Mitigation of Pb-Induced Forest Dieback in Sri Lanka: Use of Soil Organic Matter

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***Abstract*—**The forested area with 21-40% dieback severity, Horton Plains was selected for the study and twenty-four permanent plots were established. Standard compost, montane mycorrhizae, standard compost with montane mycorrhizae, and a control were used as treatments and the indicator plant used was *Syzygium rotundifolium*. Treatments were applied to five randomly selected *Syzygium rotundifolium* saplings of approximately 1m height and 0.015m diameter at the cotyledon scar existing in each plot. Soluble soil Pb and soil organic matter (SOM) were compared using soil samples collected at 0.20m depth. Foliar samples from the saplings were tested for Pb. The health status of the saplings were duly recorded during the experimental period. The results from soil and foliar analysis revealed the status of Pb (p <0.001) contamination which appears to have significantly linked with forest dieback. Positive correlations between soil Pb and leaf Pb were significant (p= 0.001). Soil amendment with compost and montane mycorrhizae was effective in reducing the Pb level significantly (p = <0.001) and the amendment appears to be significantly effective (p <0.001) in protecting saplings from dieback.

***Keywords*—** *Montane forest, dieback, compost, heavy metals*.

I. Introduction

The upper montane forest called 'Horton Plains', Sri Lanka is a low, dense, slow-growing forest with a healthy and vigorous appearance [1]. It is one of the key catchment areas of the country. Tributaries of the three major rivers which are crucial for the agriculture in the country, originate from the forest. The land area covered by the forest is approximately 3,160 ha. There are 54 woody species, of which 27 (50%) are endemic to Sri Lanka. Belonging to different sizes and age classes, tree species have been dying due to a yet unknown factor. This phenomenon was first observed in Horton Plains by [2] and [3] and about 654 ha, equivalent to 24.5% of the forest in the Horton Plains has been subjected to dieback [4]. One of the worst affected trees was *Syzygium rotundifolium* followed by *Syzygium revolutum*, *Cinnamomum ovalifolium*, *Neolitsea fuscata* and *Calophyllum walkeri* [5]. Also, seedling establishment and forest regeneration in the area is slow [4].

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 showed dramatic changes. If this dieback continues with the current rate, the majority of the large trees will disappear from the forest soon and the forest will later converted to a savanna. 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. This study was based on the hypothesis that the forest is polluted with Pb as a result of increased vehicle emissions in the country and the consequential soil pollution has strong links with forest dieback and the sapling mortality of *Syzygium rotundifolium*. Soil toxicity caused by Pb could effectively be neutralized by enhancing soil organic matter level.

II. Materials And Methods

Horton plains, the highest plateau of Sri Lanka between altitude of 1500 and 2524m and the geographical location is in the Central Highlands of the Central Province, 6'47 – 6'50'N, 80' 46'- 80'50'E [6] was the area selected for the study. The landscape characteristically consists of gently undulating highland plateau at the southern end of the central mountain massif of Sri Lanka and soil order Ultisol is characterized by a thick, black, organic layer at the surface [7]. Temperatures are low, with an annual mean of 13°C, and ground frost is common in February [8]. Annual rainfall in the region is about 2540 mm [9].

Plot locations were selected to cover a 21 – 40 % of dieback severity area and to maintain soil and topography as constant as possible. Twenty-four permanent plots of 20 m × 20 m were established and Randomized Complete Block Design (RCBD) was used with six replications. The experimental plots were mapped using GPS (Global Positioning System) points with 20 cm accuracy. Five saplings of *Syzygium rotundifolium* with approximately 1m in height and 0.015m in diameter at the cotyledon scar of saplings were randomly selected from each sampling plot. *Syzygium rotundifolium* was specifically selected as the indicator tree because it is the worst affected [4]. Four treatments (a).compost - 2kg/sapling, (b).compost and montane mycorrhizae - 4kg/sapling. (c). montane mycorrhizae - 2kg/sapling including a control were used for the study. The soil samples were collected from 0.20m depth and 0.3m-0.5m away from each sapling representing four

