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RESEARCH ARTICLE

Effect of natural rubber tire waste charcoal (NRTWC) on soil chemical properties in tea growing soils

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ABSTRACT

Soil chemical properties are playing key roles in maximizing the production and quality of tea as well as sustainable management of tea-growing soils. Therefore, this study was carried out to assess the impacts of Natural Rubber Tire Waste Charcoal (NRTWC) application on major soil chemical properties in tea-growing soils. NRTWC was applied to a tea growing soil at different rates (0, 1, 1.6, 2.2 and 2.8% w/w) and soil chemical properties such as soil pH, organic matter content, NH_4^+-N, NO_3^--N, available P and exchangeable K were assessed at 10 and 20 weeks after application of NRTWC. NRTWC amended soils showed significantly ($P \leq 0.05$) higher pH values for the application rates of 2.2% (5.85) and 2.8% (5.86) than the control where it recorded the lowest pH value (5.3) at the 20 weeks after application. According to the results, it was observed that the application of NRTWC that contained a large amount of organic carbon (~50%) contributed to a significant ($P \leq 0.05$) increase in the organic matter content of tea-growing soils. The highest organic matter (5.58%) was recorded with 2.8% NRTWC application followed by 2.2% application (4.66%) 20 weeks after application. Furthermore, slow decomposition of the NRTWC increases total N (NH_4^+-N and NO_3^--N), available P and exchangeable K content in the soils. Significantly ($P \leq 0.05$) higher NH_4^+-N contents were observed for all the treatments at 20 weeks after the application of NRTWC compared to the control. However, amended soils showed significantly ($P \leq 0.05$) higher NO_3^--N contents for the application rates of 2.2 and 2.8% (3.9 and 6.9 mg kg^{-1} soil, respectively) compared to the control (1.8 mg kg^{-1} soil) at 20 weeks after application. The 2.8% application rate recorded the highest exchangeable K content at 10 weeks (143 mg kg^{-1} soil) and 20 weeks (195 mg kg^{-1} soil) after treatment application. As revealed by the results, NRTWC can be considered as a good source of soil amendment which could enhance soil chemical properties in degraded tea soils.

***Keywords**: Charcoal, decomposition, organic amendments, natural rubber tire.*

INTRODUCTION

Over the last several decades, waste tire production has been increasing at an alarming rate due to the rapid increase in usage of passenger vehicles, trucks, motorcycles and bicycles (Hita *et al.,* 2016). They are resistant to biodegradation and cause serious threats to the environment and human health (Presti, 2013). At present, one billion the waste tire is disposed of after completing their service life and this will reach 1.2 billion within the next ten years (Czajczynska *et al.,* 2017). Though there are several possible solutions for the disposal of waste tires, such as gasification, tire retreading, landfilling, mechanical lapping, rubber reclaiming, incineration and pyrolysis (Li *et al.,* 2016) more than 50% of waste tires are disposed without using any treatment. Most countries have legally prohibited landfilling with waste tires (Junqing *et al.,* 2020) due to their very slow degradation (Juma *et al.,* 2006). It occupies substantial piece of usable lands (Alsaleh *et al.,* 2014). Their high void ratio (75% by volume) poses a large land requirement for disposal and provides breeding environment for mosquitoes and other disease carrying insects. Therefore, it is an urgent need to look for workable ways to treat rubber waste tires and recover the usable product. The pyrolysis process is considered one of the possible solutions for the disposal of waste tires. It is an efficient, economical and environmentally friendly method (Benedetti *et al.,* 2017; Debnath *et al.,* 2018) and lowers the impact on the environment (Junqing *et al.,* 2020).

The pyrolysis process recovers economical products such as pyrolysis oil, pyrolysis gas and solid coke (Williams, 2013). Solid coke an amorphous carbon material mainly contains industrial carbon black (CB), sulfur, zinc oxide, stearic acid, proprietary additives, and bead wires (Steudel and Steudel, 2006; Zhang *et al.,* 2018). This pyrolytic carbon black is similar to biochar in nature (Junqing *et al.,* 2020) and it maintains soil organic matter content for a longer period of time due to its very slow decomposition and enhances soil physicochemical properties.

