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Properties of sandy soil and allelochemical compounds of heath forest in Rantau Abang, Terengganu, Malaysia: Implication for ecological sustainability and biodiversity conservation

Suhair Kamoona[1], Razanah Ramya[2], Wan Masyitah Wan Daud[3], Farah Ayuni Mohd Hatta[4], Rashidi Othman[5*]

[1]Department of Pharmacy, Al-Manara College for Medical Sciences, Maysan, Iraq.
[2]Institute of the Malay World and Civilization, The National University of Malaysia, Bangi, Selangor Darul Ehsan, Malaysia.
[3,5]Herbarium Unit, Department of Landscape Architecture, Kulliyyah of Architecture and Environmental Design, International Islamic University Malaysia, Kuala Lumpur, Malaysia.
[4]Institute of Islam Hadhari, The National University of Malaysia, Bangi, Selangor Darul Ehsan, Malaysia.

Corresponding author: Rashidi Othman (*Email: rashidi@iium.edu.my*)

Abstract

Kerangas or heath forests are found on podzolised siliceous sands (spodosols), where gradually decomposing organic matter occurs on the soil's surface. Changes in the extent of podzol development, soil consistency, and poor nutrient contents signify the unique properties of sandy soil in the heath forest at Rantau Abang, Terengganu, Malaysia. Unfortunately, the sandy soil's chemical and physical properties are in critical condition due to human activities such as cutting and burning, impacting the sustainability of this ecosystem and its ground cover of shrubs, sparse grass and sedge. Therefore, it is crucial to study the properties of sandy soils in heath forests before their extinction. This analyzed the physical and chemical attributes of heath forest sandy soils regarding heavy metal toxicity, pH, concentrations of carbon, nitrogen, available phosphorus, cation exchange capacity (CEC), allelochemical compounds, total phenolic content in the soil, soil colour, and soil texture. The solid was found to be nutrient-deprived due to its extreme acidity and toxicity. The results showed that allelochemical matters were higher in plants but not in the soil attributes and the water bodies, along with a highly active response in young plant tissues due to their sources of phenolic content. Remarkably, the overall phenolic content was observed to be considerably high in the semi-mature phase of vegetation.

Keywords: Allelochemical, Heath forest, Heavy metals, Low pH, Nutrient deficiency, Sandy soil, Soil acidity.

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1. Introduction

Malaysia is a country that is rich in biodiversity and consists of many forest ecosystems that provide a natural home for various flora and fauna. Lowland forests, hill forests, peat swamp forests, and mixed dipterocarp forests are the forest known to the public. However, many people are unaware of the existence of another unique forest ecosystem called the heath forest. Tropical heath forests are locally called as "kerangas". This name was given by the Ibans (local community), and it means "land that cannot grow rice" [1] . These forests developed on the exposed beaches close to the shore, after declining sea level around a million years ago and further inland through the elevation of the land mass around seven million years back. The tropical heath forests existed on acidic sandy soils generated from the siliceous parent rocks of the region. The forests' sandy soil frequently lacks nutrients, particularly nitrogen, which subsequently impedes the growth of plants in these areas [2]. Gradually, the sand is wrapped by a thick coating of organic matter, letting vegetation to grow. Due to their extreme fragility, heath forests are also classified as restricted forests worldwide. Once the organic layer is gone, the forest cannot regenerate, leaving only sand. Nowadays, heath forests are experiencing a significant loss of their coverage and facing the threat of extinction due to the negative impacts of human involvement. Uncontrolled human actions like logging, land reclamation, and forest burning for agricultural purposes are severely endangering the heath forests in Malaysia. Despite being a rare tropical forest ecosystem, it remains the one forest with little study and research over it. Moreover, there is inadequate public exposure to the beauty and uniqueness of heath forests, particularly their sandy soil properties. This lack of public awareness causes people to care less about their existence, making the situation even worse.

1.1. Heath Forest

Heath forest formation happens predominantly in Borneo, where it can be seen on cuesta formations and sandstone plateaus, mainly on dip slopes in the hilly regions of Sabah, Brunei, and Sarawak. In contrast, heath forests are rarely found in peninsular Malaysia. However, it is believed that they once existed and scattered along the Terengganu beach coast on the East coast and can still be found in certain areas in Pahang and Perak. Unfortunately, the heath forests in Pahang and Perak are at high risk of extinction, and some have already disappeared [3]. In Borneo, these heath forests are called "kerangas", a term derived from an Iban word meaning a barren land that cannot be used to plant rice [4]. A variety of heath forests are found in Borneo, including dryland heath forest formations such as coastal and inland heath forests, as well as the wetland heath forest known as "kerapah" [5].

The heath forest is very distinctive from any other forest in its forest due to its unique structure, physiognomic features, tree characteristics, and habitats. These peculiar attributes of the heath forest make it a special and rare type of forest. Unlike any other evergreen forests that grow on fertile soils, heath forest grows on infertile soils. This forest type can be seen on podzolized siliceous sands (spodosols) that are drained by a black water stream [4]. Spodosols are characterized by grey acidic soils with a heavily strained surface layer. Heath forests grow on highly acidic soils, and the hydrogen ion toxicity inhibits the progression of unsuitable genera [5]. The sandy, acidic and nutrient-poor conditions of the heath forest have forced the vegetation that inhabits the forest to evolve to acquire nutrient necessary for survive in the harsh environment. The habitants of this distinct and exceptional kind of forest are extremophiles due to their extreme ecological conditions [5].

The soils in these forests degrade rapidly and turn into bleached sand after the forest cover is lost. This makes heath forest exceptionally delicate [2]. Due to the low nutrient soils in heath forests, only vegetation that can adapt to the harsh conditions can inhabits them. These forests differ from the dipterocarps and other lowland forests because of the vast contrast in species diversity and external morphology [4, 5]. In the heath forest environment, the fauna, such as wild animals, insects, or wildlife is unproductive. Water bodies in heath forests support limited fish species, and most of them are the detritivore that feed on dead plant wastes. The detritivore community in heath forest includes insects, cladocerans, annelid, rotifer, nematode, protozoa, molluscs, algae, and zooplankton, which are very rare to be found in this habitat [4]. Figure 1 illusrtaes the uniqueness of this forest and provides a better understanding of it.

Figure 1.
The view of unique characteristics of the heath forest at Rantau Abang, Terengganu, Malaysia.

Othman, et al. [6] sum up the characteristics of heath forests as follows:

i. Heath forests are vulnerable to intentionally lit fires for commercial logging and farming.
ii. Soil in heath forests degrade rapidly and turn into bleached sand after the forest cover is removed, making this kind of forest extremely delicate.
iii. Periodic water stress and a dearth of available nutrients might be vital to the growth of heath forests, which are particularly unsuitable for agriculture.
iv. The soils in heath forests are commonly known as white-sand soils.
v. Heath forests are found on well-drained, acidic soils (with a pH of less than 4) and low clay content, obtained from siliceous rocks under ever-wet circumstances.

Heath forests are a kind of tropical moist forests found in regions characterised by sandy, acidic soils, which are nutrient-deprived, thereby inhibiting the progress of non-adapted species [7]. They tend to become very during season and waterlogged in the wet season. Heath forests differ from the adjoining lowland rainforests and other forest variants in terms of species composition, texture, structure, and colour. The few species of plants found in heath forests are either rare or not present in other types of forests [8-10]. Periodic water stress and nutrients deficiency may play a vital in the development of heath forests, which are unsuitable for agriculture. Insectivorous plants and ant plants are strong indicators and characteristics of a heath forest. Remarkably, the composition of the plant species in a heath forest differs in different regions of Borneo and depending on the local conditions. *Gymnostoma nobile* and *Calophyllum incrassatum* are the most common and abundant species in the Sarawak heath forests, while *Dipterocarpus borneensis*, *Gluta beccarii*, and *Cratoxylon glaucum* are common in Brunei. *Shorea balangeran* and *Cratoxylum glaucum* are common in Kalimantan, *Shorea multiflora*, *Cleistanthus gracilis*, and *Tristaniopsis merguensis* are common in Sabah, and *Melaleuca cajuputi* is common in Terengganu [3, 11-15].

In Peninsular Malaysia, there are three geographic regions where heath forests grow and have been observed. One is located on the west coast (Perak) and the other two are on the east coast (Terengganu and Pahang). Unfortunately, the heath forest in Perak has been completely wiped out, and only two are left in Menchali, Pahang, Dungun, and Terengganu. These habitations are susceptible and in a critical state, entailing immediate response for their preservation, further exploration, and protective measures to safeguard them. MacKinnon, et al. [16] and World Bank Group [17] predicted that heath forests in Borneo would be in the 'endangered' stage in 2010 due to agricultural, industrialisation, and urbanisation activities. Today, only 48% of 66,882 km^2 is left in Borneo. Heath forests are not safe from fires set deliberately for commercial logging and farming. This pursuit for land is degrading the nutrient-deprived soils of the heath forests. These soils quickly turn into bleached sand once the forest cover is gone, making this kind of forest highly fragile. Heath forests are easily impacted by human actions such as burning and logging [18]. After degradation, they transform into an open plain of shrubs and trees over sprase grass and sedge. This formation is known as a *padang*. Although heath forests can regenerate from a *padang*, it takes a very long time. Indeed, replantation or reestablishing heath forest's natural vegetation has not been proven to be effective. Heath forests in Malaysia are being over-exploited for development, which is causing them to become rare and undervalued despite their hidden values. As such, there is an urgent need to investigate and understand in depth the ecological and functional values of heath forest ecosystems, especially the abiotic factors, to restore their habitats and for the future development of sandy soils.

