Carbon Storage and Dynamics in Soil Fractions under Shaded Perennial Agroforestry Systems

N Chatterjee[1*], V D Nair[2], P K Ramachandran Nair[1], S Gerber[2]

[1] School of Forest Resources and Conservation, University of Florida

[2] Soil and Water Sciences Department, University of Florida

Introduction

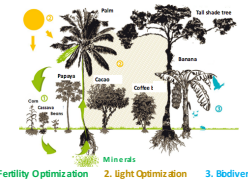


Fig. 1: A schematic diagram of a tree-dominated multi-species agroforestry system.
Source: http://www.discoverynorganics.ca/site/wp-content/uploads/2015/03/Agroforestry-2.jpg

- Agroforestry systems (AFSs) contain relatively high quantities of soil carbon (C) resulting from continuous deposition of plant residues, increased rates of organic matter addition and retention (Fig.1).
- Among the various agroforestry systems AFSs, the shaded perennial systems [such as the cultivation of coffee (*Coffea arabica*) and other shade-tolerant perennial species under tall-growing shade plants] are reported to have a high potential for sequestering C in soil.

Hypothesis

- Shaded perennial AFSs and other tree-based systems store higher recalcitrant C (i.e., C in the silt and clay fractions, <53 µm) in deeper soil layers, indicating their more efficient C sequestration potential.

Objective

- To quantify the soil C storage in whole soil and three fractionated size-classes: macroaggregates (250-2000µm), microaggregates (53-250µm) and silt + clay (<53µm) up to 1m depth in two types of shaded coffee AFSs in comparison with an adjacent natural forest in Chikmagalur, Karnataka, India.

Location and Study Sites

The following treatment groups (~65 years old) were selected from a coffee farm in Chikmagalur, Karnataka, India:

1. Coffee AFSs shaded with Grevillea (*Grevillea robusta*) (~50% tree cover),
2. Coffee AFSs with a mix of native and non native trees (>50% tree cover),
3. Native forest from an adjoining site, (Fig.2).

Fig. 2: Shaded coffee AFSs selected (a and b) for the study along with an adjacent forest (c). Both AFSs were ~65 years old.

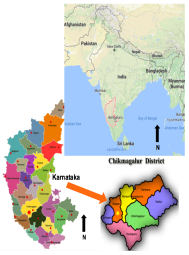


Fig. 3: Study location in Chikmagalur, India

Materials and Methods

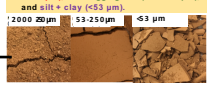
Soil Sampling

1. Randomly select plots for:
   1. Coffee AFSs shaded with Silver Oaks.
   2. Coffee AFSs with a mix of native and non native trees
   3. Native forest from an adjoining site.
2. In each plot., soils were collected from four depths (0 – 10, 10 – 30, 30 – 60, and 60 – 100 cm) from three randomly selected sampling points.

3. Four sub-samples at each location and depth class were composited to get one composite sample for each depth class per plot.
   - There were a total of 48 samples (3 land-use types × 4 replications/ plots × 4 depth classes).
4. Soil sampling for bulk density (BD) measurement was done for each depth class.

Soil Fractionation (Wet Sieving)

1. A 100 g sample of 2 mm sieved air dry soil was placed in a beaker and distilled water (~250 mL), was poured to promote slaking.
2. Soil solution was wet sieved manually by moving the sieve up and down about 5 cm each, 50 times in two minutes.
3. Two sieves of 250µm, and 53µm were used to pass slaked soil to fractionate them into 3 size classes: macroaggregates (250 – 2000 µm), microaggregates (53 – 250µm), and silt + clay (<53 µm).



4. The three soil fractions were oven dried at 65°C for 72h, weighed, ground for homogenization and stored in labelled plastic bags for further C analysis.

Soil Analyses and Calculations

- SOC content were determined for both whole and fractionated soil samples by dry combustion and gas chromatography on an automated Carlo Erba NA1500 CNHS elemental analyzer.
- The C storage was calculated as:

$$C_{storage} = C_{concentration} \times BD \times Depth \times Fraction\ weight$$

where,

C storage = C expressed in Mg ha^{-1} in each fraction class for a given depth

C concentration = C in fraction size, g per kg of soil of that fraction size

BD= Bulk Density, Mg m^{-3}

Depth= Depth of soil profile, cm and

Fraction weight= % weight of the fraction in the whole soil

Results and Discussion

Table 1: Depth wise distribution of different soil size fractions and their SOC content under three land-use systems in Chikmagalur, Karnataka, India*

