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Review

Delineate Soil Characteristics and Carbon Pools in Grassland Compared to Native Forestland of India: A Meta-Analysis

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Abstract: Grassland is a highly dynamic land use system and it provides vital ecosystem services, mainly consisting of carbon storage in the tropics and subtropics. The objective of this study was to delineate grassland in India according to soil characteristics and carbon pools in comparison to native forestland, and to discuss management strategies for improving soil carbon (SC) storage in grassland. A total of 675 paired datasets from studies on grassland and forestland in India generated during the period of 1990–2019 were used for meta-analysis study. The analysis shows that soil pH and bulk density (BD) in grasslands were greater by 1.1% and 1.0% compared to forestlands while soil organic carbon (SOC) declined by 36.3% ($p < 0.05$). Among carbon pools, labile carbon (LC), non-labile carbon (NLC), and microbial biomass carbon (MBC) were 35.5%, 35.3% and 29.5% lower, respectively, in the grassland compared to the forestland. Total carbon (TC) was 35.0% lower in the grassland than the forestland ($p < 0.05$). Soil carbon stocks (SCS) were 32.8% lower in the grassland compared to the forestland. In the grassland, MBC/SOC (%) from the surface layer and subsurface layer were lower by 2.4% and 8.5%, respectively compared to forestland. The percentage effect size was found to have decreased from surface soil to subsurface soil. Relative SCS loss and carbon dioxide equivalent emission from the grassland compared to forestland were 15.2% and 33.3 Mg ha^{-1}, respectively ($p < 0.05$). Proper management strategies like agroforestry, legume introduction, silvipastoral system, fertilization, irrigation, and quality grass species could improve SC storage and reduce SCS loss in grassland. Overall, this study gives an idea that conversion of native forestland into grassland in India has declined the SC content and hence it is necessary to adapt proper strategies to manage the soil-atmosphere carbon balance.

Keywords: total carbon; soil carbon pools; carbon dioxide equivalent emission; soil carbon storage; land use

1. Introduction

Forestland and grassland are important ecosystems whose soils store a huge amount of soil carbon (SC) [1]. Carbon storage in the soil is determined by the magnitude as well as the quality of organic matter and ability of the soil to retain SC [2]. Forestland accounts for two-fifths of the total carbon (TC) storage globally [3]. Since soil of native forestland is undisturbed and provides the maximum sink of SC storage over a long period of time, it acts as a basis for studies on the restoring potential of atmospheric carbon for any land use system [4]. Human interference, grazing, and land degradation are common phenomena that lead to losses of SC pools in the grassland. Therefore, quantifying land use change is crucial for considering the interactions among human activities, climate, and environment, and also for designing state policies [5–8].

Grasslands cover approximately one-fourth of the earth's surface area with a land area of about 3.4 billion hectares. The terrestrial carbon stocks in grassland contain roughly 12.0% of the total terrestrial carbon stocks of the earth's surface [9–11]. Grasslands are dominated by herbaceous non-woody vegetation and hence, carbon from the aboveground vegetation biomass is a small fraction of the TC pool as compared to forestland. Additionally, the biomass is relatively short-lived owing to frequent grazing, fires, senescence, and harvest. However, belowground biomass carbon that dominates in perennial grasslands is characterized by extensive fibrous root systems making up three-fourths of the total biomass carbon in these ecosystems. Understanding the potential of grassland to store a large amount of carbon in different soil depths is important for soil processes and managing climate change [12]. Therefore, depth wise SC distribution will be valuable information in the grassland.

Grassland is a highly dynamic land use system and provides vital ecosystem services like biogeochemical cycling and carbon storage [13,14]. In India, grassland occupies approximately one-fourth of the total area which is spread across a number of biogeographic regions with diverse ecological features [15]. Major grassland types in India are presented in Table 1 [16]. These grassland types have quite diverse SOC and SC pools due to differences in climate, soil types, vegetation, topography, management, and soil disturbances.

Table 1. Major grassland types of India alongwith environment and regions of distribution [16].

Major Grassland Types	Environment	Regions of Distribution
1. Sehima-Dichanthium	Dry subhumid zone except Nilgiri	M.P., A.P., Maharashtra (Mumbai), T.N., South-eastern U.P.
2. Dichanthium-Cenchrus	Semi-arid zone	Punjab, Delhi, Rajasthan, Gujarat, Eastern U.P., Bihar
3. Phragmites-Saccharum	moist subhumid zone	Terai of U.P., Uttaranchal, Bihar, Bengal, Assam, Sunderban and other deltas
4. Bothriochloa	Temperate zone	Lonavala tract of Maharashtra
5. Cymbopogon	Tropical humid zone	Western Ghats, Vindhyas, Satpura, Aravalli ranges, Odisha upto 160 kmbelt
6. Arundinella	Subtropical subhumid zone	Western ghats, Nilgiris, Himalayas, Eastern Punjab, H.P. upto 3 km
7. Deyeuxia-Arundinella	Mixed temperate zone	Himalayas, Kashmir, Uttaranchal, Bengal and Assam
8. Deschampsia-Deyeuxia	Temperate-alpine zone	Himalayas, Kashmir above 2.5 km

The SC and belowground biomass in grasslands is closely related to variation in annual rainfall and temperatures at broad spatial scales. Since grass production is directly related to rainfall, SCS is high in the areas where rainfall is abundant like the north-east region of India. The SCS decreases with increasing annual temperatures due to greater evapotranspiration [17]. Degradation of grassland due to uncontrolled intensive grazing poses a big threat to the sustainability of livestock productivity as well as SC storage [18,19]. Therefore, SC loss in the grassland of India is a big concern which, as a result of degradation, overgrazing, and human activities, can lose carbon to the atmosphere and has a detrimental effect on global climate change.