2. Method

2.1. Site Selection

The study site is situated at Rantau Abang, Terengganu, located at 4°55'N, 103°21'E. Rantau Abang is a tiny hamlet situated 80 kilometers south of Kuala Terengganu. Melaleuca cajuputi species primarily dominated this forest. The study zone is split into three classes: matured trees zone (trunk diameter between 80 and 130 cm), semi-matured trees (trunk with diameter between 25 and 50 cm), and seedling zone (trunk diameter between 2 and 10 cm) as depicted in Figure 2.

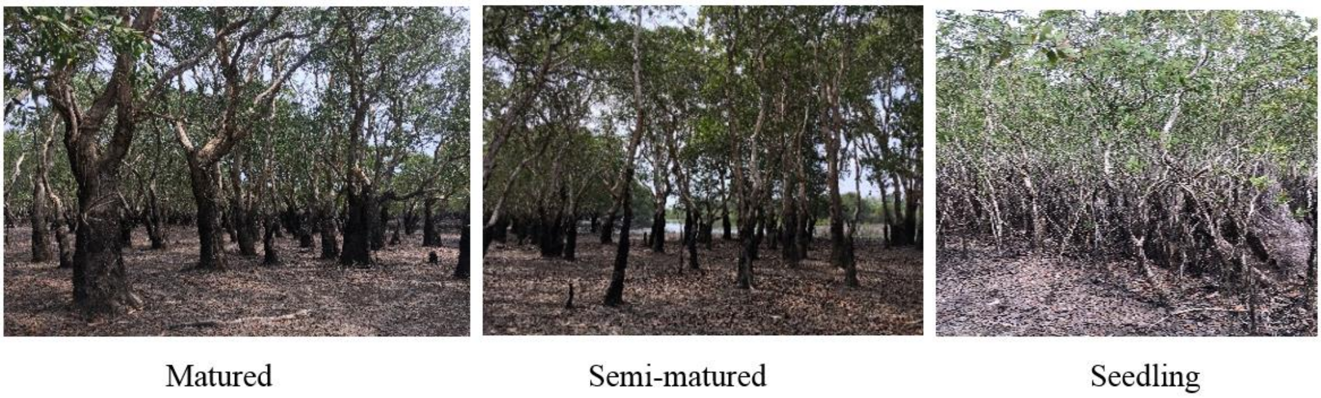

Figure 2.
Heath forest species areas based on trunk diameter at Rantau Abang, Terengganu.

2.2. Soil Sampling and Preparation

Soil samplings were collected at 1 m from the lakeside out of 10 points around the lake with a 30 cm depth as described by Othman, et al. [19]. The samples were air-dried at 60°C for a week, grind before being sieved (2.00 mm), and then stored in sampling bags. In the laboratory, each soil sample was analysed to identify soil texture, dry pH, organic carbon (OC) and cation exchange capacity (CEC. For heavy metal analysis, 0.5 g of soil sample was accurately weighed and placed into the vessels before being digested using a microwave digester, following the method outlined by United States Environmental Protection Agency (US EPA) 3051, using 10 mL nitric acid and a maximum power of 1,200 Watt. The overall digestion and cooling process required 35 minutes. The solutions were then analyzed for heavy metal content using Inductively Coupled Plasma Mass Spectrometry (ICP-MS). Soil colour variables were measured using a Colour Space (CIELAB) spectrophotometer. Soil texture distribution was determined using the pipette method. Organic matter and total organic carbon were determined using the wet digestion method Walkley and Black. Cation exchange capacity (CEC) was determined using the neutral ammonium acetate (CH_3COONH_4) saturation method.

2.3. Water Sampling Preparation

Water samplea were collected from 10 different points for each selected area, about 10 cm below the water surface. The characteristic of water bodies selected for sampling were stagnant, such as the lake, as described by Othman, et al. [20]. Surface water samples were collected using High-density polyethylene (HDPE) bottles. The whole water sample was preserved in the icebox during transportation to the laboratory for analysis. For heavy metals analysis in water, the water samples were digested using a microwave digester following the US EPA 3015 method for water samples, using 1,200 Watt maximum power for 10 vessels and a 20 min digestion process with 45 mL water sample and 5 mL of 65% nitric acid. The resulting solutions were analysed using ICP-MS for heavy metals detection, with triplicates for each point of the samples.

2.4. Determination of Heavy Metals in Soils

0.5 g of soil samples were accurately weighed in a container made of perfluoroalkoxy (PFA) polymer and digested through a microwave digestion system using the digestion method described by Radzi [21]. The soil samples were air-dried and sieved, passing through a 2 mm sieve before being ready for further analysis. The dried and the ground sample was mixed with 10 ml of concentrated nitric acid (HNO_3 65%) and digested. Acid was added for each soil sample then the digestion tubes were placed in a rotor segment using a torque wrench. The segments were inserted into the microwave cavity and connected to the temperature sensor. The mixture temperature was adjusted to ±175ºC and 1,200 Watts of power for 30 minutes using Microwave Digestion (Milestone Start D) as detailed in Method US EPA 3051. The digestion was completed when the last solution was clear, and no brownish fumes were released from the digestion vessel tubes. When digestion was completed, the samples were removed and diluted. The soil digests were adjusted to the final volume of 50mL with deionized water. This solution was further 1:1 diluted for the analysis of components by ICP-MS and divided into triplicates into 15 ml tubes.

2.5. Determination of Total Phenolic Content (TPC)

Total Phenolic Content (TPC) determination was conducted using the Folin-Ciocalteau assay, as reported by Ramya, et al. [11]. Quantification was performed with hydrolysed samples, and the results were expressed as gallic acid equivalence (GAE) per gram dry weight sample, using a microplate reader.

2.6. High-Performance Liquid Chromatography (HPLC) analysis of Phenolic Acids Content

High-Performance Liquid Chromatography (HPLC) analyses were performed using Agilent 1200 series (Agilent Technologies, Palo Alto, CA, USA), equipped with the binary pump, an autosampler, and a diode array detector (DAD). The HPLC column was a reverse-phase Zorbax SB-C18 (Eclipse 100 × 2.1 mm, 1.8 μm), and the temperature of the column was set at 25°C. For the analysis, two mobile phases were used: phase A, consisting of 1% formic acid in water/ acetonitrile 90:10 v/v, and phase B, consisting of acetonitrile. the solvent gradient used was developed as follows: 0-40% solvent B (0-20 min), 40-60% solvent B (20-25 min); 60-100% (25-25.1 min), 100% solvent B (25.1-35 min) and 100-0% solvent B (35-35.1 min) at a flow rate of 0.4 ml/min with detection at 280 nm throughout the gradient, as described by Ramya, et al. [11]. The phenolic acid contents were identified based on their retention times and Ultraviolet (UV) spectra, compared to standards.

3. Results and Discussion

3.1. Soil Physical Properties Analysis

The 60 soil samples included 20 matured trees (trunk diameter between 80 and 130 cm), semi-matured trees (trunk with diameter between 25 to 50 cm), and seedlings (trunk diameter between 2 to 10 cm), as depicted in Table 1. The analysis was conducted by using the Munsell Soil Colour Chart. In all of these samples, there were only slight differences in soil colour properties between the matured, semi-matured and seedling areas of the heath forest's sandy soil. Under the Munsell colour scheme, colour is determined by value (lightness or darkness), hue (basic colour), and chroma (intensity of basic hue). Based on the average results, the hues that indicate the heath forest's sandy soil were classified between 2.5Y and 7.5Y or from grey to white, as depicted in Table 1. The main colouring agents in heath forest sandy soils are organic matter and phenolic compounds. Both compounds impact the soil by deepening its colour. However, phenolic acid is dependent on the quantity produced by plants.

3.2. Analysis of Soil Texture

The soil texture analysis of heath forests' sandy soil has established marked differences in silt and sand contents among the three areas (A, B and C), as demonstrated in Table 1. The highest fine sand fraction, which ranged from 85 to 94%, was found in all areas, compared to coarse sand ranging from 5 to 14 %. For the silt fraction, the values were only 1%. Due to of this scenario, the soil cannot hold and store water in huge quantities, making it quite vulnerable to landslides, erosion, and sedimentation. These situations could also increase leaching of nutrients in the soil, affecting their availability for growth of plants. There is almost no vegetation on the surface of the heath forest floor. Furthermore, white sand raises the temperature of the land surface (above 37.50 ◦C) during the dry spell. Nonetheless, nature has its way of recovering itself by possessing thick organic matter on the surface part.

