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NATURAL RUBBER TIRE WASTE CHARCOAL (NRTWC) ON ORGANIC CARBON MINERALIZATION IN TEA GROWING SOILS

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ABSTRACT

The aim of this study was to assess the impact of natural rubber tire waste charcoal (NRTWC) amendment on carbon mineralization in tea cultivated soils in low country wet zone of Sri Lanka. NRTWC was applied at different rates (0%, 1%, 1.6%, 2.2% and 2.8% w/w) and carbon mineralization in soil was evaluated at 10 and 20 weeks after the treatment. Representative samples were incubated for 42 days and microbial respiration was determined. During the first seven days of incubation, a rapid carbon mineralization was observed for all the treatments. A rapid decline of carbon mineralization was then observed during the period from 14th to 28th day of incubation. No changes were observed towards the end of the incubation (35 to 42 days). Significant ($P \leq 0.05$) differences among the different rates of NRTWC application were noticed during the initial stages of the incubation. However, the variations were minimal after 14th day of the incubation. The cumulative carbon mineralization ranged from 506 to 1072 mg/kg soil for the samples taken at 10 weeks after treatment. The corresponding variation changed from 506 to 1730 mg/kg soil for the samples drawn at 20 weeks after treatment. The cumulative soil carbon mineralization increased rapidly during the early stages, then decreased gradually and finally flattened out towards the end of the incubation. The application of NRTWC resulted in a substantial increase in cumulative carbon mineralization when compared with the control. As revealed by the results, NRTWC decomposes slowly and can be considered as a sound source of soil amendment which could enhance soil carbon sequestration in degraded tea soils.

Keywords: Carbon sequestration, Soil degradation, Organic matter decomposition, Soil amendments

INTRODUCTION

Most of the solid waste materials are considered to be non-degradable, thus accumulation of them is a serious environmental problem worldwide (Adhikari *et al.*, 2000). Rubber tire waste which is comprised of 12% solid wastes is notable portion of solid waste materials produced throughout the world creating environmental, economical and social problems (Ghiasi *et al.,* 2015). The global annual tire production and their disposal as waste has increased yearly due to increased in human population (Torretta *et al.*, 2015). It is estimated that globally 4 billion tons of tires are generated annually (Czajczynska *et al.*, 2017) and the number would be increased to five billion by the year 2030 (Thomas *et al.,* 2016). Rubber tire wastes are non-biodegradable due to their physical and chemical structure and remain for several years in the environment. Landfilling, retreading, gasification, incineration and pyrolysis are some of the waste tire disposal mechanisms adopted by different countries including Japan, South Korea and China (Undri *et al.*, 2013a; Duan *et al.*, 2015; Li *et al.*, 2016). Most of the developing countries stockpile the waste tires for land filling at disposal sites. It occupies substantial piece of usable lands (Alsaleh *et al.*, 2014) and provides breeding environment for pest and insects. Such tires at the disposal sites trap gases which cause floating to the top with the time (Juma *et al.,* 2006). Some countries have legally prohibited the land filling with waste tires (Junqing *et al.*, 2020). Therefore, finding feasible and cost-effective solutions to treat rubber waste tires is paramount importance.

Pyrolysis is considered as a promising approach which could minimize the tire disposal problem (Debnath *et al.*, 2018) since it lowers the negative impacts on the environment (Junqing *et al.*, 2020). It produces potentially useful products such as Pyrolysis oil comprised of aromatic and aliphatic compounds, non-condensable mixture of pyrolysis gases and solid coke (char or pyrolytic carbon black) (Williams, 2013). This pyrolytic carbon black is similar to biochar in nature (Junqing *et al.*, 2020). Due to its very slow decomposition, it ensures maintaining soil organic matter content for a longer period of time

Tea (*Camellia sinensis* L.) is an upland perennial crop grown in many tropical and subtropical regions. Soil degradation has been identified as an inescapable threat which severely restricts the productivity of most of the tea growing soils in Sri

Lanka. Soil degradation is known to be accelerated by unfavorable environmental conditions such as high rainfall and high temperature which fasten organic matter decomposition, heavy usage of agrochemicals and soil erosion. In this regards, application of organic amendments with high organic matter content is considered as feasible approach in restoration of degraded tea soils. Soil microorganisms act as an agent for soil organic matter decomposition, nutrient mineralization and main soil processes (Li *et al.*, 2018). Amending soils with high carbonaceous material may enhance the activity of soil microorganisms. Soil carbon mineralization is considered to be a direct indicator of organic matter decomposition of a soil. The present study assessed the impacts of soil amendment with different rates of Natural Rubber Tire Waste Charcoal (NRTWC) on soil carbon mineralization (microbial respiration) in tea growing soils.

