Addition of *Leucaena*-KX2 mulch in a shaded coffee agroecosystem increases stable soil carbon fractions

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Abstract

Soil carbon (C) pool is an important part of the global C cycle and a potential sink for atmospheric carbon dioxide (CO_2). Agroforestry systems have higher potential to sequester C in soils because of the increased rates of organic matter addition and retention. We characterized soil C storage in relation to stability fractions after the addition of *Leucaena*-KX2 pruning residues (mulch) from 2006 to 2008 in shaded coffee agroecosystem in Hawaii. Soil samples were collected from mulch and no mulch plots and fractions were separated by wet-sieving, microaggregate isolation, density floatation and acid hydrolysis, resulting in five distinct fractions that differ in relative stability. Mulching in this system led to significantly increases in C sequestration in more stable fractions. In the mulch addition treatment, all soil C fractions in 2008 were greater than in 2006. In the no-mulch treatment, there was no significant change in any fractions between 2006 and 2008. Mulch application may result in a greater transfer of C from the macroaggregate fraction into the passive pool through direct inputs or indirectly through condensation reactions with organic nitrogen. This study shows that actively managed agroforestry systems can result not only in greater total soil C but also a greater proportion of more stable soil C as compared to conventional agricultural systems, even where tillage and soil disturbance are minimal.

Introduction

- Climate change from increased greenhouse gases (GHG) emissions is one of the greatest environmental and economic threats facing the world today (Nair et al, 2009).
- CO_2 is a major GHG, and atmospheric concentrations are increasing (Fig. 1)
- Agroforestry can increase (C) sequestration Nair et al. 2009).
- The soil organic carbon (SOC) pool plays a key role in the global C cycle (Walcott et al. 2009).
- Small changes can have large impacts on atmospheric CO_2.
- Conceptually SOC is generally divided into 3 stability pools: active, slow and passive (Chapin et al., 2002)
- Sequestration of SOC in passive and slow pools ensures long-term sequestration (Gama-Rodrigues et al. 2010).

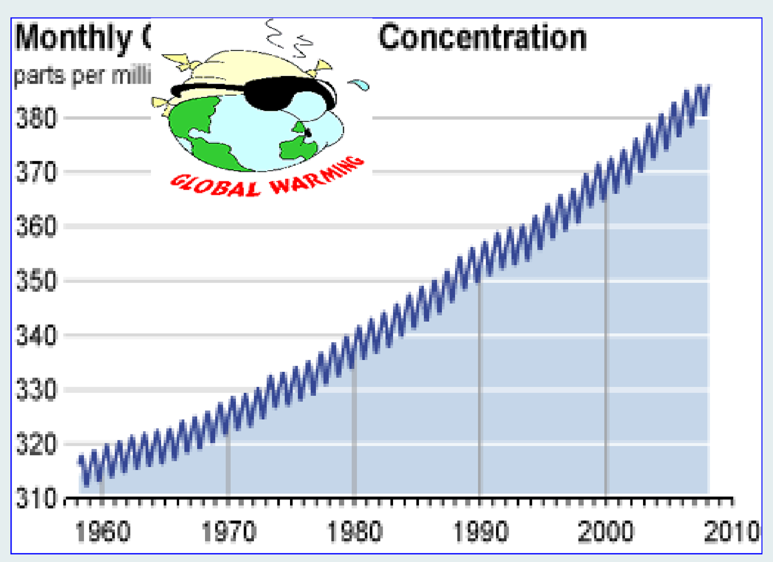


Fig 1. Atmospheric CO2 concentration (PPM)

Objectives

- ➢ Evaluate how mulching affects the relative stability of SOC pools
- ➢ We hypothesized that: mulching would affect mostly most fractions of lower stability

Statistics

- Changes in the mass of soil C in each fraction, scale per area (Mg ha^{-1}), were analyzed via repeated measures analysis of variance using the GLM procedure in SAS.
- Specific contrasts between treatments were made for 2006 and 2008.