Tea is considered to be one of the most extensively used beverages in the world (Mukhopadyay *et al.,* 2012). It is made by processing tender leaves of the plant *Camellia sinensis* (L.) (Mukhopadhyay *et al.,* 2013a; 2013b). Sri Lanka is among the major tea-producing countries in the world contributing 6.5% of global production. China (40.5%), India (23.3%), and Kenya (8.6%) are the other three countries having major shares of the global tea market. Sri Lankan tea industry is considered one of the important national agriculture-based industries in Sri Lanka and it contributes 2% to the GDP. Out of the total land area used for agriculture, 28% is used for tea cultivation. However, the long-term sustainability of the Sri Lankan tea industry is limited by severe soil degradation and high environmental risk associated with the continuous usage of chemical fertilizers and agrochemicals (Lal *et al.,* 2015).

Humid climatic conditions with an average temperature of 19 to 22 °C range, well-drained fertile acidic soils with 5.2 - 5.9 pH between and soil depth at ≥2 m are considered as most suitable conditions for tea cultivation (Willson and Clifford, 1992). As tea is a perennial crop with an economic life span of over 40 y, the long-term cultivation causes the nutrients in the soil to get depleted very faster (Wang *et al.,* 2013). Chemical properties of soil which include soil pH, organic matter content, NH_4^+-N, NO_3^--N, available phosphorous (P) and exchangeable potassium (K) play key roles in maximizing the production and quality of the tea. Against this background the present study assessed the impacts of NRTWC application on soil chemical properties in tea-growing soils.

MATERIALS AND METHODS

Experimental site

The well-managed 8 y old tea plantation located at Aturaliya Divisional Secretariat of Matara District in Southern Sri Lanka was selected as the experimental site for the study. The selected area comes under the low country wet zone (WL2) of Sri Lanka and has a tropical monsoonal climate (Mapa *et al.,* 1999) with a warm wet period (April to June) and a relatively dry period (January to March). The annual rainfall of the area is around 2,500 mm. The distribution of rain is bi-model. The annual mean air temperature of the area is 22 -30 °C and the relative humidity is about 80%. The soil in this area belongs to the Red Yellow Podzolic great soil group and is classified as Hapludults according to the USDA soil taxonomy (Mapa *et al,* 1999). Physico-chemical properties of the soil were analyzed using standard methods and values are shown in Table 1.

Table 1: Some important physico-chemical properties of experimental soil. Values given here are the means (n = 4) ± SD.

Properties	Value
Organic carbon (%)	1.29 ± 0.008
Bulk density (g cm^{-3})	1.39 ± 0.06
Porosity (%)	37.83 ± 1.1
pH	5.30 ± 0.4
EC (dS m^{-1})	0.035±0.005
NO_3^- - N content (mg kg^{-1})	1.78 ± 0.09
NH_4^+ - N content (mg kg^{-1})	11.69 ± 0.14
Available P (mg kg^{-1})	2.15 ± 0.42
Exchangeable Ca (mg kg^{-1})	146.52 ± 6.79
Exchangeable K (mg kg^{-1})	14.21 ± 0.55
Exchangeable Na (mg kg^{-1})	9 ± 0.45

Production of natural rubber waste tire charcoal

Waste tires were collected from dumping sites of tire shops in the Akuressa and Kaburupitiya areas of Matara District, Sri Lanka. Excavated pit (one cubic meter) was tightly filled with waste tires and covered with a thick metal sheet to seal up the chamber and 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 3½ h of the pyrolysis process, the thick metal sheet 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. NRTWCs were then air-dried and broken up into pieces with a hammer and crushed charcoals were passed through a 250 µm mesh to remove larger particles. Physico-chemical properties of NRTWC were determined using standard methods (Table 2).