The data presented by the union government of India to the United Nations Convention to Combat Desertification (UNCCD) during the 14th Conference of Parties (COP) showed loss of one-third of the total grassland area in the last decade (approximately 5.65 million hectares) [20]. Statistics collected from the FAO website have also reported a decline in the grassland area in India from 2001 to 2017.

Indian Himalayan forestland stores one-third of total SCS in India [21]. Grassland in Aravalli ranges in Rajasthan and other states including Maharashtra, Gujarat, and Uttar Pradesh have been severely destroyed due to local activities and land degradation [20]. Around 4.74 million hectares of grassland has been diverted to other land uses across the country. Figure 1 represents the trend share of forestland and grassland of the total land area during the period 2001–2017 as a percentage [22]. It shows a 1.5% increase in forestland and a decrease in 2.3% of the grassland area of the total land area during this period.

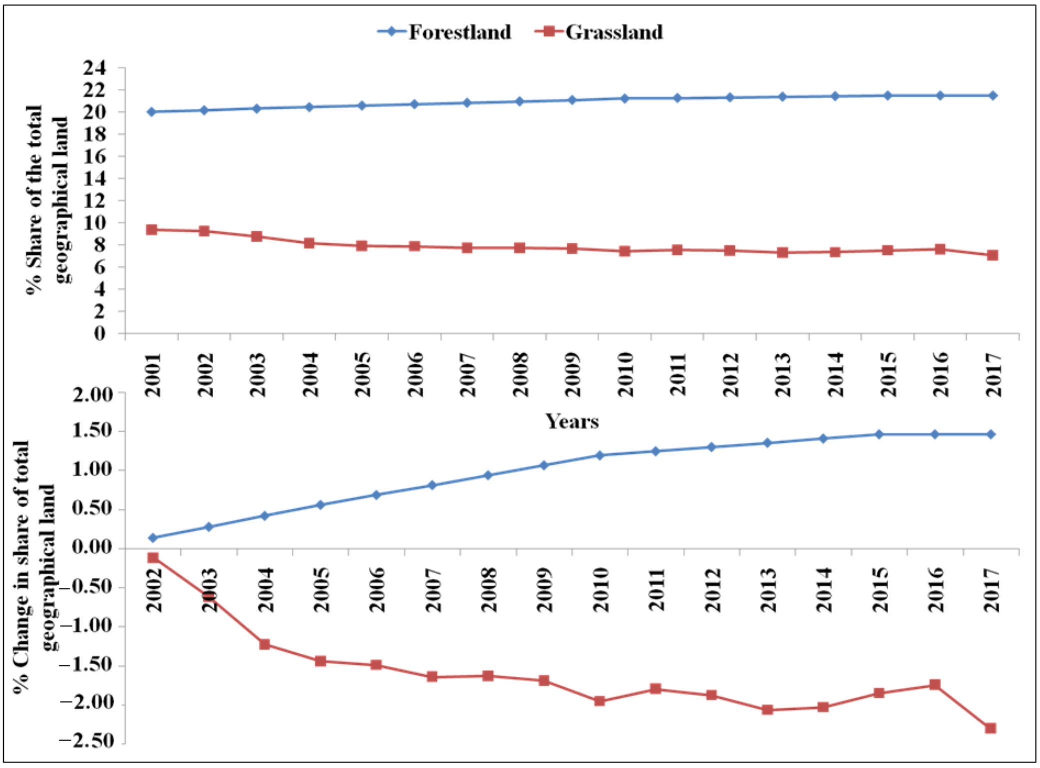


Figure 1. Trends of percent share and change in share (base year 2001) of grassland and forestland area of total land area (2001–2017) of India, Food and Agriculture Organization (FAO) [19].

The region-wise and location-specific studies in India have been done to a large extent to show the losses in SCS and soil properties in grassland but no particular attempt has been made to represent the changes in a holistic manner. This study attains a better knowledge of the Indian pattern of SOC loss in grassland over the native forestland through a comparative analysis of data sets obtained through the compilation of several studies carried out in the different parts of India. The findings from several studies under various ecological regions are analysed through a meta-analysis approach. This is a statistical tool that considers experiments to assess the magnitude and direction of treatment outcomes as well as patterns and sources of heterogeneity [23,24]. This study informs us about the change in SC pools and soil characteristics of grassland over forestland to provide quantitative information and further identified strategies to restore SC. Specifically, the objectives of this study are to analyze (1) The effect size of grassland over the forestland on soil characteristics, (2) The effect size of grassland over the forestland on SC pools and MBC/SOC (%), and (3) Strategy options for SC storage in grassland.