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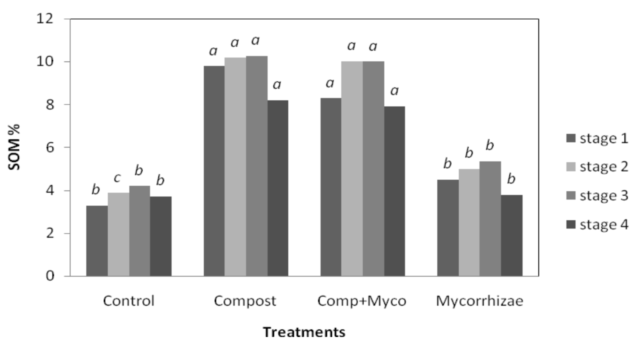
different time periods within 02 years. Soil Pb was measured by wet ash method [10] and the extracts were analyzed using Atomic Absorption Spectrophotometry [11]. Death rates of the saplings were calculated by keeping records of the selected saplings throughout the experimental period and counting the deaths at the end of the trial. Standard GENSTAT statistical software was used for the analysis of variance (ANOVA), t-test and regression analysis of the results [12].

III. Results

The results shown here are based on the work done during the two-year study period within the 21-40% dieback severity areas selected in Horton Plains.

3.1 Soil organic matter

Addition of compost has increased SOM content in the soil (Figure 1). Also, the effect of the treatments on SOM content was significant for all four stages of sampling – e.g. Stage-1 (p = <0.001), Stage- 2 (p = <0.001), Stage-3 (p = <0.001) and Stage-4 (<0.001) at the 0.20m depth.

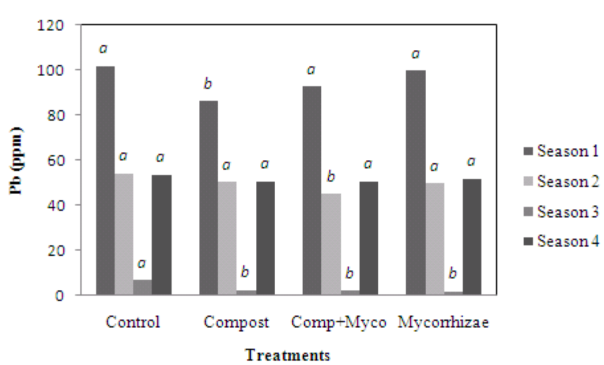


(*Mean comparison was done for different seasons separately and the means appear with same letter were not significant at p<0.05*)

Fig.1. Status of SOM% among the treatments at four different stages of sampling in 0.20m depth

3.2 Lead (Pb) in the soil

Results of soil and foliar analysis clearly indicated the status of soil contamination with Pb in Horton Plains.



(Mean comparison was done for different seasons separately and the means appear with same letter were not significant at p<0.05)

Fig. 2. Status of Pb among treatments at four different seasons of sampling in 0.2m depth.

Differences among the treatments were observed in terms of soil Pb level in 0.2m depth during Season-1 (p=0.01), -2 (p=0.004) and -3 (p=0.004) but there was no significant influence detected at Season-4 (p=0.79) (Figure 2). The highest Pb content was detected in the control during Season-1 whereas, the lowest was observed under the treatment Mycorrhizae, again during Season-1. However, the control showed the highest soil Pb level during the Season-1 while the treatments Compost, Compost with Mycorrhizae, and Mycorrhizae showed significantly lower soil Pb levels compared to the control.

3.3 Death rate of Syzygium rotundifolium saplings

Soil amendments with standard compost and mycorrhizae are effective in controlling the death of *Syzygium rotundifolium* saplings. Treatment effect on the death rate of saplings was significant (p < 0.001) and the control showed the highest death rate (Table 1).

TABLE I
VARIATION OF DEATH RATE OF *SYZYGIUM ROTUNDIFOLIUM* SAPLINGS

Treatment	Control	Compost	Comp + Mycorrhizae	Mycorrhizae
Death rate (%)	46.67	15.83	17.67	31.67
	(8.43)	(0.40)	(0.92)	(3.07)

Standard error for the respective mean is given within brackets

3.4 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) and the correlation showed that the death rate of saplings has been largely affected by the Pb concentration in the soil (Figure 4). Therefore, the death rate of the saplings used for the experiment appeared to have increased with the increasing availability of Pb in the soil. Results further revealed that the crucial level of soil Pb in relation to the survival of *Syzygium rotundifolium* saplings was around 60ppm in the area and beyond this level, even a slight increase of available Pb in the soil may impose severe damages on plant's metabolism leading to dieback. The results are in agreement with the work done by [13].

