

## Soil Carbon Sequestration Potential of Analog Forests in Comparison to Tea Plantation Areas of Up Country Intermediate Zone of Sri Lanka

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### ABSTRACT

Carbon sequestration can be used to reduce atmospheric carbon dioxide levels, thereby mitigating climate-change implications. Land-use changes determine the soil's ability to sequester and store carbon. This study aims to assess the soil organic carbon stock between the analog forest system and the cultivated tea area. Soil samples were collected from 0 to 10 cm, representing topsoil and 0 to 30 cm representing the subsoil. Analysis of the Variation (ANOVA) was used to compare the soil quality parameters of land-use types at two depths levels. Soil organic carbon stock (SOCS) was calculated for each sample location in the analog forest, and the SOCS was spatially predicted for

other areas in the analog forest using the Arc GIS 10.7.1 software. The study results revealed that analog forest systems have higher below-ground carbon fixation potential than monoculture systems. According to the statistical analysis, the amount of SOCS was 13 % higher in analog forests (33.95 Mg/ha > 29.93 Mg/ha). The application of the general linear model confirmed that both land use and soil depths are the significant driving forces of SOCS ( $P < 0.05$ ).

**Keywords:** Analog forest, Land use, Soil carbon sequestration, Soil organic carbon stock

### INTRODUCTION

The increasing greenhouse gas (GHG) concentration in the atmosphere is a critical issue for the natural functioning of the climate system. The third session of the conference of the parties to the United Nations Framework Convention on Climate Change (UNFCCC) in Kyoto, Japan, in 1997 completed the discussion on the atmospheric build-up of GHGs and their role in global warming (IPCC, 2014). The signing of a protocol had pushed participating countries to develop measures to reduce GHG

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concentrations in the atmosphere. Three mechanisms were suggested to reduce GHG levels, including emission reduction, joint implementation, and clean development (Kenye *et al.*, 2019). Further, carbon reduction targets are initially assigned to developed countries. The practice of those mechanisms helps to reduce anthropogenic carbon dioxide (CO<sub>2</sub>) emissions and improve carbon sinks in the biosphere (Albrecht and Kandji, 2003).

Under such circumstances, short- and long-term plans are required at different scales, such as local and international, to mitigate the adverse effects of global warming. Two alternative strategies are currently underway to mitigate climate change implications due to the rapid increase of GHG in the earth system. The first is emission reduction which concerns renewable energy use, reduction of fossil fuel use and improvements in the production lines targeting less pollution. The second is carbon fixation or carbon offset (Nunes *et al.*, 2019). Carbon fixation involves the removal of CO<sub>2</sub> from the atmosphere and storing them in different carbon reservoirs, including forest, soil and other land use systems in terms of biomass. Emission

reduction schemes are short-term, while carbon offset programs are long-term strategies. Forest restoration, sustainable forest management, reforestation and afforestation programs are some of the carbon offsetting mechanisms (Grubb *et al.*, 2019) that account for the absorbance of CO<sub>2</sub> from the carbon sources and neutralize their effect (Berndes *et al.*, 2016). Thus, the tree plantings, forest conservation and management practices will help to compensate for the harmful effect of CO<sub>2</sub> released from the combustion sources.

Establishing man-made forests is one of the sustainable solutions for mitigating climate change at a minimum cost (Valentini *et al.*, 2000), mainly in developing countries as a contribution to climate change mitigation. Analog forestry is a revolutionary silvicultural strategy for replanting degraded land that aims to create trees structurally and ecologically comparable to the region's original climax or sub climax vegetation (Veintimilla *et al.*, 2020). The establishments of analog forests are one of the potential solutions to offset atmospheric GHGs. In forests, 340 Gigatonnes of C (Gt C) are stored in above-ground and below-ground

pools. Maintaining a comparable system to forests is a useful strategy to remove excess CO<sub>2</sub> from the earth system. Tropical forest systems can hold a significant amount of carbon; for example, 62 % of the world's carbon pool is located in tropical forests (Reddy and Price, 1999).