2. Materials and Methods

2.1. Data Sources and Compilation

The relevant papers were searched using specific keywords from the databases of various journals and websites. Papers (original articles, review papers, and theses) were collected and reviewed for the period 1990–2019 in context of the impact of grassland and forestland on SOC, SC pool, SCS and other soil properties in different regions of India with an aim of finding the comparative changes in these soil parameters. After a general review, data were critically analyzed and data pertaining to forestland was selected as the control treatment. Grassland was taken as the other treatment for this study. Native forestland was adjacent to grassland. Forestland covered all types of situations' in existence like being open to the dense forest, single-species tree cover to several species tree cover, Himalayan to the plain forest and low aged to high aged trees. Grassland considered for the study had no specific grasses species. Selected 675 paired data sets from these papers were analyzed using meta-analysis for three soil depths including (i). 0–0.15 m, (ii).0.15–0.30 m and 0.30–0.45 m.

The papers were separated based on requirements keeping several criteria in mind:

- The collected papers should show a comparative analysis between the two land uses, the grassland and the forestland, in the Indian context,
- The collected papers should have required sets of soil parameters (soil pH, bulk density (BD), cation exchange capacity (CEC), soil organic carbon (SOC), SC pools, and soil carbon stocks (SCS), detailed in Section 2.3,
- Forestland was considered as a control treatment over the grassland,
- The study paper should represent subtropical climatic conditions of India, and
- The study was not bounded with particular parameters like soil types, soil classes, soil taxonomy, and management practices, cropping systems, specific trees, and grass species.

2.2. Location Map of the Study Area

Figure 2 shows the location map for climate, altitude, soil types, and SCS/total carbon density of the major study areas (nearby areas have been included in the same area point of major study areas in the location map). The climate of the study regions can be categorized as subtropical, warm humid, sub-temperate, humid tropical, subtropic subhumid, and semi-arid. The altitude of the study areas ranged from 43 m above mean sea levels (msl) to 1250 m above msl. Soil types are sandy, loamy sand, loamy, sandy loam, clay loam, and clayey soil. SCS/Total carbon density ranges from 1.85 Mg ha^{-1} to 210.0 Mg ha^{-1} with a mean of SCS 59.80 Mg ha^{-1}. The maximum SCS was found in silt clay loam textured soil present in the tropical humid climate of northern-eastern state Assam, whereas the minimum SCS was found in sandy textured soil present in the semi-arid climate of Rajasthan. SCS has declined tremendously in the western state of India, Rajasthan, due to semi-arid climate and human disturbances causing the loss of vegetation and organic matter from the soil in different land uses.

2.3. Soil Parameters Used in This Study

Table 2 represents the soil parameters considered for this study alongwith the measurement unit of the soil parameters.

Table 2. Parameters used in this study.

S. No.	Soil Parameters		Measurement Units	Methods
1.	Soil properties	Soil pH	No unit	Soil water suspension ratio 1:2 or 1:2.5
		Bulk density (BD)	Mg m^{-3}	Core method (Oven-dried core mass divided by the core volume)
		Cation exchange capacity (CEC)	cmol (p+) kg^{-1}	sodium acetate saturation method
		Soil organic carbon (SOC)/Total organic carbon (TOC)	%	Dry combustion method
		Total carbon (TC)	%	Sum of TOC and total inorganic carbon (TIC)
		Soil carbon stocks (SCS)/total carbon density	mg ha^{-1}	Products of SOC/TOC, BD and Soil depth
2.	Soil carbon pools (SC pools)	Labile carbon (LC)	mg kg^{-1}	Potassium permanganate method
		Non-labile carbon (NLC)	mg kg^{-1}	Deduction the LC from TOC
		Microbial biomass carbon (MBC)	mg kg^{-1}	chloroform fumigation extraction method