Table 2: Some important physico-chemical properties of Natural Rubber Tire Waste Charcoal. Values given here are the means (n = 4) ±SD.

Properties	NRTWC
Organic carbon (%)	49.92 ± 0.1
Bulk density (g cm^{-3})	0.2±0.005
Porosity (%)	61.53±1.33
pH	7.76±1.41
EC (dS m^{-1})	0.89±0.1
NO_3^- - N content (mg kg^{-1})	1.5±0.3
NH_4^+ - N content (mg kg^{-1})	23.98±0.6
Available P (mg kg^{-1})	4.96±0.05
Exchangeable Ca (mg kg^{-1})	416.29±57.22
Exchangeable K (mg kg^{-1})	358.16±7.04
Exchangeable Na (mg kg^{-1})	82.52±3.44

Treatment selection

It has been recognized that high-yielding tea lands should have soil organic matter above 2.0% (Han *et al.,* 2002). Generally, the well-managed tea plantations in Red Yellow Podzolic soil should have 5% soil organic matter (Sandanam and Coomaraswamy, 1982). The soil organic matter content was expressed as 2.25% (organic carbon content 1.3%). The organic matter content of NRTWC was measured as 85.8%. Therefore, treatment calculations were done assuming that the addition of NRTWC which contain 50% organic carbon could increase the organic carbon content of the experimental soil up to 2.9%,. Accordingly, there were five NRTWC application rates 1% (20% less than a requirement), 1.6% (requirement), 2.2% (20% higher than the requirement), 2.8% (40% higher than the requirement) and a control (without NRTWC application). These values are equal to a 21, 33.6, 46.2and 58.8 t ha^{-1} and, a control application rates.

Application of NRTWC

NRTWC was mixed with the topsoil to a depth of 10-15 cm throughout the manure circle of tea plants. The treatments were arranged in the trial area (0.01 ha) following a complete randomized block design with four replicates (20 plots). The size of an individual plot was 1.5 x 1.5 m and a buffer zone of 1.5 m was left between the plots to minimize the effect of NRWTC on untreated plots. Each experimental plot consisted of 10 tea bushes.

Soil sampling and preparation for analysis

Representative soil samples were taken randomly from 0-15 cm depth after 10 and 20 weeks of treatment application. The surface litter of the soil was removed and soil samples were drawn using an auger. They were well-mixed to make composite samples and were sealed in plastic bags before transportation to the laboratory. They were then air-dried at room temperature for a week, crushed with a rubber-tipped pestle and sieved through a 2 mm mesh.

Soil analysis

Soil samples were tested for their chemical properties such as soil pH, organic matter content, NH_4^+-N, NO_3^--N, available P and exchangeable K. All the laboratory investigations were conducted at the Department of Soil Science, Faculty of Agriculture, University of Ruhuna, Sri Lanka. Soil pH was measured in 1:2.5 soil: water suspension with a pH meter. 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). Available phosphorous extracted by the bicarbonate method was determined following the molybdate blue colour method (Murphy and Riley, 1962). Exchangeable K was determined using a flame photometer (Blackmore *et al.,* 1987) and the wet oxidation method (Tiessen and Moir, 1993) was applied to determine soil organic matter content.

Statistical analysis

One way analysis of variance (ANOVA) for all the data was performed using the SAS package (SAS, 1999). Samples means were separated by Duncan's Multiple Range Test (DMRT) at $P \leq 0.05$. Values were expressed as means ± SD for replicate samples.

RESULTS AND DISCUSSION

Changes in soil pH at 10 and 20 weeks after the application of NRTWC are shown in Figure 1.