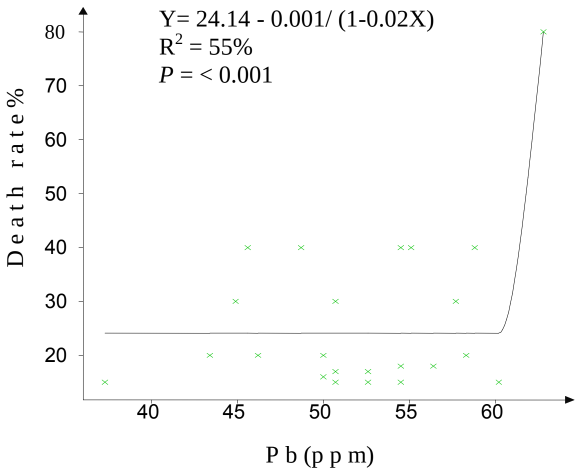


Fig. 3 Pb concentrations in the soil Vs Death rate of saplings

3.5 Lead (Pb) concentrations in soils vs Pb concentrations in foliage parts

Parallel to the increment of Pb levels in the soil, the Pb level in the leaves of *Syzygium rotundifolium* saplings have also increased. The relationship between soil Pb and the leaf Pb was significant (p = 0.01) and the nature of the relationship is linear – by –linear (hyperbola) (Figure 4).

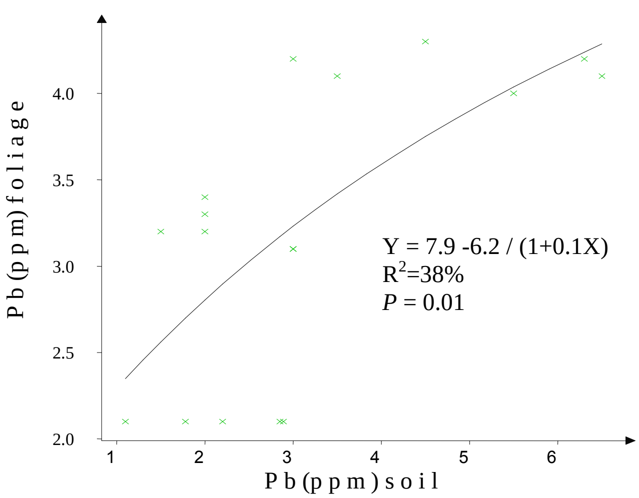


Fig 4. Pb concentrations in soils Vs Pb concentrations in foliage.

3.6 Soil organic matter vs Pb in the soil

The content of soil Pb is inversely proportional to the SOM content and the relationship between them 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 decline of soil Pb with the increasing SOM level seems to be linear-by-linear (Figure 5). Immobilization of soluble Pb by the humic and fulvic acid molecules present in SOM has been documented by several researchers (e.g., [14]).

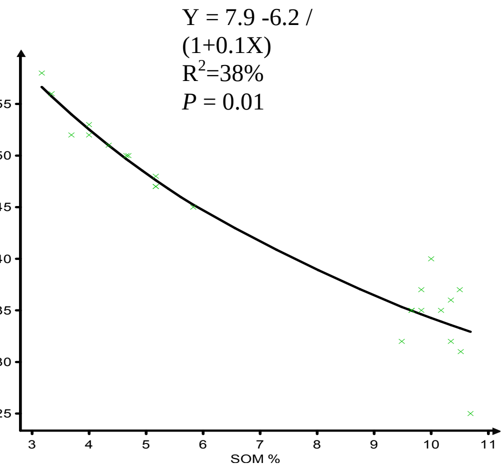


Fig 5. Soil organic matter Vs Pb in the soil at four different stages

3.7 Soil organic matter content in the soil and dieback of plants

Results showed that the increase of SOM level helps to reduce the death of saplings. The relationship between SOM level and the death rate of saplings *(Syzygium rotundifolium*) was significant (p = 0.05). The nature of the relationship seems to be linear-by-linear and it further indicates that maintenance of SOM level approximately above 4% will result a significant reduction of the death rate of the saplings (see figure 6).