Besides above-ground carbon pools, soil also plays an active role as a carbon reservoir, contributing to maintain the global carbon cycle. Soil is the biggest sink of organic carbon in the terrestrial ecosystem. It stores more than three times the amount of carbon stored in the atmosphere and 3.8 times the amount stored in the biotic pool (Kenye *et al.*, 2019). Vegetation controls soil organic carbon (SOC) through organic matter intake and litter decomposition. Therefore, SOC strongly depends on vegetation composition, climate change, and land cover change (Jobbagy and Jackson, 2000).

In the context of carbon assessment in forested ecosystems, many studies are concerned with estimating above ground carbon stocks. Even though much is known about above ground carbon stocks in tropical forests, below ground carbon content is

not well studied yet, specially in the restored forest areas in the tropics that humans developed. This research suggested that analog forests are positively linked with below-ground carbon storage. Therefore, this study hypothesizes that analog forests have high carbon sequestration potential so that these man-made systems will have higher below-ground carbon storage than the monoculture land-use systems.

The main objectives of this study were (1) to assess the soil organic carbon stock in topsoil (0-0.1 m) and subsoil (0.1-0.3 m) in analog forest and compare them with the adjacent tea cultivations which share a similar climate and geologic conditions, (2) to evaluate major drivers of soil organic stock and (3) to develop spatial maps to represent SOCS distribution in the analog forest system in two depths layers.

## **MATERIALS AND METHODS**

### ***Study Area***

Analog forest located at Belipola, Mirahawatte, (longitude 80. 93397<sup>0</sup> E, latitude 6. 87515<sup>0</sup> N), Badulla district, intermediate zone of Sri Lanka (Figure 1) was selected to represent man-made

forest system and adjacent tea lands that share the same climatic, and geological conditions (Table 1) were selected to represent an agricultural land-use system for comparing the soil organic stock and other soil quality parameters.

### *Sampling and Data Collection from Sites*

Random locations for collecting soil samples in analog forest and tea lands were determined using Geographic Information System (GIS). Altogether, 42 sampling locations were established in 21 Acre extent of analog forest, and an extent of 2 Acre tea lands in Belipola, Mirahawatta, Welimada areas. From each sampling point, soil samples were collected from 0-0.1 m (D1) and 0.1-0.3 m (D2) depth levels to represent topsoil and subsoil, summing up to 168 total

soil samples; from that 84 samples were collected to check the bulk density and other 84 samples were collected to record the other soil quality parameters such as organic carbon %, pH and Electrical Conductivity (EC).

