Carbon Mineralization Dynamics of Organic Materials and Their Usage in the Restoration of Degraded Tropical Tea-Growing Soil

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Introduction

- Tea cultivating soils in Sri Lanka
  - Ultisol (RYP, IBL, RBL) (Dassanayake, Hettiarachchi, 1999)
  - Ultimate stage of the weathering sequence
  - Tea soils subjected to heavy rainfall and erosion(Jayman, 1981),
  - Continuous exploitation over 150 years (Ananthacoomaraswamy, *et al*. 2003)
  - Application of fertilizers and other agrochemicals(Lehman, 2007)

Land degradation

Climate change

- Severe without proper GAPs (Lal, 2015)

Soil Restoration…………??

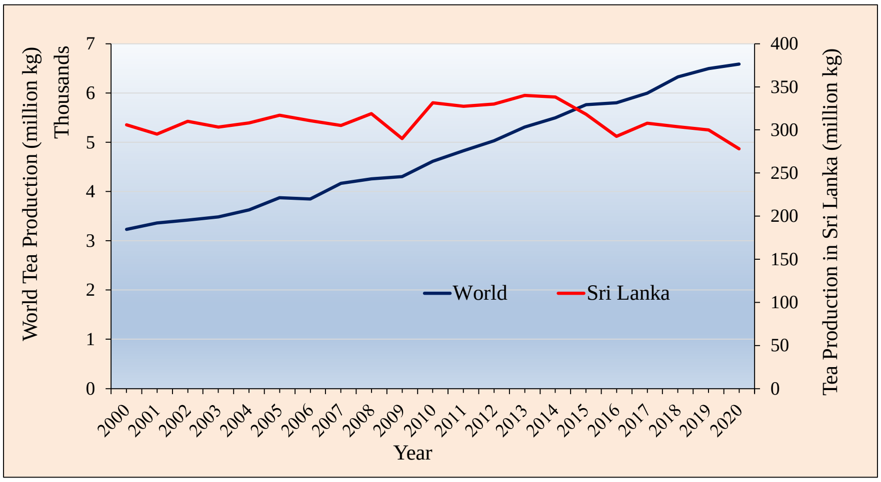
Soil health/quality

- Physical
- Chemical
- Biological
- Hydrological

Soil restoration becomes mandatory in tea lands for sustainable tea production

Background of the study

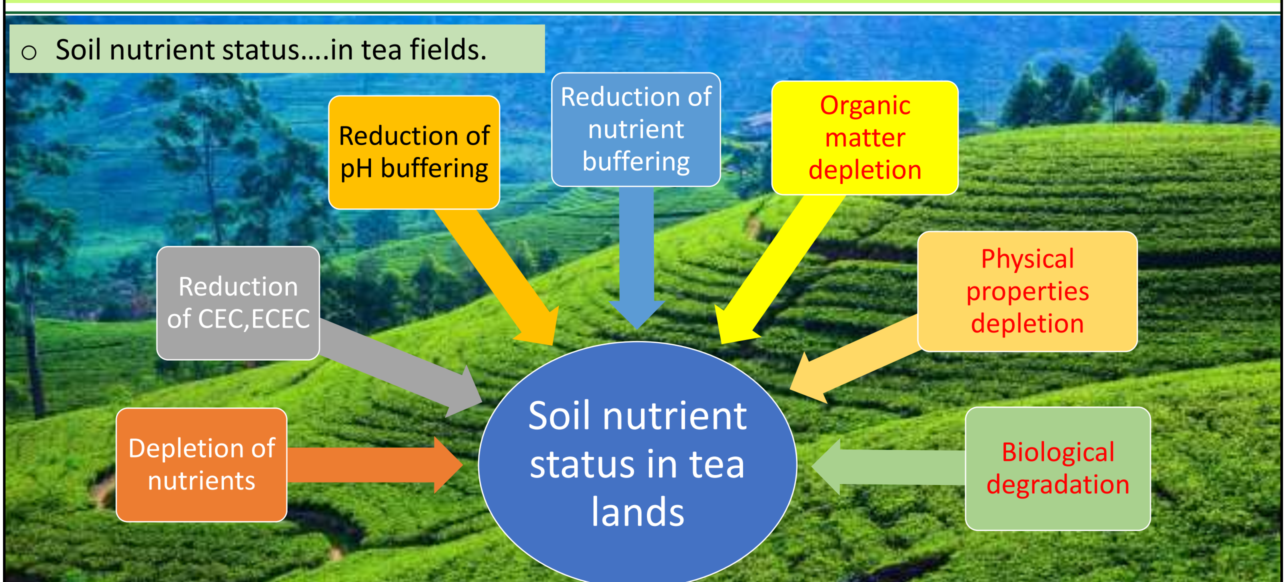
Annual tea production in the world vs Sri Lanka