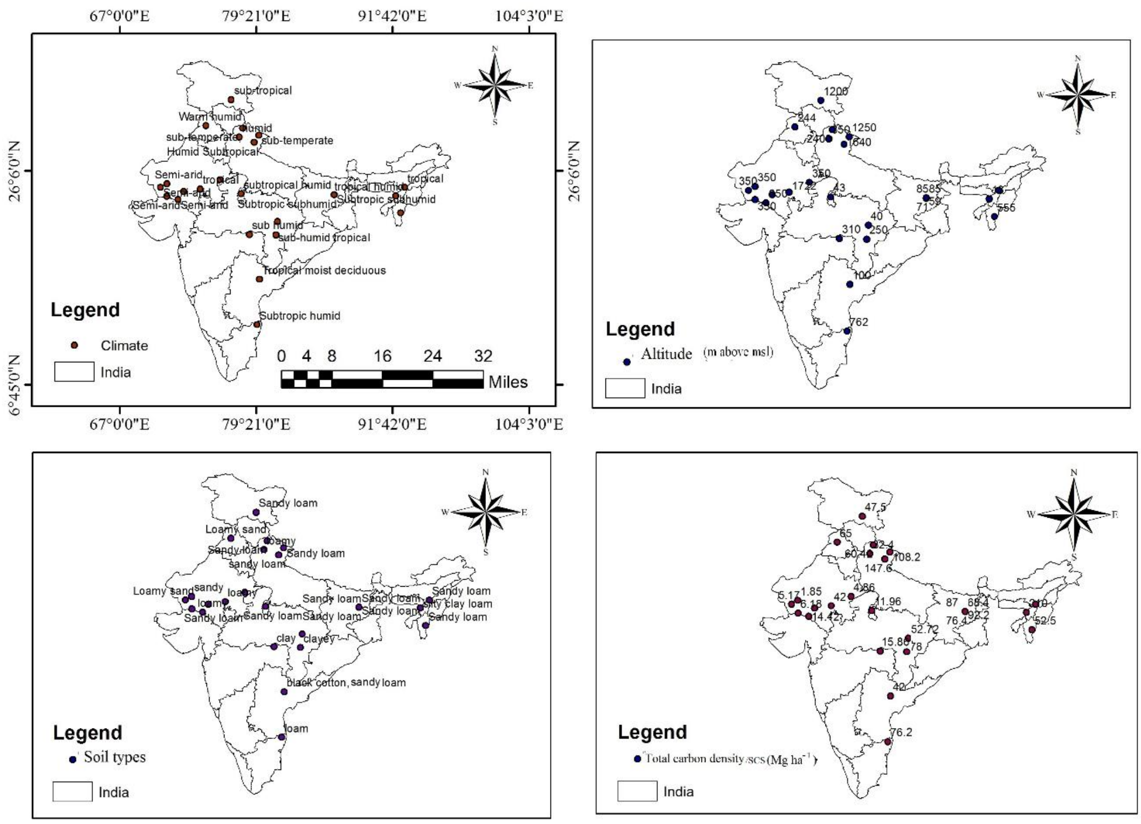


Figure 2. Location map of the major study areas showing climate, altitude, total carbon density/soil carbon stocks (SCS) and soil types in a clockwise direction.

SCS loss related with land use conversion was determined by using Equation (1).

$$\text{Relative SCS loss } (\%) = [(\text{SCS forestland} - \text{SCS grassland})/\text{SCS forestland}] \times 100 \quad (1)$$

The carbon dioxide equivalent emissions from SCS loss were estimated as the amount of carbon in the oxidized form using respective molecular weights by using Equation (2):

$$\text{carbon dioxide equivalent} = \text{carbon} \times 44/12 \quad (2)$$

The SCS loss values for respective land use were used to measure the carbon dioxide equivalent emissions in $\left(\text{Mg ha}^{-1}\right)$.

2.4. Meta-Analysis: Method of Analysis Using Diverse Datasets

Meta-analysis is a potential statistical approach to analyze the effect of management practices on the control treatment of different distinct studies, and to evaluate the evolution of a universal trend. This approach has attracted researchers from all over the world in order to better understand the variables.

Two stage-based meta-analyses (MetaWin 2.1) were used to analyze the database and understand the comparative changes [25,26]. Within this, the effect size (*ES*) was calculated for individual parameters using the equation [23]:

$$ES = lnR = ln\left[\frac{X_T}{X_C}\right] \quad (3)$$

where R is the ratio between response variables X_T and X_C; X_T is the average of response variables (Soil parameters) of the treatments; and X_C is the average of these variables in forestland as control.

The studies from variable conditions were the basis of multiple replications and the standard deviation was calculated through number of observations with a simple statistical procedure.

ES from individual studies were then combined using a mixed-effect model to calculate the cumulative effect size and the 95% confidence intervals (CIs) through bootstrapping with 4999 iterations [27]. The mixed-effect model is a random-effect meta-analytic model for categorical data [28,29], assuming random variation among studies within a group and fixed variation between groups.

2.5. Interpretation of Results

Results were back-transformed and presented as mean effect size in percent caused by treatments in relation to control in the tables and bar graph. Significant differences were considered only for *p* value of less than 5 percent. The meta-analyzed values are presented in tables and bar graphs to clearly show the significant effect of grassland over forestland.

3. Results

3.1. Soil Characteristics of Grassland Compared to Forestland

Data pertaining to physical and chemical characteristics of soils in grassland and forestland is presented in Table 3 for surface soil (0–15 cm) and subsurface soil (15–30 cm). Soil reaction (soil pH) was found to be acidic to slightly acidic in both land uses and had a higher value in grassland than forestland in both soil depths. The average soil pH in the surface soil of grassland and forestland was 5.78 and 5.66, respectively, whereas in subsurface soil it was 5.91 and 5.82 (Table 3). Soil BD was also observed to be higher in grassland than forestland. The average value of BD for grassland was 1.50 Mg m^{-3} and forestland was 1.47 Mg m^{-3} in the 0–15 cm and 1.57 Mg m^{-3} and 1.50 Mg m^{-3}, respectively in the 15–30 cm. SOC and CEC were found to be greater in forestland than grassland (Table 3). The average value of SOC for grassland and forestland was 1.30% and 1.85%, in the surface soil and 0.91% and 1.59% in the subsurface soil. The average value of CEC for grassland and forestland was 14.0 cmol p^{+} kg^{-1} and 15.3 cmol p^{+} kg^{-1}, in 0–15 cm soil depth whereas CEC was 14.4 cmol p^{+} kg^{-1} and 15.8 cmol p^{+} kg^{-1}, in the soil depth 15–30 cm. Higher TC was recorded in forestland than grassland. In grassland, the average value of TC in both the soil depths was observed to be similar while in forestland the average value was highest in surface soil (34.0 Mg ha^{-1}) followed by subsurface soil (27.2 Mg ha^{-1}) (Table 3).