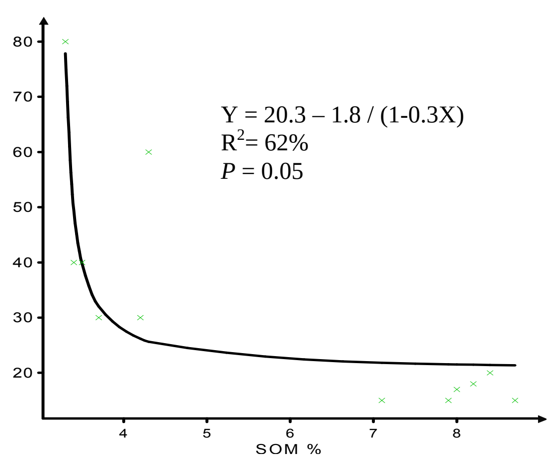


Fig 6. Soil organic matter content in the soil vs Death rate of saplings

IV. DISCUSSION

Deterioration of both quantity and the quality of soil organic matter in terms of humic substances appears to have influenced on the development of Pb toxicity on *Syzygium rotundifolium*. Forest dieback may be linked with dozens of reasons which include Pd toxicity as well. Effect of the treatments consisted of SOM justified the argument that improvement of SOM will be effective in controlling the dieback of *Syzygium* *rotundifolium*. One of the most important fractions of SOM, the humic substances, are highly effective in neutralizing the effects of toxic substances (e.g. Pb) in the soil [14].

Soil organic matter is often viewed as the thread that links the biological, chemical and physical properties of a soil. It has been associated with numerous soil functions such as nutrient cycling, water retention and drainage, erosion control, disease suppression and pollution remediation etc.

Just as soil organic matter buffers the soil from rapid changes in soil pH, it also binds organic pollutants, keeping them out of the soil solution where they would be taken up by plants or leached into ground water. Soil Organic Matter (SOM) also provides sites for microbes to colonize and decompose organic pollutants [15].

The lower the level of SOM, the higher the level of available soil Pb and therefore, the enrichment of forest soils in the affected areas with quality organic matter with standard levels of humic substances could be recommended as a control measure of forest dieback. This argument is backed by the death rate of the saplings where the results showed that the lowest level of SOM represents the highest death rate.

The level of soil Pb has gone up to 106 ppm. However, it should be noted that the maximum allowable limit for soil Pb is about 100 ppm [16]. Even the smallest amount of Pb may impose severe damages on plant's metabolism leading to dieback. Lead (Pb) at toxic levels has been identified as an agent causing damages on plants' respiratory mechanism in particular. [13]. Horton Plains is an upper montane forest consisting of specific montane forest vegetation which is considered to be much more sensitive to the changes in the environment [17]. Therefore, together with other unidentified causative agents, soil Pb at toxic level may have caused a severe impact on the forest vegetation triggering forest dieback.

The main source of Pb to the soils in Horton Plains must be the rain for several reasons. For example, external addition of soil amendments are not taken place within this well-protected reserve and also the underlying bed rock mainly consists of rock types Khondalite and Charnokites do not contain Pb [18].

Status of air pollution in Kandy with vehicle emissions and dust loaded with Pb and some other contaminants has been documented by [19]. Kandy is a city less than 50km away from Horton Plains. [20] also has identified Pb as one of the major air pollutants in Sri Lanka. As identified by [21], troposphere above another two cities in Sri Lanka, Colombo and Kurunegala, is polluted with Pb and the researchers have identified vehicle emission as the main source of Pb to the troposphere. Therefore, during rainy seasons, continuous addition of Pb to the soil with rain is anticipated. Rapid industrialization in the neighboring India may also have some links with the polluted airflow with Pb and many other pollutants towards Horton Plains.

The soil samples collected during the rainy periods were all found in moist condition with rain water soaked into the soil. Air-drying the samples only removes water from the samples leaving Pb behind. Hence, the laboratory analysis would have reflected these metals in higher concentrations for the soil samples collected during rainy periods.

Parallel to the increase of soil Pb, leaf Pb has also been increased. It means that the root absorption of Pb appears to be enhanced by the increasing concentration of soil Pb. Therefore, the development Pb toxicity in the forest appears to create Pb toxicity in the vegetation.

V. Conclusions

One of the toxic heavy metals, Pb, may have exceeded the tolerable level by the montane vegetation studied. Improvement of the quantity and the quality of SOM in terms of humic matter content appears to mitigate the Pb toxicity on forest vegetation. The level of SOM had better be maintained roughly above 3.5% in order to help the saplings to escape from untimely death.

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