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RESEARCH

Effects of Conversion of Rubber to Oil Palm Plantations on Soil Properties and Hydrological Dynamics in the Low Country Wet Zone of Sri Lanka.

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ABSTRACT

A study was conducted to investigate the impacts of converting rubber plantations into oil palm plantations on soil properties and soil hydrology. Soil organic carbon (SOC), bulk density (BD), aggregate stability (AS), saturated hydraulic conductivity (Ks), soil water retention, texture, thermal properties, and pH were determined using soil samples collected from different depths of a twelve-year-old oil palm and rubber cultivated fields located in low country wet zone of Sri Lanka. In each field, volumetric water content (VWC) of soil was continuously measured at four soil depths (0-25, 25-50, 50-75, and 75-100 cm) over a seven-month period. While the study revealed a 40% lower SOC in 0-25 cm soil layer of the oil palm field compared to the rubber field, no significant changes were observed in BD, porosity, pore size distribution, AS, and Ks for the two fields. However, the volumetric heat capacity of rubber grown soil was significantly higher than that of the oil palm grown soil. Oil palm utilized the most water from 25-75 cm soil layer; whereas, rubber extracted more water from deeper soil layers (75-100 cm). Soil water depletion in oil palm field was faster during dry periods than in rubber fields highlighting the need to examine the soil water extraction patterns of oil palm during extended dry spells in future studies. Overall, the conversion of rubber into oil palm plantations showed no significant impact on most of the soil properties and soil hydrology after twelve years of conversion.

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INTRODUCTION

Oil palm is one of the most important oil crops in the globe, which has risen gradually in recent decades due to its superior productivity than other oil crops. Oil palm contributes to approximately 40% of the world's edible oil while occupying only 5% of the vegetable oil-producing lands and 0.4% of the agricultural lands (Jackson et al., 2019). One hectare of oil palm plantation can produce up to ten times more oil than other leading oilseed crops (Muhammad-Muaz and Marlia, 2014). Therefore, oil palm has been introduced as the most efficient oilseed crop globally. It is reported that in recent years, oil palm cultivation had increased steadily to achieve market demand (USDA, 2016). Oil palm and rubber cropping systems cover a significant extent in the tropical region (FOA, 2016) and purports to expand further (Van der Laan et al., 2016). In most of the South East Asian countries, oil palm is established by replacing natural forest. The conversion of tropical rainforests into oil palm plantations has garnered increased attention, primarily due to its significant and potentially devastating impacts on tropical biodiversity (Gilbert, 2012). Barnes et al*.* (2014) reported a 45% decrease in species diversity, density, and biomass of invertebrate communities suffered due to land-use transformation from tropical forests to oil palm plantations. Due to its negative impacts on the environment, wildlife and to local communities, oil palm is known as the most hated crop in the world (Yan, 2007).

Rubber was introduced to Sri Lanka in 1876 and it had become one of the major export crops that contributes 0.6% to GDP in Sri Lanka (Central Bank report, 2020). Well-managed rubber plantations are identified as environment-friendly, sustainable agroecosystems (Gan et al., 2021). The area under rubber cultivation in Sri Lanka exceeded 200,000 ha in 1990, but later it has declined to 123,000 ha because of low productivity, a shortage of skilled labor, and low prices (Waidyanatha, 2019). Oil palm was then introduced as an alternative crop to replace rubber by growers because of its high productivity. Oil palm cultivation in Sri Lanka increased rapidly due to its higher production and profitability (Arachchige et al., 2019). In 2015, the oil palm extent was about 9,000 ha, and in 2018 it expanded to 11,132 ha (Ministry of plantation industries, 2018). Different stakeholders, including the general public, environmentalists, and policymakers, have raised concerns regarding oil palm cultivation and its impact on surface water resources, biodiversity, and soil degradation. Conversion of rubber plantation to oil palm had significant economic, ecological, and social impacts on both the areas turned into oil palm and their surroundings (Merten et al., 2016). The most commonly raised concerns associated with oil palm cultivation are, soil degradation, suppression of undergrowth, and the significant depletion of water resources in the surrounding areas (Banabas et al., 2008). Moreover, in 2018, the Central Environment Authority of Sri Lanka released a report detailing the effects of oil palm cultivation, primarily relying on findings from international research. A policy decision was made in 2020 to ban the further expansion of oil palm, particularly in response to increased public concern.

Soil properties are important as they determine the productive capacity of soil and are related to various ecosystem functions. The differences in net carbon input to the two cropping systems could have a substantial impact on soil physical properties such as bulk density (BD), aggregate stability (AS), moisture retention (Zhao et al., 2016) and pore size distribution and hence on the hydrological and temperature dynamics of soil. For example, soil organic carbon (SOC) plays a crucial role in improving soil structure which influences porosity and pore size distribution, consequently impacting water infiltration, water flow, and water storage in the soil (Angers, 1996). Moreover, SOC is subsequently impacting heat transmission and heat storage capacity of the soil. In a comparative study examining alterations in soil properties between oil palm and rubber cultivated fields in Indonesia, Guillaume et al*.* (2016) observed that soil within oil palm fields exhibited greater degradation. This was attributed to its lower carbon content (<2 %), diminished nitrogen content (<0.15%), and elevated BD (>1.2 gcm^{-3}), as compared to the soil in rubber cultivated fields. More than one-third of new oil palm plantations replaced forested landscapes in Southeast Asia between 1990-2010 (Gaveau et al., 2016), with rates as high as 90 % in regional hotspots (Carlson et al., 2013). Hence, a majority of studies have undertaken comparisons of soil properties between oil palm plantations and natural forests. However, in Sri Lanka, the predominant shift has been from rubber plantations to oil palm plantations, and the consequences of this transformation have been comparatively underexplored when contrasted with the impacts on rubber plantations. Limited number of studies have investigated the changes in soil properties due to converting rubber plantations into oil palm in Sri Lanka. For example, Upekshani and Dharmakeerthi (2009) observed that the saturated hydraulic conductivity in oil palm cultivated soil was significantly lower (3.4×10^{-5} ms^{-1}) compared to that of rubber (6.6×10^{-5} ms^{-1}) cultivated soil and soil of a natural forest (6.4×10^{-5} ms^{-1}) in 0-15 cm and 15-30 cm depths in the low country wet zone of Sri Lanka. It was reported there were no significant differences in BD and available water content between rubber and oil palm fields across the two depths. Soil water content (SWC) is an important parameter affecting the hydrological process in soil by influencing water infiltration, movement, storage, and distribution. SWC plays a vital role in processes such as infiltration, percolation, groundwater recharge, and evapotranspiration which collectively regulate water availability in the environment. The temporal and spatial variability of SWC is influenced by different factors such as soil properties (Gwak and Kim, 2017), topography, climate, and vegetation type (Zheng et al., 2015). These diverse factors affect the dynamics and distribution of SWC, contributing to its variability across different timeframes and geological locations. The rooting behavior of plants governs its capacity to utilize stored water in soil and nutrient uptake (Ali et al., 2019). Zhou et al. (2013) observed that shoot characteristics such as leaf area, stomatal conductance, and transpiration rates directly influence the rate of water extraction from the soil.

Unfortunately, no local studies have quantified and compared the changes in soil hydrological dynamics in the oil palm and rubber cultivated soils, given their importance to understand the underlying mechanisms related to the potential hydrological changes that could happen with the conversion of rubber plantations into oil palm plantations. Due to the absence of comprehensive long-term SWC data, comparing the factors governing soil water storage and their seasonal variations beneath oil palm and rubber cultivation becomes challenging. Nonetheless, grasping these insights is crucial for comprehending the potential repercussions on soil hydrology arising from the shift from rubber to oil palm plantations. Additionally, there exists a dearth of knowledge concerning the influence of oil palm cultivation on soil physical properties. Alterations in soil physical properties can significantly impact on infiltration, retention, and movement of water within the soil. Drawing conclusions from a restricted set of global research studies presents challenges, primarily due to variations in climate, soil characteristics, and agricultural management methods. Moreover, the existing body of research on the water consumption patterns of oil palm and rubber plantations, as well as the dynamics of soil water, remains limited and fragmented. These studies often focus solely on either oil palm or rubber, thereby complicating the process of making meaningful comparisons. Hence, there is a need for extensive research aimed at gaining insight of the consequences stemming from the transformation of current rubber plantations into oil palm cultivation. The aim of this study is to investigate the impacts of converting rubber into oil palm plantations on soil properties and soil hydrology of selected mature oil palm and rubber plantations in the low country wet zone of Sri Lanka. Results of this study will enable us to understand the possible effects of converting existing rubber plantations to oil palm on soil properties and hydrological dynamics. The outcomes derived from this research will also provide valuable insights for forthcoming studies aimed at comprehending the eco-hydrology of oil palm and rubber plantations across diverse local soil and climatic conditions.

