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Remediation of Pb/Cd-Contaminated Forest Soils by Compost and Mycorrhizae: will it be a solution to the Forest Dieback?

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Abstract. Horton Plains is an upper montane forest in Sri Lanka that acts as the most important water catchment of the island. Soil pollution and forest dieback (FDB) have become the major threat for this sensitive natural ecosystem. Increasing vehicle emissions in the nearby cities and the rain polluted with Pb and Cd falling on forest soils has been the key 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 *Sysygium 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. 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). 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.

Keywords: Forest dieback, Compost, heavy metals.

1. Introduction

The Upper Montane Forest in 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°C, 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 the most important catchments area of the countryand tributaries of three major rivers originate from within the reserve. 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. 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

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dieback [5]. One of the worst affected trees was *Syzygium rotundifolium* followed by *Cinnamomum 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 show 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 is to check the ability of SOM in effectively remediating Pb and Cd in the affected soils.

2. Materials and Methods

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. 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. 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.

3. Results and Discussion

The results shown in this paper are based on the work done during the two-year study period within the 61-80% dieback areas selected in the Horton Plains National Park (HPNP), Sri Lanka. Soil organic matter content and heavy metals such as Pb and Cd were compared first among treatments under three stages of sampling. In addition, the data collected were compared with the death rate of the saplings.

3.1. Soil organic matter

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 $^{\circ}$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 1(a)). 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.

3.2. Heavy Metals in soil (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 2(a)) 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 2(b)). 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 [19].

3.3. 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. Treatment effect on the death of saplings is significant (p=< 0.001) whilst the control clearly shows the highest death rate (Fig 1(b)). 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 [20]. In addition, standard compost is a good reservoir of all forms of essential plant nutrients and growth factors of plants [20]. 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.

3.4. Soil organic matter Vs Pb in the soil

The content of soil Pb is inversely proportional to the SOM content (Fig 3(a)) and the relationship was statistically significant(p = <0.001). The findings indicate that the availability of Pb in the soil for plants in the study area could be reduced by increasing SOM level. The nature of the decline of Pb with the increasing SOM level seems to be linear-by-linear type. 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]).

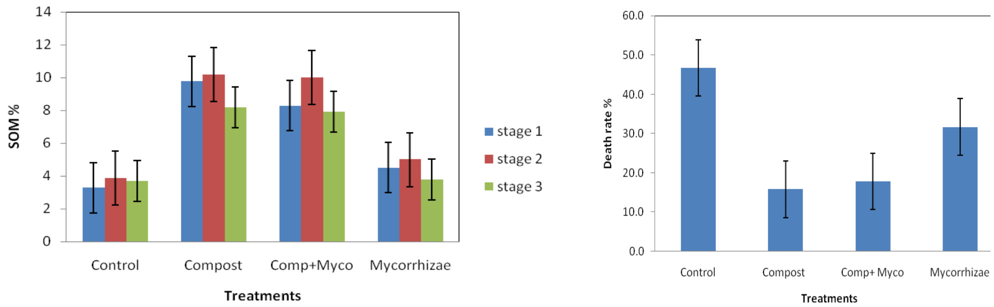

Fig. 1: (a) Status of SOM% among the treatments; (b) Death rate of the saplings after 2 years with four different treatments

3.5. Soil organic matter Vs Cd in the soil

The relationship between the availability of Cd in the soil and SOM content was significant at p = 0.01. The nature of the relationship was a linear-by-linear as shown in fig. 3(b). 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. Action of humic and fulvic acid on immobilization of Cd may have resulted these relationships [18]. The results in general indicate that the maintenance of SOM will help to mitigate Cd toxicity on forest vegetation.

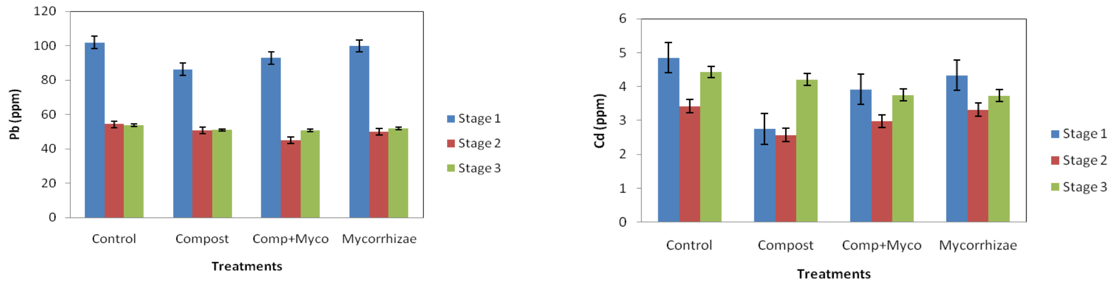

Fig.2: (a) Status of Pb among treatments at four different stages of sampling; (b) Status of Cd among treatments at four different stages of sampling

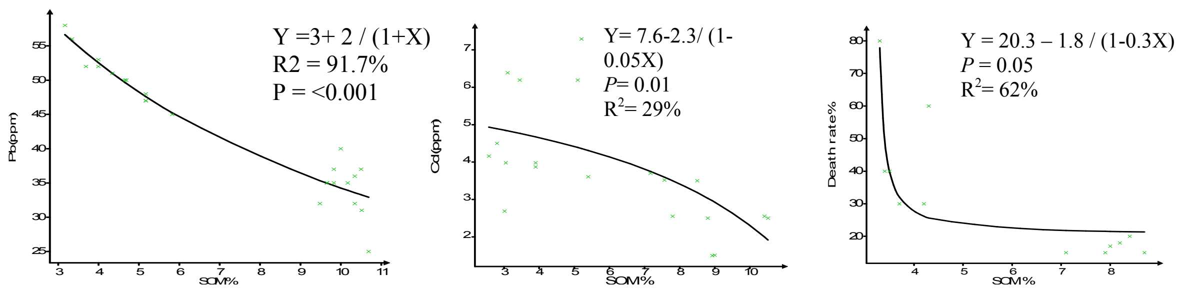

Fig.3: (a) Soil organic matter Vs Pb in soil; (b) Soil organic matter Vs Cd in soil; Soil organic matter content in the soil Vs Death rate of saplings

3.6. Soil organic matter content in the soil and dieback of plants

Results 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 *(Sysigium rotudifolium*) 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 3(c)). Humic and fulvic acid molecules in SOM effectively immobilize toxic metals such as Pb and Cd in the soil [16].

4. Conclusions

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 deterioration of the vegetation by forest dieback. 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 soil 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. Maintenance of SOM at satisfactory levels in the soil appears to be effective in reducing the levels of both Pb and Cd in the soil.

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