Soil Pollution and Forest Dieback: Will the Compost and Mycorrhizal Treatments be Effective in Mitigating Forest Dieback?

Gunadasa H. K. S. G., Yapa. P. I., Nissanka S. P., and Perera S. P.

Abstract*—Forest dieback has become a key threat to Horton Plains (an upper montane forest) in Sri Lanka. Increasing vehicle emissions in the nearby cities and the polluted rain with Pb and Cd falling on forest soils has been the main focus of the study. In the experiment, twenty-four permanent plots were established within an area of 61-80% dieback severity and three soil amendments through addition of (a) compost, (b) montane mycorrhizae, and (c) compost and montane mycorrhizae, alongside the control made up the four treatments used in this study. Treatments were applied to five randomly selected *Syzygium rotundifolium* saplings of approximate height of 1m and 0.015m diameter breast height (DBH) residing in each plot. Soil organic matter content (SOM) and Pb and Cd were compared from soil samples collected at 0.2m depth. Foliar samples were collected from the 'treated' saplings, and were analyzed to investigate the levels of Pb and Cd. These comparisons were done for samples collected at three different stages and during the experimental period, the selected saplings were closely monitored and changes in health were accordingly recorded. The soil analysis shows clear indications of Pb and Cd contamination which impairs plant metabolism leading to dieback. Effect of standard compost and montane mycorrhizae on protecting saplings from Pb and Cd was significant (p = <0.001). The level of soil Pb above ~60ppm appears to be disastrous for the *Syzygium rotundifolium* saplings. Moreover, compost and mycorrhizae appeared to be effective in reducing the effect of Pb and Cd on sapling's mortality. Significant decline of Cd (p = 0.01) and Pb (p = 0.01) with the increasing SOM level were observed. A significant inverse relationship between SOM level and the mortality rate of *Syzygium rotundifolium* saplings was also observed (p= 0.05) and the severity of the mortality sharply increases when the SOM level decreases below ~4%.

***Index Terms*—Forest dieback, soil organic matter, lead, cadmium.**

I. Introduction

In tropical mountains, it is common to encounter forests of different structure and physiognomy similar to temperate/pigmy forests depending on the altitude compared to lowland forests. One of the best examples for a typical montane cloud forest in the world is "Horton Plains", Sri Lanka, as it was in 1947, was described as a low, dense, slow-growing forest with a healthy and vigorous appearance [1]. It is located on the highest plateau of Sri Lanka, which lies between 1,500 and 2,524m average sea level [2] and the geographical location is in the Central Highlands of the Central Province, 6'47 – 6'50'N, 80' 46'- 80'50'E. Annual rainfall in the region is about 2540 mm. Temperatures are low, with an annual mean of 13 ℃, and ground frost is common in February [3]. The landscape characteristically consists of gently undulating highland plateau at the southern end of the central mountain massif of Sri Lanka. Soil order Ultisol is characterized by a thick, black, organic layer at the surface. Horton Plains is considered to be the most important catchment area of the country as it is the originating point of the tributaries of three major rivers, the *Mahaweli* river flowing to the north, the *Keleni* river to the west and *Walawe* to the south of Sri Lanka. *Belihul Oya*, a small stream feeding the *Walawe*, tumbles over a cliff as a large and spectacular waterfall within the reserve itself. These forests remained largely untouched by the 3000-year-old history of human agricultural activity on the island and the hydraulic civilizations that shaped the landscapes of the lowlands left a comprehensive record that attests to this fact. Horton Plains is rich in biodiversity and most of the fauna and flora within the park are endemic while some of them are confined to highlands of the island.

The land area covered by this montane rain forest is approximately 3,160 ha. There are 54 woody species, of which 27 (50%) are endemic to Sri Lanka. The area covered grasslands are locally known as "*patana*". The canopy of commonly found cloud forest is dominated by the endemic keena (*Calophyllum walkeri)* in association with varieties of Myrtacea (*Syzygium rotundifolium* and *S. sclerophyllum*) and Lauraceae (*Litsea*, *Cinnamomum* and *Actinodaphne speciosa*). Horton Plain is also home to a number of wild relatives of domesticated plants, such as pepper, guava, tobacco and cardamom.