METHODOLOGY

Study area

Given that over 80% of oil palm cultivation is concentrated in the low country wet zone of Sri Lanka (Pathiraja et al., 2023), the study site was chosen at *Yatadolawatta* estate in *Mathugama* (central coordinates, 6° 50′N, 80° 05′E), located within the low country wet zone (WL1) of Sri Lanka (Figure 1). In this region, the mean annual rainfall is more than 3200 mm, and the temperature is 26.10 ^{0}C on average. (NRMC, 2003). The soil in the area is Typic Hapludults (Soil taxonomy, 1999) and the local great soil group is *Red Yellow Podzolic* which belongs to *Agalawaththa* soil series (Senarath and Dassanayake, 1997). The elevation was less than 300 m from the mean sea level and the land has undulating (2-8% slope) terrain.

Twelve-year-old (adult age category) oil palm (13 ha) and rubber (7.94 ha) plantations, which located in nearby fields were selected for a better comparison. Oil palm clone *tenera* had been planted at 8*8 square meter pattern in 2011 in a field which was previously under rubber. The rubber clone *121* had been replanted at 5*5 square meter pattern in 2011. There was a uniform grass cover under the rubber field while the oil palm site had a patchy grass cover.

Soil sampling

Soil sampling took place in two distinct campaigns. During the initial phase, thirty-two (32) intact soil core rings (5 cm diameter & 3 cm height) and sixteen (16) minimally disturbed samples were collected from the depths of 0-25 cm and 25-50 cm (surface layers). The soil samples were collected within one-meter radius of six representative trees and also from the inter-rows of trees. The soil samples were used for detailed characterization of soil properties such as soil texture, SOC, BD, Ks, AS, water retention, and thermal properties. During the second phase, five (05) soil profile pits in each rubber and oil palm field were excavated up to 1 m depth for the purpose of installing soil moisture sensors. The soil profile pits located within one-meter radius of trees and also within tree inter rows (Figure 2). Disturbed soil samples were collected at four depths (0-25 cm, 25-50 cm, 50-75 cm, and 75-100 cm) from each excavated soil pit before installation of the soil moisture sensors. These disturbed samples were used for the measurement of soil properties such as texture, SOC, and pH.

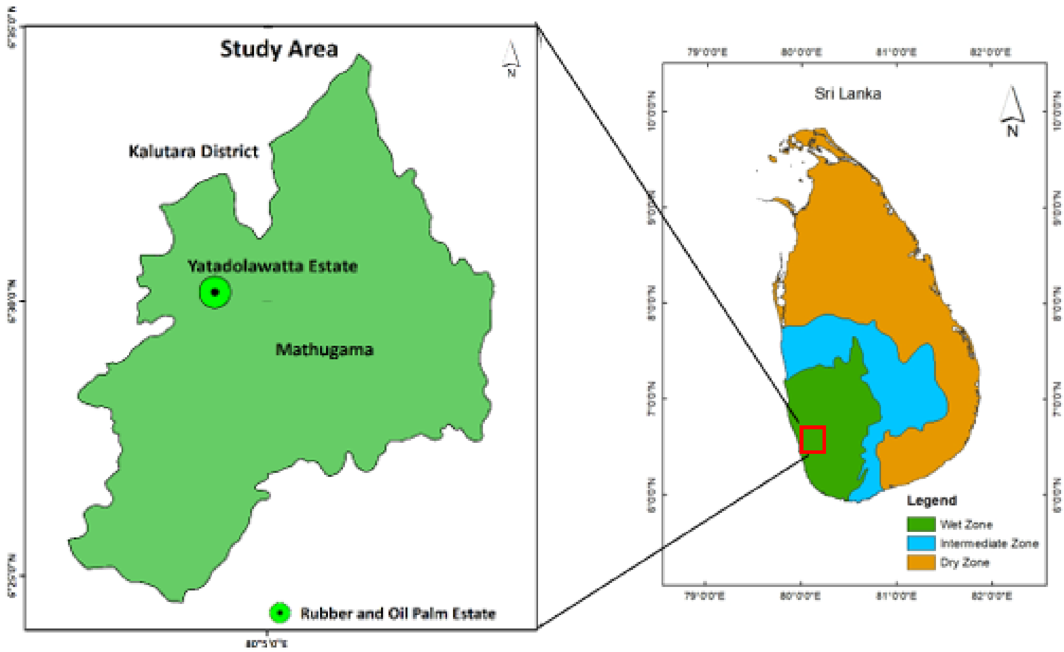

Figure 1 – Location of the *Yatadolawatta* estate, Mathugama, Sri Lanka

Soil water content measurement

Soil moisture sensors (BGT-SM1, Beijing Guoxinhuayan technology, Beijing, China) were installed in the middle of the soil layers of 0-25 cm, 25-50cm, 50-75 cm, and 75-100 cm in each profile pit (Figure 2). The LSPF – 15 type data logger collected volumetric moisture content data at each depth and location of the rubber and oil palm field. The data was recorded at one-hour time interval. Soil volumetric moisture content data was collected over seven months, from December 25, 2022, to July 27, 2023. The data was downloaded from a central cloud storage system, to which the data logger sends the recorded information. A mini weather station was established in each rubber and oil palm site to obtain rainfall, air temperature, solar irradiation, humidity, wind speed, and wind direction at one-hour time interval. Between 2nd February, 2023 and 14th March, 2023 there was a gap in the data recorded at the rubber-grown site due to an issue related to the power supply unit.

Calibration soil moisture sensors

Disturbed soil samples collected from each soil layer of excavated pits were used for calibrating the soil moisture sensors. Depth-wise calibration was carried out using soil moisture sensors on re-packed soil containers, giving due consideration to the field BD at the Soil Physics Research Laboratory of the Department of Soil Science, University of Peradeniya. Soil volumetric water content was determined using the gravimetric method, and the corresponding raw sensor readings (mV) were recorded. Calibration equations were derived for each depth, which were then employed to convert the raw data into volumetric water content for each specific layer.

Soil analysis

Ks was measured on intact soil core samples according to the constant head method (Klute and Dirkson, 1986). Then, soil thermal properties such as thermal conductivity (K), thermal diffusivity (D), and volumetric heat capacity (C) were measured using SH-1 dual probe heat pulse sensor (KD2 PRO, Decagon Devices, Pullman, USA) on saturated soil core samples. At the end, soil in each core was oven dried at 105 °C to determine the BD (Black and Hartge, 1986). Porosity was calculated using BD and particle density of 2.65 Mg m^{-3}. Soil dry aggregate stability was measured using a nest of sieves as described by White (1993). At the end, mean weight diameter (MWD) was calculated as a fraction of both dry weight of aggregates remaining on each sieve and the total dry weight of the sample. Wet aggregate stability was

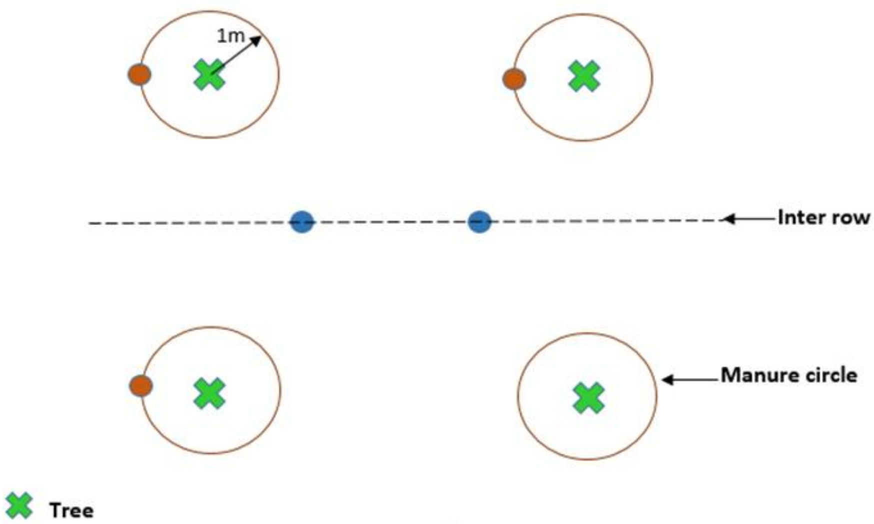

Figure 2 – Locations where soil moisture sensors were installed. The brown circles show the locations within 1 m radius from the tress and blue circles shows the locations in the inter row

measured using the aggregates of 1-2 mm size secured from the dry sieving, using single sieve apparatus (Kemper and Rosenau, 1986). Soil texture was analyzed using the pipette method (Gee & Or, 2002). SOC was determined according to the Walkley and Black method (Nelson and Sommers, 1982). pH was measured using 1:5 soil water suspension (Rowell, 1994). All above analyses were performed for soil samples collected from both 0-25 cm and 25-50 cm layers. Only texture, SOC, and pH were analyzed for samples collected from 50-75 cm and 75-100 cm layers.