SC pools were found to be higher in forestland than grassland. LC, NLC, and MBC were observed to be higher in the surface soil compared to subsurface soil. LC was 1640 mg kg^{-1} and 2220 mg kg^{-1}, respectively for grassland and forestland in the soil depth 0–15 cm while 762 mg kg^{-1} and 2041 mg kg^{-1}, for the land use in the soil depth 15–30 cm. Similarly, NLC was 3400 and 4410 mg kg^{-1}, respectively in the surface soil and 2580 mg kg^{-1} and 3190 mg kg^{-1}, respectively in the subsurface soil for the grassland and forestland (Table 3). The mean value of MBC for grassland and forestland was 548 mg kg^{-1} and 799 mg kg^{-1} in the surface soil and 342 mg kg^{-1} and 415 mg kg^{-1} in the subsurface soil (Table 3).

Table 3. Physical and chemical characteristics of soil in grassland and forestland from the collected studies.

Soil Properties	Soil Depths (cm) / Land Uses	Range 0–15	Range 15–30	Mean Value 0–15	Mean Value 15–30
Soil pH	Grassland	4.92–6.19	6.19–5.59	5.78	5.91
	Forestland	4.84–6.04	5.39–6.32	5.66	5.82
BD (Mg m^{-3})	Grassland	1.31–1.63	1.33–1.69	1.50	1.57
	Forestland	1.30–1.57	1.30–1.65	1.47	1.50
SOC (%)	Grassland	0.39–2.48	0.29–2.41	1.30	0.91
	Forestland	0.53–4.82	0.38–3.72	1.85	1.49
CEC (cmol p^+ kg^{-1})	Grassland	10.5–16.7	12.6–17.3	14.0	14.4
	Forestland	14.1–18.1	14.1–17.6	15.3	15.8
TC (%)	Grassland	0.65–1.29	1.03–1.13	1.09	1.08
	Forestland	1.0–1.94	1.20–1.22	1.52	1.21
LC (mg kg^{-1})	Grassland	300–4400	325–1900	1640	762
	Forestland	353–6200	210–8861	2220	2041
NLC (mg kg^{-1})	Grassland	1690–4100	1130–3600	3400	2580
	Forestland	1750–6200	2110–4100	4410	3190
MBC (mg kg^{-1})	Grassland	220–720	80.0–680	548	232
	Forestland	300–1060	210–840	799	415

Note: BD: bulk density, SOC: soil organic carbon, CEC: cation exchange capacity, TC: total carbon, LC: labile carbon, NLC: non-labile carbon, and MBC: microbial biomass carbon.

3.2. Changes in Soil Characteristics by Land Use Change from Forestland to Grassland

The native forestland was taken as a control to observe the changes in the grassland soil due to conversion from forestland. Although the variability has been reported in most of the soil parameters in different studies, the soil parameters with insufficient datasets for meta-analysis have not been mentioned in this study. Other parameters with no significance but that are nonetheless important to mention, and significant parameters have been presented in this study.

Soil parameters like SOC, CEC, TC, LC, and NLC were significantly decreased in the grassland compared to the forestland (Figure 3). Soil reaction and BD increased in the grassland compared to forestland. The percent mean effect size of soil pH and BD was 1.1 and 1.04, ($p < 0.05$) (Figure 3). The percent positive change of soil pH for the grassland compared to native forestland was found to be greater due to variability in plant species of vegetations, topography, and soil disturbance. SOC had a significant negative change in the grassland compared to forestland. SOC was found to be 36.31% lower in the grassland than the forestland (Figure 3). Similarly, TC significantly decreased in the grassland compared to the forestland. TC in the grassland was lowered by 34.99% compared to the forestland (Figure 3). TC was found to be lower in grassland due to the lower addition of root residues and litter that finally contributes towards lower above and below biomass carbon than in the forestland. CEC was significantly lower (7.39%) in the grassland than in the forestland (Figure 3). This information shows that leaching losses of cations were greater in grassland than forestland. This might be due to overgrazing, human activity and soil degradation resulting in greater cations loss in the grassland than the forestland.