METHODOLOGY

Experimental Site

Well-managed 8 years old tea plantation located at Aturaliya D.S. Division of Matara District in Southern Sri Lanka was selected for the study. The selected area comes under the agro-ecological region low country wet zone (WL2). The annual rainfall, annual mean air temperature and relative humidity of the area were 2500 mm, 22-30 ^{0}C and 80 % respectively. As listed in the United States of Department of Agriculture soil taxonomy, the soil of this area belongs to Red Yellow Podzolic (local classification) and falls under Rhodudults (Soil survey staff 2014, USDA classification). Table 1 depicts some key physico-chemical properties of the soil determined through standard methods.

Hydrometer method (Gee and Or, 2002) was used in determining soil texture and soil pH was measured using (1:2.5 soil: water) pH meter (HI 98127 HANNA). Walkley and Black method (Nelson and Sommer, 1996) was used in calculating organic carbon (OC) content and thereby determined the organic matter (OM) content using the formula (OM% = 1.721 × OC). Exchangeable K^+ was extracted by ammonium acetate (NH_4OAC) and determined using a flame photometer (Helmke and Sparks, 1996). Available soil phosphorous was extracted according to borax method (Dick and Tabatabai, 1977) and determined using a spectrophotometer (UV-VIS 160 Shimadzu). The NH_4^+ - N content was determined utilizing the Berthelot reaction (Searle, 1984) and the NO_3^- - N by sodium salicylate yellow colour method (Bremner, 1960).

Table 1: Some important physico-chemical properties of natural rubber tire waste charcoal and experimental soil. Values given here are the means (n = 4) ± standard deviation.

Properties	NRTWC	Soil
Organic matter (%)	85.8 ± 0.1	2.25 ± 0.008
Bulk density (g/cm^3)	0.2±0.005	1.39 ± 0.06
Porosity (%)	61.53±1.33	37.83 ± 1.1
pH	7.76±1.41	5.3 ± 0.4
EC (dS/m)	0.89±0.1	0.035±0.005
NO_3^- - N content (mg/Kg)	1.5±0.3	1.78 ± 0.09
NH_4^+ - N content (mg/Kg)	23.98±0.6	11.69 ± 0.14
Available P (mg/Kg)	4.96±0.05	2.15 ± 0.42
Exchangeable Ca (mg/Kg)	416.29±57.22	146.52 ± 6.79
Exchangeable K (mg/Kg)	358.16±7.04	14.21 ± 0.55
Exchangeable Na (mg/Kg)	82.52±3.44	9 ± 0.45

Production of natural rubber waste tire charcoal (NRWTC)

Waste tires were collected from dumping sites of tire shops from Akuressa and Kamburupitiya areas of Matara District, Sri Lanka. Excavated pit (one cubic meter) was tightly filled with waste tires. A thick metal sheet was used to seal up the chamber to limit the oxygen supply slowing down the burning process, reducing the emission of carbon monoxides (CO) which ensured good quality charcoal with higher carbon content. After about 3 and ½ hours of the pyrolysis process, the lid was removed, and some water was poured to avoid aerobic oxidation. This method is considered to be one of the oldest and simplest methods of charcoal making which is still widespread (Seijo and Teira-Brion, 2019). NRTWCs were then air dried, broken up to pieces with a hammer and crushed charcoals were passed through 250-µm mesh to remove larger particles. Some physico-chemical properties of NRTWC were determined following the standard procedures (Table 1).

Treatments

Generally, well-managed tea plantations in Red Yellow Podzolic soil should have 5% soil organic matter content (Sandanam and Coomaraswamy, 1982). The organic matter content of the present experimental soil and NRTWC were measured as 2.25% and 85.8% respectively. Therefore assuming that addition of NRTWC which contain 85.8% organic matter could increase the organic matter content of the experimental soil up to 5%, treatment calculations were done. Accordingly, there were five NRTWC application rates as 1% (20% less than requirement), 1.6% (requirement), 2.2% (20% higher than requirement), 2.8% (40% higher than requirement) and a control (without NRTWC application - 0%). These values are equal to a 21 t/ha, 33.6 t/ha, 46.2 t/ha, 58.8 t/ha and a control application rates.