Table 1.
Descriptive statistics.

Area of soil	Soil colour (Munsell chart)	Soil texture (%)		
		Coarse sand	Fine sand	Silt
Plant with less than 10 cm diameter area (A)	Grey 2.5y 6/1	14	85	1
Plant with more than 25 cm diameter area (B)	Light grey 7.5y 7/1	5	94	1
Plant with more than 80 cm diameter area (C)	Light grey to white 5y 7/1 – 8/1	7	92	1

3.3. Characterisation of Heavy Metals Content and Composition in Heath Forest Sandy Soils

Samples of soil collected from this location were examined to check the content of heavy metals and their composition to identify the characteristics of the sandy soils of the heath forest. The heavy metals detected in the examination were Al, Cd, Cu, Cr, Fe, Mn, Ni, Pb and Zn. Figure 3 to Figure 10 show the outcomes of the heavy metal content analysis in the heath forest's sandy soils. There were notable differences in composition and concentration among all heavy metal types in every soil layer. The soil's upper layer (0-10 cm) had a higher concentration compared to the middle layer (10-20 cm) as well as the bottom layer (20 -30 cm). The outcomes indicated that the region where there were seedling trees contained more heavy metals than the region of the matured and semi–matured trees. As shown in Figure 3, the highest concentration was that of Al content, which really reached the permissible content of heavy metal in soil which has a high potential of causing toxicity to the environmental concentration. Among all the analysed heavy metal contents, Fe and Al concentrations were noted (Figures 3 and 4) to be among the highest for sandy soils of heath forests, ranging from 9.09 to 46.69 mg/kg and 61.95 to 353.41 mg/kg, respectively. On the other hand, only a slight amount was observed in the case of other heavy metals at different soil layers and plant maturity regions of the sandy soils of the heath forest, as given in Table 2, as well as Figures 5–10. In solid form, aluminium is a usual part of every soil and is harmless or even beneficial, but it can prove toxic to plants in the form of a solution. Moreover, the aluminium can be carried by surface and groundwater supplies, where, in sufficiently high concentration, it can be potentially toxic to animals (including humans) that rely on these resources.

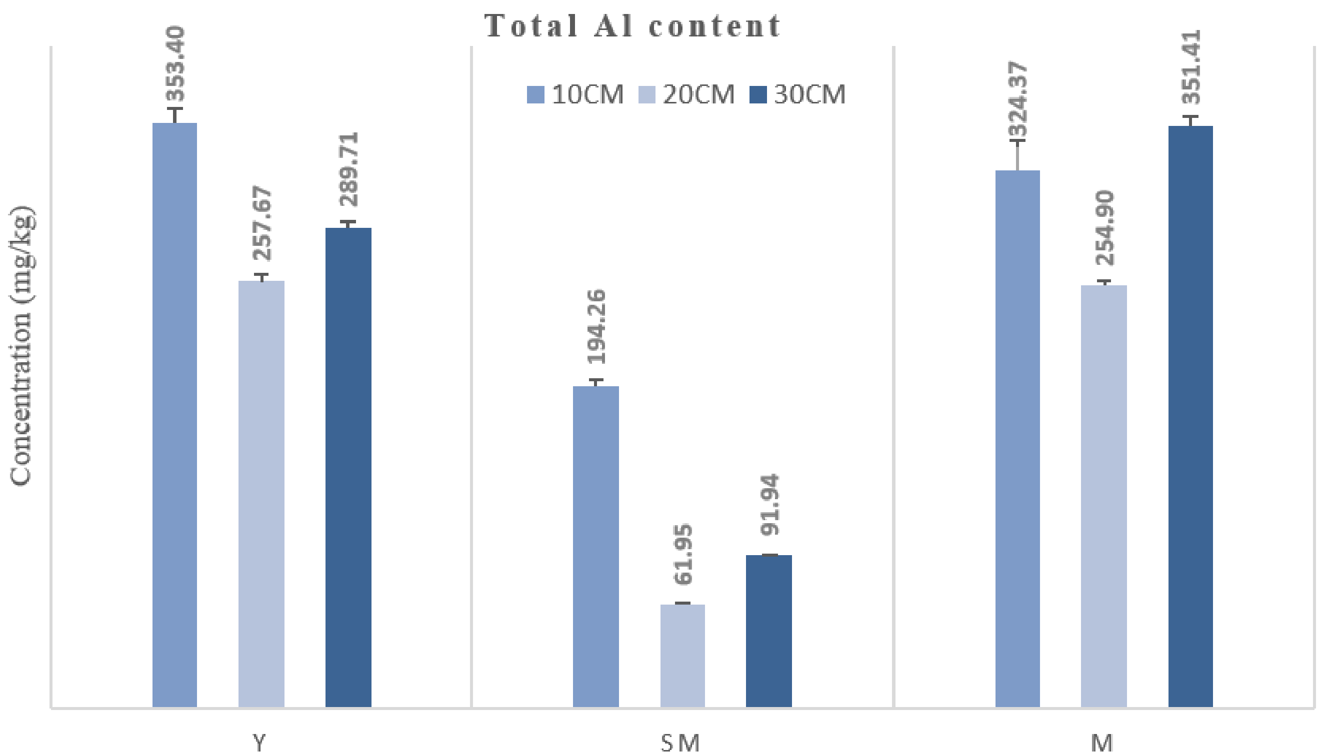

Figure 3.
The average Al concentration in heath forest sandy soil samples for matured trees area (M), semi-matured trees (SM) and seedling area (Y) at three different soil depths.

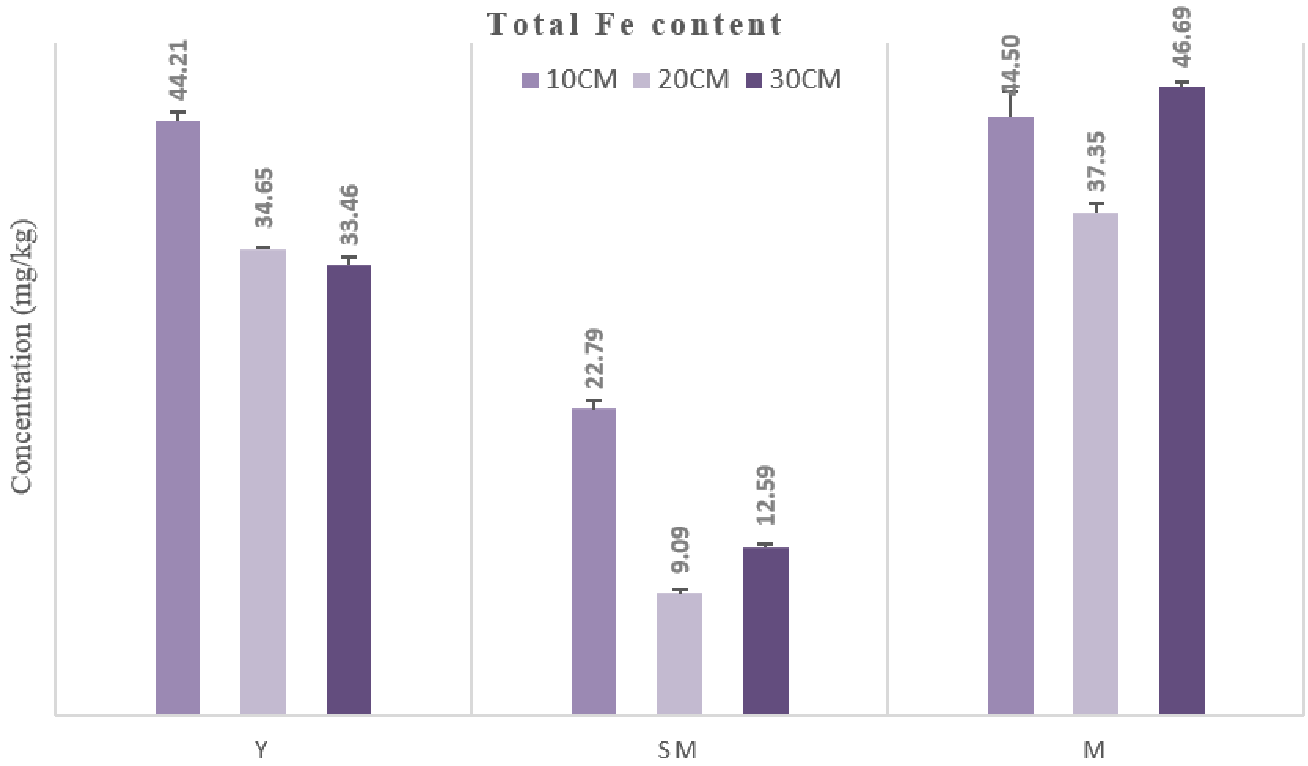

Figure 4.
The average Fe concentration in heath forest sandy soil samples for matured trees area (M), semi-matured trees (SM) and seedling area (Y) at three different soil depths.