Materials and Methods

Site - CTAHR Waimanalo Research Station, Honolulu, Hawaii.

- 16 plots established, each with 6 trees of *Leucaena* hybrid KX2 and 2 coffee (*Coffea arabica* var. 'Kona typica') planted on 2 x 2 m spacing.
- On Sept 2005 all *Leucaena*-KX2 trees were pollarded at 1 m above ground level, chipped and distributed uniformly back to the plots as a green manure.
- On Sept 2006 all trees were pollarded as before. The chipped mulch was distributed uniformly back to the mulch-addition plots, and this was repeated in 2007 and 2008.

Physical and chemical fractionation:

- Soil samples from each plot during 2006 and 2008 were subjected to physical and chemical fractionation according to Elliott (1986) and Six et al. (2002) (Fig. 2).
- The proportion of soil C as particulate organic matter (POM) and soil organic matter (SOM) in different size fractions was estimated by simple wet-sieving
- A microaggregate isolator was used to break up the macroaggregates and isolate microaggregates-within-macroaggregates (Fig. 3).
- The fractions collected were: (i) coarse POM in the >250-µm fraction, (ii) POM within macroaggregates in the 53-250-µm fraction, and (iii) silt+clay SOM within macroaggregates in the <53-µm fraction.
- Density flotation and dispersion were used to separate the POM and SOM in the 53-250-µm size fraction

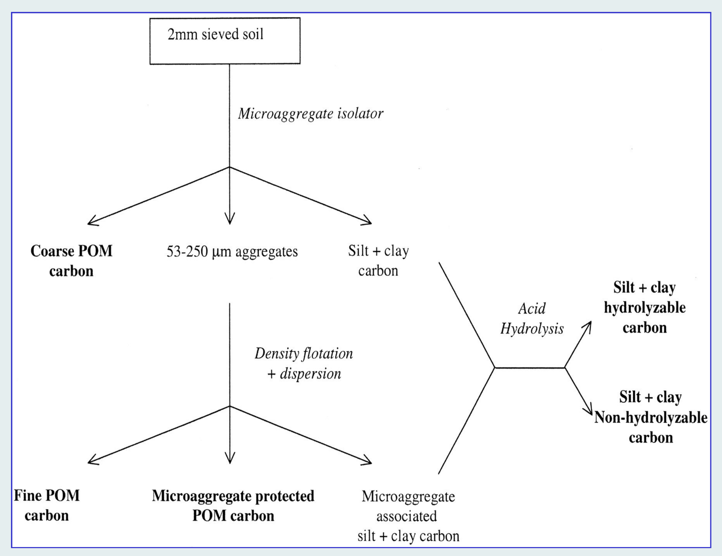


Fig 2: Fractionation scheme

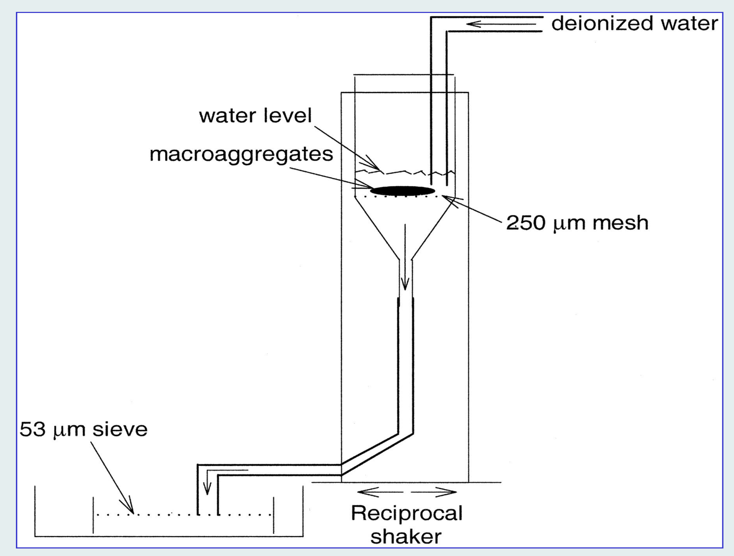


Fig 3: Migroaggregate isolator

- Three fractions were isolated by this procedure: (i) fine POM in the light fraction, (ii) microaggregate protected POM in the heavy fraction remaining on the 53-µm sieve, and (iii) silt+clay SOM in the < 53-µm fraction.