Application of NRTWC

NRTWC was incorporated to the top 10 -15 cm layer of the manure circle of tea plants using hand-held shovels. The experimental area was 0.01 ha which contained 20 individual plots each having 1.5 m X 1.5 m size. A complete randomized block design was used with four replicates. NRWTC treated and untreated plots were separated with a 1.5 m wide buffer. Each experimental plot consisted of 10 tea bushes

Soil sampling

Soil samples were collected after 10 and 20 weeks of treatment application. Surface litter of the soil was removed and each plot of soil was randomly sampled using the five-point composite method throughout the entire experimental site from 0-15 cm depth using an auger. The composite soil samples were kept in polythene bags and transported to the laboratory. Then, soil samples were air-dried and sieved through a 2 mm mesh for the chemical characterization and incubation study.

Carbon mineralization

Soil carbon mineralization in the soils treated with different rates of NRTWC was assessed in a laboratory incubation conducted under dark condition for 42 days. Air dried and 2 mm sieved soil samples (50 g) were placed in gas-tight glass containers along with a vial containing 10 ml of 1 M NaOH to trap CO_2 and a vial of water to maintain the humidity. The treated and untreated soils in glass bottles were watered to adjust the moisture content to 60% field capacity before the incubation. There were three replicates per treatment. A control treatment (without soil samples) in triplicate was also included. Control and treated samples were arranged as a Randomized Completely Design. Soil was incubated at room temperature (27 ºC) and NaOH traps were replaced at 7, 14, 21, 28, 35 and 42 days after the treatment. Unreacted alkali in the NaOH traps was titrated with 0.5 M HCl to determine CO_2 -C released from the soil (Alef, 1995). Sufficient soil moisture content was maintained throughout the incubation period.

Statistical analysis

All the data derived from the experiment were subjected to analysis of variance (ANOVA) using SAS package (SAS, 1999). The Duncan's Multiple Range Test (DMRT) was applied to test the significance of treatment means at $P \leq 0.05$.Values were given as means ± SD for the replicated samples.

RESULTS AND DISCUSSION

Periodic changes in carbon mineralization (as measured by CO_2 evolution) in soil amended with different rates of NRTWC are depicted in Figure 1 (a and b respectively for 10 and 20 weeks after application).

The highest C mineralization was observed in the soil treated with NRTWC at 2.8% followed by 2.2%. The soil which did not receive NRTWC exhibited significantly ($P \leq 0.05$) lower C mineralization compared to all the other treatments. During the early stage of incubation (1 to 7 days), a rapid C mineralization was observed in all treatments for both incubated soils. Thereafter, C mineralization was rapidly declined (14 to 28 days) and reached to a constant towards end of the incubation period (35 to 42 days). Significant ($P \leq 0.05$) differences among the different rates of NRTWC were observed at the initial stages of the incubation, however, the variations were minimal after day 14 of the incubation in both soils.

During the first 7 days of incubation, C mineralization ranged from 279 mg/kg (control) to 401 mg/kg (2.8% application rate) after 10 weeks of NRTWC application. The corresponding figures after 20 weeks of application were 258 mg/kg (control) and 668 mg/kg (2.8% application rate) The cumulative C mineralization of both soils are shown in Figure 2. The cumulative total carbon mineralization were significantly different among the four treatments (1%, 1.6%, 2.2% and 2.8%), ranging from 506 to 1072 mg/kg soil for after 10 weeks of treatment application and 506 to 1730 mg/kg soil for 20 weeks after treatment application (Figure 2). The application of NRTWC showed a substantial increase in cumulative carbon mineralization when compared with the control (Figure 2). There were significant ($P \leq 0.05$) differences in carbon mineralization in soils 10 and 20 weeks after treatment application.

Periodic changes in cumulative carbon mineralization after 10 and 20 weeks of different rates of NRTWC application are depicted in Figure 3 (a) and (b) respectively. Significantly ($P \leq 0.05$) higher carbon mineralization was observed in soil amended with NRTWC compared to the control both at 10 and 20 weeks after treatment application. However in the case of cumulative carbon mineralization, no significant ($P \leq 0.05$) difference was observed between the application at rates 1% and 1.6%.

Continuous degradation of tea soils in Sri Lanka is becoming matter of great concern as it causes severe yield reduction. Use of organic amendment to improve organic matter and organic carbon content is an accepted practice as it could ensure the restoration of degraded soils. Furthermore,