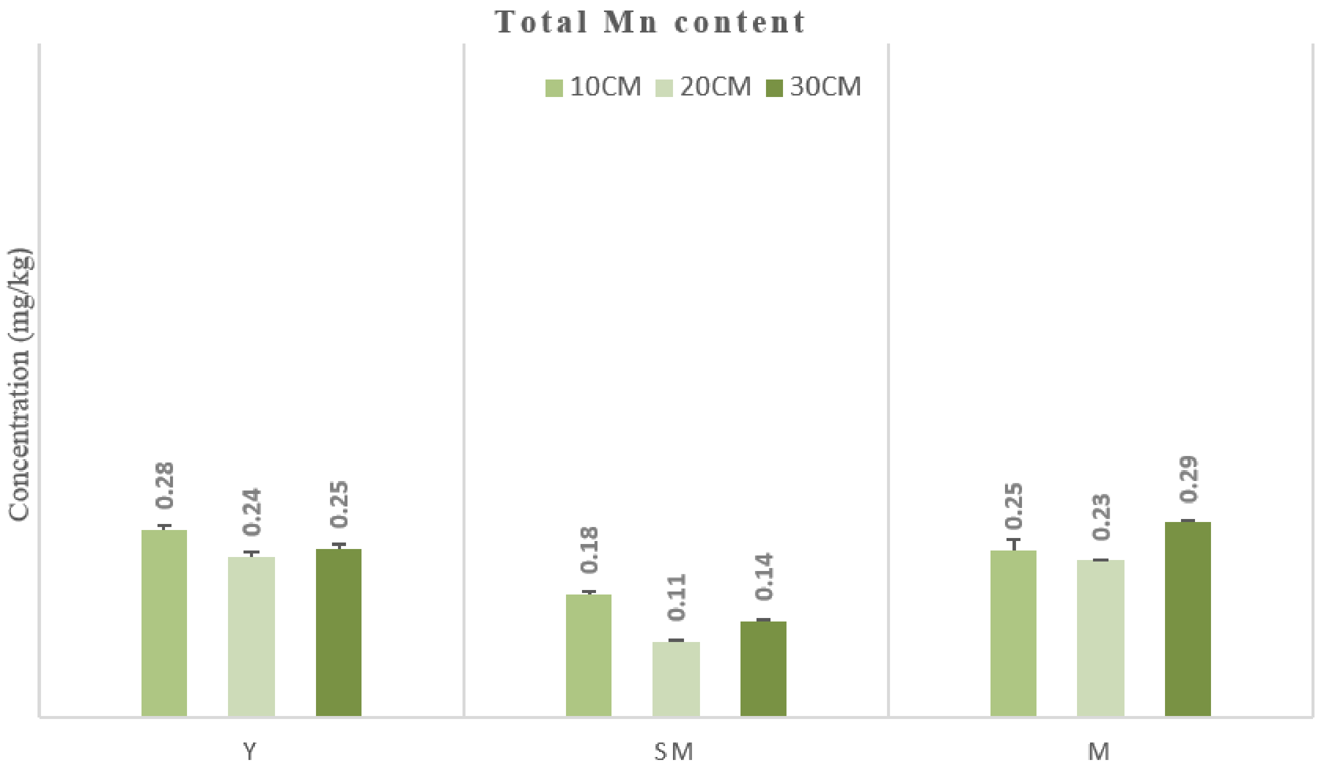

Figure 5.
The average Mn concentration in heath forest sandy soil samples for matured trees area (M), semi-matured trees (SM) and seedling area (Y) at three different soil depths.

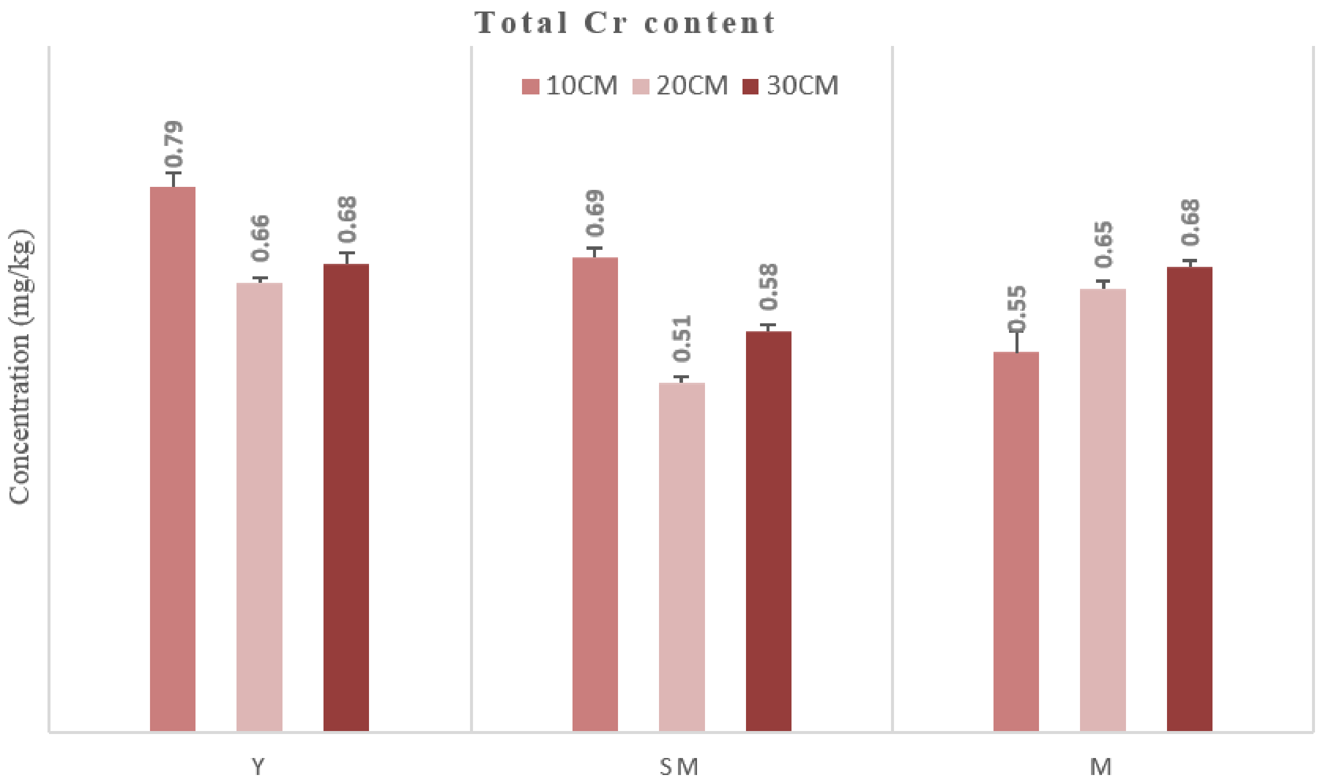

Figure 6.
The average Cr concentration in heath forest sandy soil samples for matured trees area (M), semi-matured trees (SM) and seedling area (Y) at three different soil depths.