### *Soil Analysis*

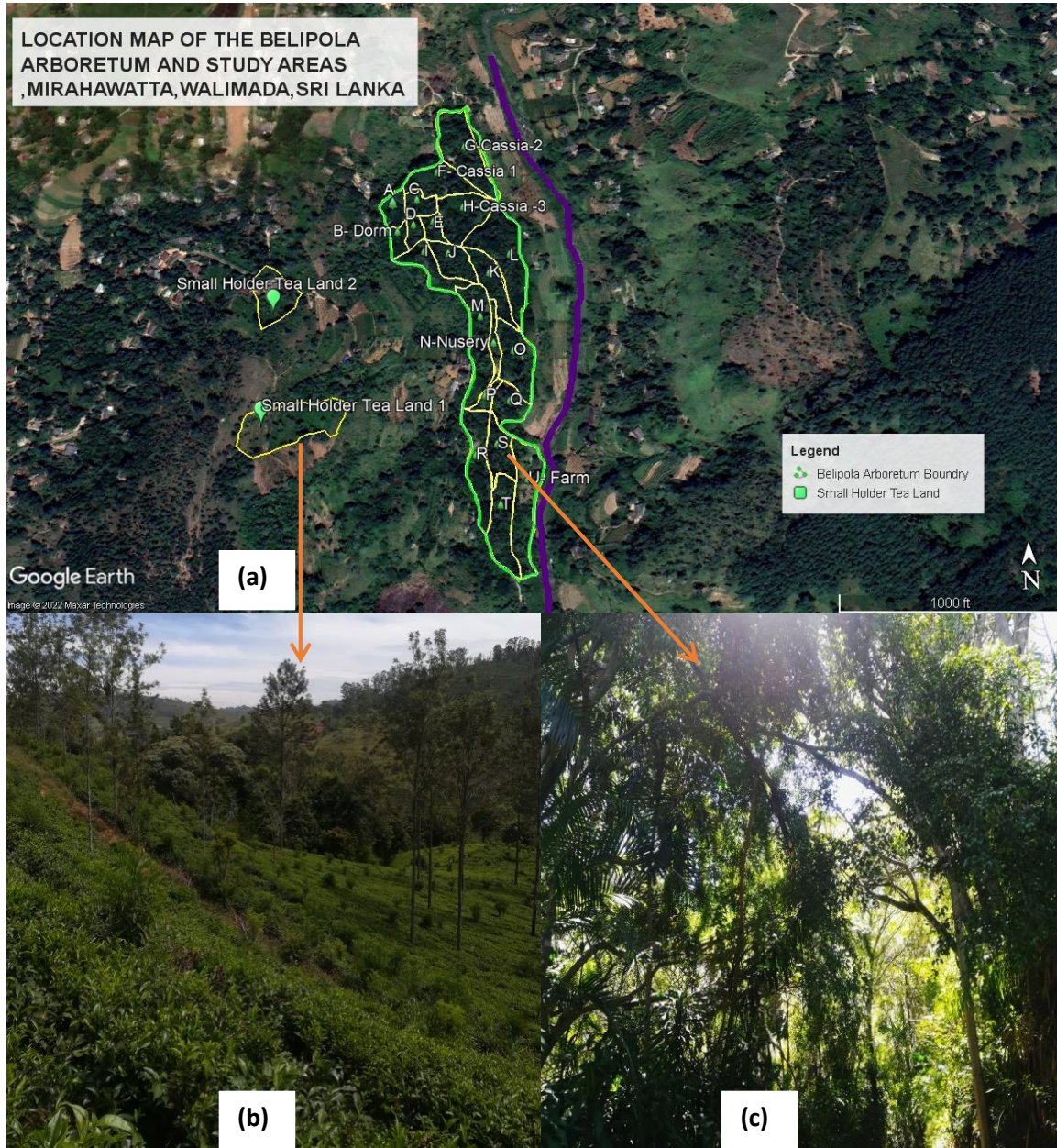
The laboratory analysis was carried out at the Faculty of Agriculture and Plantation Management, Wayamba University of Sri Lanka, Makandura, Gonawila (NWP), Sri Lanka. Before the laboratory analysis, soil samples were air-dried at room temperature and sieved using a 2 mm sieve. Soil samples were analyzed for pH, CaCl<sub>2</sub>, and electrical conductivity using a portable pH/ EC meter (Dharmakeerthi *et al.*, 2007). Soil organic carbon was quantified by using

**Table 1.** Climate and other site characteristic

| Information on climate/soil / other | Site Characteristics                            |
|-------------------------------------|-------------------------------------------------|
| Location                            | Lat: 06. 87515 N, Long: 80.933397 E             |
| Agro-ecological region              | Up Country Intermediate zone (IM <sub>1</sub> ) |
| Elevation                           | 1100 - 1350 m                                   |
| Mean Annual Rainfall                | 2500 mm                                         |
| Mean Annual Temperature             | 26 °C                                           |
| Dry season                          | May to September                                |
| Wet season                          | October to February                             |

Walkley and Black method (Walkley and Black, 1934). Finally, bulk density

was determined by the core sample method (Blake and Hartage, 1986).