Measurement of soil water retention

Soil water retention curves were developed using the soil core samples (3 cm height) collected from both rubber and oil palm cultivated fields at soil layers of 0-25 cm and 25-50cm. The sand box apparatus (Eijkelkamp soil and water, Giesbeek, Netherlands) and the pressure plate apparatus (Soil moisture, California, USA) were used respectively to obtain the wet and dry endpoints of the curve. The volumetric water content at 0, 0.4, 1, 1.1, 1.2, 1.3, 1.4, 1.5, 1.6, 1.7, 1.8, 1.9 and 2 pF (suction) levels was obtained using the sand box apparatus while the pressure plate apparatus was used to obtain the volumetric water content at 2.48, 3, 3.48, 3.7, and 4.2 pF levels. At the equilibrium of each point, the fresh weight was taken. At the end of the experiment, soil in core samples were oven dried and volumetric water content at each pF level was calculated.

Parametrization of the van Genuchten water retention model

An inverse modeling approach was used to estimate the best fitted parameters of the model. Volumetric water content data measured at corresponding water potential values were used to fit to the van Genuchten (1980) model (equation 3).

$$\boldsymbol{\theta} = \boldsymbol{\theta r} + \frac{(\boldsymbol{\theta s} - \boldsymbol{\theta r})}{[\mathbf{1} + (\boldsymbol{\alpha} * \boldsymbol{h})^{\boldsymbol{n}}]^{\boldsymbol{m}}} \quad (1)$$

$$m = 1 - \frac{1}{n} \quad (2)$$

$$\theta = \theta r + \frac{(\theta s - \theta r)}{[1 + (\alpha * h)^n]^{1-(\frac{1}{n})}} \quad (3)$$

where, θ is the soil volumetric water content ($cm^3\ cm^{-3}$); θ_r is the residual volumetric water content ($cm^3\ cm^{-3}$), θs is the saturated volumetric water content ($cm^3\ cm^{-3}$), α is the fitting parameter related to the inverse of the air-entry suction; h is the soil water tension and n and m are the model fitting parameters of the curve.

Through the fitting process, we were able to estimate the best-fitted model parameters of the van Genuchten model. The Solver optimization algorithm available in MS Excel was used to find these parameters by minimizing the root mean square difference between the measured and predicted volumetric water content data. Subsequently, the best-fitted parameters for each replicate water retention curve from both rubber and oil palm grown soil were subjected to statistical analysis to determine if there were any significant differences between them.

Determination of field capacity and permanent wilting point

Volumetric water content at field capacity (FC) and permanent wilting point (PWP) were determined from the water retention curve for 0-25 cm and 25-50 cm soil layers. Accordingly, volumetric water content at 2.48 pF pressure was used as the FC as the soil textural class for both oil palm and rubber grown soil was sandy clay loam (medium textured soil) (Klute, 1986). The volumetric water content at 4.2 pF was determined as the PWP representing the moisture level at which the plant is unable to extract water from soil. As water retention data was not measured for the 40-60 cm and 70-90 cm soil layers, the FC and PWP for these layers were estimated using the Soil, Plant, Atmosphere and Water (SPAW) model (version 6.02.75). The SPAW model utilized input parameters such as soil particle size distribution, soil organic matter content, salinity, and gravel content data to estimate FC and PWP for the respective soil layers.

Determination of soil water storage, plant available water storage, and relative water depletion

Soil water storage (SWS) at a given time was calculated using volumetric water content data for each soil layers (0-25 cm, 25-50 cm, 50-75 cm, and 75-100 cm) in oil palm and rubber grown site for during the study period (equation 4) (Zhao et al., 2017).

$$SWS = \theta * \Delta h * 10 \quad (4)$$

where, SWS is the soil water storage in a specific soil layer at a given time (mm); θ is the volumetric water content (cm^3 cm^{-3}) of the specific soil layer at the given time; Δh is the thickness of the soil layer in cm. The equation was multiplied by 10 to obtain the SWS in millimeters.

Plant available water storage (PAWS) was calculated using equation 5.

$$PAWS = (\theta_{FC} - \theta_{PWP}) * \Delta h * 10 \quad (5)$$

where. θ_{FC} is the volumetric water content in FC; θ_{PWP} is the volumetric water content in the PWP.

Relative water depletion (RWD) was calculated using equation 6 as suggested by Waller (2016). The ratio of water depletion from the FC to the plant available water storage at the specific depth and crop. This calculation provided insights into the extent of water depletion over time, indicating the relative water availability for the crop.

$$RWD\% = \frac{(SWS_i - SWS_{FC})}{(SWS_{FC})} * 100 \quad (6)$$

where, RWD % is the relative water depletion percentage, SWS_i is the soil water storage at the i^{th} time point, SWS_{FC} is the soil water storage at the FC at the given depth.

Statistical Analysis

Analysis of variance (ANOVA) was conducted to test the effect of crop type on measured parameter at 0.05 probability level using

SPSS (IBM, SPSS statistics 16). Crop type and the soil property were the independent (X) and dependent (Y) variables, respectively. The R package corrplot was used to calculate and visualize the correlation among soil properties of oil palm and rubber grown soils using R Studio software (R studio, 576). A general additive model (GAM) was fitted to the mean daily RWD% data using R software.

RESULTS & DISCUSSION

Basic soil properties

Soil cultivated with oil palm and rubber had sandy clay loam texture (USDA classification) across all depths including 0-25 cm, 25-50 cm, 50-75 cm, and 75-100 cm (Table 1). The *Agalawatte* soil series was the predominant soil series in the area and had similar textural classes up to about 110 cm depth (Senarath et al., 1997). Furthermore, there was a notable rise in clay content observed in the 50-100 cm layers in contrast to the surface layers (0-25 & 25-50 cm). Senarath et al. (1997) observed an increasing trend in clay content in the *Agalawatte* soil series as the depth increased, which is consistent with findings in rubber and oil palm-grown soil (Table 1). This phenomenon can be attributed to the presence of argillic horizons, a distinctive trait of this soil type, as highlighted by Mapa et al. (1999). Despite soil from both fields belonging to the same textural class, the clay content of rubber grown soil was significantly higher than that of oil palm-grown soil except for the 50-75 cm soil layer (Table 1). Soils rich in clay content have more micropores, which can store more water (Rosse et al., 2009) and decrease the Ks of the soil (Higashino et al., 2021). As a consequence of the elevated clay content in the rubber-cultivated soil, it exhibited lower Ks values in both 0-25 cm and 25-50 cm soil layers compared to the oil palm-cultivated soil (Table 2). A distinctive feature of the *Agalawatte* series is the presence of a substantial amount of gravel content within

Table 1- Soil textural separates (sand, silt, and clay), textural class, and soil organic carbon (SOC) percentages across different soil layers in twelve-year-old oil palm and rubber grown soils.

Depth cm	crop type	Sand%	Clay%	Silt%	Textural class	SOC%
0-25	Oil palm	67.3±0.98[a]	20.7±1.20[b]	11.9±0.84[a]	SCL	1.45±0.21[b]
	Rubber	63.1±1.14[b]	25.3±1.78[a]	11.6±1.08[a]	SCL	2.51±0.16[a]
25-50	Oil palm	63.7±0.67[a]	25.4±0.70[b]	10.8±0.49[a]	SCL	1.07±0.12[a]
	Rubber	59.8±0.98[b]	30.1±1.81[a]	10.1±1.14[a]	SCL	1.44±0.23[a]
50-75	Oil palm	63.5±0.90[a]	27.3±0.57[a]	09.2±0.32[a]	SCL	0.68±1.35[a]
	Rubber	58.8±2.45[b]	29..0±2.63[a]	12.2±1.76[a]	SCL	0.89±0.02[a]
75-100	Oil palm	62.9±0.54[a]	27.5±0.05[b]	09.5±0.49[a]	SCL	0.73±0.00[a]
	Rubber	51.5±3.74[b]	35.8±3.14[a]	12.7±0.69[a]	SCL	0.35±0.01[a]

SCL=Sandy Clay Loam
Means with different letters for a soil property are significantly different at the 0.05 probability level.
Mean ± standard error

the entire profile consisting of an ample amount of 2-5 mm size quartz gravel (Mapa and Somasiri, 1999). The study revealed high gravel content in both 0-25 cm and 25-50 cm soil layers of oil palm and rubber grown soil, with a significantly higher gravel content at 25-50 cm depth in rubber cultivated soil compared to oil palm cultivated soil (Table 2). Both oil palm and rubber cultivated soils had more than 40% of gravel content in 0-50 cm soil layer.