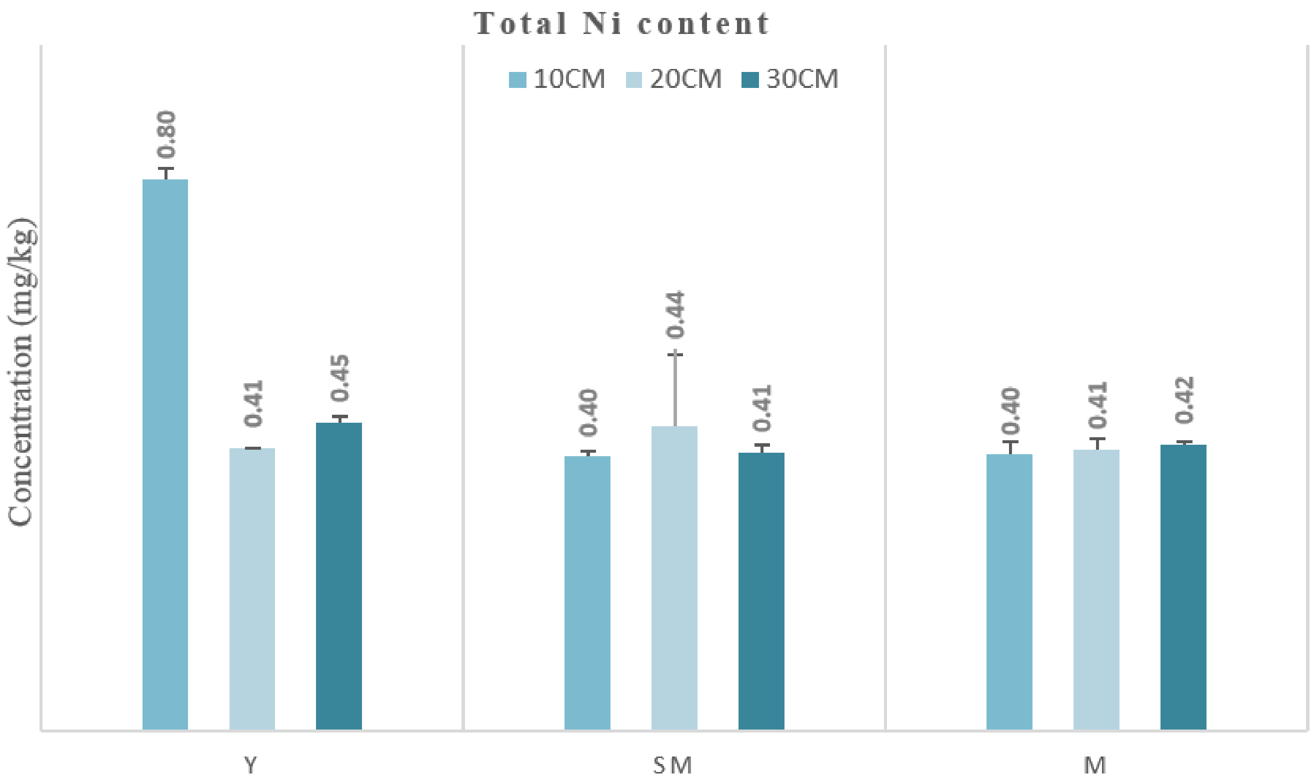

Figure 7.
The average Ni concentration in heath forest sandy soil samples for matured trees area (M), semi-matured trees (SM) and seedling area (Y) at three different soil depths.

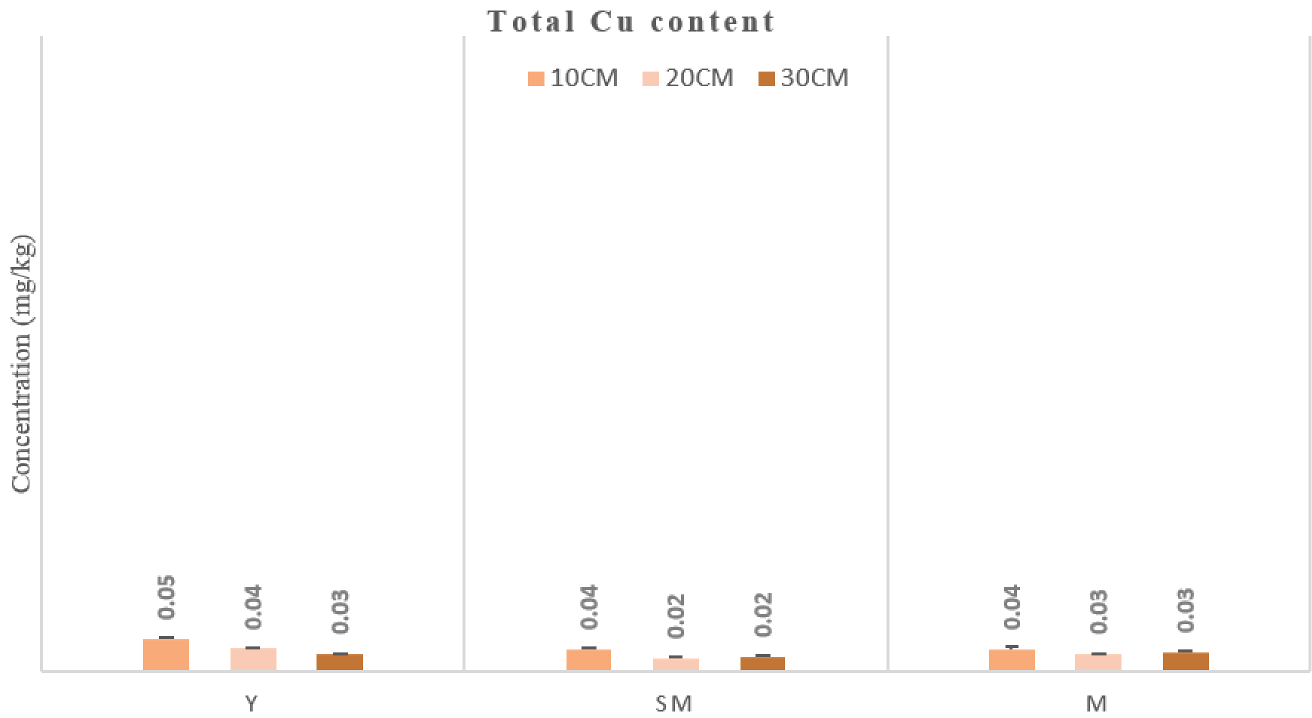

Figure 8.
The average Cu concentration in heath forest sandy soil samples for matured trees area (M), semi-matured trees (SM) and seedling area (Y) at three different soil depths.

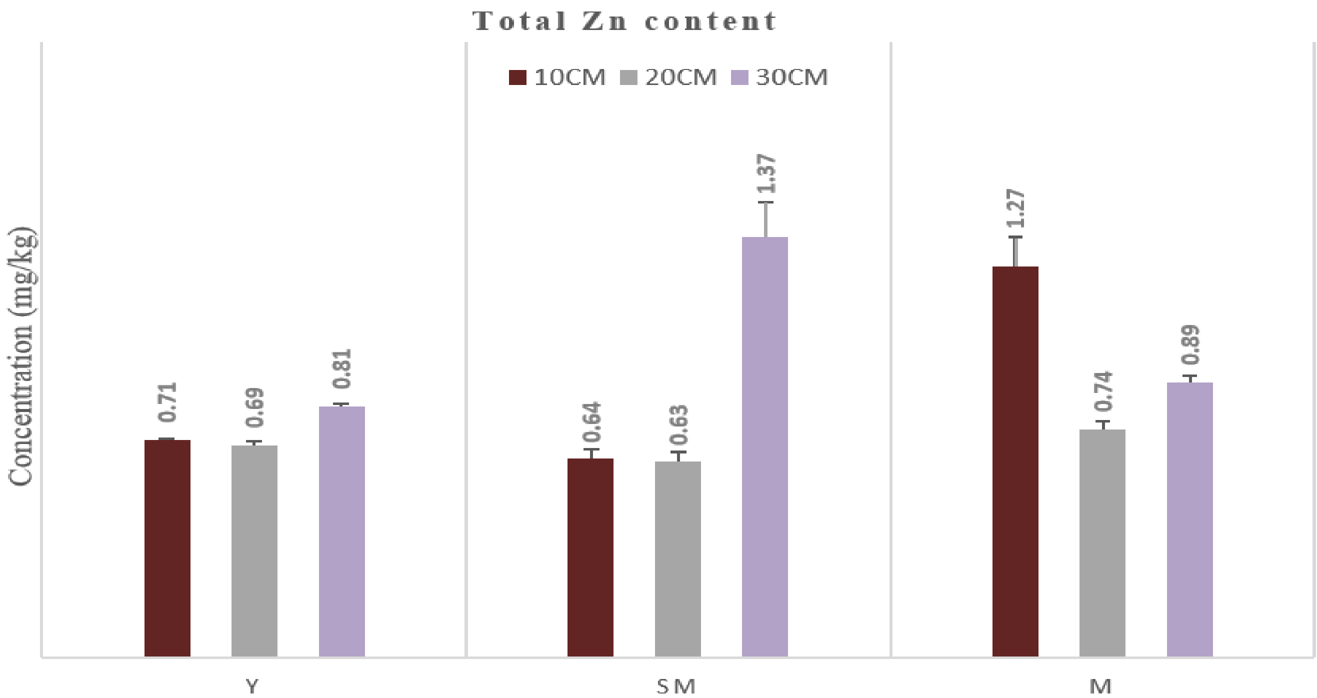

Figure 9.
The average Zn concentration in heath forest sandy soil samples for matured trees area (M), semi-matured trees (SM) and seedling area (Y) at three different soil depths.

