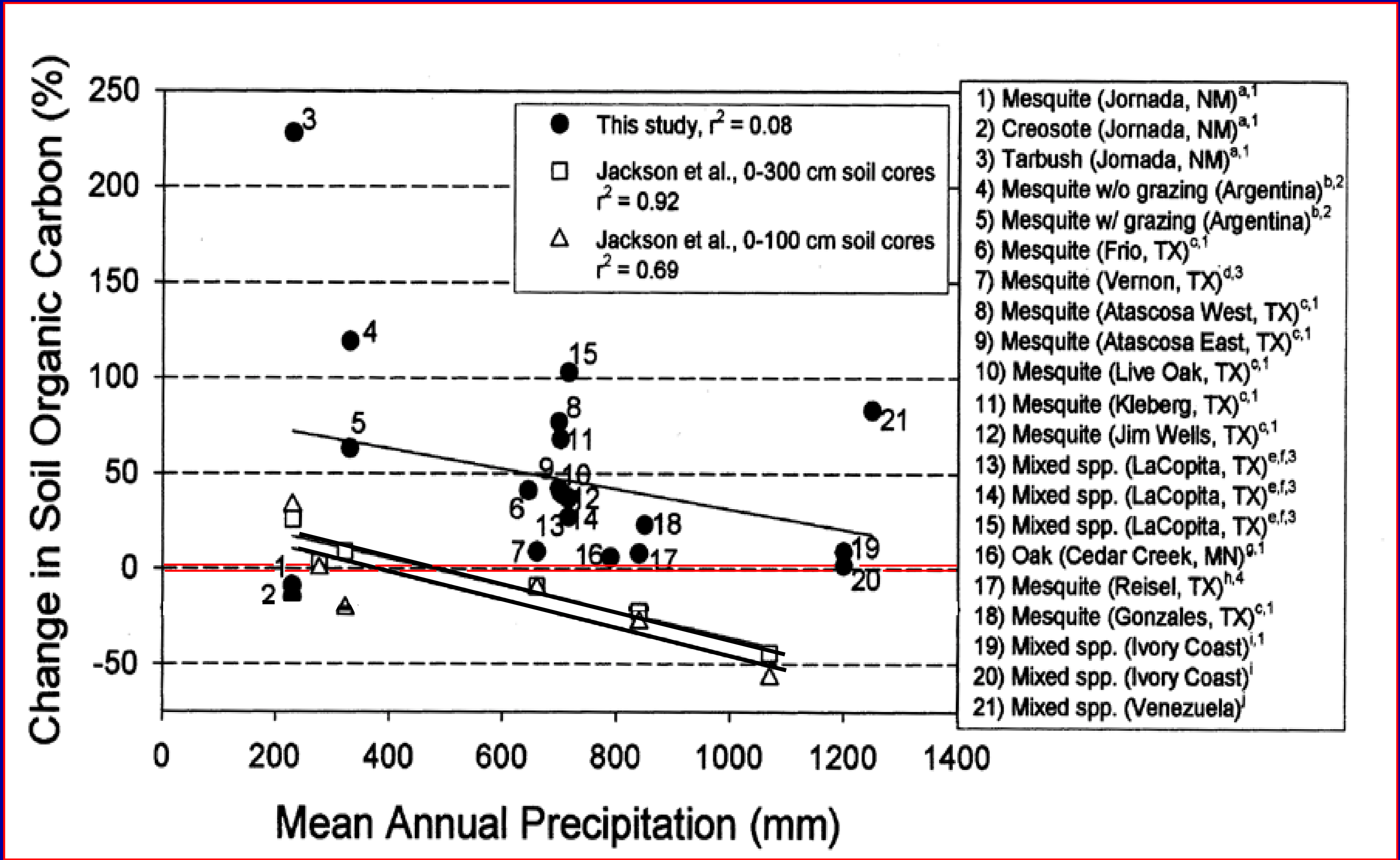
Conclusions

5. Shortest MRTs (34 yrs) were associated with POM not protected within aggregates.

6. Silt+clay had the longest MRTs (369 yrs) regardless of position within aggregates.

7. Interactions between SOM and soil structure may provide a mechanistic explanation for C processes and dynamics following land cover changes in terrestrial ecosystems.

8. Grassland → woodland transformations are geographically extensive in grasslands and savannas throughout the world, suggesting this phenomenon may have consequences for the global C cycle and the climate system.



(From: Asner, Archer, Boutton, Johnson – unpublished)