The SOC plays a crucial role in regulating water and heat storage, ultimately soil productivity (Cambardella and Elliott, 1993). There was a significant difference between the SOC of rubber grown soil and that of the oil palm grown soil in the 0-25 cm soil layer (Table 1). According to Senarath et al. (1997), the SOC content in mature rubber with grass cover was 1.35% in the Agalawatta soil series. However, Chathurika et al. (2010) reported that the SOC was 28% higher under cover crop; *Mukuna bracteata* in rubber plantations than the bare soil in rubber. According to the present study, SOC content in the rubber-grown soil under uniform grass cover was 40% higher than that in the oil palm-grown soil, which had sporadic grass cover. Upekshani and Dharmakeerthi (2009) also observed relatively higher SOC in rubber grown surface soil as compared to that in oil palm grown soil. However, no statistically significant difference was observed in SOC between oil palm and rubber cultivated sandy clay loam soils which had the same natural ground cover. The variations in SOC at 0-25 cm depth is likely due to distinct levels of net carbon input in the two systems. Within rubber plantations, the surface soil accumulates carbon from the yearly leaf litter of rubber trees and the organic matter generated by the cover crop. Chen et al. (2017) also observed higher SOC in surface soil of rubber plantations with regular leaf litter fall in southwestern China. In the case of oil palm cultivation, there was an absence of leaf litter, despite the presence of occasional grass cover and cleared areas around the trees.

The pH range in the *Agalawatte* series extends from 4.6 to 4.9 across a depth of 0-110 cm (Senarath et al., 1997). The results showed a significantly higher pH value in the surface of oil palm-cultivated soil (0-25 cm) compared to that of rubber-cultivated soil (Table 2) indicating that the surface soil layer of rubber-cultivated soil is more acidic in nature. Cristancho et al. (2011) discovered that oil palm grows well under acidic soil conditions. However, it was found that strongly acidic soil, inhibit the root growth of Hybrid varieties of oil palm (Cristancho et al., 2011). Therefore, in order to maximize the harvest, proper management should focus on management of soil acidity in both rubber and oil palm fields.

Table 2 – pH, bulk density, porosity, hydraulic conductivity, and gravel percentage at different soil depths in twelve-year-old oil palm and rubber grown fields.

Depth (cm)	crop type	pH (1:5soil: water)	Bulk Density (g/cm3)	Porosity	Hydraulic conductivity (cm/min)	Gravel %
0-25	Oil palm	4.61±0.24[a]	1.33±0.02[a]	0.49±0.01[a]	1.0±0.19[a]	41.28±2.89[a]
	Rubber	3.78±0.04[b]	1.40±0.05[a]	0.47±0.03[a]	0.7±0.11[a]	34.13±4.95[a]
25-50	Oil palm	3.99±0.02[a]	1.36±0.03[a]	0.50±0.02[a]	1.3±0.21[a]	41.41±2.62[b]
	Rubber	4.00±0.01[a]	1.43±0.03[a]	0.46±0.02[a]	0.7±0.10[a]	53.56±3.42[a]
ANOVA						
Significant level 0-25		0.007	0.075	0.335	0.193	0.221
Significant level 25-50		0.412	0.086	0.207	0.070	0.013

Means with different letters for a soil property are significantly different at the 0.05 probability level.
Mean ± standard error

Although there was a notable distinction in SOC of surface soil, there were no significant differences detected in BD and porosity between soils cultivated with rubber and oil palm (Table 2). The sensitivity of BD to variations in SOC appears to be relatively limited, as shown by the weak correlation observed between BD and SOC (Figure 3). Rawls et al. (2003) indicated that the impact of SOC changes on BD was more evident in sandy soil; whereas, soils with higher clay content did not exhibit the same sensitivity. The notably stronger correlation between clay content and BD (Figure 3) further supports the notion that the BD of the two soil layers is influenced more by soil textural composition than by SOC.

The findings for soil BD in two soil layers (0-25 cm & 25-50 cm) were consistent (ranging from 1.30 to 1.40 g cm^{-3}) with the BD measurements reported for the Agalawatta soil series (Senarath et al., 1997). Soil BD and porosity determine the soil compaction (Newell-Price et al., 2013; Tracy et al., 2011) and are widely used as an indicator of land use quality (Lestariningsih et al., 2013). Excessive soil compaction leads to the inhibition of root growth and adversely affects their functions (Głąb, 2013; Hargreaves et al., 2019). The compacted soil creates as a physical barrier that impedes root penetration and limits root elongation, reducing access to water, nutrients, and oxygen. As a result, plants may exhibit stunted growth, reduced nutrient uptake, and decreased water absorption, ultimately compromising their overall health and productivity. Zuraidah et al. (2015) observed that the oil palm growth and distribution were affected by soil compaction. The USDA soil quality test guide (1999) categorized soil BD into three groups ideal, affecting, and restricting pertaining to root growth, with classification determined by the soil textural class. Accordingly, they have identified the BD of less than 1.4 g cm^{-3} is ideal for root growth of crops grown in sandy clay loam soils. Since the BD of both oil palm and rubber cultivated soils ranged from 1.3 to 1.4 g cm^{-3} (Table 2), it can be assumed that there are no negative consequences that occur in both soils due to the compaction.

Mean weight diameter (MWD) is an indicator of the predominance of larger, more stable aggregates over smaller and less stable fractions (Le Bissonnais, 1996; Amézketa, 1999). High MWD indicates a high resistance to wind erosion and the predominance of macro aggregates. SOC plays a key role in forming soil aggregates and stabilizing soil structure (Onweremadu et al., 2007). SOC positively correlated with the MWD (Figure 3). While the SOC content in the 0-25 cm soil layer of rubber-grown soil was significantly higher than that of oil palm-grown soil, there was no statistical difference observed in the

MWD between rubber and oil palm grown soils for the same soil layers (Table 3). It was evident that the cultivation of oil palm has not impacted the soil's ability to resist wind erosion at the time of sampling. Further, the MWD was relatively low in the sub-surface (25-50 cm) layer compared to the surface (0-25 cm). But Senarath et al. (1997) observed higher MWD (2.02mm) in 20-40/43 cm soil layer than 0-20 cm soil layer (1.25 mm) in *Agalawatte* soil series. Water stable aggregate percentage (WSA %) in soil refers to the proportion of soil aggregate that can break down when exposed to the disruptive forces of water erosion. These aggregates are formed through the binding of soil particles by organic matter, microbial activity, and clay particles, creating stable structures. The WSA% is a crucial indicator of soil quality and erosion ability (Feng et al., 2023; Elhaja et al., 2014), soil water and carbon storage and soil microbial activity (Trivedi et al., 2015). A higher percentage of water-stable aggregates indicates better soil structure and reduced vulnerability to erosion. According to the study, both soil depths of oil palm and rubber cultivated soil showed more than 90% of WSA% (Table 3). Therefore, both fields indicate higher resistance to soil erosion and enhanced soil quality.

Soil thermal properties

Volumetric heat capacity (C) is an important thermal property that impacts heat storage in soil (Wang et al., 2019; Alnefaie and Abu-Hamdeh, 2013). Soils with large heat capacity can hold a larger amount of heat energy without experiencing a significant rise in temperature. Different factors such as SOC, clay content, water content, and BD affect C, (Alnefaie and Abu-Hamdeh, 2013). According to the study, SOC and BD positively correlated with C (Figure 3). The C of the 0-25 cm soil layer was significantly higher in rubber grown soil than that in oil palm grown soil while the C of 25-50 cm layer showed no significant difference between oil palm and rubber grown soils (Table 3). The high C in the 0-25 cm layer (Table 3) can be attributed to the greater SOC in rubber grown soil as compared to that of oil palm. This was evidenced by the notable correlation between SOC and C, as depicted in Figure 3.