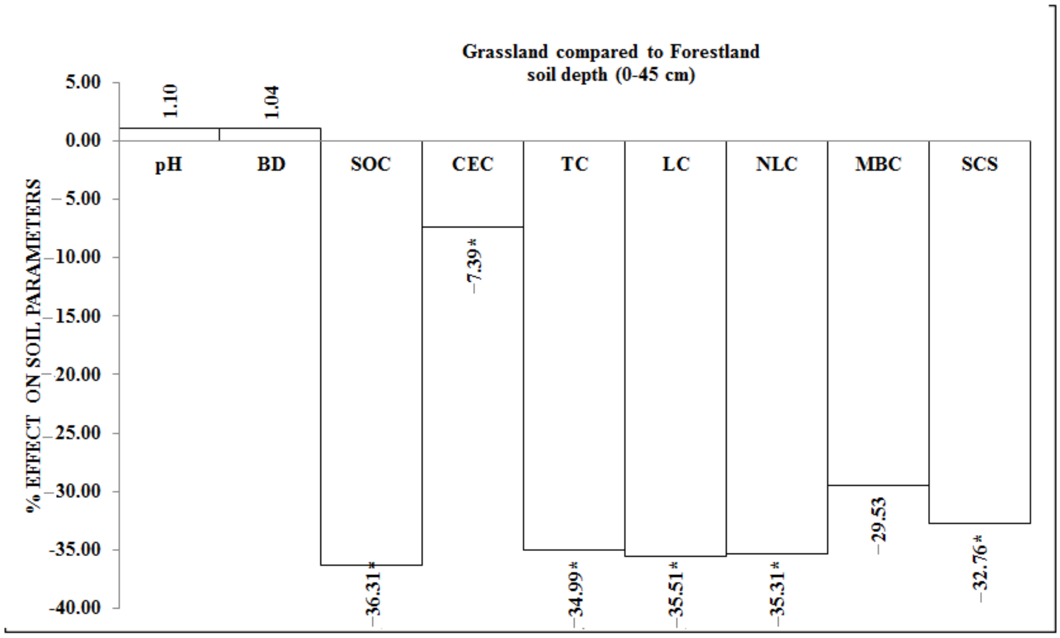


Figure 3. Percent mean effect of grassland compared to forestland in cumulative soil depth 0–45 cm on soil parameters in India (* indicates significant difference at p value < 0.05. Here, BD: bulk density, SOC: soil organic carbon, CEC: cation exchange capacity, TC: total carbon, LC: labile carbon, NLC: non-labile carbon, MBC: microbial biomass carbon and SCS: soil carbon stocks).

SC pools had negative effect in grassland than forestland (Figure 3). LC and NLC were significantly lower by 35.51% and 35.31%, in the grassland over the forestland whereas MBC was non-significantly lower (29.53%). The SC pools were lower in the grassland, which might be due to more exposure of organic matter resulting in accelerated organic carbon oxidation in this land use system. SCS also observed a negative effect on the grassland compared to the forestland. SCS was found to be 32.76% lower in the grassland than the forestland (Figure 3). The soil disturbance and removal of the vegetative cover from the grassland might be the reason for lower SCS.

3.3. Changes in Soil Characteristics by Land Use Change from Native Forestland to Grassland

In the study, the soil characteristics like soil pH and BD increased whereas SOC, CEC, and TC decreased in the grassland compared to the forestland (Table 4). The soil pH in grassland had a slightly positive edge in the soil depths 0–15 cm and 15–30 cm, while no difference was observed in the soil depth 30–45 cm. BD was significantly higher in the surface soil (0–15 cm) with no significant change in the subsurface soil. BD in the surface soil was 1.65% higher in the grassland than forestland (Table 4).

Table 4. Percent mean effect of grassland compared to forestland on soil characteristics at various depths in India.

Soil Depths (cm) \ Soil Characteristics	% Mean Effect of Grassland Compared to Forestland				
	Soil pH	BD	SOC	CEC	TC
0–15	0.91	1.65 *	−27.46 *	−5.95	−41.40 *
15–30	1.36	1.05	−41.35 *	−8.79 *	−11.19 *
30–45	0.00	−5.04	−63.71 *	##	##
Paireddatasets (*n*)	28	53	48	12	22

* indicates significant difference at p value < 0.05. Here, BD: bulk density, SOC: soil organic carbon, CEC: cation exchange capacity and TC: total carbon; ## insufficient data for analysis.

SOC was significantly lower in grassland than the forestland in all soil depths (Table 4). SOC was 27.46%, 41.35%, and 63.71% lower in the grassland than the forestland at 0–15, 15–30 and 30–45 (in cm) soil depths, respectively (Table 4). This showed that the trend of percent mean effect size of SOC in the soil depths were 0–15 > 15–30 > 30–45 (in cm). CEC was also found to have a negative effect in grassland compared to forestland, but the change was non-significant. Similar to SOC, TC was found to be significantly lower in the grassland compared to the forestland. TC was 41.40% lower in the grassland in surface soil and 11.19% in sub-surface soil compared to forestland (Table 4).

3.4. Effect on Soil Carbon Pools in Grassland Converted from Native Forestland

SC pools decreased in the grassland compared to the forestland (Table 5). LC was found to be significantly lower across all the soil depths. The LC was 28.42%, 55.64%, and 64.57%, lower, at soil depths of 0–15, 15–30 and 30–45 cm, respectively, in the grassland than the forestland (Table 5). The percentage trend means that the effect size of LC in the soil depths is similar to SOC, i.e., 0–15 > 15–30 > 30–45 (in cm). This suggested that the effect on LC was greater on the surface soil than the subsurface soil.

