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Increased Vehicle Emissions, Soil Pollution and Forest Dieback: Has Soil Pb Played a Key Role in Deteriorating Montane Forests of Sri Lanka?

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Abstract. Soil pollution and forest dieback appears to be a major threat to the most important montane forest in Sri Lanka, named "Horton Plains". This study focused on tracing key causes for the problem. The experiment consisted of twenty-four permanent plots within an area of 61-80% severity of dieback and three soil amendments through the addition of compost, montane mycorrhizae, and compost + montane mycorrhizae, alongside the control that made up four treatments. Treatments were applied to *Syzygium rotundifolium* saplings of approximate height of 1m and 0.015m diameter breast height (DBH) residing in each plot. Soil Pb content was compared using soil samples collected at 0.2m and 0.5m depths. These comparisons were done for the samples collected during a dry period and three rainy periods. Foliar analysis was also done for Pb. During the experiment, saplings were closely monitored and changing health status was duly recorded. The results show the contamination of soil and leaves with Pb which may impair plant metabolism leading to dieback. Compost and montane mycorrhizae significantly reduce the death rate of saplings (p = <0.001). Soil Pb has dropped significantly (p = <0.001) during the dry period and soil Pb and leaf Pb was significantly correlated (p= 0.001).

Keywords: Vehicle emission, Air pollution, Soil Pollution, Forest dieback.

1. Introduction

An identical tropical montane forest, the Horton Plains, occupies the eastern boundaries of the anchor shaped central hills of Sri Lanka, which lies between 1500 and 2524m ASL [1]. Geographical location is about 32 km south of Nuwara Eliya in the Central Highlands of Central Province, 6'47 – 6'50'N, 80' 46'-80'50'E. The land area covered by this montane rain forest is approximately 3,160 ha. Rocks are of Achaean age, belonging to the highland series of the pre-Cambrian, and include khondalites and charnokites [2] and soil order Ultisols is characterized by a thick, black, organic layer at the surface and is acidic (pH_{water} 4-6)[2]. Park receives rainfall from both northeast and southwest monsoons as well as inter-monsoonal rains. Frequently occurring mist and clouds are one main source of precipitation. Annual rainfall in the region is about 2540 mm [3], but for Horton Plains may exceed 5000 mm [4]. Rain covers throughout most of the year but there is a dry season from January to March. Temperatures are low, with an annual mean of 13°C, and ground frost is common in February [5]. Strong winds at gale scales are common during the south west monsoons period [6]. There are 54 woody species, of which 27 (50%) are endemic to Sri Lanka, 21 (39%) are restricted to the forest of south India and Sri Lanka, and the remaining 6 species (11%) are ubiquitous to the forests of south east Asia. [7] and [8] observed patches of dead and dying forest trees on the slopes of Thotupolakanda, 100m above the plains. Dieback in the Horton Plains involved a large number of species.

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Thirty-seven of the fifty species have been identified, belonging to 19 families were susceptible to dieback. One of the worst affected trees is *Syzygium rotundifolium*. Recent evaluations discovered that about 654 ha, equivalent to 24.5% of the forest in the park has been subjected to dieback [9]. The work done so far by many researchers on tracing the causes for the forest dieback have ended up with little or no success. Therefore, the main objective of this study was to identify the key causes for the forest dieback in this montane forest under the hypothesis that soil contamination with Pb as one of the key causes.

2. Methodology

The location of the experiment was in Horton Plains, the highest plateau of Sri Lanka between altitudes of 1,500 and 2,524m [1]. Twenty-four permanent plots of 20 m × 20 m were established to represent an affected area in the Horton Plain National Park. Randomized Complete Block Design (RCBD) was used with six replications. Plot locations were selected to cover a 61 – 80 % dieback of trees and to maintain soil and topography as constant as possible. The area is generally exposed to the wind since it has been reported that wind accelerates dieback [9]. A sketch of the area and the experimental plots mapped using GPS (Global Positioning System) points with 20 cm accuracy. Five saplings of *Syzygium rotundifolium* (approximately 1m in height and 1.5cm in Diameter of Breast Height (DBH)) were randomly selected from each sampling plot. 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. 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 Pb in the soil samples was measured by wet ash method [10] and the extractants were analyzed for the above elements by Atomic Absorption Spectrophotometry [11]. The soil samples were collected from 0.2m and 0.5m depths 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