Table 03- Mean weight diameter, water stable aggregate percentage, thermal conductivity, volumetric heat capacity, and thermal diffusivity values at different soil depths in twelve-year-old oil palm and rubber grown fields.

Depth cm	crop type	Mean weight diameter (mm)	Water stable aggregate (%)	Thermal conductivity (W/ m·K)	Volumetric heat capacity (MJ/ m^3·K)	Thermal Diffusivity (mm^2/s)
0-25	Oil palm	2.26±0.09^a	92.77±0.85^a	1.09±0.05^a	2.44±0.07^b	0.41±0.02^a
	Rubber	2.37±0.16^a	97.46±2.09^a	1.20±0.02^a	2.86±0.14^a	0.46±0.01^a
25-50	Oil palm	1.57±0.04^a	98.19±0.61^a	1.21±0.03^a	2.44±0.06^a	0.43±0.01^a
	Rubber	1.52±0.10^a	91.08±4.06^a	0.98±0.07^b	2.47±0.04^a	0.50±0.07^a
ANOVA						
Significant level 0-25		0.831	0.886	0.085	0.021	0.188
Significant level 25-50		0.653	0.087	0.010	0.723	0.242

Means with different letters for a soil property are significantly different at the 0.05 probability level.
Mean ± standard error
MWD – Mean Weight Diameter

Hence, the soil layer at 0-25 cm depth in rubber cultivated field can be recognized as exhibiting enhanced thermal buffering, effectively mitigating extreme temperature fluctuations.

Thermal conductivity (k) indicates the capability of transmitting heat through soil (Haruna et al., 2017). The absence of any significant difference in k within the 0-25 cm soil layer of both rubber and oil palm grown soils (Table 3) indicated that the conversion of rubber plantations into oil palm plantations resulted no notable changes in the heat transfer properties of the surface soil. At the 25-50 cm soil layer, there was a significant increase in gravel content (Table 2) in rubber grown soil relative to the oil palm grown soil. Presence of higher gravel content decreased the k in the 25-50 cm soil layer of the rubber grown soil due to increase in air filled voids in soil (Table 3). There was a significant negative correlation between gravel content and thermal conductivity (Figure 3) which supported the assumption. Soil thermal diffusivity (D) represents a measure of the soil's ability to conduct heat relative to its effectiveness in storing heat. The D is influenced by factors as C, soil texture, moisture content, BD and SOC. BD showed a positive correlation with D (Figure 3). However, both oil palm and rubber grown soils showed no significant difference in D for both 0-25 cm and 25-50 cm soil layers.

Soil water retention curve (SWRC)

The soil water retention curve (SWRC) shows the functional relationship between the soil water content and the soil water potential (or soil suction) of a specific soil. Soil water retention depends on soil texture (Salter and Williams, 1965), soil structure (Reeve et al., 1973), SOC (Klute, 1986), the swelling clay content, composition, and the concentration of the solutes (El-Swaify and Henderson, 1967). Rubber grown soil showed higher water contents than oil palm cultivated soil at the corresponding matric potentials in both 0-25 cm and 25-50 cm layers (Figure 4). This contrast stemmed from the comparatively elevated SOC and clay content in rubber grown soil (Table 1). This observation was reinforced by the significant correlation between SWS and both clay content and SOC (Figure 3).

There are 3 major regions in the water retention curve as air entry region, capillary region, and adsorption region. The air-entry region occurs at matric potential values of near zero. In this range, SWC is high and nearly constant. The capillary region occurs in the middle range of matric potential and the shape of this region of the curve reflects the pore-size distribution. The adsorption region occurs at very negative matric potentials where water content is low and nearly constant. A slight gap between the air entry and adsorptive regions and a wider gap in the capillary regions were observed in SWCRs of oil palm and rubber grown surface soils (0-25 cm). All three regions of SWRCs in the 25-50 cm soil layer exhibited a wider gap despite having similar shapes. This might be due to smaller differences in SOC, and clay content.

According to the Van Genuchten model, θ_r, θ_s, α and n describe the fitting parameters for soil water retention function (Radcliffe and Šimůnek, 2010). Study of Saxton and Rawls (2006) reported that the θ_r, the residual water content tends to increase with the higher proportion of the fine particles in the soil. Accordingly, the highest θ_r was observed in the 25-50 cm soil layer of rubber grown soil which had the highest clay content (Tables 1 &4). Despite such slight differences, no significant differences among the model parameters (θ_r, θ_s, α and n) were observed for both soil layers of oil palm and rubber cultivated soils (Table 4). This, clearly indicated that there was no significant difference observed between the pore size distributions of oil palm and rubber grown soils.

Soil water storage dynamics

Soil water storage (SWS) refers to the amount of water held within the soil profile and a key variable affecting a number of surface and subsurface hydrological processes such as run-off, infiltration, evapotranspiration (ET) and drainage across various spatial and temporal scales (Famiglietti et al., 1998; Grayson and Western, 1998; Yan et al., 2017).

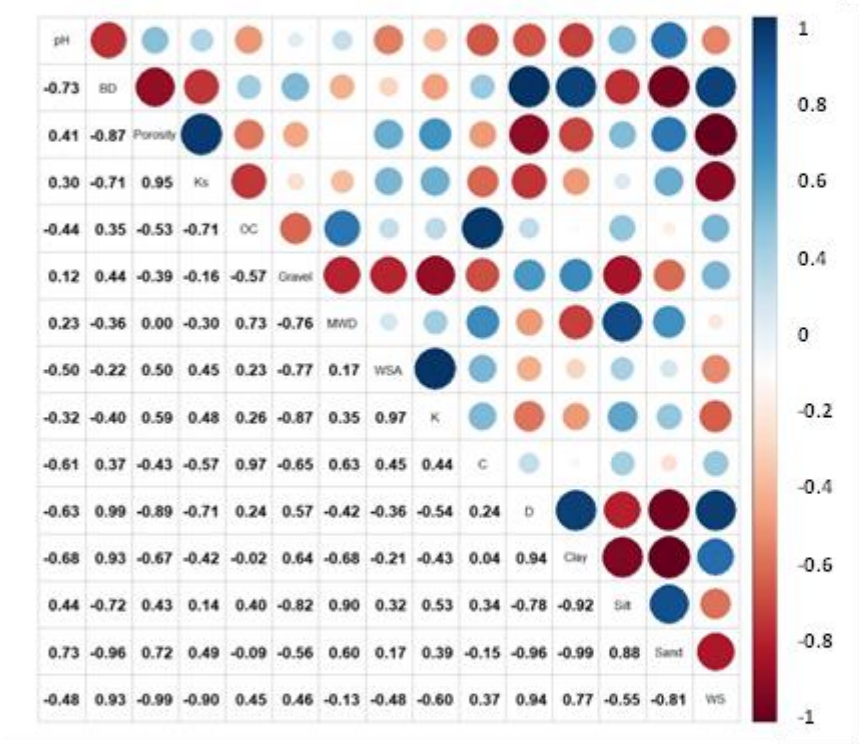

Figure 3- Correlation between soil properties of twelve-year-old oil palm and rubber grown soils. Circle size and the darkness represent the magnitude of the correlation, while red and blue colors indicate negative and positive correlation respectively. BD-bulk density, Ks-saturated hydraulic conductivity, OC-organic carbon, MWD-mean weight diameter, WSA-water stable aggregates, K-thermal conductivity, C-volumetric heat capacity, D-soil thermal diffusivity, WS-water storage

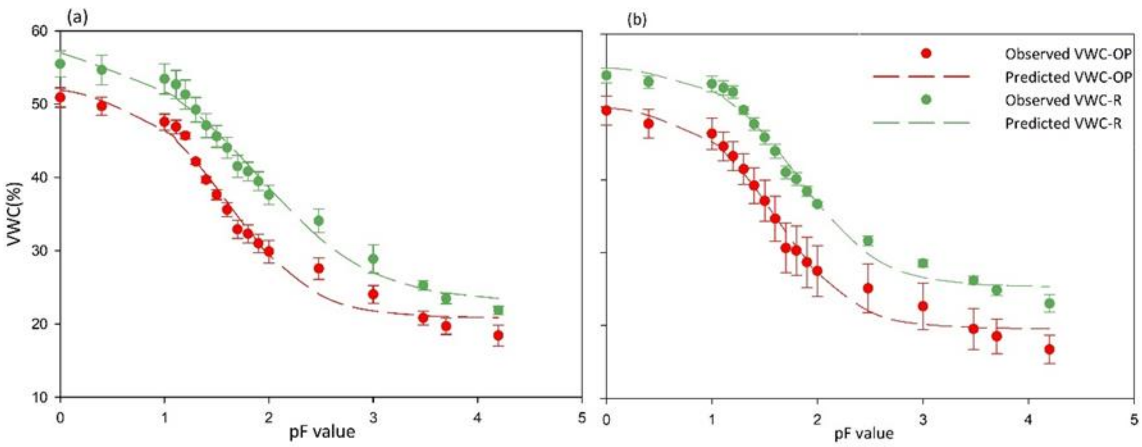

Figure 4 – (a) soil water retention curve of 0-25 cm soil layer and (b) of 25-50 cm soil layer of oil palm and rubber grown soils. Circles show the measured volumetric water content data at corresponding matric potential values whereas the dotted lines show the fitted Van Gunuchten model.