**Figure 1.** Selected study locations in the study area at Mirahawatta, Welimada, Sri Lanka. (a) Google earth image of the study area, outlining analog forest and tea cultivated areas in polygons. (b) Photograph illustrating adjacent tea cultivated area that was selected for data collection (c) Photograph illustrating analog forest and its canopy development at Belipola Arboretum.

### ***Calculation of Soil Organic Carbon Stock (SOCS)***

Soil Organic Carbon Stock (SOCS) was estimated in both analog forest and tea cultivation field at 0-0.1 m (D1) and 0.1-0.3 m (D2) depth levels to represent topsoil and subsoil. SOC was calculated as expressed by equation 1 (Kunlanit *et al.*, 2019).

$$\text{SOCS} = \text{OC} (\%) \times \text{BD} (\text{Mg/m}^3) \times \text{D} (\text{cm}) \times 100 \text{ (1)}$$

where; SOCS is the Soil Organic Carbon Stock (Mg/ha), OC is Organic Carbon percentage, BD is the bulk density (Mg/m<sup>3</sup>) and D is the depth of the soil (cm).

### ***Soil Mapping***

A portable global position system (GPS) was used to locate the soil sample collection points. The analyzed data were imported into the geographical information system (GIS) database, version 10.7.1. The spatial variation of soil organic carbon stock for the analog forest was developed for the top soil and sub soil layers using point data on SOCS.

### ***Statistical Analysis***

Statistical significance of the effect of land-use type and the soil depth on organic carbon stock was evaluated by using ANOVA test, using Minitab, version 15 and R Studio team 2018. In addition, multiple comparisons across land-use type and soil depth layer were undertaken with Tukey's pairwise comparison test.

## **RESULTS AND DISCUSSION**

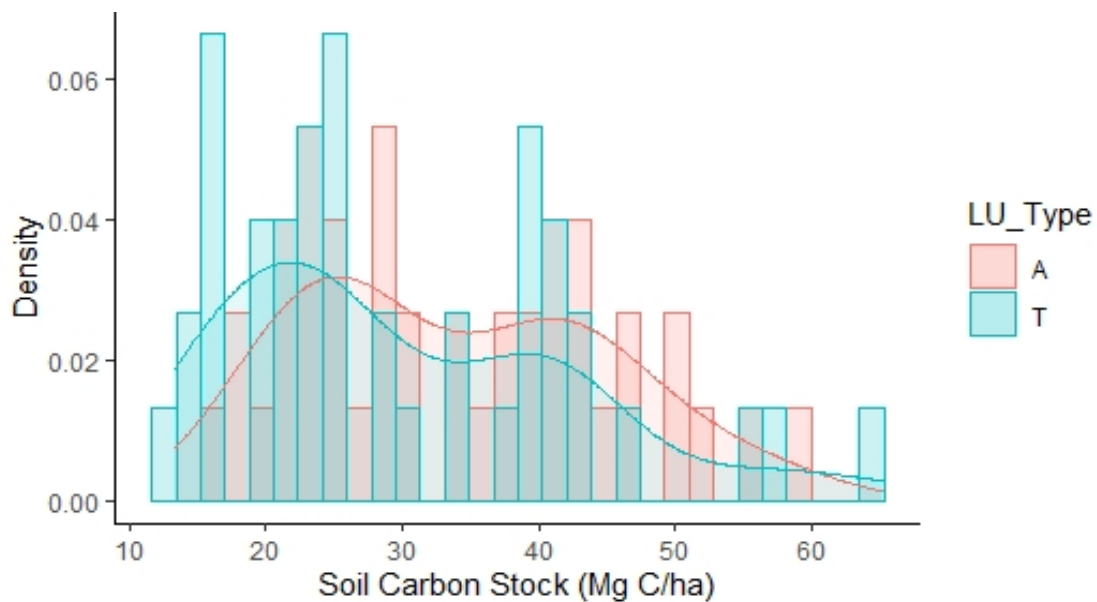
### ***Comparison of Soil Quality between the Analog Forest and the Tea Cultivation***