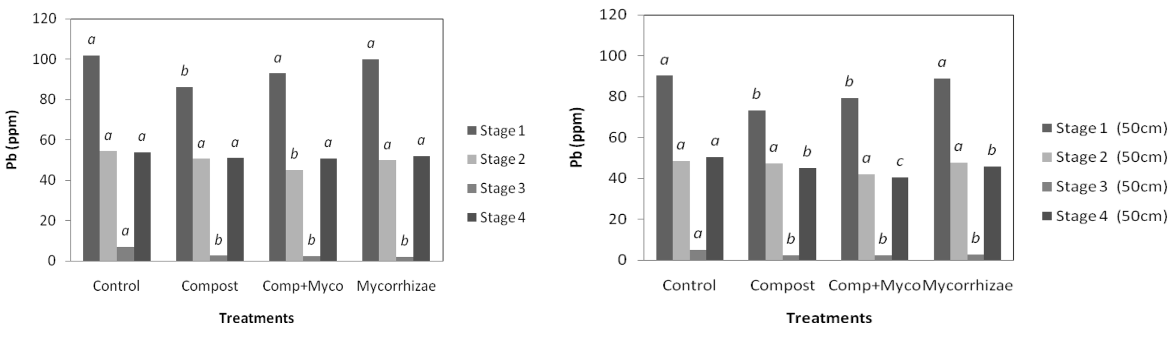
Two sets of soil samples taken during contrasting rainy and dry periods were compared. The results shown for stages 1, 2 and 4 indicate the Pb content in the forest soils during the rainy season while the results for stage 3 exhibits the levels of soil Pb during the dry season. Rainfall, temperature, wind speed/direction data for the area under investigation are shown in table 1.

Table 1: Weather conditions prevailed during the study period (Meteorological Station - Nuwara Eliya - Latitude: 6° 58' 11 N, Longitude: 80° 46' 12 E).

Sampling Stage	Sampling Months	Monthly Rainfall (*mm*)	Monthly Temperature (^oC)			Wind Data	
			Max	Min	Mean	Speed (*Knot*)	Direction (^{o}) From North
Stage 1	November/2008	154.7	20.01	12.29	16.15	5.1	285
Stage 2	May/2009	258	21.17	11.42	16.29	12.2	282
Stage 3	February/ 2010	19.4	22.09	11.97	17.03	7.9	97
Stage 4	June/ 2010	283.6	20.17	13.45	16.81	11.5	275

3.1. Lead in the soil

Results from both soil and foliar analysis clearly indicated the contamination of soil and vegetation in the Horton Plains from this trace element. Treatment effects on soil Pb at 0.2m depth were significant at sampling stages -1 (p=0.01),-2 (p=0.004) and -3 (p=0.004) but was not significant at the stage-4 (p=0.79) (Fig 1(a)). The highest Pb content was observed in the control. The results for the soils collected at 0.5m depth also showed significant differences among the treatments at the sampling stage -1 (p=0.03), -3 (p=0.03) and -4 (0.04) but not at the stage-2 (Fig 1 (b)). The level of soil Pb in the samples collected at 0.2m depth has gone up to 106 ppm in the control at the stage-1 sampling. The maximum allowable limit of Pb is 100 ppm [12] however, depending on the situation, even a tinny amount may impose severe damages on plant's metabolism leading to dieback [13]. The level of soil Pb at 0.2m and 0.5m depths was not significantly different. Gradual downward movement of Pb with rainfall may have distributed Pb almost evenly throughout the profile. It was clearly evident that the levels of Pb in the soil were significantly higher (p=0.001) during the rainy period when compared to the dry period. The main source of Pb to the soils of 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 Khondalite and Charnokites groups which are not considered to be rich with Pb [14]. Status of air pollution in Kandy, a city that is less than 50 km away from Horton Plains has been documented by [15]. Vehicle emissions loaded with Pb and many other toxic elements and compounds have been blamed for this air pollution menace [16]. Therefore, during rainy periods, continuous addition of Pb to the soil with rain water may be unavoidable. The soil samples collected during the rainy periods were all 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 this metal in higher concentrations for the soil samples collected during rainy periods. Burning diesel, gasoline and lubricants releases Pb to the atmosphere. Additionally, the friction by brake pads, clutch liners and tires release these elements to the atmosphere. Strong monsoon winds seem to be the most possible transportation source of Pb from the polluted south western part of the country and following pioneer studies, Pb is subjected to long-range atmospheric transportation to a greater extent [17] where Pb can be transported for a distance greater than 120km [18]. 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. According to past studies, [19] have reported several –fold increase of Pb concentration in the moss, *Hypnum cupressiforme* in Horton Plains during the period 1860 -1970. A fraction of Pb 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 into the plant bodies (see table 2). When the levels of Pb in the soil during the dry period are considered, plots treated with mycorrhizae showed lower values when compared to the values observed in the other plots. Even though this decline is not statistically significant, the results cannot be ignored. Mycorrhizae significantly increase the absorption of various elements from the soil including Pb [20]. Therefore, it could be assumed that the mycorrhizae are responsible for the reduction of Pb in the soil treated with mycorrhizae.