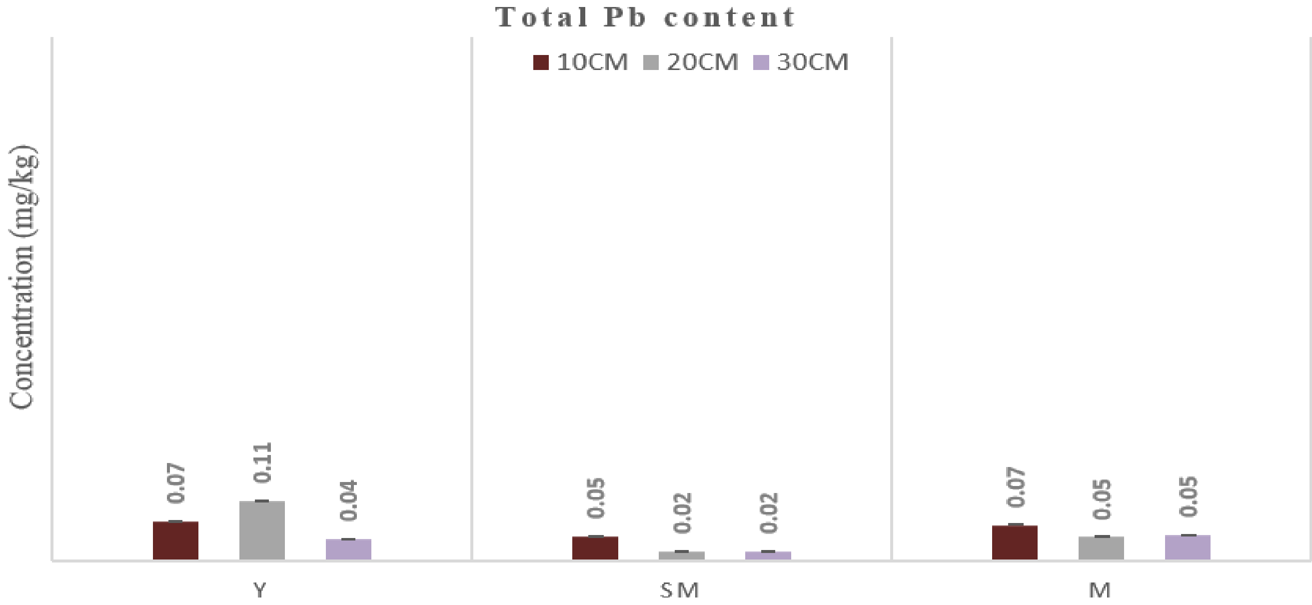

Figure 10.
The average Pb concentration in heath forest sandy soil samples for matured trees area (M), semi-matured trees (SM) and seedling area (Y) at three different soil depths.

Table 2.
Soil quality index of heavy metal content and composition of heath forest sandy soil.

Parameters	Unit	Average	Quality index	Status
Al	mg/kg	353.40	≤ 70 000	Normal
Cr	mg/kg	0.79	≤ 370.0	Normal
Mn	mg/kg	0.28	≤ 300.0	Normal
Fe	mg/kg	44.21	≤ 50 000	Normal
Ni	mg/kg	0.80	≤ 52.0	Normal
Cu	mg/kg	0.05	≤ 270.0	Normal
Zn	mg/kg	0.71	≤ 410.0	Normal
Cd	mg/kg	0.00	≤ 10.0	Normal
Pb	mg/kg	0.07	≤ 220.0	Normal

Note: The symbol ≤ means less than or equal to.

Moreover, free aluminium scan replace plant nutrient ions such as potassium, magnesium and calcium on negatively charged soil surfaces when it enters the solution. In a short period, it can render these ions more accessible to plants, but over time, it makes them more prone to elimination from the soil by seepage. To sum up, the analysis of heavy metals found that all of the heavy metals were within the range suggested by Malaysia Soil Quality Index. Several causes affected the availability of heavy metals in the soil, including the region from where the samples were collected (seedling region, semi-matured trees region, and matured trees region), the soil's physical appearance and depth, climate, and water bodies. All these factors may be responsible for the reaction of heavy metals because they can be transferred from one place to another place and are non-degradable [22]. Aluminium toxicity at low levels of phenolic compounds and organic matter, low pH levels, and high sand content appear to be the chief limiting factors for plant growth in acidic soils. However, it must be kept in mind that different plants possess different properties of resistance to aluminium toxicity, different composition and nutrient content, and pH level requirements for ideal growth.

3.4. Analysis of Soil pH, Total Nitrogen Content (N), Total Organic Carbon (TOC), Total Available Phosphorus (P) and Cation Exchange Capacity (CEC) of Heath Forest Sandy Soils

Soil analysis factors, such as P, N, CEC, TOC and pH, were further evaluated to characterise the sandy soil of heath forests and determine their correlation with factors such as soil texture, soil depth, colour, heavy metals and plant maturity. Soil pH is a central soil chemical property as it affects several other factors such as nutrient seepage effect, nutrient accessibility, soil structure, and toxic elements. The soil pH can be easily determined and it provides prompt and important information to estimate slope stability. Determination of P, N, CEC and TOC helps to evaluate the organic matter content in heath forest sandy soils along with the capacity of the soil to hold nutrients, and prevents nutrients loss by seepage. All of these properties of soil chemicals are closely associated with each other as binding instruments which can either make the structure of the soil weaken or strengthen the soil structure. Table 3 shows that the pH of the soil in all study regions was acidic, with a range from 4.11 to 4.31, while the total nitrogen had a range from 0.11 to 0.18%, indicating that it has very low efficiency as a source of nutrients for plants. However, the total nitrogen in the soil region of the plant having a diameter of more than 80 cm (C) had an active response in comparison to other soil regions as displayed in Figure 11. The lowest preferable amount for the total content of nitrogen in the soil is 0.25% to support plant growth. This outcome also suggests that non-adaptive plants are unable to survive in an ecosystem of heath forests due to this issue.

Table 3.
Average of soil pH, total nitrogen content, total organic carbon, total available phosphorus and cation exchange capacity of heath forest sandy soil.

Area of soil	pH		Total nitrogen (%)	Total organic carbon (%)	Total available phosphorus (%)	Cation exchange capacity (CEC) (cmol(+)/kg)
	Wet	Dry				
Plant with less than 10 cm diameter area (A)	4.11	4.76	0.18	1.23	9.30	6.66
Plant with more than 25 cm diameter area (B)	4.31	4.76	0.11	1.17	10.24	5.43
Plant with more than 80 cm diameter area (C)	4.16	4.69	0.13	1.57	11.07	7.40

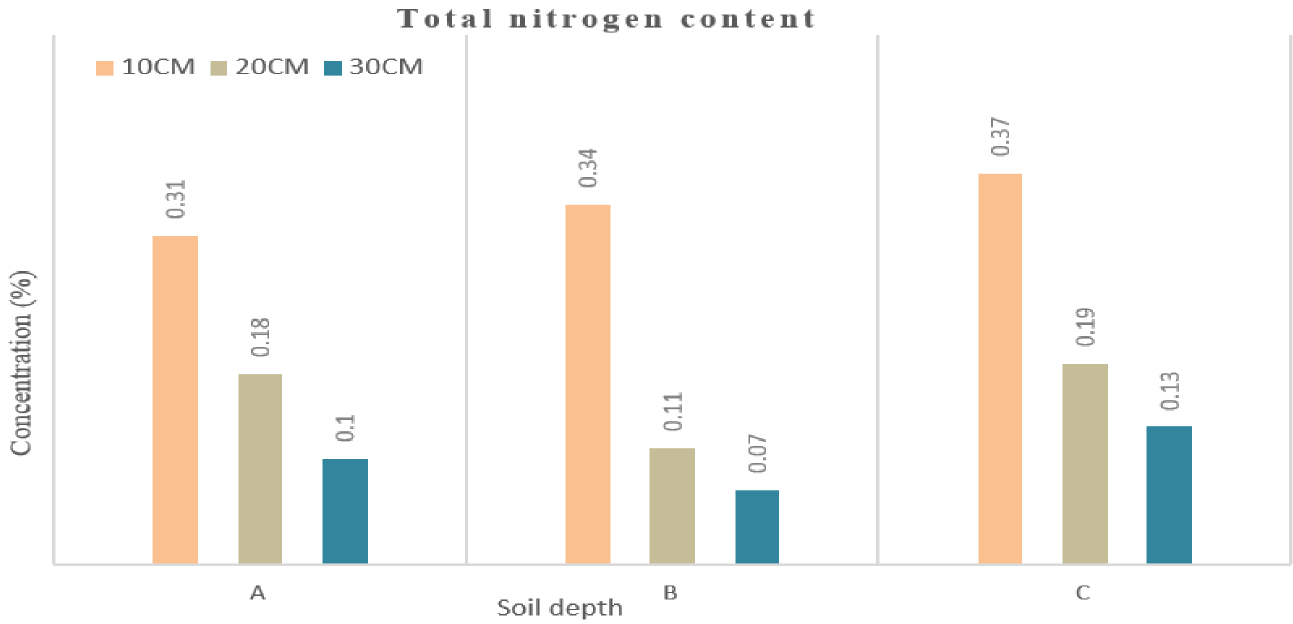

Figure 11.
The total nitrogen content in heath forest sandy soil samples for matured trees area (M), semi-matured trees (SM) and seedling area (Y) at three different soil depths.