Belonging to different size and age classes of these forest, have been dying due to a yet unknown factor. This phenomenon was first observed in the Horton Plains National Park and the earliest reports of a significant level of dieback in the forest were by [4]. Estimations using recent satellite images combined with ground surveys revealed that about 654 ha, equivalent to 24.5% of the forest in the park has been subjected to dieback [5]. One of the worst affected trees was *Syzygium rotundifolium* followed by *Cinnamomum*

Manuscript received March 29, 2012; revised June 12, 2012.

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ovalifolium, *Neolitsea fuscata*, *Syzygium revolutum* and *Calophyllum walkeri*. Also, seedling establishment and forest regeneration in the area is slow [5]. Healthy forest in the park amounts to about 2012 ha. The extent of the damage to the forest from dieback appears to be so severe that the stand structure in affected areas shows dramatic changes. If this dieback continues with the current rate, the majority of the large trees will disappear from the forest soon. The vital functions offered by this precious forest will then be subjected to significant changes most probably towards the negative side. Work done by many researchers so far has ended up with no significant clues about the causal agents and remedial measures for the dieback though work done by [6] has indicated the contamination of soils in the Horton plains by Pb and Cd and possible links of the soil pollution to forest dieback. Therefore, the main objective of the study was to assess the influence of SOM in remediating Pb and Cd pollution in the affected soils. The specific objectives will include how the different concentrations of Pb and Cd`in the soil affect on the mortality of *Syzygium rotundifolium* saplings.

Fig. 1. A map of sri lanka locating the horton plain.

II. Materials and Methods

The location of the experiment was in Horton Plains, the highest plateau of Sri Lanka between altitudes of 1,500 and 2,524m. Twenty-four permanent experimental plots of 20 m × 20 m were demarcated using GPS (Global Positioning System) points with a 20 cm accuracy to represent an affected area in the Horton Plain National Park. Randomized Complete Block Design (RCBD) was used with six blocks to replicate each and every treatment six times. Plot locations were selected to cover a 61 – 80 % dieback of trees and to maintain soil and topography as constant as possible. Canopy health was assessed using a map published by [5]. Four soil amendments a) compost-2kg/sapling, b) compost and montane mycorrhizae-4kg/sapling. c) montane mycorrhizae-2kg/sapling including a control were used for the study while taking *Syzygium rotundifolium* as the indicator plant. The most important reason for the selection of the tree species *Syzygium rotundifolium* was due to the fact that of all species that have been affected, this specie was the worst affected. The second reason is that it is one of the dominant canopy tree types in the forest [5].

An Investigation of harmful elements such as Pb and Cd in the soil samples were measured by wet ash method [7] and the extractants were analyzed for the above elements by Atomic Absorption Spectrophotometry [8]. In addition, the soil organic matter content was determined using the method of total organic C by Walkley and Black described by [9]. The soil samples were collected from 0.20m depth and 0.3m-0.5m away from each sapling representing three different time periods. Furthermore, Death rates of the saplings were calculated by keeping records of the selected saplings throughout the experimental period and counting the deaths at the end of the trial. Standard GENSTAT statistical software was used for analysis of variance (ANOVA), t-test and regression analysis of the results.

III. Results and Discussion

A comprehensive research done for two years within a 61-80% dieback area in the Horton Plains National Park (HPNP), Sri Lanka was the base the following outcomes. Soil organic matter content and heavy metals such as Pb and Cd were compared first among the treatments under three stages of sampling. In addition, the data collected were compared with the death rate of the saplings as well.