Table 4 – Fitted hydraulic parameters according to the Van Gunuchten model in oil palm and rubber grown soils at two different depths.

Depth	Crop	θ_r	θ_s	α	N
0-25	Oil palm	17.28±1.69[a]	50.51±1.48[a]	0.08±0.01[a]	3.73±0.51[a]
	Rubber	15.30±2.83[a]	55.18±1.45[a]	0.07±0.01[a]	3.81±0.88[a]
25-50	Oil palm	17.52±2.27[a]	49.00±2.43[a]	0.06±0.00[a]	2.65±0.25[a]
	Rubber	20.58±1.60[a]	52.54±1.50[a]	0.06±0.02[a]	3.69±1.36[a]
ANOVA					
Significant level 0-25		0.565	0.049	0.735	0.824
Significant level 25-50		0.361	0.240	0.842	0.418

θs and θr: saturated and residual water content; α and n: coefficients in the van Genuchten (1980) model
Means with different letters for hydraulic parameters are significantly different at the 0.05 probability level.

SWS is controlled by a suite of environmental factors operating across multiple scales (Blöschl and Sivapalan, 1995).The complexity of the environmental factors and their multivariate effects result in strong spatial and temporal variability of SWS across multiple spatial and temporal scales. The mean SWS across the all the four soil layers was higher in rubber grown soil than that of the oil palm grown soil. The variability of SWS was not governed by a singular factor; instead, it was shaped by a combination of factors that collaboratively influenced the dynamics of SWS throughout the observation period. Soil water storage showed a positive correlation (r = 0.77) with clay content and a negative correlation (r =-0.81) with sand content (Figure 3). Studies by Biswas et al. (2012); Cosh et al. (2008); Jacobs et al. (2004); Vachaud et al. (1985) also reported strong correlation between soil water storage and sand content. High sand content favored the vertical fluxes of water in soil resulting low retention(Gómez-Plaza et al., 2001; Pan and Wang, 2009), on the other hand high clay content favor the water storage capacity of soil by preventing the deep percolation of surface soil water and thus increasing the SWS. The increases in SWS during corresponding rainfall events exhibited more notable changes in the soil of rubber cultivation as opposed to the soil in oil palm cultivated field. For example, there were ten events in which SWS exceeded field capacity in the rubber-grown soil while oil palm had only two events (Figure 5a and 5b) throughout the study period. This observation further supported the idea that the soil in the oil palm field encountered greater vertical fluxes, as depicted in Figure 5. Apart from soil textural composition, there was also a positive correlation (r = 0.45) between SOC and SWS (Figure 3). This suggested that SOC might play a role in governing SWS within the uppermost soil layer (0-25 cm). In the field where rubber was cultivated, the mean SWS within each soil layer displayed relative increases of 24%, 44%, 25%, and 7% for the soil layers of 0-25 cm, 25-50 cm, 50-75 cm, and 75-100 cm, respectively. The 75-100 cm soil layer of rubber grown field had the lowest relative increase in mean SWS (7%) despite having the highest clay content and lowest sand content among all layers. Generally, SWS of rubber grown soil fluctuated

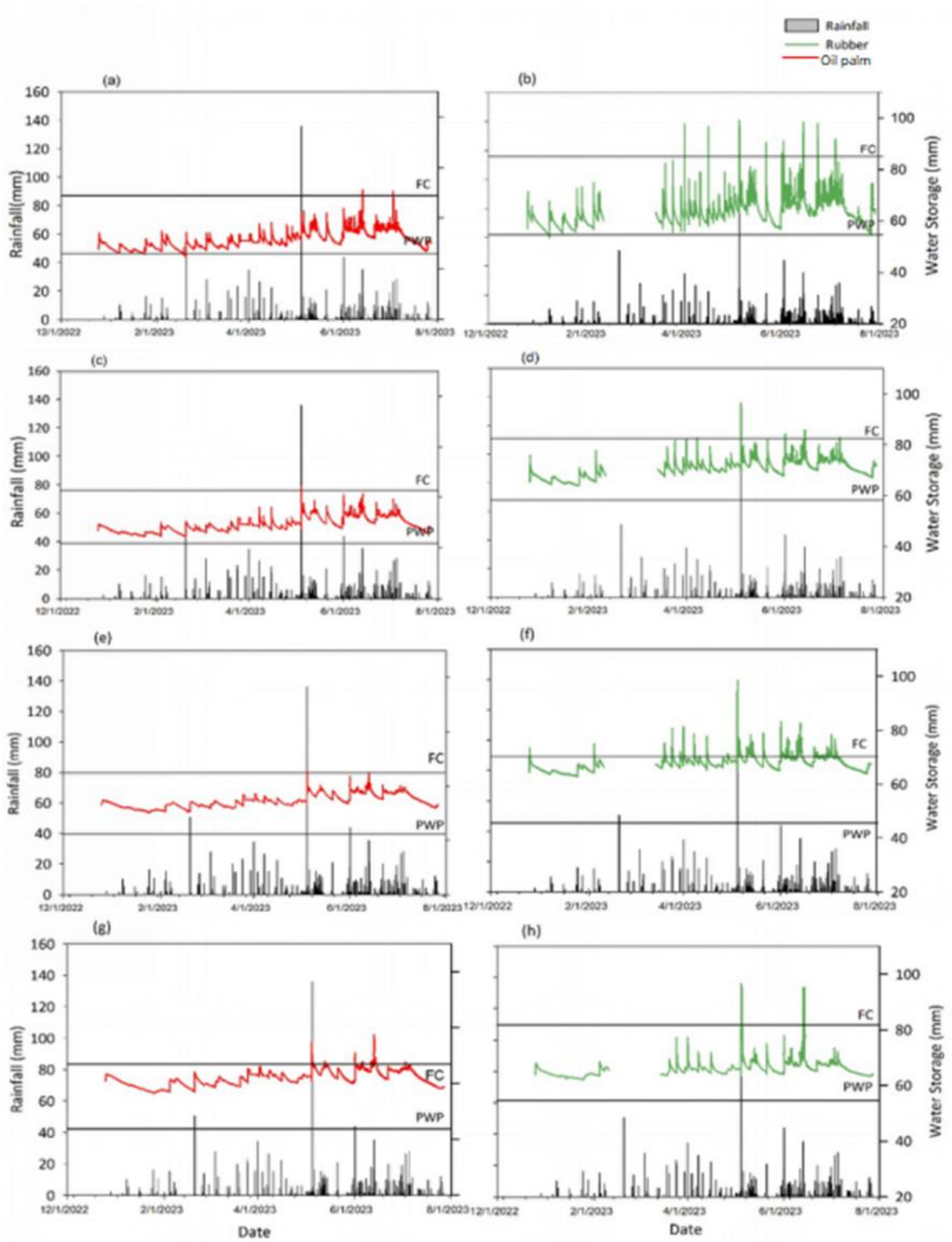

Figure 5- Temporal pattern of soil water storage at (a-b) 0-25 cm, (c-d) 25-50 cm, (e-f) 50-75 cm, (g-h) 75-100 cm soil layer of twelve-years-old oil palm and rubber grown soil, respectively.

more than that of the oil palm (Figure 5). In both rubber and oil palm cultivated soil, the uppermost soil layer (0-25 cm) displayed significant fluctuations in SWS compared to the deeper layers, as evidenced by the higher values of coefficient of variability (CV %) (Table 5).