The results were supported to accept the first research hypothesis that the mean SOCS varies significantly with the land use. The frequency distribution of SOCS shows analog forests hold higher organic carbon stock than cultivated tea areas (Figure 2). The amount of SOCS was 13 % higher in the analog forest than in the nearby tea cultivated land (33.95 Mg/ha > 29.93 Mg/ha, Table 1). Soil organic carbon content depends on various factors, including soil type, land-use type, land-use change, climate and soil management practices (Houghton *et al.*, 2012; IPCC, 2014).

Some areas in the analog forest system represent the trees with a dense canopy and a considerably developed root system. According to Sheikh and Tiwari (2013) high carbon accumulation was reported in the areas where taproot trees are available. This can be attributable to relatively higher SOCS revealed in the analog forest system compared to the cultivated tea area. However, this analog forest is still in the progression of the succession as it is on the sub-climax status. In the analog forest, areas that reach the climax vegetation, similar to natural forests, are relatively smaller in extent. Besides that, high SOCS in the analog forest can be related to high biomass presence in

this system, which returns to the soil as organic carbon as forms of litter layer and decaying organic compounds.

SOCS in the tea land is closer to the analog forest and it may be due to the farmers' good agricultural practices, including pruning and mulching. These practices help to return the organic C to the soil (Young, 1997). Although these selected tea cultivations near the analog forest located in the sloping terrain, soil rehabilitation practices, soil erosion conservation methods, shade tree management and drain management practices would help to keep the SOCS amounts close to the analog forest.



**Figure 2.** The probability density of soil organic carbon stock (Mg of Carbon ha<sup>-1</sup>) in Analog forest and Tea cultivated area. LU-Land Use, A-Analog Forest, T-Tea Land.

We found that bulk density (BD) in tea land was significantly lower than that of analog forest (Table 2). Due to limited activities within the analog forest to improve the soil, soil compaction may be higher in the analog forest than in the cultivated tea area. In contrast, weeding and fertilization had done in the smallholder tea cultivation lands that we selected for data collection during this study. This could be the reason for the reported lower bulk density for cultivated tea areas.

The one-way ANOVA results show that soil pH is significantly lower in the cultivated tea areas (Table 2) than in the analog forest (pH: 4.0 and pH: 3.3 in analog forest and tea cultivation, respectively,  $P < 0.05$ ). Aweke *et al.*, (2013) stated that prolonged application of nitrogen fertilizer causes depleted soil pH in monoculture areas.

Therefore, nitrogen fertilizer application could be the causal factor for this pH difference between the two land-use systems.

On average, Electrical Conductivity (EC) is significantly lower in the analog forest than in the tea cultivation (50.86  $\mu\text{S cm}^{-1}$ , 71.67  $\mu\text{S cm}^{-1}$ ,  $P < 0.05$ , analog forest and tea cultivation, respectively).

#### *Variation of SOCS and Other Soil Quality Parameters between Top and Subsoil Layers*

Our second research hypothesis (the mean SOCS varies significantly between top and subsoil) was accepted as SOCS varied considerably between 0-0.1 m and 0.1-0.3 m soil layers (Table 3).

**Table 2.** Land use effect on soil parameters (Results of one-way ANOVA, land use as a factor)

| Parameter                    | Forest | Tea cultivation | F-value | <i>p</i> -value |
|------------------------------|--------|-----------------|---------|-----------------|
| SOCS ( $\text{Mg ha}^{-1}$ ) | 33.95  | 29.93           | 3.78    | 0.050*          |
| BD ( $\text{Mg m}^{-3}$ )    | 1.23   | 0.87            | 30.61   | 0.000***        |
| pH ( $\text{CaCl}_2$ )       | 4.09   | 3.38            | 31.80   | 0.000***        |
| EC ( $\mu\text{S cm}^{-1}$ ) | 50.86  | 71.60           | 5.39    | 0.023**         |

BD: Bulk Density, pH, EC: Electrical Conductivity, SOCS: Soil Organic Carbon Stock, \*, \*\* and \*\*\* denote significance with  $P < 0.05$ ,  $P < 0.01$  and  $P < 0.001$ , respectively.