A. Soil Organic Matter

The soil organic matter content in a soil expresses the relationship between the sources of organic materials and the decomposing factors (soil biota). Soil organic matter (SOM) level in the study area of Horton Plains has not reached upper levels in the range, up to 12%, as expected in tropical moist evergreen forests [10]. In ordinary tropical moist evergreen forests, SOM content varies around 6% [10]. Relatively low plant nutrient levels in montane forests are not unusual according to past studies (e.g., ([11].). For each 1000m rise in altitude, there is a 7^{o}C drop in temperature [12]. This has a dramatic effect on plant and animal distribution in this ecosystem. With the elevation of about 2524m, Horton Plains is cold (mean annual temperature 15 $^{°}$C) and contains a very specific vegetation which is much more sensitive to the changes in the environment than normal tropical forests [13]. Under the prevailing conditions in the montane environment –low sunlight, low temperature, shallow soil depth and so on, production of SOM is weaker in the Horton Plains than in an ordinary tropical forest [14]. As far as the SOM content is concerned, there are significant differences among the treatments at soil sampling stage 1 (p = <.001), stage 2 (p = <.001), and stage 3 (<.001) in the 0.2m depth (Fig 2). The soils treated with compost and compost + mycorrhizae mixture showed the higher values of soil organic matter though soils treated with mycorrhizae only and the control showed the lowest at all three stages. Fluctuation of SOM levels in the area may be linked with temperature, rainfall, soil depth and addition of organic debris from the aggressively growing undercover vegetation such as *Strobilanthus* spp. The function of SOM springs from its effects on soil structural stability (its action as a bonding agent between primary and secondary mineral particles leads to enhanced amount, size and stability of aggregates) and soil water retention (as a water adsorbing agent, it enhances water acceptance and availability) and, hence, on infiltration and percolation. At the same time, SOM controls soil nutrients that affect biomass. [15] emphasized that soil structural stability is influenced by the type of organic matter, as well as its amount. Therefore, in some cases, high SOM content is not accompanied by high structural stability. [16] pointed out that some fungi exude oxalic acid, which enhances dispersion and breakdown of aggregates. Humic substances are the components of SOM which play the key role in detoxifying the soil from pollutants such as Pb and Cd residues of Agro-chemicals from surrounding areas [15]. Unsatisfactory levels of SOM exhibit the poor activity of humic substances and resultant soil pollution. It should also be noted that even a milder form of soil contamination in the Horton Plains cannot be afforded since the montane vegetation is highly sensitive to the changes in the environment.

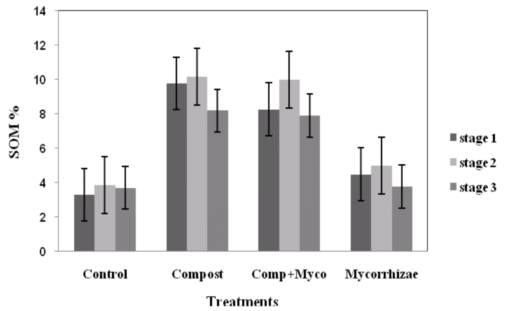

Fig. 2. Status of SOM% among the treatments.

B. *Heavy Metals in Soil and Plants (Pb and Cd)*

The level of soil Pb and Cd has gone up to 106 and 7.29 ppm respectively. The maximum allowable limit of Pb is 100 ppm while it is 3ppm for Cd [17]. Even the smallest amount of both Pb and Cd may impose severe damages on plant's metabolism leading to dieback [18]. Results from soil analysis clearly indicated contamination of soil from these two trace elements in Horton Plains. Treatments used for the study have significantly influenced the soil Pb at sampling stages 1 (p=0.01) and 2 (p=0.004) but there is no significant influence detected at stage-3 (p=0.79) (Fig 3) and the highest Pb content was observed in the control. Cadmium content in the soils of the study area is not significantly different with the treatments at stage-1 (p=0.18), -2 (p=0.35), and -3 (p=0.51) though the highest is observed in the control (Fig 4). A fraction of those elements may leach out from the top soil while another fraction may be absorbed by the vegetation. Results from foliar analysis indicate the entry of Pb and Cd into the plant bodies (see table 1).

Kandy, a major city, has been identified as the worst polluted city in Sri Lanka with heavy motor traffic and resultant vehicle emissions [19]. Burning diesel, gasoline and lubricants releases Pb and Cd to the atmosphere. Additionally, the friction by brake pads, clutch liners and tires releases these elements to the atmosphere. Strong monsoon winds seem to be the most possible transportation source of Pb and Cd from the polluted south western part of the country and following pioneer studies, Pb and Cd are subjected to long-range atmospheric transportation to a greater extent [20] and [21] where, Pb can be transported for a distance greater than 120km [22] . Past studies reported that forest soils exceeding 1800m elevation were contaminated with higher levels of Pb and the atmospheric origin of the excess soil Pb was confirmed by high Pb levels in precipitation [23] and [24] . Moreover, with increasing visitors to the Horton Plains, motor traffic within the Horton Plains itself has increased. Therefore, contamination of atmosphere may have been increased to an alarming level so that it is very unlikely the rain falling onto the area is free from Pb and Cd.

Mycorrhizae significantly increase the absorption of various elements from the soil including heavy metals such as Pb and Cd [18]. Therefore, it could be assumed that mycorrhizae are responsible for the reduction of Pb and Cd in the soil treated with mycorrhizae. Soil microorganisms play a vital role in maintaining overall soil quality. They have been proved to be effective in detoxifying pollutants in the soil that include heavy metals such as Pb and Cd. Soil microbes (e.g, mycorrhizae) on the other hand, maintain extremely useful symbiotic associations with the forest vegetations which provide additional advantage for the plants to mine nutrients and water [25].