Acid hydrolysis:

- The silt+clay fractions were combined and subjected to acid hydrolysis based on the procedure by Paul et al (1998) (Fig. 4).
- The material remaining after digestion was the silt+clay non-hydrolyzable fraction. The silt+clay hydrolyzable fraction was calculated as the difference between the total silt+clay fraction and the non-hydrolyzable fraction.

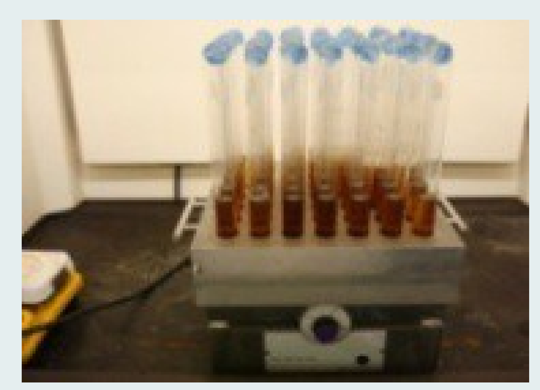
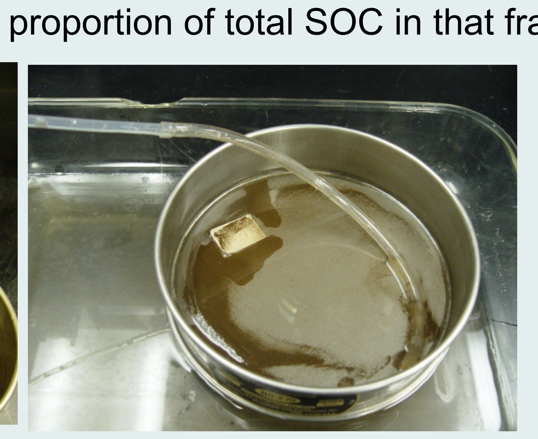


Fig 4: Acid hydrolysis

Soil C analysis:

- Each of the 5 soil fractions from each replicate plot of the mulch and no-mulch treatments from 2006 and 2008 was analyzed for total C using an elemental analyzer. The average C concentration of each fraction was multiplied by the proportional weight of the fraction to estimate the proportion of total SOC in that fraction.



Results and Discussion

- Mulching significantly increased C sequestration in more stable fractions (Fig 6).
- Additional C storage was observed in slow and passive fractions after 2 years of mulching (2006 to 2008) (Table2) and a proportional increase in these fractions as a part of total soil C (Fig 6).
- In no mulch there were no significant differences between treatments in soil aggregate distribution of fraction-size classes 2000–250, 250-53, <53 µm or the mass of C per area for any of the 5 fractions (Table 2).
- In 2008: significant increases in soil C in the hydrolysable and non-hydrolysable silt+clay fractions in mulch-addition treatment.