(International tea committee, 2020)

Soil degradation is one of the reasons for this yield stagnation/ decline for last 2 decades

Background…



Restoring of soil has become an unavoidable practice to combat these conditions

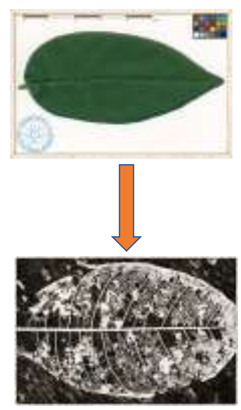
Background…

Organic materials (OMs)/ organic amendments

- Widely accepted and common mechanism (Goyal *et al.*, 1999)
- Comparatively cheaper (than other chemical and mechanical methods)
- Improves most of the parameters required for plant growth – other methods address one or few parameters at once (Tejada, 2009)

Importance of the knowledge on mineralization

- Can add OM based on the objective
  - If the objective is health improvement –then what OMs
- Different OMs mineralized in different rates
- Also differs in mineralizable contents/ potentials
- Some OM improves specific enzymes
  - Gliricidia increase urease but not catalase and for catalase tea waste
- Higher the N in OMs higher the rate of mineralization



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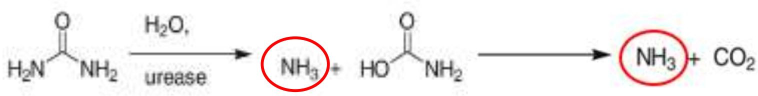
Soil Enzymes

Why enzyme activities in soil are important?

Soil enzymes play a vital role in the soil and fertility
Eg. Urea – urease



Dehydrogenase (DH)

- A measure overall microbial activities
- Governs the biological oxidation of OMs
- Key parameter for the evaluation of soil quality
- Help in determining how much the soil is degraded

Catalase (CAT)

- Measure of oxidoreductase activities
- Significant role in C decomposition

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Major Objective:

Find the restoration potentials of organic materials (OM) abundantly available within the tea ecosystem to restore the degraded tea-growing soils

Specific Objectives:

1. Study the mineralization patterns of each OM
2. Quantify the mineralization rates and mineralizable carbon contents of OM
3. Examine soil microbial activities changes with the addition of OM
4. Study the changes of soil enzymes activities which are responsible for C mineralization DH and CAT with the addition of the organic materials.

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Methodology

- Incubation experiment was conducted with different organic materials frequently available in the tea ecosystem
- Treatments
  - Green manure lopping (*Gliricidia*) – GLI 
  - Compost (made using materials available in tea fields) – CMP 
  - Tea waste (from processing factories) – TW 
  - Biochar (prepared using tea waste and charged with nutrients) – CBC 
  - Tea waste biochar without charging – RBC 
  - Untreated – CTRL
- Incubated for 90 days (low carbon soil) and 120 days (high carbon soil) under controlled conditions (T^0, RH)