Table 5. Mean effect of grassland compared to forestland on soil carbon pools at various depths in India.

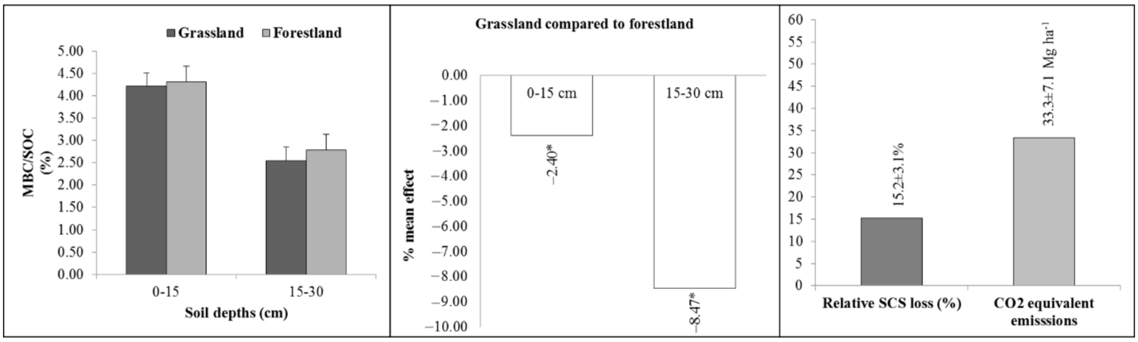
Soil Depths (cm) \ Soil Carbon Pools	% Mean Effect of Grassland Compared to Forestland		
	LC	NLC	MBC
0–15	−28.42 *	−40.05 *	−32.71
15–30	−55.64 *	−15.63 *	−25.06
30–45	−64.57 *	−51.04 *	##
Paired datasets (*n*)	34	13	15

* indicates significant difference at p value < 0.05. Here, LC: labile carbon, NLC: non-labile carbon, and MBC: microbial biomass carbon; ## insufficient data for analysis.

NLC significantly decreased across all the soil depths (Table 5). The NLC was 40.05%, 15.63% and 51.04% lower in soil depths of 0–15 cm, 15–30 cm and 30–45 cm, respectively, in the grassland compared to the forestland (Table 5). NLC was affected more at the soil depth of0–15 cm than soil depth of 15–30 cm. MBC decreased in the grassland compared to the forestland (Table 5).

3.5. Effect on MBC/SOC (%) and Equivalent Carbon Dioxide Emissions from Grassland Compared to Native Forestland

Data pertaining to MBC/SOC (%) of grassland and native forestland have been presented in Figure 4. The percent ratio was found to be higher in forestland than grassland and more in the surface soil than the subsurface soil. The percent ratio was 4.22 in grassland and 4.32 in forestland in the surface soil, while, in the subsurface soil the ratio was 2.55 in grassland and 2.79 in forestland. The addition of litter and root residue is greater in forestland in the surface soil, showing a higher percent ratio value. The study showed that surface and subsurface soil on MBC/SOC (%) were significantly decreased in grassland compared to forestland. The MBC/SOC (%) was 2.4% and 8.47% lower for 0–15 and 15–30 cm (Figure 4).



(**a**) (**b**) (**c**)

Figure 4. Effects of grassland compared to native forestland on (**a**). Microbial biomass carbon (MBC)/soil organic carbon (SOC) (%), (**b**). Percent mean effect on MBC/SOC (%), and (**c**). Relative soil carbon stock (SCS) loss and carbon dioxide (CO_2) equivalent emissions (Note: Metadata has been represented as mean ± S.E.).

Relative SCS loss was 15.2% in the grassland compared to forestland in the surface soil, and carbon dioxide equivalent emissions were 33.3 Mg ha^{-1} (Figure 4).

4. Discussions

4.1. Impact of Land Use Change on Soil Characteristics

The increase in the soil pH was 2.1% and 1.5%, respectively in the surface and subsurface soil of grassland as compared to native forestland. A meta-analysis of the datasets showed an increase in soil pH in grassland compared to native forestland in surface and sub-surface soil depths (0–15 cm and 15–30 cm). This might be due to differences in land management practices and land use histories in the grassland compared to forestland. In the forestland, it was observed that heavy rainfall resulted in leaching losses of bases, consequently decreasing the soil pH. However, in the grassland, grazing increased the soil pH. Similar findings on soil pH were found by several researchers [30–33]. BD is an important soil physical quality indicator that has a direct influence on land uses and management practices. The increase in the BD was 2.0% and 4.7%, respectively in the surface and subsurface soil of grassland as compared to native forestland. A meta-analysis of the datasets showed an increase in soil BD in grassland compared to native forestland in soil depths of 0–15 cm and 15–30 cm. The increase in BD in grassland might be an effect of soil trampling resulting from cattle grazing. A higher BD value was obtained in subsurface soil than surface soil in both land uses. The trend of BD's increase with soil depths is due to the effects of the load of the overlying soil and the corresponding decrease in SOC [4,34]. CEC is one of the important soil chemical quality indicators greatly influenced by land uses, climate, soil types and management practices. The decrease in CEC was 8.5% and 8.9%, in the surface and subsurface soil of grassland as compared to native forestland. The variability in vegetation, climatic conditions, and topography in both land uses is the main reason for the difference in CEC.