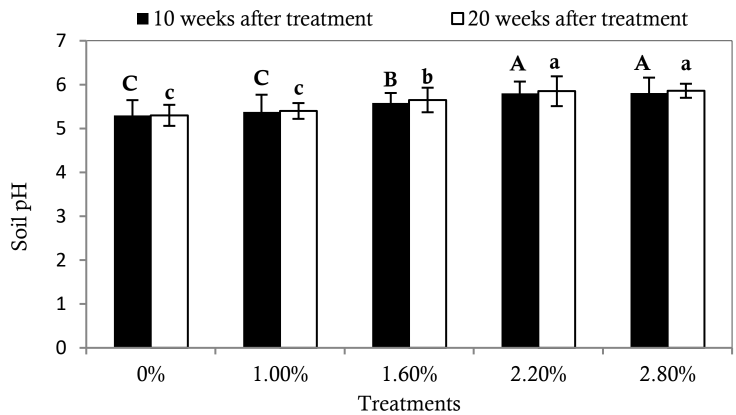

Figure 1: Changes in soil pH at 10 and 20 weeks after application of NRTWC. Same letters are not significantly different according to Duncan's Multiple Range Test ($P<0.05$). Different capital letters indicate a significant difference at 10 weeks after NRWTC application and different lower-case letters indicate a significant difference at 20 weeks after NRWTC application. Values are the means ± SD (n = 4).

With the increasing rate of NRTWC applications, soil pH was found to be increased slightly. However, pH values were not significantly ($P \leq 0.05$) changed among the application rates of 1 and 1.6% in both 10 and 20 weeks after the NRTWC application. NRTWC-amended soils showed significantly ($P \leq 0.05$) higher pH values for the application rates of 1.6, 2.2 and 2.8% than the control (0%) which recorded the lowest pH value (5.3) at the 10 and 20 weeks after application. However, there were no significant ($P \leq 0.05$) differences among the application rates of 2.2 and 2.8% at the 10 and 20 weeks after application.

The organic matter content of the soil was found to be increased significantly ($P \leq 0.05$) with increasing NRTWC application rates at 10 and 20 weeks (Figure 2).

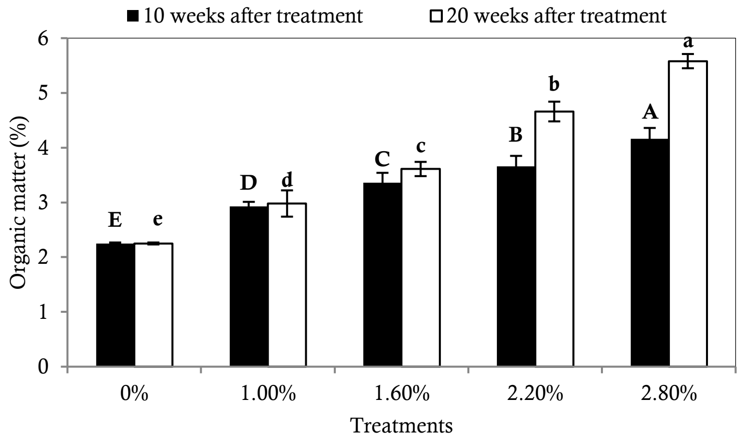

Figure 2: Changes in organic matter content at 10 and 20 weeks after application of NRTWC. Same letters are not significantly different according to Duncan's Multiple Range Test ($P < 0.05$). Different capital letters indicate a significant difference at 10 weeks after NRWTC application and different lower-case letters indicate a significant difference at 20 weeks after NRWTC application. Values are the means ± SD (n = 4).

The highest organic matter (5.58%) was recorded with the 2.8% NRTWC application followed by 2.2% application (4.66%) at 20 weeks after application. During the period from 10 to 20 weeks, soil organic matter contents increased from 4.16 to 5.58% and from 3.66 to 4.66%, respectively, for 2.8 and 2.2% application rates.

The changes in NH_4^+-N and NO_3^--N release at 10 and 20 weeks after the application of different rates of NRTWC are shown in Figure 3 and 4, respectively.