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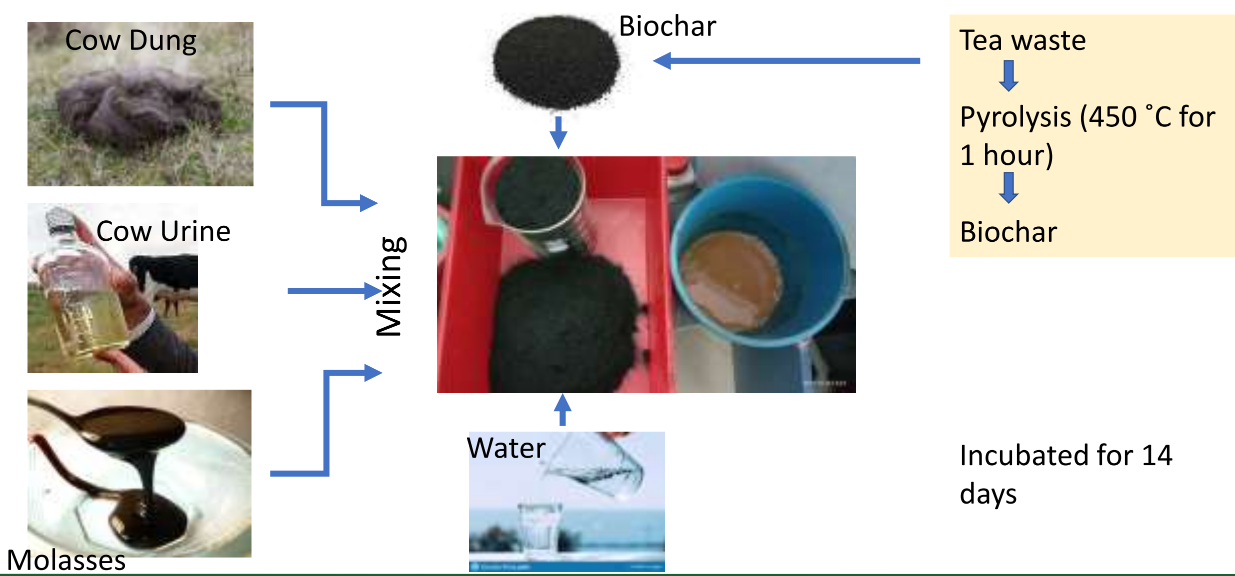
Charged biochar production



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Organic Materials Incubation

- Soils from Banting Tea Garden representing 2 soil types based on organic carbon content were selected
    - Low organic carbon (1.43%)
    - High organic carbon (3.40%)
- Organic material application rate 0.5g carbon/100g of soil (dry basis) for each soil mesocosms
- Emitted CO_2 was measured daily for first week and then with elapsed time for 120 days
- Finally, MBC, MBN, Dehydrogenase, Catalase activities of incubated soil were measured
- C mineralization patterns of each OM was plotted
- N mineralization was also determined with incubated mesocosms weekly up to 120 days

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Methodology..

Charging of biochar

Treatments

Mesocosms

CO_2 measurement with flux analyzer

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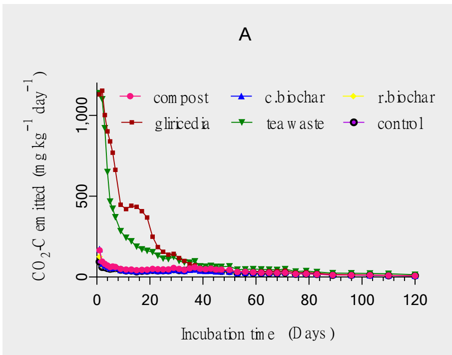
Daily CO_2 emission

High Carbon soil (120 days) | Low Carbon soil (90 days)



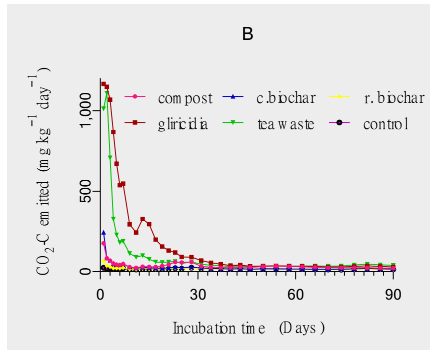


Fig: CO_2 emission over 90 days and 120 days period in Low carbon and high carbon soils

- CO_2 production was significant different among treatments everyday from the first day