Table 5 -Summary statistics of SWS at different soil layers in twelve-year-old oil palm and rubber grown soils

Crop	Depth (cm)	Mean SWS (mm)	Std. Dev.	Max. SWS	Min. SWS	CV (%)
Oil palm	0-25	51.05	3.42	71.21	43.27	6.69
	25-50	49.04	3.00	63.50	43.27	6.12
	50-75	54.24	2.50	64.93	49.15	4.61
	75-100	61.53	2.79	77.43	26.16	4.53
Rubber	0-25	63.31	4.79	99.18	54.55	7.57
	25-50	70.66	3.27	93.59	63.82	4.63
	50-75	67.69	2.72	97.17	62.80	4.02
	75-100	65.87	3.13	95.62	62.12	4.76

CV – coefficient of variation

The precipitation observed throughout the study period was derived from three main sources: the latter part of the Northeast Monsoon (December to February), the First Inter-Monsoon (March to April), and the Southwest Monsoon (May to September). A cumulative rainfall of 244.40 mm was recorded from late December to February, with a notable dry spell occurring between late December 2022 and January 2023, during which the total rainfall amounted to 80 mm. Furthermore, during the First Inter-Monsoon period, the region received a total of 444.60 mm of rainfall. The most substantial rainfall, reaching 1207.8 mm, was observed from May to July, coinciding with the Southwest Monsoon. In addition, there was a distinct dry period with a recorded rainfall of 51.8 mm from mid-July to the end of July 2023. Consequently, we can categorize the period extending from February to mid-July as a relatively wet season, whereas the periods from December to February and from mid-July to the end of July can be designated as distinct dry periods.

SWS within the 0-25 cm soil layer for both oil palm and rubber fields displayed a significant decline, dropping to over 50% of the plant available water storage during the dry periods. Notably, this reduction was more pronounced in the soil layer of oil palm cultivated field compared to that of rubber (Figure 5a & 5b). The increase of SWS of rubber grown soil in response to rainfall events was more pronounce during the wet periods. During the wet period, SWS within the 0-25 cm soil layer of the rubber cultivated site surpassed the SWS at field capacity on ten occasions (Figure 5b). In contrast, the SWS within the soil layer of the oil palm cultivated field exceeded the field capacity only twice throughout the same wet period. Consequently, SWS within the 25-50 cm and 50-75 cm layers of soil cultivated with rubber exhibited an elevation due to the replenishment of water from the upper layer. However, this replenishment was less prominent in the corresponding soil layers where oil palm was grown. For example, the SWS within the 25-50 cm soil layer of the rubber cultivated field predominantly remained above 50% of the plant available soil water storage capacity. Conversely, in the oil palm cultivated field, SWS in this same soil layer remained considerably lower until early May (Figure 5c & 5d) and then a notable shift in SWS occurred following the early days of May, coinciding with the period of maximum cumulative rainfall (506.6 mm) for the month of May. Moreover, the SWS within the 50-75 cm soil layer of the rubber cultivated field displayed consistent fluctuations near the field capacity. The elevated water storage observed in the subsurface soil layers (25-50 cm & 50-75 cm) of the rubber cultivated field might be attributed in part to the replenishment of water from the surface layer during periods of higher precipitation. Nevertheless, the relatively sustained higher SWS observed throughout the wet period signified a reduced rate of water extraction by rubber roots from the 25-50 cm and 50-75 cm soil layers in comparison to that observed in the case of oil palm cultivated soil. However, the increase in SWS within the 75-100 cm soil layer of the rubber cultivated field during the wet period was not as noticeable as the increase in the 25-50 cm and 50-75 cm soil layers. In contrast, the SWS within the 75-100 cm soil layer of the oil palm cultivated field consistently fluctuated above 50% of the plant available soil water storage capacity throughout the entire study period. The reason behind this could be that the rubber trees tend to draw more water from the deeper soil layers (75-100 cm), despite the fact that this layer have the highest clay content.

The SWS of the whole soil profile (0-100 cm) of the rubber field consistently exceeded that of the oil palm field over the course of the study. The SWS of the whole soil profile within both the rubber and oil palm fields exhibited fluctuations in response to the observed dry and wet periods. For instance, during the dry spells in December 2022 to January 2023 and in July 2023, the SWS of the whole soil profile in the rubber field exhibited slight fluctuations slightly above 250 mm. In contrast, the corresponding SWS in the oil palm field displayed oscillations around 200 mm (Figure 6). Furthermore, the SWS of the whole soil profile in the oil palm field increased with the commencement of the wet period in early May. Nonetheless, the SWS remained below 250 mm, except for three instances in which the three highest recorded rainfall events led to temporary increases beyond 250 mm.

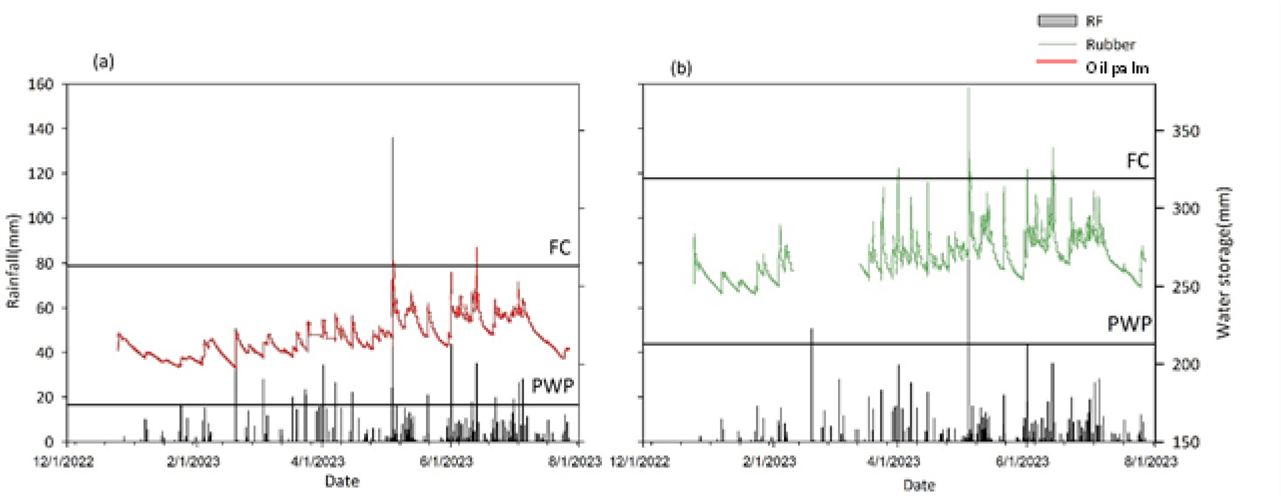

Figure 6- Temporal pattern of soil water storage in 1m profile of twelve-year-old oil palm grown soil (a) and rubber grown soil (b).

Relative Water Depletion

The RWD denoted the variation in water content in relation to the water content at FC. Negative values of RWD indicated a depletion in soil water storage compared to FC; whereas, positive values indicated the replenishment of water (SWS is above FC) in the respective soil layer or the entire profile. Figures 7 and 8 display the fitted Generalized Additive Models (GAMs) (Hastie and Tibshirani, 1986) for the daily mean relative water depletion percentage (RWD %) across various soil layers and the entire soil profile, respectively. The continuous line represented the overall RWD% pattern, while the shaded area depicted the 95% confidence interval band. When the confidence interval bands of rubber and oil palm overlap, it indicated an absence of significant difference between in RWD of rubber and oil palm and conversely. The depletion in SWS within the uppermost soil layer (0-25 cm) consistently remained elevated, exceeding 20%, in both rubber and oil palm fields when compared to the deeper soil layers (Figure 7a).