Table 1: Changes in total soil C (Youkhana & Idol 2009)

	No mulch	Mulch	No mulch	Mulch
Year	C (g / kg)		C (Mg / ha)	
2006	28.3	28.3	53.9	53.9
2008	29.2	39.0†	49.1	64.7†
Change	0.9	10.7*	-4.8*	10.8*

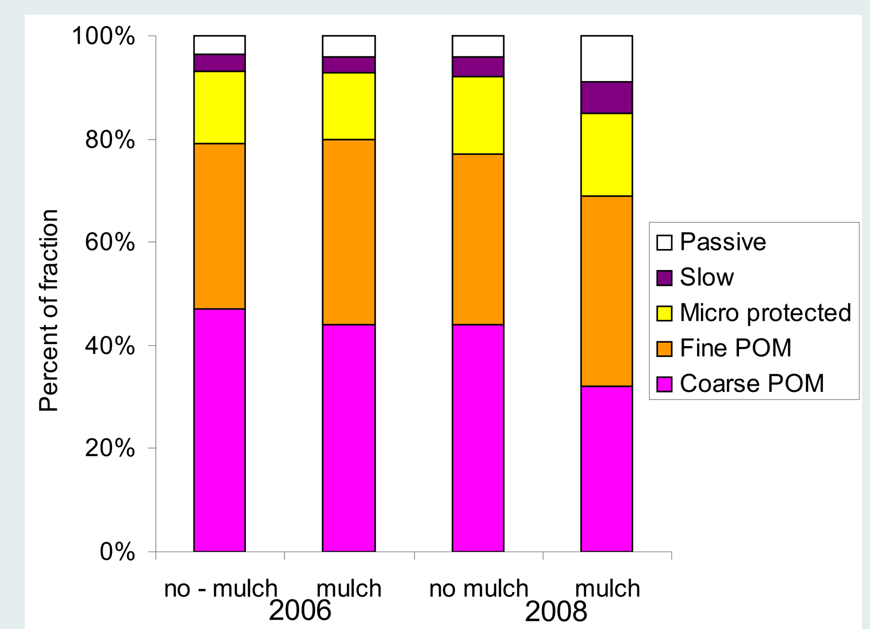


Fig 6: Changes in soil C fraction percent

- A previous study reported that mulch addition in these plots from 2006-2008 led to an increase in whole-soil C (Youkhana and Idol 2009) (Table 1).
- At least half of the increase in total soil C in response to mulch addition was due to increases in the relatively stable silt+clay fractions. It also represented a more than doubling of the size of these two fractions in just two years.

Table 2: Change in soil C fractions (Mg/ha)

Year	No mulch	Mulch
Coarse particulate OM		
2006	3.57	2.39
2008	5.07	1.94 †
Fine POM C (Low density)		
2006	33.06	36.88
2008	28.85	35.92 †
Microaggregate protected POM		
2006	4.57	4.67
2008	3.79	4.08
Slow (Silt+clay hydrolyzable C)		
2006	1.54	1.12
2008	1.69	3.22 †
Change	0.15	2.1*
Passive (Silt+clay non-hydrolyzable C)		
2006	1.96	2.92
2008	3.04	5.95 †
Change	1.08	3.03*

* significant change between 2006 & 2008.
† significant difference between mulch & no- mulch

Conclusions

- Mulching in this system led to increased C sequestration, especially in more stable fractions.
- Actively managed agroforestry systems can result in not only greater total soil C but also a greater proportion of more stable soil C as compared to conventional agricultural systems, even where tillage and soil disturbance are minimal.
- Sequestration in stable fractions may allow SOC gains to count as C credits in C offset markets.

Selected References

- Gama-Rodrigues, E.F., Nair, P.K.R., Nair, V.D., Gama-Rodrigues A.C., Baligar, V.C., and Machado, R.C.R. 2010. Carbon storage in Soil Size Fractions Under Two Cacao Agroforestry Systems in Bahia, Brazil. Environmental Management,10.1007/s00267-009-9420-7.
- Six J, Conant, RT, Paul, A., and Paustian, K. 2002. Stabilization mechanisms of soil organic matter: implication for C-saturation of soils. Plant and Soil 241: 155-176.
- Youkhana, A and Idol, T. 2009. Tree pruning mulch increases soil C and N in a shaded coffee agroecosystem in Hawaii. Soil biology and Biochemistry 41, issue 12: 2527-2534.