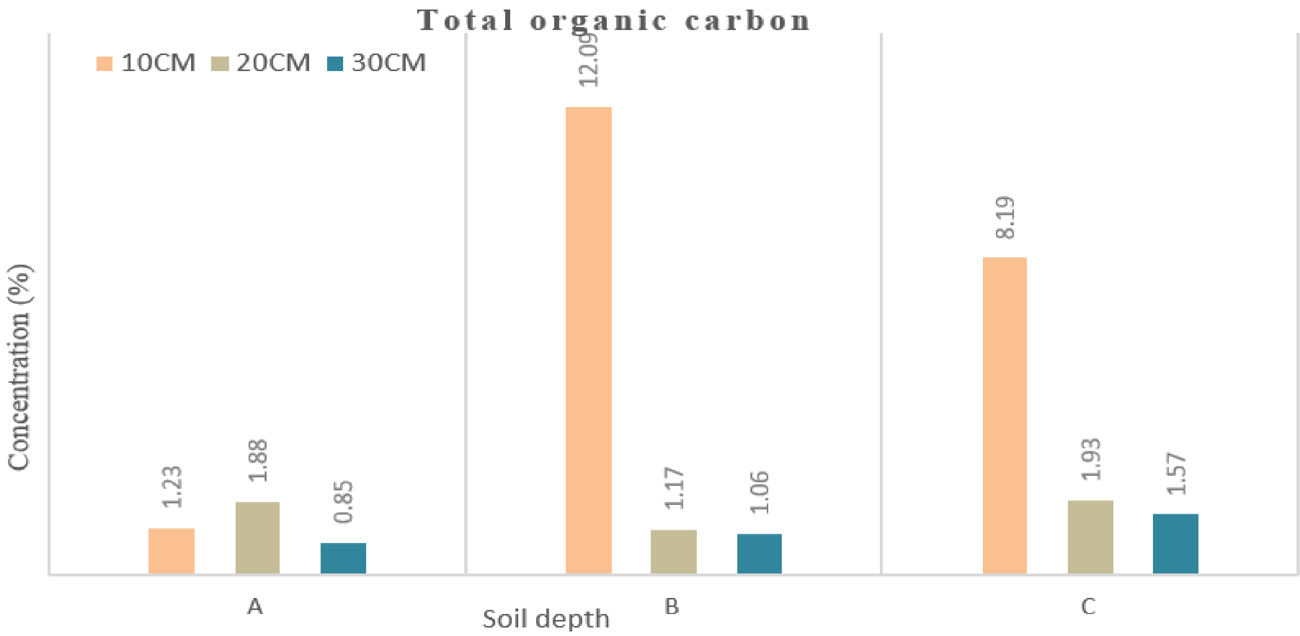

Figure 12.
The total organic carbon in heath forest sandy soil samples for matured trees area (M), semi-matured trees (SM) and seedling area (Y) at three different soil depths.

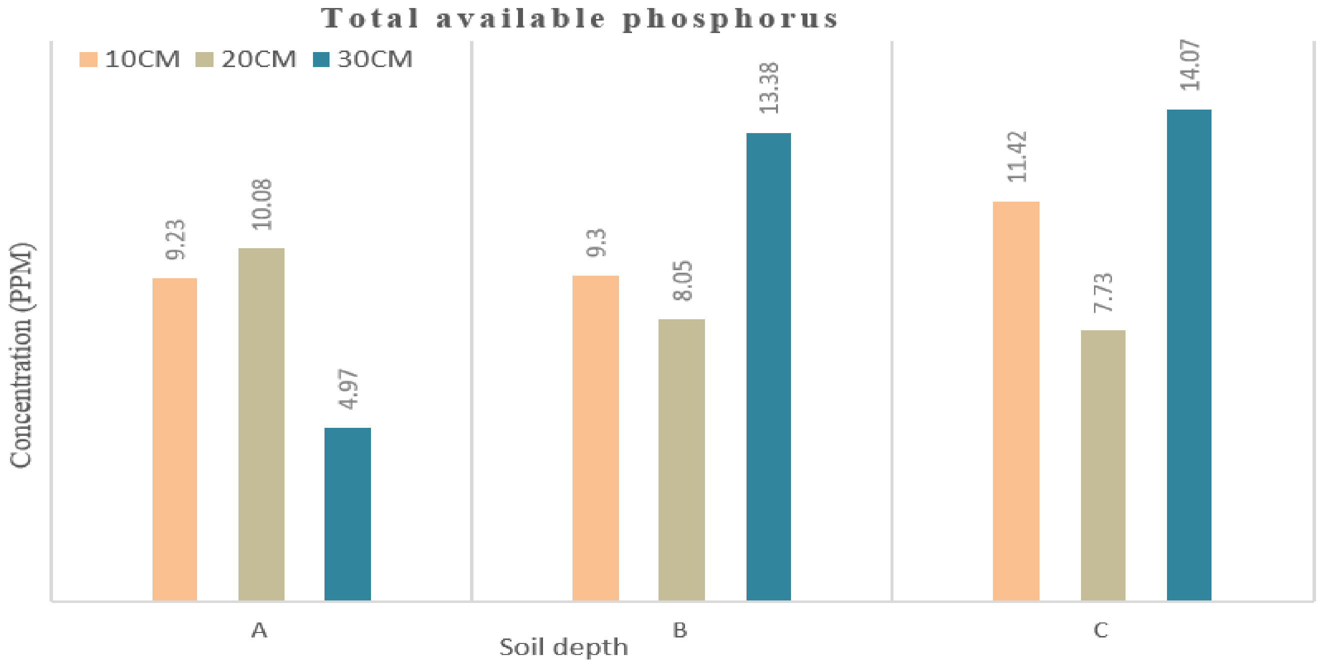

Figure 13.
The total available phosphorus in heath forest sandy soil samples for matured trees area (M), semi-matured trees (SM) and seedling area (Y) at three different soil depths.

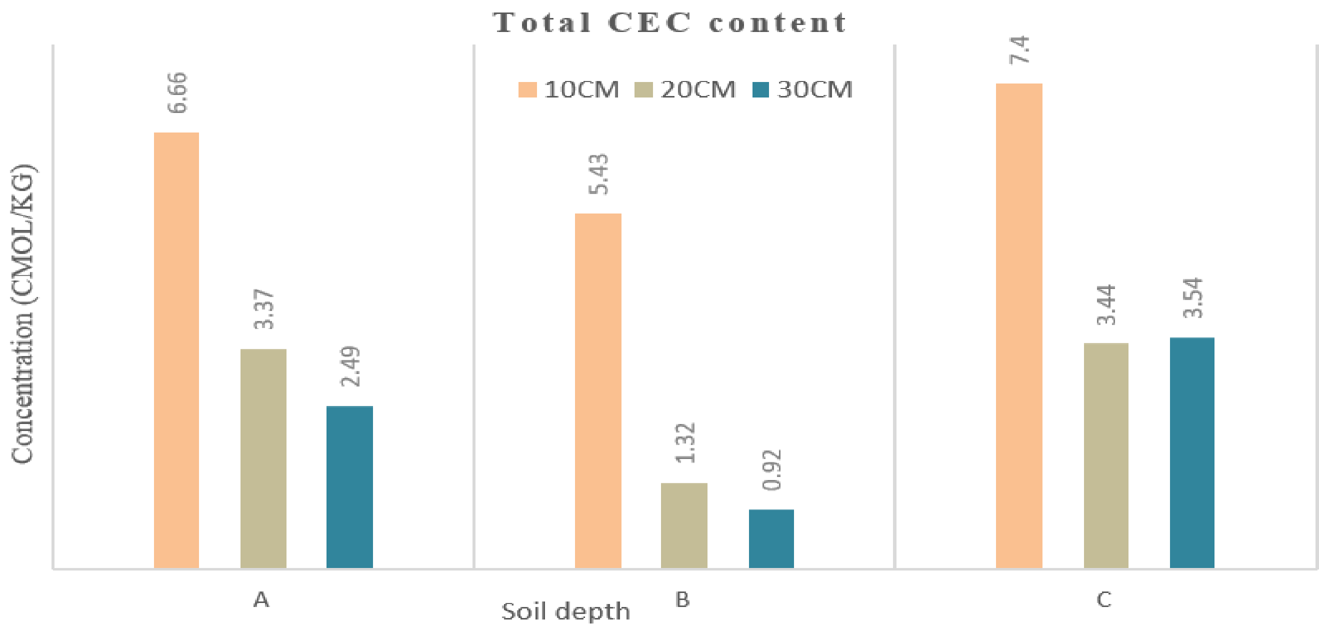

Figure 14.
The CEC content in heath forest sandy soil samples for matured trees area (M), semi-matured trees (SM) and seedling area (Y) at three different soil depths.

The amount of TOC in the soil was also observed to be greater in the C region. The ideal level of organic carbon content in the soil must be over 2% to sustain the biological efficiency of plant growth. The level of TOC in the soil of heath forest regions ranged from 1.17 to 1.57%, as displayed in Figure 12 and Table 3. In fact, all soil carbon is organically bound, and a strong linear correlation between nitrogen and total organic carbon signifies this. The soil in the heath forest is classified as sandy, which is characterised by low organic carbon concentrations. Therefore, a lack of carbon will directly the loss of nitrogen, which provides the nutrients for the growth of plants in these forests. Thus, this is one of the causes for the growth of only certain species in the ecosystem of heath forests.