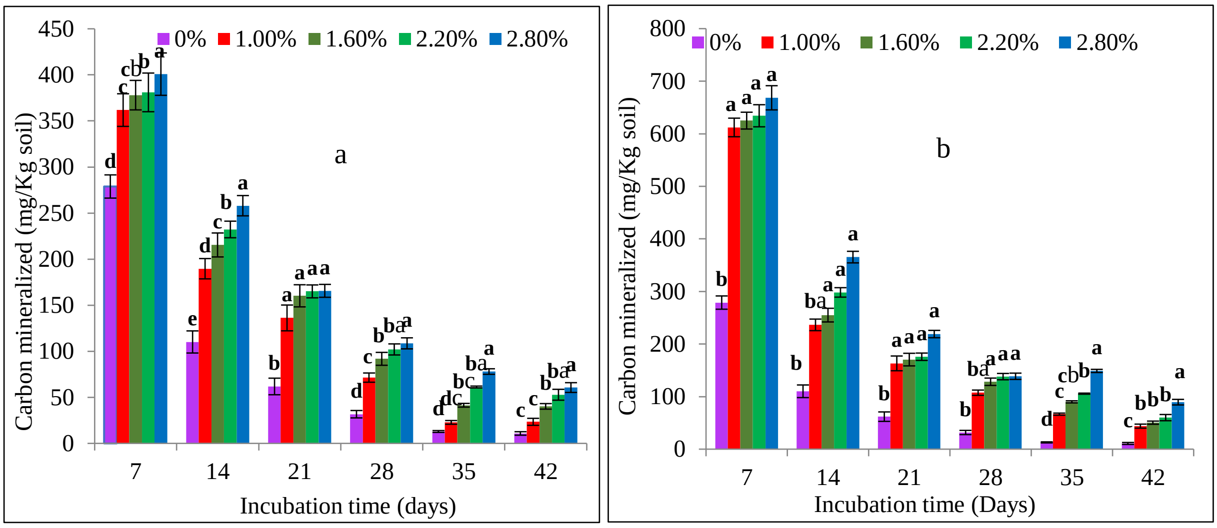

Figure 1: Carbon mineralization after the incubation of soil treated with different rates of NRTWC (a) 10 weeks after treatment application (b) 20 weeks after treatment application. Means with the same letters are not significantly different at $p \leq 0.05$

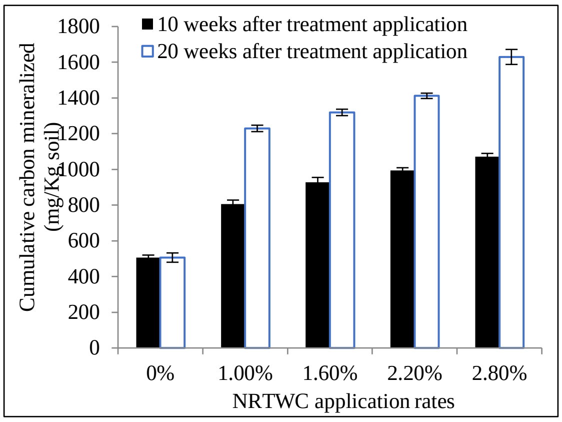

Figure 2: Cumulative carbon mineralization by soil treated with different rates of NRTWC at 10 weeks and 20 weeks after treatment application. Means with the same letters are not significantly different at $p \leq 0.05$.

increase in soil organic matter content stimulates the soil microbial biomass, microbial activity and nutrient mineralization (Larkin, 2015; Francioli *et al.*, 2016). Such degradation could be evident in the present experimental soil as it contains low organic matter content, low soil pH (acidic), and high bulk density (Table 1). Therefore, maintaining desirable soil organic matter level in the soil is crucial to enhance soil productivity and soil quality. Pyrolytic carbon black which can be recovered as main product of natural rubber tire pyrolysis is very much similar to biochar in nature (Junqing *et al.*, 2020).

Soil organic carbon mineralization was high during the first week of incubation. Similarly intense increase in carbon mineralization/microbial activity during initial days of the incubation was observed by other researchers (Tsai and Chang, 2019; Luo *et al.*, 2016). This may be due to starting microbial activity following watering to adjust the moisture content to 60% field capacity in treated and control soil before the incubation. NRTWC is a highly porous carbonaceous amendment and its high porosity (macropores) can serve as vital habitats for growth and breeding sites for microorganisms (Pietikäinen *et al.*, 2000). Therefore comparatively higher carbon mineralization could be seen throughout the incubation period when soils treated with NRTWC. Both aerobic and anaerobic bacteria can effectively decompose tire rubber polymers (Stevenson *et al.*, 2008). The microorganisms which are capable of decomposition tire rubber have been isolated by many researchers (Atagana *et al.*, 1999; Bode *et al.*, 2001; Bredberg *et al.*, 2001; Rifaat and Yosery 2004; Khoshgoftarmanesh *et al.*, 2012).