However, high levels of heavy metals in soils have been shown to decrease populations of soil microorganisms [26] . Contribution of the microbes in humification process during organic material decomposition should also be noted because humic substances formed during the process play a very special role in controlling the effects of organic and inorganic pollutants in the soil [27]. So, the deterioration of the activities of soil microorganisms as a result of the acidity conditions in the soils of Horton Plains may have placed the forest vegetation in a vulnerable state for soil contaminants like Pb and Cd. Acidic pH conditions also increase the availability of micronutrients in the soil unnecessarily and this situation results in the development of toxic conditions from micronutrients on plants [28].

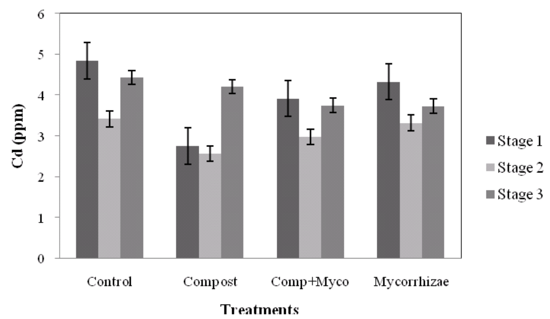

Fig. 3. Status of Cd among the treatments at three different stages of sampling.

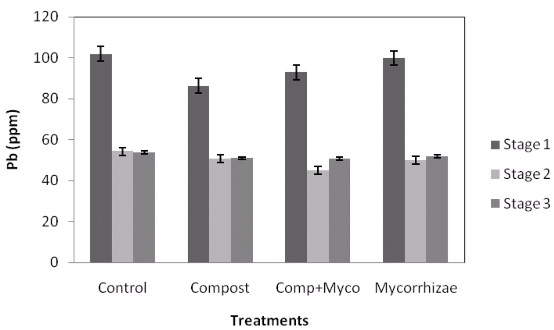

Fig. 4. Status of Pb among treatments at three different stages of sampling.

TABLE I: VARIATION OF PB AND CD IN THE LEAVES FROM DIFFERENT TREATMENTS

	Treatments	Control	Compost	Comp+ Myco	Mycorrhizae
Pb (mg/kg)	Mean	4.133	2.1	4.217	4.217
		(0.04)	(0.0)	(0.05)	(0.02)
Cd (mg/kg)	Mean	6.467	3.267	3.6	6.183
		(0.12)	(0.08)	(0.09)	(0.06)

Standard error for the respective mean is given within brackets

C. *Death Rate of Syzygium Rotundifolium Saplings*

It was clearly evident that the addition of standard compost and mycorrhizae has significantly controlled the death of *Syzygium rotundifolium* saplings (Fig 6). Treatment effect on the death of saplings is significant (p=< 0.001) whilst the control clearly shows the highest death rate (Fig 5). The standard compost consists of humic and fulvic acids that are formed during the microbial decomposition of organic materials. These specific molecules, known as humic substances, possess extraordinary capability of immobilizing soil contaminants such as Pb and Cd. Additionally, dozens of fractions in compost help the plants to withstand stressful conditions such as drought, nutrient imbalances, acidity and so on [29]. In addition, standard compost is a good reservoir of all forms of essential plant nutrients and growth factors of plants [29]. Mycorrhizae, on the other hand, act as a remarkable symbiotic mechanism for the plants to survive under stressful conditions such as droughts, nutrient deficiency, soil contaminants such as Pb and Cd [18]. Thus, it could be argued that treating the *Syzygium rotundifolium* samplings with standard compost and mycorrhizae until they become grownup trees might help to fill the gaps caused by the dieback in the forest.

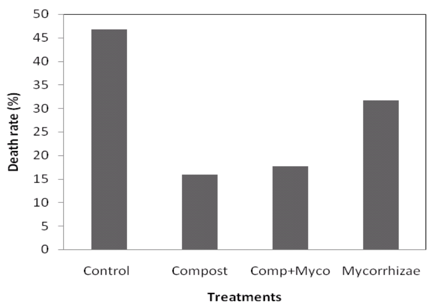

Fig. 5. Death rate of the saplings after 2 years with four different treatments.