Confidence intervals of SOCS for 0-0.1 m and 0.1-0.3 m were not overlapped for both analog and tea cultivation areas, which shows the significant difference in SOCS between the two soil layers ( $P < 0.05$ ). In this analog forest system, SOCS in the topsoil (0-0.1 m) was lower than that in the subsoil (0.1-0.3 m). Our results are in line with the observations from secondary forests in the Intermediate Zone of Sri Lanka (Rathnayake *et al.*, 2018), which indicated that the topsoil contained less SOCS than the subsoil. They showed that the secondary forest contained more canopy gaps and is yet to be developed into the fully covered vegetation. Thus the soil is more exposed to soil erosion and displacement of topsoil particles is

possible in secondary forests. Similarly, less organic matter in the topsoil in the analog forest system may be attributed to lower levels of canopy development in some areas (not attained to the climax level yet and canopy gaps in the forest overstorey) and relatively higher soil erosion in other parts of the studied analog forest due to the terrain with a steep slope.

Boyle (2005) stated that forests with steep slopes and rocky landscapes bear shallow topsoil, low organic matter amount and therefore have less water holding capacity. For Examples, Norwegian and Swedish mountain forests, the Alps, and Rocky Mountains of North America.

**Table 3.** Comparison of soil parameters between analog forest and tea land in topsoil (0-0.1 m) and subsoil (0.1-0.3 m)