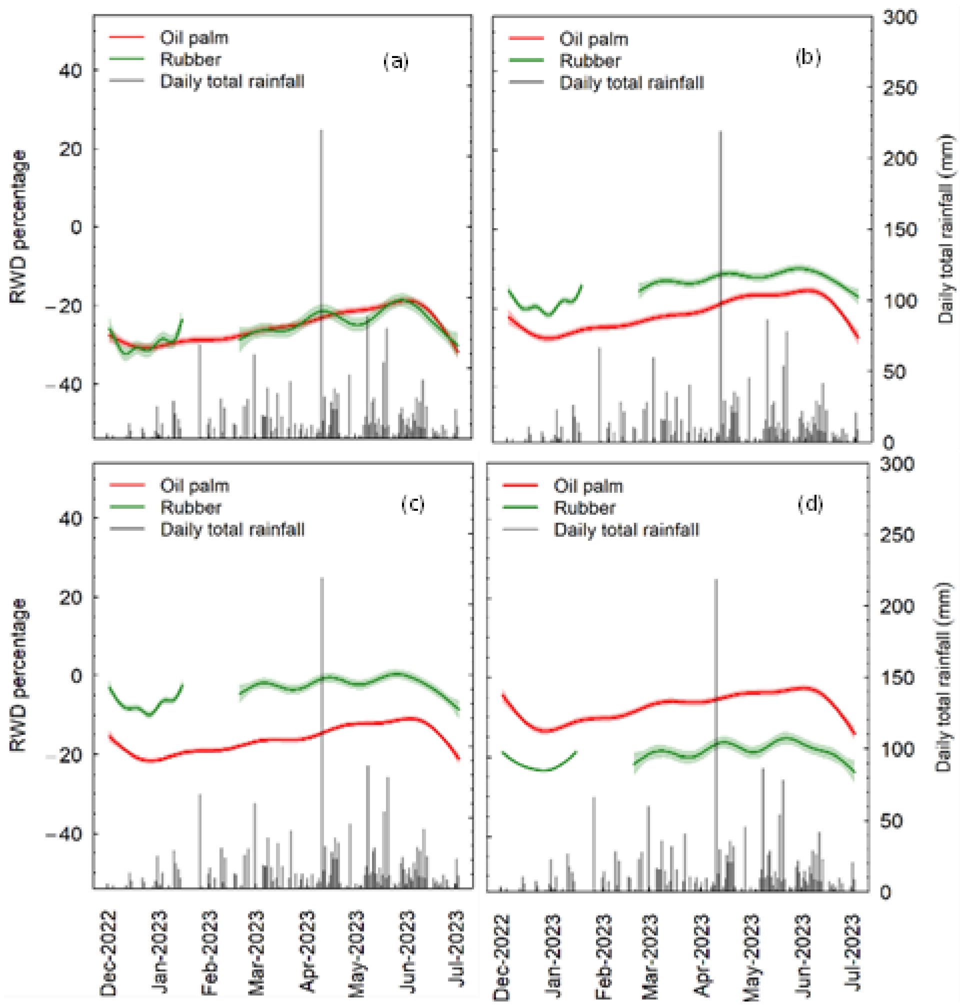

Figure 7 – Temporal changes in the percentage of relative water depletion (daily average) across different soil layers (a) 0-25 cm, (b) 25-50 cm, (c) 50-75 cm, and (d) 75-100 cm in rubber and oil palm fields. The solid lines represent fitted GAM models, while the shaded bands indicate the 95% confidence interval. The vertical bars show the daily rainfall received during the study period.

As the surface soil layer functions as an interface at the atmospheric boundary, the water contained in this layer experiences greater fluctuations due to rainfall and evaporation, in contrast to the deeper soil layers. The increased reduction in water content within the uppermost layer of soil in rubber and oil palm fields can be ascribed to a combination of factors: the extraction of water by roots and soil evaporation due to the soil's exposure to the environment. The shaded 95% confidence interval bands indicated a significant overlap in soil water depletion (0-25 cm layer) between rubber-cultivated and oil palm-cultivated soil, suggesting no significant difference in water depletion in 0-25 cm soil layers between rubber and oil palm. The daily SWS depletion in 25-50 cm and 50-75 cm soil layers was significantly higher in oil palm grown soil than that of rubber cultivated soil. Further, the disparity between SWS depletion of oil palm and rubber was relatively higher in 50-75 cm soil layer than that of the 25-50 cm soil layer. Soil water depletion was more pronounced during the drier periods from late December to early May and from mid-July to the end of July. The depletion of water stored in soil from the field capacity could reflect differences in root extraction patterns and soil properties. Overall, the significant depletion of water within the 25-75 cm soil layer of oil palm grown soil than that of the rubber could be due to more extraction of water by oil palm roots which was more rapid during the drier periods. It was evident that the decrease in water content within the 25-75 cm soil layer was primarily attributable to the uptake of water by roots, as evaporation predominantly occurs in the surface soil layer. Zhang et al. (2023) mentioned that when evaporation is dominant, water depletion mainly occurs from the surface soil layer and when transpiration is dominant, water depletion is localized mainly in the soil layers with the dense roots. In a study by Safitri et al. (2019), it was found that 13-year-old oil palm trees had the highest root density in the 0-50 cm soil layer. Additionally, Carr (2011) observed that oil palm roots are predominantly located in the top 60 cm of soil. This suggests that the considerable depletion of SWS in the 25-75 cm soil layer might be influenced by the water uptake of oil palm tree roots, contrasting with rubber.

Despite the higher clay content in the 75-100 cm soil layer of rubber-cultivated soil, the water depletion within this layer was markedly greater compared to oil palm-cultivated soil (Figure 7d). Studies by Giambelluca et al. (2016); Ling et al. (2022) reported that a larger portion of water is extracted from deeper layers of rubber plantations. The temporal variation in SWS depletion for oil palm and rubber cultivated soil exhibited similar patterns, albeit with different degrees of magnitude corresponding to dry and wet periods. For instance, SWS depletion was more pronounced during two distinct dry periods (from December 2022 to January 2023 and from mid-July to the end of July 2023), whereas it was comparatively lower during the wet period (February to June 2023). A rapid drying of oil palm cultivated soil was observed, particularly during the two distinct dry periods (cumulative rainfalls of 80 and 51.8 mm), in comparison to the rubber-grown soil. This trend was consistent across all depths except for the surface soil layer (0-25 cm). The average daily soil water loss from the entire soil profile (0-100 cm) in oil palm-cultivated soil was marginally greater than that in rubber-grown soil (Figure 8) during the drier periods from late December to early May and from mid-July to the end of July. Nevertheless, no statistically significant difference was observed in the water depletion within the entire soil profiles of oil palm and rubber during the wetter periods from May to mid-July. The selection of either oil palm or rubber as a crop may exert a marginal influence on soil water depletion during dry periods, yet it

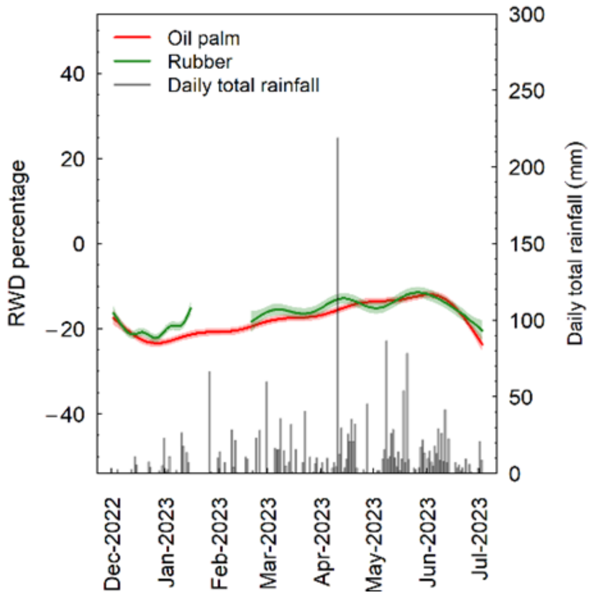

Figure 8 – Temporal changes in the percentage of relative water depletion (daily average) across the entire soil profile (0-100 cm) in rubber and oil palm fields. The solid lines represent fitted GAM models, while the shaded bands indicate the 95% confidence interval. The vertical bars show the daily rainfall received during the study period

appears to have no significant effect on water storage during wetter periods.

CONCLUSIONS

The findings of the present study indicated that the organic carbon content in the topsoil (0-25 cm) of oil palm plantation was 40% lower compared to that of rubber plantation. However, this disparity has caused no significant changes in soil properties such as bulk density, porosity, pore size distribution, and aggregate stability, except for soil volumetric heat capacity at twelve-years after the conversion. The surface soil cultivated with rubber would exhibit a greater ability to buffer against temperature fluctuations compared to that in oil palm cultivated soil. Further, there were no significant changes in soil water retention due to the conversion of the rubber plantation into an oil palm plantation after twelve years. However, it was clear that oil palm trees utilized most water from the 25-75 cm depth of the soil, whereas rubber trees tended to draw more water from deeper soil layers, specifically the 75-100 cm depth. Accordingly, it can be concluded that oil palm plantations have no negative impacts on groundwater levels, as they consume less water from deeper soil layers compared to that of rubber. However, the rapid decline in water content within the entire soil profile of oil palm cultivated soil compared to rubber during drier periods emphasizes the importance of thoroughly examining the effects of oil palm cultivation on soil water depletion during extended dry spells. Overall, the conversion of rubber plantations into oil palm plantations has caused no significant adverse effects on soil properties and, consequently, soil hydrology after a twelve-year period. These findings should be validated through additional studies conducted in various locations and across different age categories of oil palm and rubber fields in Sri Lanka.

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