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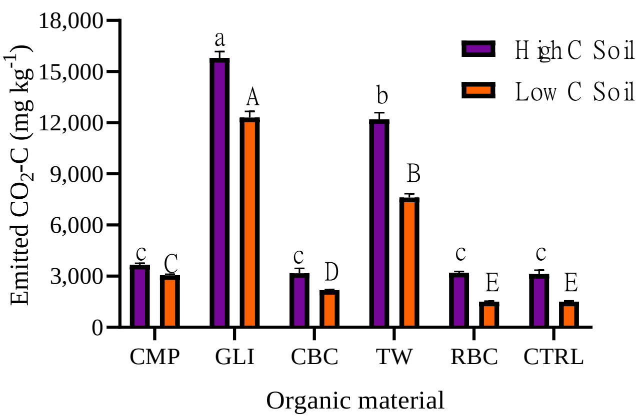
Cumulative CO_2 emission

Cumulative CO_2 emission



- Gliricidia (GLI) produced the highest CO_2
- Lowest CO_2 efflux from CBC for high C soil while RBC for low C soil even below the control

- GLI > TW> CMP> CBC> RBC

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CO_2 emission

% of added carbon respired during 120 days		
Organic material	High C soil	Low C soil
Compost (CMP)	2.97	8.46
Gliricidia (GLI)	69.18	58.92
Charged biochar(CBC)	0.27	3.69
Tea waste (TW)	49.54	33.30
Raw Biochar (RBC)	0.41	0.01

- Low CO_2 emission in BC and CMP due to higher stable organic components during processing CMP and pyrolyzing BC
- Adsorption of OM and produced CO_2 into BC
- Higher N content, lower C:N ratio and the presence of readily available organic molecules in Gliricidia caused to emit the highest cumulative CO_2 of 69 and 58% of the total C added into high C soil and low C soil

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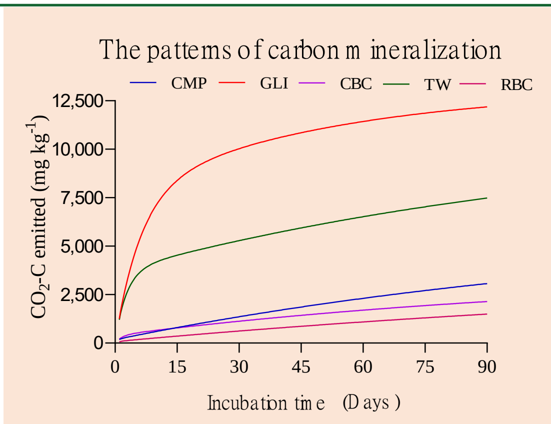
Organic material mineralization patterns



Parallel first order model fitted well for both soils

$$C_{min} = C_f(1 - e^{-kft}) + C_s(1 - e^{-kst})$$

- Two phases of mineralization representing two different carbon pools
  - Faster degradable C pool – C_f
  - Slow degradable C pool – C_s
- Gliricidia has the lowest contribution to the stable C pool in the soil
- Tea waste and Compost equally contributed to the stable C pool
- RBC and CBC had the highest contribution into the stable C pool

Gliricidia has the least contribution for C storage while BC showed the highest contribution

Mineralizable C content

Soil	Organic amendment	First-order model $C_{min} = C_0 (1-e^{-kt})$			Parallel first-order model $C_{min} = C_f (1-e^{-kft}) + C_s (1-e^{-kst})$				
		C_0 (mg kg^{-1})	K day^{-1}	R^2	C_f mg kg^{-1}	C_s mg kg^{-1}	k_f day^{-1}	k_s day^{-1}	R^2
High C (3.40%) soil	Compost	4,691.07	0.016	0.995	2,217.56	2,473.50	0.016	0.016	0.995
	Gliricidia	15,349.54	0.071	0.994	13,228.33	4,590.96	0.087	0.008	0.999
	Charged BC	4,070.22	0.016	0.995	1,924.98	2,145.24	0.016	0.016	0.995
	Tea waste	11,514.35	0.059	0.949	4,432.87	8,571.35	0.266	0.027	0.999
	Biochar	4,371.99	0.014	0.998	2,078.31	2,293.68	0.014	0.014	0.999
Low C (1.43%) soil	Compost	4,504.63	0.012	0.992	175.76	5,983.69	0.570	0.007	0.999
	Gliricidia	11,367.72	0.092	0.975	7,687.30	5,459.07	0.162	0.019	0.999
	Charged BC	2,199.87	0.026	0.950	395.37	3,322.02	0.602	0.008	0.997
	Tea waste	6,358.44	0.100	0.821	3,703.11	7,196.00	0.370	0.008	0.997
	Biochar	2,570.42	0.009	0.995	75.94	3,902.74	0.962	0.005	0.999