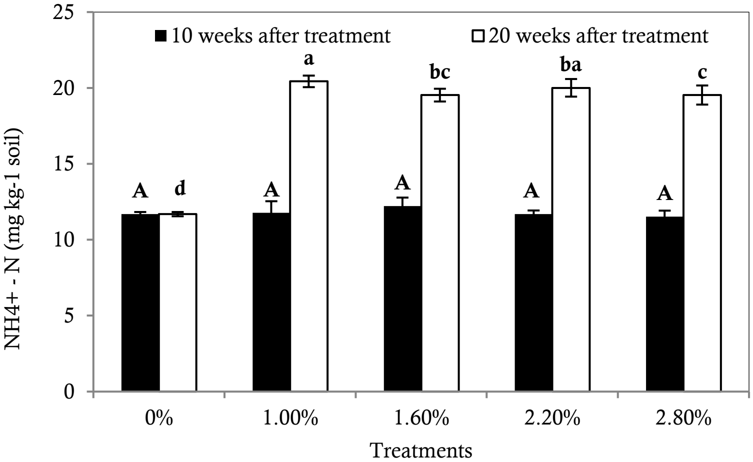

Figure 3: Changes in NH_4^+-N content at 10 and 20 weeks after application of NRTWC. Same letters are not significantly different according to Duncan's Multiple Range Test (*P*<0.05). Different capital letters indicate a significant difference at 10 weeks after NRWTC application and different lower-case letters indicate a significant difference at 20 weeks after NRWTC application. Values are the means ± SD (n = 4).

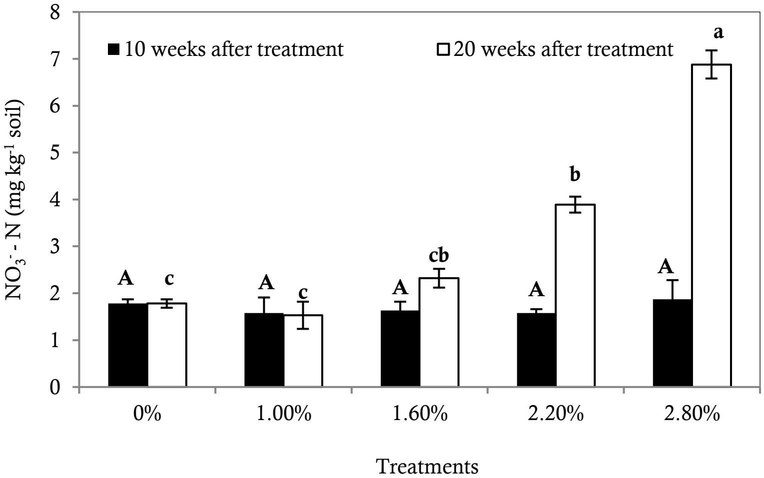

Figure 4: Changes in NO_3^--N content at 10 and 20 weeks after application of NRTWC. Same letters are not significantly different according to Duncan's Multiple Range Test (*P*<0.05). Different capital letters indicate a significant difference at 10 weeks after NRWTC application and different lower-case letters indicate a significant difference at 20 weeks after NRWTC application. Values are the means ± SD (n=4).

There were no significant differences ($P \geq 0.05$) in N mineralization (NH_4^+-N and NO_3^--N release) at 10 weeks from application of NRTWC at any rate. However, a significant difference ($P \leq 0.05$) was observed in NH_4^+-N at 20 weeks after the application of NRTWC for all application rates compared to the control. Significant difference ($P \leq 0.05$) was observed for NO_3^--N release for the application rates of 2.2 and 2.8% at 20 weeks after the application of NRTWC. As expected, the control soil recorded a low level of NH_4^+-N and NO_3^--N compared to that of NRTWC amended soils.

Changes in soil available P at 10 and 20 weeks after the application of NRTWC were shown in Figure 5. Soil available P content was significantly increased (*P*≤0.05) in all treatments at 10 and 20 weeks after application compared to the control. However, there were no significant (*P*≤0.05) differences among different application rates at 10 and 20 weeks after the NRTWC application. Discuss the percentage and an actual increase compared to the control.