D. *Lead in the Soil and Dieback of Plants*

The relationship between Pb concentration and the death rate of *Syzygium rotundifolium* saplings was significant (p = <0.001) while the correlation showed the death rate of the saplings has been largely affected by the Pb concentration in the soil (Fig 7). Findings clearly exhibits that the death rate of saplings used for the experiment increases with the increasing availability of Pb in the soil. Results further revealed that the critical level of Pb in relation to the survival of *Syzygium rotundifolium* saplings was around 60ppm in the Horton Plains soil and above this level, an abrupt increment of death rate of the saplings could be observed. It means that even a slightest increase of available Pb in the soil above the threshold of 60ppm appears to impose severe damages on plant's metabolism leading to dieback [18].

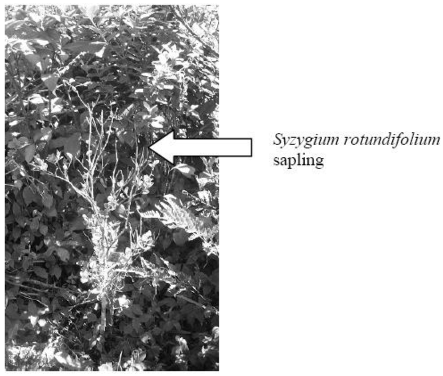

Fig. 6. A dying sapling of *syzygium rotundifolium.*

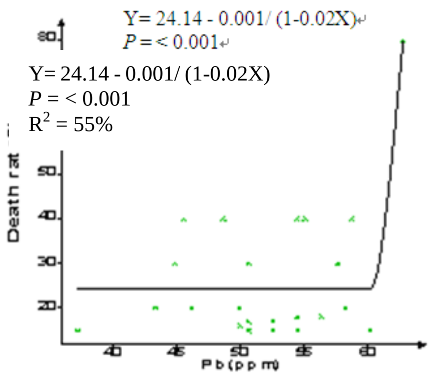

Fig. 7. Pb concentrations in the soil Vs Death rate of saplings.

E. *Cadmium in the Soil and Dieback of Plants*

Death rate of the saplings (*Syzygium rotundifolium*) used for the experiment appears to be increased with increasing Cd availability in the soil. Some linear relationship between increasing death rate of the saplings and the increment of available soil Cd was observed though the correlation was not significant under the α level 0.05 (p=0.08) (Fig 8). It has been proven that the heavy metal Cd has disturbing effects on some crucial metabolic functions of plants leading to death[30]. However, the nature of the Cd toxicity on *Syzygium rotundifolium* is different from the nature of Pb toxicity on the same plant. A threshold level of soil Cd in relation to the death rate of *Syzygium rotundifolium* saplings cannot be observed within the range of soil Cd found in the study area.

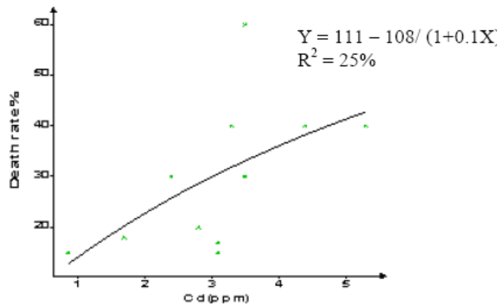

Fig. 8. Cd concentrations in the soil Vs Death rate of saplings.

F. Soil Organic Matter Vs Pb in the Soil

An inversely proportional relationship between soil Pb and the SOM content was observed (Fig 9) and the relation was also statistically significant (p = <0.001). The findings clearly indicate that the availability of Pb in the soil for the vegetation in the study area could be reduced by increasing SOM level. The nature of the decline of soil Pb with the increasing SOM level seems to be a linear-by-linear type. It means that the concentration of soil Pb decreases with the increasing SOM level but the rate of decline of Pb gradually decreases. Immobilization of soluble Pb in the soil by the humic and fulvic acid molecules present in SOM has been documented by several researchers (e.g., [18] and [30]).

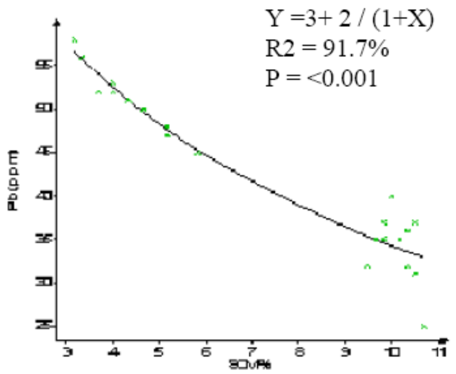

Fig. 9. Soil organic matter Vs Pb in soil.

