Characterization of Degree of Eco-restoration by Tree-Grass Interaction in Degraded Lands of Semi-Arid Tropics

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Abstract
Land degradation majorly declines soil health. Eco-restoration through tree-grass interaction provides a perfect solution to restore degraded lands. The study was carried out at Jhansi district of India during 2010 to 2019 with three fodder trees *viz namely, Ficus infectoria, Morus alba,* and *Acacia nilotica* and a shrub *Leucaena leucocephala* (along with three grasses (*Cenchrus ciliaris, Chrysopogon fulvus and Panicum maximum*). The main objectives of these study were to a) assess the changes in soil organic carbon pools and responses of soil enzymes as impacted by different eco-restoration strategies involving trees and grasses; and b) develop an index to measure efficiency of eco-restoration strategies to aid the community.Grass and tree biomass yield were the highest for *Panicum maximum* and *Ficus infectoria,* respectively.After 9 years, land under *Ficus*, *Morus*, and *Acacia* had ~ 63, 105, and 87% greater total organic carbon and *Cenchrus*, *Panicum*, and *Chrysopogon* increased total organic carbon by 84, 91 and 77% at surface layers, respectively, over fallow land. Microbial biomass C increased by 2-2.5 folds in both soil layers after. There were positive correlation among all the C fractionsand eco-restoration efficiency. Carbon management index (CMI) enhanced by 51, 84, and 70% at surface layers under *Ficus*, *Morus*, and *Acacia* based systems, respectively over fallow land. Similarly, grasses also improved CMI by >60%. Accumulation of soil organic carbon under *Ficus*, *Morus*, and *Acacia* were ~55, 91, and 77 % higher than fallow land at surface layers. By combining CMI and biological activity index, we developed eco-restoration efficiency index and found *Morus* + *Panicum*, *Acaia* + *Panicum* to be effective restoration strategies for eco-restoration under degraded lands of tropical climates. Our study indicated that implementation of these eco-restoration strategies could be a quantitatively important component of climate change mitigation strategies in India and should be continually paid a great attention.

Introduction
Land degradation has been one of the major causes of diminishing soil quality in recent years. Restoration of degraded lands has been challenging. It involves careful planning and adopting land use options. Land use options promoting sustainability and livelihood security are desirable by society for enhancing food, fodder and firewood as well as mitigation and adaptation to climate change (Kumar et al., 2019).

There has been many studies on response of land restoration strategies to SOC storage in temperate climates. However, the knowledge on response of land restoration strategies to SOC storage in tropical climates, distribution of C in different pools, soil enzyme activities has remained scanty. The most discriminant factors among eco-restored land are also unknown under tropical climate. There is no available index to measure the efficiency of eco-restoration strategies. Systematic information on the capability of these strategies to fulfil the commitment of Paris Agreement are also unavailable. The main objectives of the study were to a) assess the changes in soil organic carbon pools as affected different eco-restoration strategies involving trees and grasses; b) find out the response of soil enzymes due to eco-restoration of degraded land in tropical climate and c) develop an index to measure efficiency of eco-restoration strategies to aid the community.

Methods and Study Site
The study site is located at Jhansi, India (longitude 250 26′08″ N, latitude 780 30′21″ E and altitude 216 m above mean sea level). Geologically, the area belongs to the part of the Bundelkhand region, which is characterised by devastating drought, barren soil and extreme climate. Rocks like gneisses and granites with highly ferruginous beds and basic igneous intrusions are observed in this tract. The soil of the experimental site belongs to the hypothermic family of Typic Haplustepts with clay loam texture.Three native fast growing fodder trees, namely, *Ficus infectoria, Morus alba, Acacia nilotica and* a shrub i.e.*Leucaena leucocephala* (occurring naturally in most of arid and semiarid regions) were selected for fodder supply from March to June. Combination of three grass species viz., *Cenchrus ciliaris, Chrysopogon fulvus and Panicum maximum* were tried along with tree component to test their compatibility for higher biomass and quality

during August to February.In April 2019, soil samples were collected in four replicates from each eco-restored land at two depth layers (0–15 and 15–30 cm). Total organic C (TOC) was measured following dry combustion method after HCl treatment with a CHN analyser. Carbon management index (CMI) was calculated using the following equations (Blair et al., 1995) using fallow land as reference.A biological activity index (BAI) was computed as (Ghosh et al., 2021). Eco-restoration efficiency of each system (ERE) was calculated as

ERE= (BAI ×CMI)/100

Results

TOC

Land under *Ficus, Morus, Acacia and Leucaena* had ~ 63, 105, 87 and 81% greater TOC than fallow land in surface layer and 78, 97, 109 and 77% greater TOC than fallow land in subsurface layer, respectively (Table 1). Among the grasses, *Cenchrus, Panicum, and Chrysopogon* increased TOC by a) 84, 91 and 77% at 0-15 and b) 101, 91 and 79% at 15-30 cm soil layers, respectively, over fallow land.