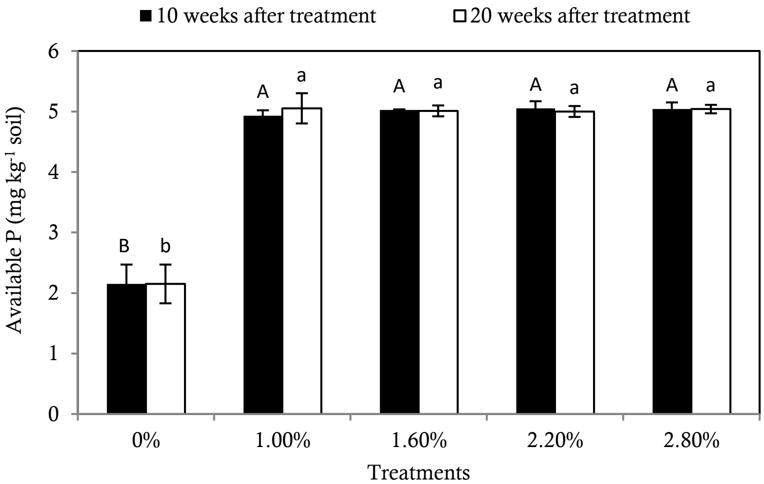

Figure 5: Changes in available P content at 10 and 20 weeks after application of NRTWC. Same letters are not significantly different according to Duncan's Multiple Range Test (*P*<0.05). Different capital letters indicate a significant difference at 10 weeks after NRWTC application and different lower-case letters indicate a significant difference at 20 weeks after NRWTC application. Values are the means ± standard deviation (n = 4).

Changes in exchangeable K content at 10 and 20 weeks after the application of NRTWC were shown in Figure 6. A significant (*P*≤0.05) difference was observed for all the application rates compared to the control at 10 and 20 weeks after treatment. There was no significant (*P*≤0.05) difference in exchangeable K content among different treatments at 10 and 20 weeks after the application of NRTWC. The 2.8% application rate recorded the highest exchangeable K content at 10 weeks (143 mg kg^{-1} soil) and 20 weeks (195 mg kg^{-1} soil) after treatment application, but it did not significantly differ from other NRTWC application rates.

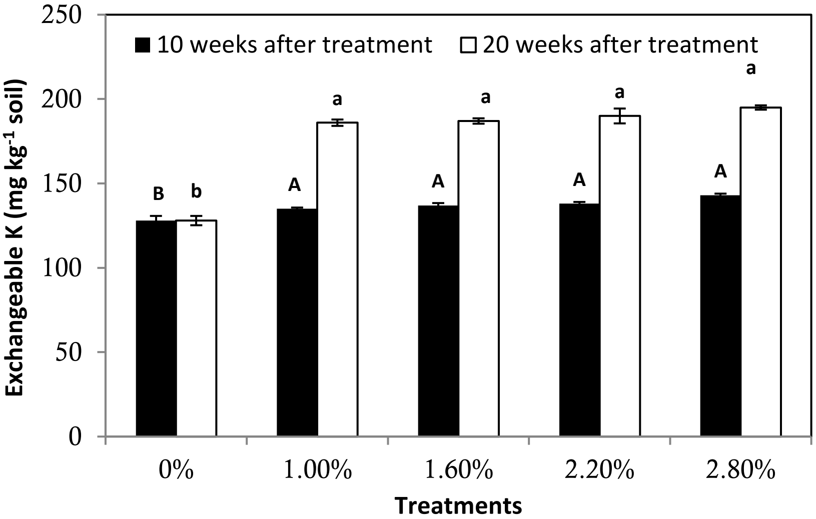

Figure 6: Changes in exchangeable K content at 10 and 20 weeks after application of NRTWC. Same letters are not significantly different according to Duncan's Multiple Range Test (*P*<0.05). Different capital letters indicate a significant difference at 10 weeks after NRWTC application and different lower-case letters indicate a significant difference at 20 weeks after NRWTC application. Values are the means ± standard deviation (n = 4).