Depth Classes (cm); BD (Mg m^{-3})	Size Fraction (µm)	SOC (Mg ha^{-1}) up to 1m depth		
		Coffee + Grevillea	Coffee + Mixed Shade	Natural Forest
0–10	2000–250	14.66 ^{b}	15.29 ^{b}	17.81 ^{a}
	250–53	8.49 ^{b}	9.36 ^{b}	14.76 ^{a}
	<53	7.72 ^{b}	5.98 ^{a}	5.54 ^{a}
BD		0.95	1.01	0.78
10–30	2000–250	15.87 ^{b}	14.7 ^{b}	20.66 ^{a}
	250–53	10.79 ^{b}	10.11 ^{b}	15.63 ^{a}
	<53	6.01 ^{b}	6.88 ^{b}	12.37 ^{a}
BD		0.92	1.07	1.21
30–60	2000–250	17.28^{b}	13.31^{bc}	15.62^{a}
	250–53	12.85^{b}	11.77^{b}	15.84^{a}
	<53	6.85^{b}	8.31^{a}	8.48^{a}
BD		0.91	0.96	0.73
60–100	2000–250	10.33^{b}	11.24^{ab}	12.33^{a}
	250–53	7.76^{b}	11.78^{a}	13.12^{a}
	<53	4.32^{b}	5.57^{a}	5.26^{a}
BD		0.77	0.98	1.01

*lowercase letters indicate differences (at the 0.05 probability level) in SOC among land-use systems.

Statistical Analyses

- The data were analyzed by analysis of variance (ANOVA) as a completely randomized design.
- Statistical analyses were performed with R Studio (*R Studio Team, 2015*) separately for all depth classes, and differences were considered significant at P<0.05.

Mean values for Soil Organic Carbon (SOC) in fractionated and whole soil

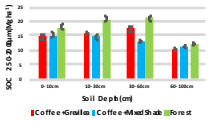


Fig. 4: SOC storage in macroaggregates (250 – 2000 µm).

SOC in macroaggregates (250-2000 µm)

- The total SOC of macroaggregates within 1m soil profile were 58.14 Mg ha^{-1} for Coffee + Grevillea, 54.54 Mg ha^{-1} for Coffee + Mixed Shade and 66.42 Mg ha^{-1} under forest (Fig.4).

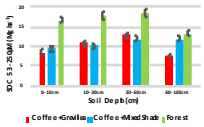


Fig. 5: SOC storage in microaggregates (250–53 µm).

SOC in microaggregates (53-250µm)

- The total SOC of microaggregates within 1m soil profile were 39.89 Mg ha^{-1} for Coffee + Grevillea, 43.02Mg ha^{-1} for Coffee + Mixed Shade and 59.35 Mg ha^{-1} under forest. Beyond 60 cm, SOC under Coffee + Mixed shade and forest did not show any significant differences in mean SOC values (Fig. 5).

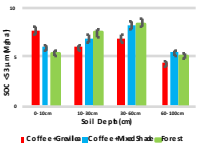


Fig. 6: SOC storage in silt and clay fractions (<53 µm).

SOC in silt and clay fraction (<53µm)

- The total SOC of the silt and clay fraction within 1m soil profile was also highest under forest, followed by Coffee + Mixed Shade and least in Coffee + Grevillea. Beyond 30 cm, SOC under Coffee + Mixed shade and forest did not show any significant differences in mean SOC values (Fig. 6).

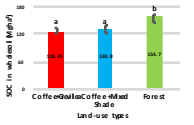


Fig. 7: Total soil organic carbon (SOC) content in the whole soil up to 1m depth *.

*(Lowercase letters indicate differences (at the 0.05 probability level) in SOC among land-use systems).

SOC storage in whole soil

- The amount of SOC in whole soil (0 – 100 cm depth; all depth classes combined) varied with the land-use systems.
- The SOC was significantly higher in the forest (154.7 Mg ha^{-1}) while the two coffee AFSs showed similar SOC at 130.8 and 128.25 Mg ha^{-1} (statistically insignificant) (Fig. 7).

Conclusions

- Land-use systems with higher tree density contributed to greater soil C storage, an indicator of higher C sequestration in soil. Highest SOC stock was found in the forest and the lowest in the Coffee + Grevillea AFS.
- The results show storage of higher amounts of C in the <53 µm fraction, the most stable form of C in soil, up to one-meter depth, in land-use systems with high stand density of trees such as forests and Coffee + Mixed Shade AFSs.
- Comparatively, more SOC was found in the lower half of 1 m depth soil profile in forest and Coffee + Mixed Shade than Coffee + Grevillea AFSs, indicating the possible contribution of tree density and tree roots to C storage.
- In a broader context, these results have implications on the role of tree-based systems, especially sustainable, integrated systems such as shaded perennial AFSs, in greenhouse mitigation through soil carbon storage.

Acknowledgment

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