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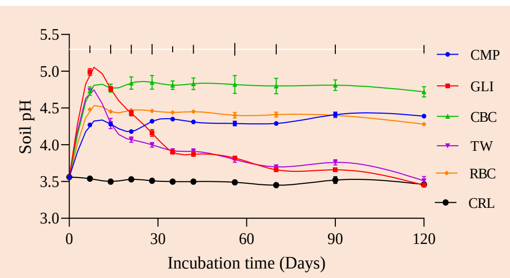
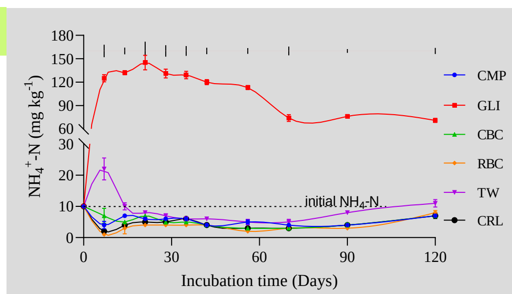
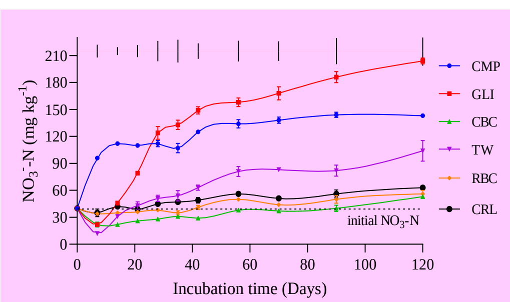
Nitrogen mineralization



pH

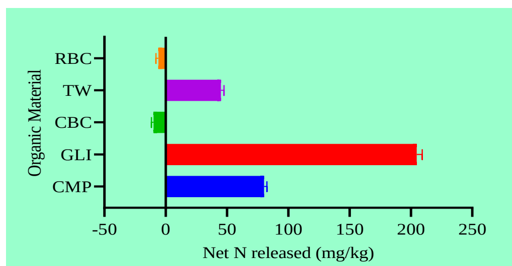
NH_4





NO_3

OM	%
GLI	94
CMP	43
TW	23
RBC	-12
CBC	-17



Net mineralization or immobilization

Microbial activities

Soil	Organic material	MBC	MBN	SMQ
		$\mu g\ C\ g^{-1}$ ± SEM	$\mu g\ N\ g^{-1}$ ± SEM	% ± SEM
High C Soil	Compost	662.3 ± 22.0 a	70.03 ± 4.45 b	2.18 ± 0.07 a
	Gliricidia	692.3 ± 14.4 a	90.68 ± 3.41 a	2.28 ± 0.05 a
	Charged biochar	687.7 ± 18.6 a	85.53 ± 9.75 ab	2.26 ± 0.06 a
	Tea waste	672.7 ± 32.1 a	82.34 ± 7.64 ab	2.21 ± 0.10 a
	Raw biochar	579.2 ± 13.0 b	50.80 ± 2.31 c	1.90 ± 0.04 b
	Control	375.0 ± 29.1 c	45.95 ± 4.47 c	1.24 ± 0.10 c
Low C Soil	Compost	390.5 ± 10.2 ab	58.89 ± 7.45 ab	2.73 ± 0.07 ab
	Gliricidia	409.0 ± 16.4 a	74.98 ± 8.36 a	2.86 ± 0.12 a
	Charged biochar	409.0 ± 29.3 a	68.51 ± 7.37 ab	2.86 ± 0.21 a
	Tea waste	386.1 ± 13.6 ab	69.29 ± 7.58 a	2.70 ± 0.10 ab
	Raw biochar	340.7 ± 14.5 b	48.12 ± 3.55 bc	2.38 ± 0.10 b
	Control	211.8 ± 11.8 c	45.90 ± 4.22 b	1.48 ± 0.10 c