Despite the fact that the tea industry plays a vital role in the Sri Lankan economy, it is reported that the extent of tea cultivation has dramatically decreased compared to the other major tea-growing countries such as China, India and Kenya. This would have some negative impacts on competing in the world market. It is an urgent requirement to pay attention on upgrade tea production in Sri Lanka. Well-grown tea plant generally attains their optimum bearing stage after 10 y and continues their productive stage for more than 30 y (Karak *et al,* 2015). However, continuous nutrient uptake and continuous removal of the products from the field leads to soil nutrient imbalance of plants in the field (Giller *et al.,* 1997). Long-term cultivation of tea, without proper management practices, caused nutrient depletion in soils (Oh *et al.,* 2008; Wang *et al.,* 2013). Soil chemical properties such as soil pH, organic matter content, NH_4^+-N, NO_3^--N, available P, Exchangeable K, Ca and Na are prime important factors in maximising tea production. Therefore, amending soils with high carbonaceous material may enhance the chemical properties of tea soils (Xiaoyun *et al.,* 2022).

Though tea plants usually prefer moderately acidic soil conditions (pH 5.2-5.8) for optimum and quality production, soil pH in tea lands generally decreases with time (Han *et al.,* 2007). This is in agreement with Xue *et al.* (2006) who also observed a decreasing trend of soil pH (4.22, 4.01 and 3.71) with increasing stand age (8, 50 and 90 y, respectively. Similarly, Thompson and Whitney (2000) also reported a decrease in soil pH with continuous cultivation of tea on the same land.

Frequent application of urea and ammonium sulfate-based fertilizers to tea lands is also found to have some contribution towards the acidification of soils. During the nitrification process, some nitrifying bacteria could convert ammonium ions into nitrate ions (NO_3^-) which releases H^+ ions into the soil solution causing the reduction of soil pH (Guo *et al.,* 2010). Most of the tea-growing soils in Sri Lanka are subjected to severe soil erosion due to the steep slopes of the lands. This may enhance soil acidity due to the leaching of soil bases with rainwater. The tea plants generally tend to absorb more basic nutrients such as calcium, potassium, and magnesium for their growth and the systematic removal of soil bases also causes the acidification of tea soils. Apart from that aluminium cycling in tea litter caused significant soil acidification. Tea leaves acquire a relatively higher amount of aluminium from the soil and the plant has an efficient mechanism to tolerate aluminium toxicity (Karak *et al.,* 2015). Therefore, tea plants grow well in acid soils and aluminium could be one of the essential nutrients for tea plants (Hajiboland *et al.,* 2013a, b). It is crucial to correct soil acidity and soil pH should be maintained at an optimum level throughout the lifespan of the tea plants. This can be achieved through the application of organic amendments. NRTWC application increased soil pH by 0.5 units compared to the control after 20 weeks of application of NRTWC at the rate of 2.8%. Aguilar-Chávez *et al.* (2012) reported that soil pH can be slightly corrected by applying charcoal because it has a pH-neutralizing effect due to its slightly alkaline property. In that sense, it is obvious that the application of NRTWC not only corrects soil acidity but also increases the soil pH buffering capacity and thus avoids re-acidification of tea soils.

In addition, to serve as a source of fertility, soil organic matter could act as an important indicator as well. Generally, tropical and subtropical soils contain relatively low organic matter contents (Grorge and Barpujari, 2005). Most of the tea soils in Sri Lanka are also subjected to a continuous decline in soil organic matter leading to poor soil fertility. Generally, tea-cultivated lands are characterized by less biomass accumulated lands compared to tropical forests and mature tree plantations (Kamau *et al.,* 2008) due to less litterfall and the removal of the huge amount of younger shoots as harvest (Tchienkoua and Zech, 2004). Apart from severe soil erosion and heavy use of agrochemicals, the rapid decomposition of existing organic matter is also responsible for low organic matter contents in tea-growing soils in Sri Lanka.