CMI and BAI

CMI was significantly improved by eco-restoration strategies. After 9 years of restoration, *Ficus, Morus, Acacia* and *Leucaena* boosted up CMI by a) 51, 84, 71 and 65% b) 61, 75, 84 and 59% at surface and subsurface layers, respectively over fallow land (Table 1). Similarly, *Cenchrus, Panicum,* and *Chrysopogon* resulted in a) 68, 73 and 62% and b) 78, 70 and 61% improvement in CMI at surface and subsurface soil layers.Hence, grasses although improved CMI over fallow land, but their impacts were similar at surface layers. However,CMI was higher in subsurface soils than surface soils for land under *Ficus*, *Acacia*, and *Cenchrus*. BAI describes the overall improvement in nutrient cycling in the ecosystems as it encompasses the activities of C, N and P cycling enzymes. However, BAI under *Ficus, Morus, Acacia* and *Leucaena* were ~a) 3.6, 6.2, 3.7 and 4.5 times and b) 3.8, 4.6, 8.8 and 4 times greater than fallow land at surface and subsurface soil layers, respectively (Table 1). Although, impacts of grass species were similar for individual enzyme activities at surface layers, BAI of land under *Cenchrus* and *Chrysopogon*were ~ 11 and 10% higher than *Panicum* at surface layer, respectively. However, *Panicum* improved BAI by ~31 and 73% over *Cenchrus* and *Chrysopogon* respectively, at subsurface layer.

Table 1: Total soil organic carbon (TOC), carbon management index (CMI), biological activity index (BAI) and eco-restoration efficiency (ERE) in surface (0-15 cm) and subsurface (15-30 cm) soil layers as influenced by 9 years of eco-restoration strategies in a tropical Inceptisol

	0-15 cm				15-30 cm			
	TOC (g kg^{-1})	CMI	BAI	ERE	TOC (g kg^{-1})	CMI	BAI	ERE
Ficus	7.33c	150.7c	3.59c	5.47d	6.6c	160.5c	3.81c	6.19d
Morus	9.21a	184.2a	6.18a	11.53a	7.3b	175.1b	4.64b	8.28b
Acacia	8.43b	170.4b	3.66c	6.21c	7.73a	184.2a	8.8a	17.25a
Leucaena	8.13b	165b	4.49b	7.71b	6.53c	159.1c	4.04bc	6.68c
Fallow	4.5d	100d	1d	1.0d	3.7d	100d	1d	1.0e
	TOC (g kg^{-1})	CMI	BAI	ERE	TOC (g kg^{-1})	CMI	BAI	ERE
Cenchrus	8.3b	168a	4.68a	8a	7.45a	178.2a	5.21b	9.38b
Panicum	8.58a	172.9a	4.21c	7.34c	7.05b	169.9ab	6.82a	12.94a
Chrysopogon	7.96c	161.8a	4.55b	7.85b	6.63c	161b	3.93c	6.47c
Fallow	4.5d	100b	1d	1.0d	3.7d	100c	1d	1.0d

Discussion[Conclusions/Implications]

Based on ERE values, we found that *Morus* and *Acacia* were the most efficient trees for restoration of degraded land and *Panicum* was the most efficient grass for restoration of degraded land under tropical climate of *Bundelkhand* region of India and their eco-restoration efficiency was ~10 times greater than fallow land (Table 1). Hence, *Morus* + *Panicum*, *Acaia* + *Panicum* could be effective restoration strategies for eco-restoration under degraded lands of tropical climates. Despite, clearly indicating effective system for eco-restoration, we plan to test the index under diverse soil orders, eco-restoration strategies to improve the positive correlations observed here. We also plan to develop baseline data set for diverse soil type and climate for its rapid application and uses so that this easy, quick effective index can be made operational for calculating efficiency of eco-restoration strategies at ease for urgent implementation of effective strategies to meet the commitment of Paris agreement.

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