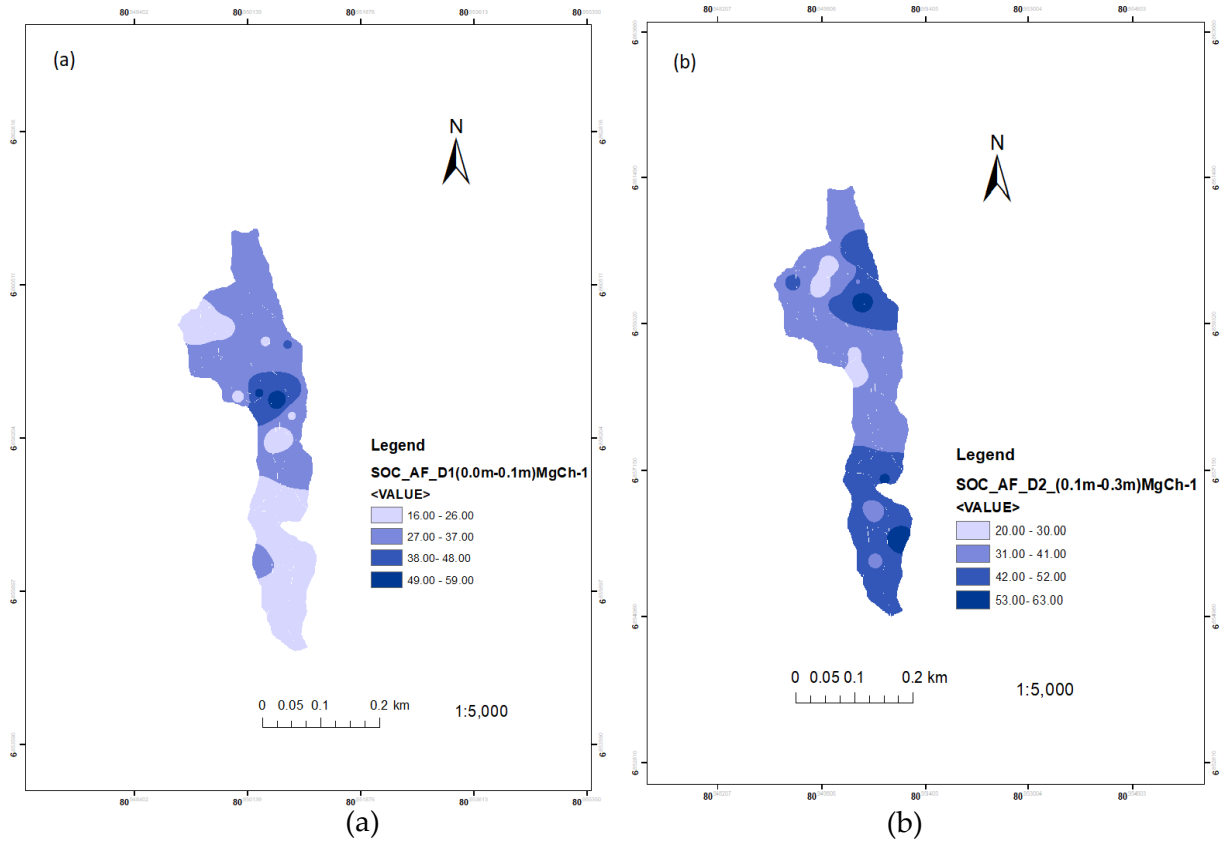
| Parameter                   | Analog Forest |           |          | Tea Land |           |         |
|-----------------------------|---------------|-----------|----------|----------|-----------|---------|
|                             | Mean          |           | P-Value  | Mean     |           | P-Value |
|                             | 0-0.1 m       | 0.1-0.3 m |          | 0-0.1 m  | 0.1-0.3 m |         |
| SOCS (Mg ha <sup>-1</sup> ) | 27.17         | 40.71     | 0.000*** | 21.94    | 37.92     | 0.048*  |
| BD (Mg m <sup>-3</sup> )    | 1.36          | 1.11      | 0.022*   | 0.94     | 0.81      | 0.048*  |
| PH (CaCl <sub>2</sub> )     | 4.13          | 4.05      | 0.630    | 3.55     | 3.21      | 0.070   |
| EC(μS cm <sup>-1</sup> )    | 61.60         | 40.12     | 0.005*   | 63.62    | 54.98     | 0.333   |

BD: Bulk Density, pH, EC: Electrical Conductivity, SOCS: Soil Organic Carbon Stock, \* and \*\*\* denote significance with  $P < 0.05$  and  $P < 0.001$ , respectively.

Further, results suggested that bulk density and electrical conductivity significantly differed between top and subsoil in the analog forest system. In tea cultivation, bulk density and pH were significantly changed with the soil depth, not the electrical conductivity (Table 3). Finally, applying the general linear model confirmed that both land use and soil depth are the significant driving forces of SOCS.

### *Spatial Mapping of SOCS in the Analog Forest System*

SOCS were interpolated for the whole analog forest system using the measured SOCS from sampling points of the analog forest. Spatial variation of SOCS in 0-0.1m (D1) and 0.1-0.3 m (D2) depths are shown in Figures 3(a) and 3(b).



**Figure 3.** Developed spatial scale maps for showing the variation of SOCS in Analog forest (Mg of carbon ha<sup>-1</sup>); (a) SOCS variation at top soil D<sub>1</sub> (0.0 m-0.1 m), (b) SOCS variation at sub soil D<sub>2</sub> (0.1 m-0.3 m).

## CONCLUSION

This study has shown that analog forest systems have higher below-ground carbon fixation potential than monoculture systems (tea cultivation). The amount of SOCS was 13 % higher in the analog forest than in the cultivated tea area. This study reveals that higher SOCS in the analog forest system is a function of high biomass levels, rich species composition, and ecological restoration abilities.

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