Stage 1= Rainy season; Stage 2= Rainy season; 3= Dry season; Stage 4= Rainy season (Means appear with same letter are not significant at p<0.05).

Fig. 1: (a) Status of Pb among treatments at four different stages of sampling in 0.2m depth; (b) Status of Pb among treatments at four different stages of sampling in 0.5m depth.

Table 2: Variation of Pb in the leaves from different treatments

	Treatments	Control	Compost	Comp+ Myco	Mycorrhizae
Pb (ppm)	**Mean**	4.133	2.1	4.217	4.217
		(0.04)	(0.0)	(0.05)	(0.02)

Standard error for the respective mean is given within brackets

3.2. 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 was significant (p=< 0.001) since the control clearly showed the highest death rate (Table 3). The standard compost consists of humic acid and fulvic acid 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. 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].

Table 3: Variation of death rate of *Syzygium rotundifolium* saplings

	Treatment	Control	Compost	Comp+Myco	Mycorrhizae
Death rate (%)	**Mean**	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

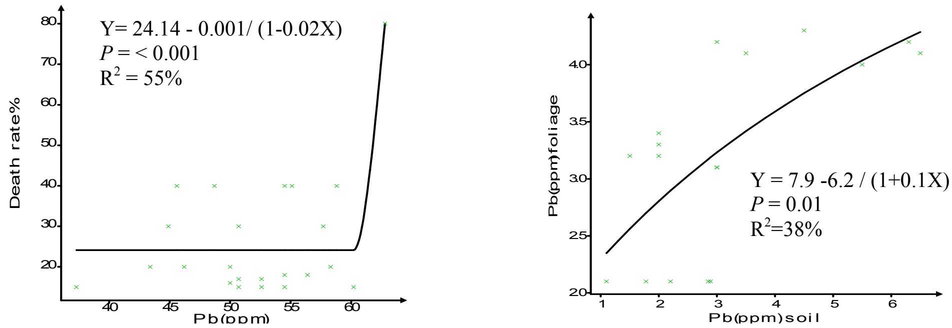


Fig. 2: (a) Pb concentrations in the soil Vs Death rate of saplings; (b) Pb concentrations in soils Vs Pb concentrations in foliage parts

3.3. 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 saplings has been largely affected by the Pb concentration in the soil (Fig 2(a)). Therefore, the death rate of the saplings used for the experiment has appeared to be increased with the increasing availability of Pb in the soil. Results further revealed that the crucial level of Pb in relation to the survival of *Syzygium rotundifolium* saplings was around 60ppm in the Horton Plains soil, beyond this level, even a slight increase of available Pb in the soil may impose severe damages on plant's metabolism leading to dieback [13].

3.4. Lead concentrations in soils vs Pb concentrations in foliage parts

Results showed that the increase of Pb level in the soil results in an increase of the level of Pb in leaves of *Syzygium rotundifolium* saplings. The relationship between soil Pb level and the Pb in leaves was significant (p = 0.01) and the nature of the relationship is linear – by –linear (hyperbola) (Fig 2(b)).

4. Conclusions

Soils of the montane forest have been contaminated with Pb. The key source of the contaminant appears to be the contaminated rain that may have been a result of air pollution. Increased vehicle emissions in congested cities nearby and rapid industrialization of India may have some links with this air pollution. Saplings of *Syzygium rotundifolium* are severely affected when the concentration of soil Pb exceeds ~60ppm. Increment of soil Pb increases the entry of Pb into the saplings.

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