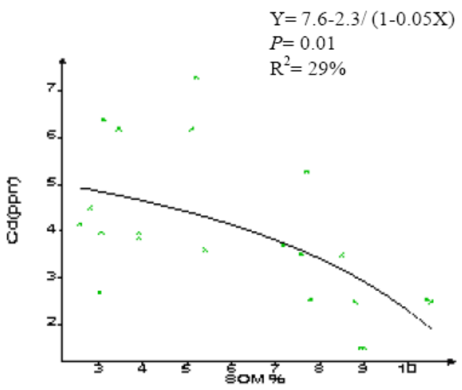

Fig. 10. Soil organic matter Vs Cd in soil.

G. Soil Organic Matter Vs Cd in the Soil

The relationship between the availability of Cd in the soil and SOM content was significant (p = 0.01). The nature of the relationship was a linear-by-linear as shown in fig. 10. According to the graph, soil Cd levels gradually decreased with the increasing SOM level. The results clearly show that the effect of available soil Cd on montane vegetation could be reduced by improving SOM level. Humic and fulvic acids are also proven to be effective in immobilizing Cd as well [18]. The results in general indicate that the maintenance of SOM will help to mitigate the Cd toxicity on forest vegetation.

H. Soil Organic Matter Content in the Soil and Dieback of Plants

Results clearly show that the increase of SOM level helps to reduce the death of saplings. The relationship between SOM level and the death rate of the saplings *(Syzygium rotundifolium*) was significant (p = 0.05). The nature of the relationship seems to be linear-by-linear and it further indicates that by maintaining SOM level somewhere above 4%, the death rate of the saplings could significantly be reduced (see fig 11). Humic and fulvic acid molecules in SOM effectively immobilize toxic metals such as Pb and Cd in the soil [16].

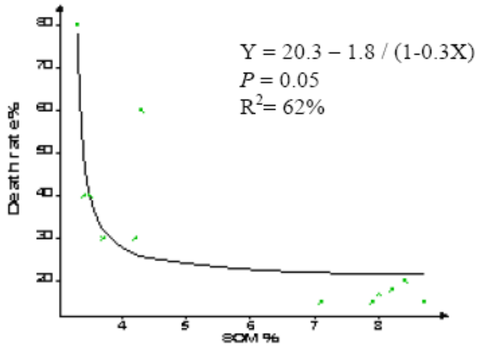

Fig. 11. Soil organic matter content in the soil vs death rate of saplings.

IV. Conclusion

Soil pollution in the montane forest with Pb and Cd as affected by increasing vehicle emissions and consequential polluted rain appears to be one of the key causes for the forest dieback and resultant disappearance of the most precious natural forests in Sri Lanka. Extra sensitivity of the montane forest vegetation to the changes in the soil may have triggered the impact of soil pollution. Enrichment of the polluted forest soils with standard compost and montane mycorrhizae appears to be effective in saving the saplings of *Syzygium rotundifolium* (one of the worst affected trees) from untimely death but, the compost treatment may be applicable under emergence situations and could therefore be considered as a short-term remedy.

As a long-term solution, reestablishment of the deteriorated areas of forest with native flora with a creation of identical multilayered tropical moist evergreen forest architecture and a climax of biodiversity will be suggested. The suggested design will enrich the soil with good quality organic matter which is recognized as the basis of the success of tropical moist evergreen forests.

Maintenance of good quality SOM at satisfactory levels in the soil appears to be effective in reducing the toxicity levels of both Pb and Cd in the soil. Therefore, enriching the status of SOM will maintain the continuity of natural vegetation of the forest flora by minimizing the death rates of the plant species. Threshold levels of Pb should be taken into a specific consideration during forest management. Every possible measures should be taken to not to allow the soil Pb level to exceed the threshold level of 60ppm. It would also be important to maintain the SOM level in the forest soil above 4% so that severity of the effect of soil pollution on forest flora could be avoided.

Acknowledgement

This study was conducted with the financial support of Sabaragamuwa University of Sri Lanka and the Department of Wildlife Conservation. We are also grateful to the Park Warden and the rest of the staff at Horton Plains National Park for their support given throughout the study. Our very special appreciation should go to the Rubber Research Institute of Sri Lanka for helping us to complete all the sophisticated laboratory analysis related to the research.

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