Another issue of challenging soils, such as heath forests' sandy soil, is the likeliness of the phosphorus becoming inaccessible for plant consumption. The total content of phosphorus accessibility in all regions of the sandy soil is considerably low, ranging from 9.30% to 11.07% as shown in Figure 13 and Table 3, which can be regarded as poor in providing the nutrients required for ideal plant growth. Therefore, the preferable amount of total phosphorus available must be more than 20%, which is the concentration amount that may regulate the balancing of nutrient mineralisation in sandy soils. This is in contrast to several other lowland rainforests where phosphorus is abundant. Moreover, the amount of CEC in the soil was found to be greater in region C compared to regions A and B in samples of heath forests' sandy soil (Table 3, Figure 14). The average CEC ranged from 5.43 to 7.40 cmol/kg, which is a relatively very low value. This condition will create sluggish growth for any non-adaptive plant species. Furthermore, the CEC value is affected by several characteristics, including pH, organic matter and clay. Organic matter and sandy soil will slightly reduce the ability of colloids to exchange ions in the soil, which causes a low value of CEC. The preferred CEC content level in sandy soil is between 150 and 300 cmol/kg. The outcomes of heath forest soil analysis demonstrated certain correlations and similarities in terms of chemical and physical properties. In the analysis of heavy metals, the Al concentration was found to be having the highest content in comparison to other metals. Thus, aluminium (Al) toxicity is one of the primary constraints on plant growth efficiency due to acidic soil [23]. Al is lethal to the plants when dissolved at acidic pH values in soil solution. As shown in Table 2, when the soil pH value drops to nearly 4.0, the availability of the majority of plant nutrients diminishes, while aluminium and a small number of micronutrients become more soluble and toxic to plants. According to Othman, et al. [24], the correlation between pH and aluminium was determined based on the amount of aluminium that is sufficient for the ion charges to function below pH 5.5. Aluminium compound, $Al(OH)^{3-}$, in this hydrolysis reaction at the suitable pH values, reacts with hydrogen ions to free aluminium. That is, for each aluminium ion, 3 hydrogen ions can be "consumed". Hence, pH changes at a sluggish rate compared to the acidification reactions. Consequently, the aluminium renders the soil acidic. Moreover, its tendency to move into the surface and groundwater stores increases, where in large concentration amounts, it is potentially toxic to humans and animals when they ingest the supplies.

Moreover, soil pH also influences nutrient availability due to the presence of H^+ ions that occupy space on the negative charges adjacent to the soil surface. The impact on the availability of nutrients depends on the charge and size of the nutrient molecules and if they can be dissipated through seepage. Generally, organic carbon and nitrogen (N) are more available in the soil with a value of pH ranging from 6.5 to 8, whereas CEC and phosphorus content are most available in soil with a pH value ranging from 5.5 to 7.5 [24]. Therefore, aluminium toxicity and soil acidity are the major constraints that reduce plant growth efficiency or nutrient obtainability for plant consumption, thereby affecting the growth of most of the target plants in the long run. The soils of heath forests are extremely nutrient-deficient due to their high amount of acidity and low amount of CEC levels.

3.5. Allelochemical Compounds and Total Phenolic Content Analysis

The presence of allelochemical compounds was only observed in plant samples and not in the soil samples or the water bodies as displayed in Figure 15.

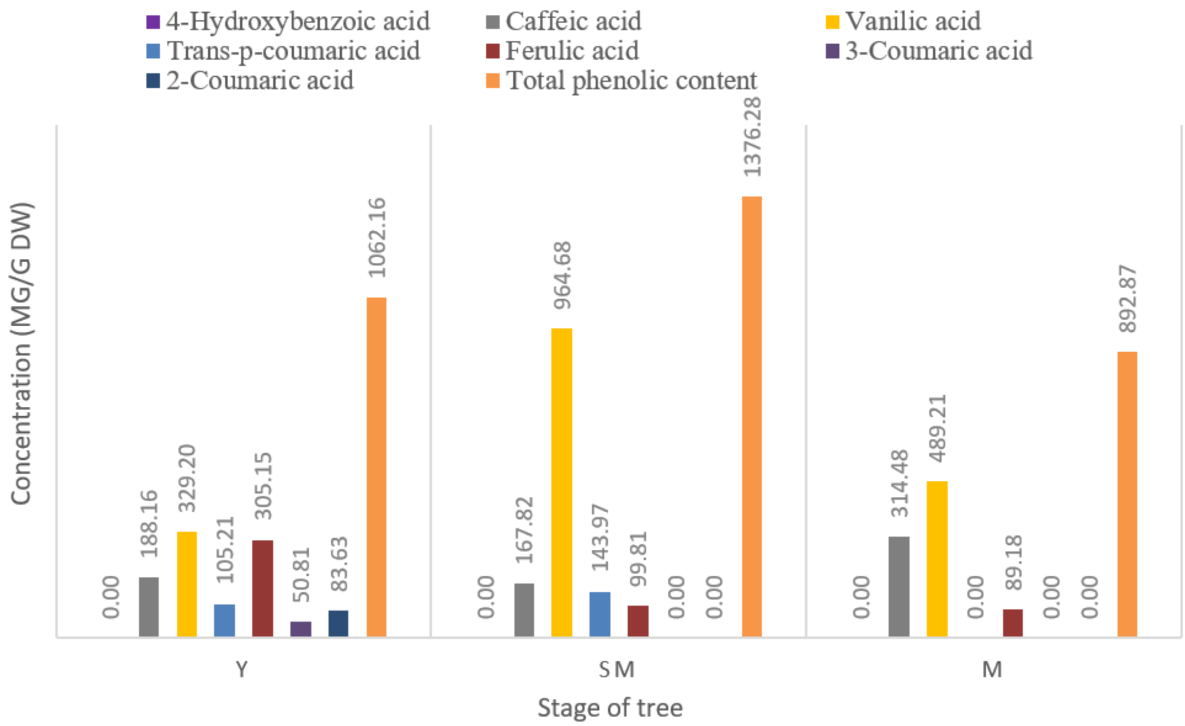

Figure 15.
Allelochemical compounds and total phenolic content analysis in heath forest matured trees area (M), semi-matured trees (SM) and seedling area (Y) at three different soil depths.

Based on this observation, the active response was noted in young plant tissues because of the origin phenolic content sources (young vegetative), as stated by Othman, et al. [6]. In addition, the plants with a diameter area of 12 inches exhibited the maximum production of total allelochemical compounds and total phenolic content. In contrast, all compounds started to decline when the plants reached the mature stage (refers to plants having a diameter area of 40 inches). The allelochemical activity and phenolic content were greatly influenced by environmental parameters. As found out in the study of previous literature, plant materials harvested in monsoon had a higher total allelochemical and phenolic content than those harvested in the dry season.

Phenolic compounds are essential in the allelopathy of plants. Ramya, et al. [11] observed that these contain a hydroxyl group (-OH) directly bonded to an aromatic hydrocarbon group. The range of the compound types includes structures such as hydroxy and substituted benzoic acids, simple phenols, vanillic, ferulic, caffeic and perhaps a little of the coumaric acid. This outcome suggests that phenolic compounds are involved in allelopathy in the *M. cajuputi* plant. They are completely distributed in plants and are quite common in plant decomposition products. In addition to their natural functions, these compounds have extensive allelopathic applications in landscape preservation as fungicides, insecticides and herbicides. However, the allelopathy processes of phenolic compounds can also cause increased cell membrane porosity, leading to death or slow growth of plant tissue. Furthermore, phenolic allelochemicals can prevent plants from absorbing nutrients from the environment and impact the normal plant growth. they also affect plant respiration by reducing oxygen absorption capacity, and photosynthesis by decreasing chlorophyll content and the rate of photosynthesis.

In addition, some phenolics such as coumaric acid and ferulic acid can inhibit the protein synthesis process of plants. All phenolics can decrease the integrity of deoxyribonucleic acid (DNA) and ribonucleic acid (RNA), which play an essential biological function in the growth of plants. In conclusion, phenolic allelochemicals from the species *M. cajuputi* have several ability to diminish further growth of treated plants [1].

4. Conclusion

The outcomes of soil colour examination by employing the Munsell Soil Colour Chart demonstrated that the shades of sandy soils of heath forest were categorised from 2.5Y to 7.5Y or grey to white. In contrast, the soil texture examination of sandy soils of heath forest indicated that the chief component of the soil was fine sand. There were notable differences in composition and concentration among each kind of heavy metal in every layer of the sandy soils of the heath forest. The soil's upper layer (0-10 cm) had a greater concentration in comparison to the bottom layer (20 -30 cm) and middle layer (10-20 cm). These findings clearly demonstrated that the region of seedling trees had a higher content of heavy metals in comparison to matured and semi–matured tree. From the analysis of all heavy metal concentrations, Al and Fe concentrations were observed to be among the highest for sandy soils of heath forest.

The outcome also demonstrated that allelochemical contents were only observed in plants and not in the water bodies or the soil. The highly active response was observed in tissues of young plants owing to the phenolic content originating from young vegetative sources. Surprisingly, the highest total phenolic content was observed when the plants were semi-mature.

Overall examination of the soil of the heath forest indicated that it was extremely nutrient-deficient. This was due to the soil's high-level toxicity and acidity levels, as well as its low CEC content.

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