4.2. Soil Carbon Loss from Grassland

Our analysis indicated that SOC and SC pools were lower in grassland than the forestland in India, owing to the subsequent increased mineralization, leaching losses, and soil erosion. Land conversion from either forestland to grassland and further degradation of grassland affected the soil quality (including physical, chemical and biological properties of soil) due to overgrazing, burning, variation in shrub/grass species composition, and soil disturbances [35–41]. Such conversions may change the rate of inflow and outflow of SC as well as other nutrients [37,42,43]. In this study, the average SOC declined by 29.7% in the surface soil and 38.9% in the subsurface of grassland compared to native forestland. The decline in SOC in the grassland with respect to forestland is due to loss of organic matter due to overgrazing, poor management, deforestation, and land use conversion from grassland into croplands. Average TC reduced by 27.9% in the surface soil and 11.0% in the subsurface soil of grassland compared to forestland. LC pools are used as important soil quality indicators because they are likely to be more sensitive than TOC [44–49]. Among SC pools, average LC, NLC, and MBC in the surface soil was 26.1%, 22.9% and 31.4% lower, respectively, in the grassland than forestland. A similar trend was observed in the subsurface soil for SC pools. Extensive grazing reduced the belowground carbon in the grassland by 22%, with a higher decline in microbial biomass [42]. The meta-analysis data study on different SC parameters was found to be concurrent with the above-mentioned average decline in SC. The conversion of grassland from native forestland decreased SC and further affected nutrient cycling [50]. The increase in BD and decrease in SOC could explain the effect of SCS on the land uses in this study. The impact of SOC loss from 27–64% in this analysis represents a large quantity of carbon dioxide emissions associated with land conversion. In this study, SCS loss was 32.76% in grassland converted from native forestland. Land use can have a large effect on the size of soil C pool through conversion from forestland to cultivated land or grassland; SCS loss was 20–40% in India [51]. Within a land use type, variations in management practices can affect SC storage, particularly in cropland and grassland [52]. The average loss of SCS in carbon dioxide equivalent emissions in the study was 33.3 Mg ha^{-1}.

4.3. Management Strategies for Increasing Soil Carbon Storage in Grassland

This study presented the fact that, in India, SOC and SC pools were substantially lower in grassland compared to native forestland. The area under grassland has also declined due to either conversion to cultivated land or to degraded land. Hence, to mitigate SOC losses in grassland, proper management strategies are required for improving carbon storage in the soil [53,54]. SC storage can be improved through management practices like the establishment of land use system which is a combination of grasses with shrubs and trees known as a silvi-pastoral system that can significantly increase the biomass and help to add more litter and root residue [55–60]. Silvopastoral systems that include live fences, fodder banks, scattered trees on pasturelands, and tree planting at high density can enhance the SC storage [55,61,62]. Land spared in the grassland can be used for planting forests and increases the SCS within the livestock production units [63]. In Chilean Patagonia, comparison of the silvopastoral system and treeless grazing lands showed increased SCS of 0.06 Mg ha^{-1} year^{-1} translating to higher total SC storage by 47 Mg ha^{-1} in soil depth 0–40 cm [64]. In the humid tropics of India, SCS was observed to be higher in the coconut-based silvopastoral system (1.3 Mg ha^{-1} year^{-1}) than in open pastures [65]. In Central Matalagalpa Nicaragua, in the silvopastoral systems, SCS under trees was higher (16.4 Mg ha^{-1}) than in open grasslands [66]. In Guanacaste, Costa Rica, SCS improved by 43% after the continuous inclusion of leguminous trees in tropical pasturelands [67,68]. The use of legume species into degraded grasslands can improve soil fertility through nitrogen fixation. In Florida, USA, SCS improved by 51 Mg ha^{-1} in the silvopastoral system compared to subtropical pasturelands [69]. Alternative management options like rotational grazing, regulating appropriate grazing intensity, controlling soil erosion, and the escaping of biomass from fire can also improve SCS [70]. Worldwide studies have reported that management of grassland with improved irrigation, introducing earthworms, quality grass species and legumes, and balanced fertilization can store upto 0.54 Mg ha^{-1} year^{-1} [71].

5. Conclusions

Based on the analysis and discussions, it was found that for various soil properties, the soil pH and BD increased and SOC and SC pools decreased due to land use conversion. The loss of SCS from the conversion of native forest ecosystems to grasslands was significant at approximately 33%. Decrease in MBC/SOC (%) has detrimental impact on microbial activity and soil quality. Therefore, proper management strategies like agroforestry, introduction of legumes, silvi-pastoral system, improved fertilization, irrigation, and introduction of quality grass species could increase SCS in grassland and conserve the capability of soil to undertake SC storage.

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