Due to the rapid degradation of organic matter content in tropical and subtropical soils (Tisdall and Oades, 1982), commonly available organic amendments are found to be short lasting in the soils (William and Shenker, 2016). According to the research findings the char produced from waste tire pyrolysis can be used to produce activated carbon or carbon black (Sainz-Diaz and Griffiths, 2000) and the pyrolytic carbon black produced from natural rubber tire wastes is similar to biochar in nature (Junqing *et al.,* 2020). Therefore, NRTWC is a carbonaceous material which contains 50% organic carbon produced through the thermal degradation of natural rubber in the absence or presence of a very low amount of oxygen at high temperatures. Organic carbon produced from NRTWC is recalcitrant to decomposition due to its aromatic and crystalline structure. Therefore, NRTWC is a stable form of carbon and can last for thousands of years (Greer *et al.,* 2021) and maintain the soil organic carbon status in tea-growing soils.

Harvested succulent shoots contain the largest portion of nutrients in the tea plants and therefore the nutrient requirement of tea plants for their growth is relatively high compared to other cultivated crops (Dang, 2005). Nitrogen and potassium are the most important two macronutrients required for tea plants. Harvested succulent shoots contain approximately 5% (on a dry basis) of nitrogen (Barooah *et al.,* 2005) and made tea 1 kg contains approximately 20 g of K_2O (Ranganathan and Natesan, 1985). According to this, it is estimated that an average harvest of 3,000 kg ha^{-1} tea will remove around 150 kg N and 60 kg K_2O ha^{-1} y^{-1} from the soil. Apart from that large amounts of some of the other important nutrients are retained in the bush frame and parts of them are rarely reacquired in the soils. Under this situation continued uptake and removal of nutrients from tea plants caused an overall nutrient imbalance in tea cultivation (Giller *et al.,* 1997).

The lowest NH_4^+-N and NO_3^--N contents were recorded from the control soil probably due to its low total nitrogen and organic matter content, suggesting the low fertility of tea-growing soils. The amount of released NH_4^+-N did not change at 10 weeks after application of NRTWC which might be due to the initial rapid nitrification combined with denitrification. Similarly, no change in NO_3^--N content was also observed during the same period, possibly due to denitrifies involvement in taking up NO_3-N. This close coupling between nitrification and denitrification resulting in a substantial loss of mineralized N as N gas has repeatedly been reported (Meyer *et al*, 2002). Peaks for mineralized N (NH_4^+-N and NO_3^--N) were observed 20 weeks after the application of NRTWC. This implies that NRTWC is characterized by their resistance to decomposition and this may be associated with their aromatic and crystalline nature. As revealed by Hamidi *et al.* (2021) charcoal improves nitrogen availability by enhancing NH_4^+-N sorption and NO_3^--N retention in soil solution by entrapping these ions inside the pores due to its high specific surface area and internal porous structure.

Charcoal provides reactive negatively charged surfaces, which enhance nutrient holding in the synchrony of crop nutrient uptake. Therefore, high available P content recorded in NRTWC treated soil could be due to chelating acidic cations such as Al^{3+} and Fe^{2+}, which were implicated in P fixation.

Most tea soils are suffered from an adequate amount of available K and this amount will reduce further due to the acidity of tea soils (Singh and Pathak, 2018). Application of NRTWC increased plant available K, exceeding the amount required (≥ 100 mg kg^{-1} soil K) for optimum tea yield (Singh and Pathak, 2018). NRTWC has pH-neutralizing effect due to its slightly alkaline property and therefore it ensures the availability of base cations such as K.

CONCLUSIONS

Based on the results, it could be stated that application of NRTWC which contained a high percentage of content organic carbon (~50%) could increase the organic matter content of tea soils significantly. Furthermore, NRTWC could add N (NH_4^+-N and NO_3^--N), P and K to tea growing and enhance soil fertility. Application of NRTWC increases the soil pH buffering capacity and minimizes the adverse impact of acidification of tea soils. However, it is needed to conduct long term field experiments to make a comprehensive assessment of NRTWC application on agronomic and environmental effects.

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