After the first week of incubation, C mineralization showed a decreasing trend during the later part of the incubation which might due to decrease in easily degradable of labile organic carbon for microbial decomposition. Generally, most of the easily available soil organic amendments are found to be readily decomposed and last for a short period of time. NRTWC was produced using pyrolysis process with high temperature with the absence of oxygen. This carbonaceous material contains very high amount of organic carbon (50%) and their aromatic and crystalline structure relatively resistant to microbial decomposition and chemical transformation. Therefore NRTWC could be considered as a stable form of carbon which could remain in the soil for years maintaining the soil organic carbon status. The reduction of carbon mineralization after first week of incubation indicates the reduction in organic matter decomposition. It enhances carbon sequestration and nutrient storage in soil which could therefore minimize the application of inorganic fertilizer (Tsai and Chang, 2019).

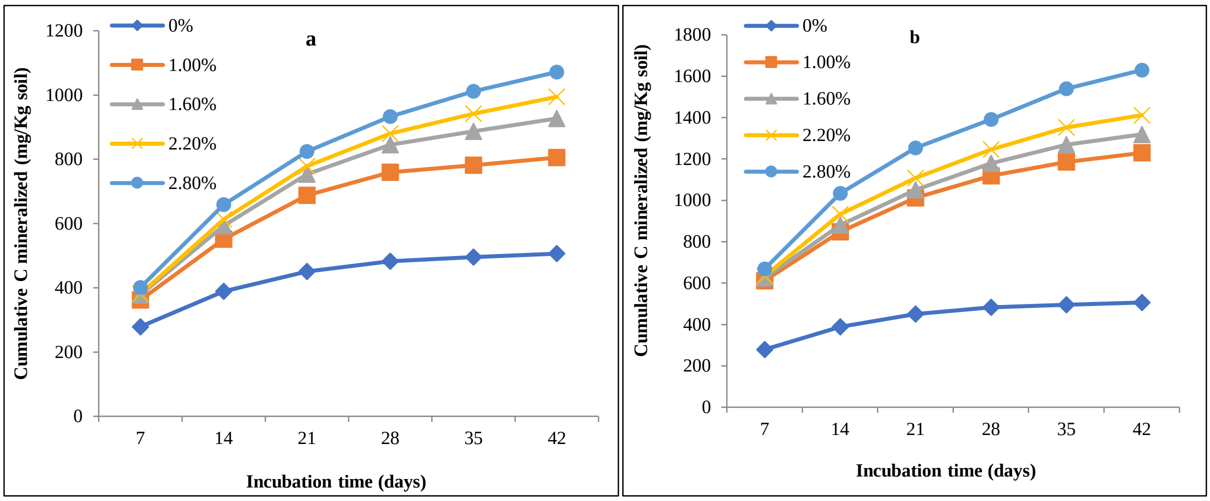

Figure 3: Cumulative carbon mineralization after incubation of soil treated with different rates of NRTWC (a) 10 weeks after treatment application (b) 20 weeks after treatment application. Means with the same letters are not significantly different at $p \leq 0.05$.

As stated by Kuzyakov *et al.* (2009), char begins mineralizing in early stages (during first week), and slow, partially decomposition occurring during the later stage, and finally incorporation into the soil. According to them, addition of char to many low pH agricultural soils can result in major physico-chemical improvements such as microbial activity and availability of soil nutrients. Tea soils have an inhibitory influence on soil microorganisms due to acidity and aluminum toxicity (Karak et al., 2015). As stated by Arafat *et al.* (2020), soil pH in tea estates is significantly lower than in the bulk and 2-year garden soil. According to Xu *et al.* (2014), when char was applied to acidic soil, it enhanced crop yield through improving soil chemical conditions (neutralizing soil pH) and changing the availability of nutrients. It can also have some impacts on the soil microbial community. However, it needs a longer period of time to ameliorate the soil properties and to show a significant impact on plant growth.

CONCLUSIONS

According to the results, rapid carbon mineralization could be observed during the first week of incubation followed by a decline. The cumulative carbon mineralization ranged from 506 to 1072 mg/kg soil for the samples taken at 10 weeks after treatment. The corresponding variation changed from 506 to 1730 mg/kg soil for the samples drawn at 20 weeks after treatment. However, the variations were minimal after second week of the incubation and no changes were observed towards the end of the incubation (35 to 42 days). The cumulative soil carbon mineralization increased rapidly during the early stages, then decreased gradually and finally flattened out towards the end of the incubation. Availability of easily degradable labile organic carbon for microbial decomposition could be the reason for rapid mineralization during the early stages. The gradual reduction of carbon mineralization after the first week of incubation indicates the reduced organic matter decomposition. NRTWC could improve the carbon sequestration and nutrient storage in the soil. Therefore, NRTWC application could increase soil quality while enhancing the carbon sequestration in soil.

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