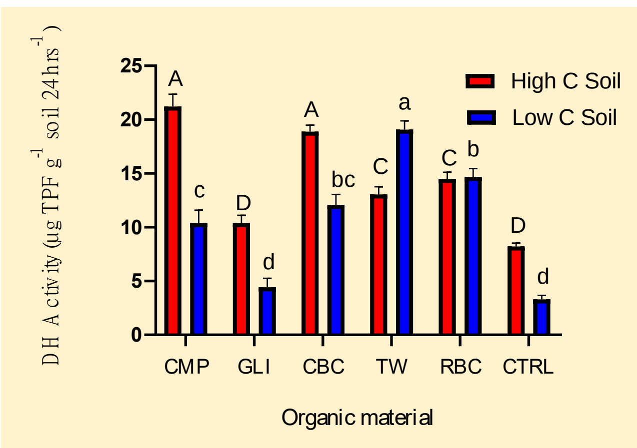
RBC recorded the lowest microbial activities

Charging of raw biochar helped in increasing soil microbial activities

GLI recorded the highest MBC, MBN and q_{mic} in both soils

Soil Dehydrogenase activity

DH is a measure of the soil's metabolic capacity



- Compost recorded the highest DH activity followed by CBC in high C soil
- Whereas in low C soil the highest DH was observed in TW followed by RBC
- Higher the DH higher the microbial activities
- Gliricidia has lower DH after 120 days of incubation

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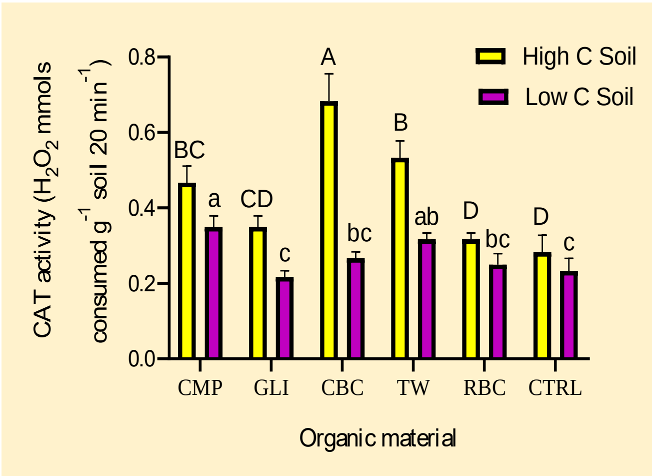
Catalase Activity

CAT represents microbial oxidoreductase metabolism



- Gliricidia has least effects on catalase activity in both soil
- CMP and CBC improve soil oxidative capacity of microbes in the soil which facilitate mineralization process

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Restoration potentials of organic materials in tea ecosystem

- Gliricidia (GLI) decomposed rapidly escaping higher amount of C from the soil (58-69%), leading to lower sequestration and least contribution to buildup humic substances
- Gliricidia improved the microbial activities, (high MBC, MBN and SMQ) indicating a higher potential to restore soil in short periods of time
- Compost (CMP) has comparatively a higher stable C, thus emission of CO_2 was as low as 3-8% of added C. Compost showed increased microbial activities and DH activity, demonstrating higher restoration capacity
- Tea waste behaved similar to the CMP demonstrating similar restoration potentials
- Gliricidia releases N quickly up to 94% of its N in 120 days enabling plants to uptake

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Restoration potentials of organic materials in tea ecosystem

- RBC showed the lowest mineralization rate, resulting the highest C sequestration ability
- The MBC, MBN, SMQ and catalase activities are also lower in RBC than that of other amendments. Raw biochar has some short-term negative effects for soil fertility thus charging of BC is useful
- CBC increased DH, CAT, MBC, MBN and SMQ in the soil while reducing C emission, exhibiting greater potential of restoring degraded soil. Charging improves nutritional value as well.

Field evaluation continues to confirm these findings to make recommendation

In the overall context, GLI showed restoration potential in short-term while CBC had the greater potentials in long term, thus combine application of GLI and CBC would be much effective in restoring degraded tea growing soils

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