

# Mitigation of Soil Pb Toxicity by Soil Organic Matter

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**Abstract** — Soil contamination with Pb has become a common problem in many farm lands and natural ecosystems as well. Thus, the contamination of food produced in those farms has become a serious concern. For the study, twenty-four permanent plots were established in the forested area. Three soil amendments or treatments: addition of compost, mycorrhizae, compost with mycorrhizae, and a control were used. The indicator plant used to identify the response to soil Pb 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 residing in each plot. Soluble soil Pb and soil organic matter (SOM) were compared using soil samples collected at 0.20m depth level. Soil samples were collected three times. Foliar samples from “treated” saplings were tested for Pb. During the experimental period, the selected saplings were closely monitored and changes in health were duly recorded. Effect of standard compost and mycorrhizae on protecting saplings from stressful conditions was significant ( $p < 0.001$ ). The results from soil and foliar analysis revealed the status of Pb contamination during rain which appears to have links with the death of *Syzygium rotundifolium* saplings. Positive correlations between soil Pb and leaf Pb were significant ( $p = 0.001$ ). Soil amendment with compost and mycorrhizae reduced the Pb content below the threshold levels ( $p = < 0.001$ ). Application of compost and mycorrhizae appeared to be effective in reducing Pb toxicity in the soil. Soil improvement with standard compost and mycorrhizae appears to be effective in treating contaminated soils with Pb.

**Keywords** — Soil Contamination, Pb, Compost, Mycorrhizae.

## I. INTRODUCTION

Contamination of soil with lead has occurred on a global scale. Exposure to lead may cause adverse effects to human health and the environment. Heavy metals such as Pb become toxic when they do not get metabolized by the body and end up accumulating in the soft tissues. Ingestion is the most common route of exposure to Pb. In plants, uptake of Pb depends on the plant species and bio-availability of Pb in the soils. Since most of the ingestion of Pb occurs from consumption of plants, then addressing how Pb become unavailable for plants can aid in controlling Pb toxicity. High concentrations of heavy metals in soils often characterize industrial and postindustrial regions. Sites located in the vicinity of smelting works may have extremely high levels of toxic metals accumulated in soil, particularly in the upper layers. Although the levels of toxic pollutants emitted into the atmosphere have decreased, heavy metals accumulated in soils may persist and affect terrestrial ecosystems for a long time. Vehicle emissions where Pb containing gasoline is used contributes to toxic metal and soil pollution. For busy roads, Pb levels in soil and vegetation indicated a significant level of Pb pollution in the areas nearby [1]. [2]

in one of their studies have proved the presence of many trace metals in both leaded and unleaded petrol, diesel oil, anti-wear substances added to lubricant, brake pads and tires and emission of them through vehicle exhaust pipes. A great part of metal pollutants are deposited in adjacent soils, where they may be transformed and transported to other parts of the environment, e.g., to vegetation. In addition to soil, forest vegetation in particular acts as a sink for atmospheric pollutants because of its capacity to act as an efficient interception to airborne matter [3]. Soil organic matter (SOM) is, together with soil pH, the most important parameter controlling toxic metal behavior in soils. Toxic metals bound on insoluble humic substances (i.e. an important fraction of SOM) are relatively immobile. On the other hand, binding on smaller organic molecules may increase metal mobility and bioavailability (e.g. [4]). Sorption sites on organic matter can be highly specific [5]. [6] reported high ability of Pb to form complexes with insoluble humic substances of low molecular weight. Humic carboxylic -COOH and phenolic -OH groups are mainly involved in the formation of metal-humic complexes [7]. The strength of metalhumic complexes is influenced by soil pH and ionic strength [8], [5] and [9]. Binding on humic acids may enhance metal sorption on mineral particles [10]. Detailed knowledge of the interaction of toxic metals with humic substances in soils could be used in the development of remediation methods for polluted soils [11]. Mycorrhiza is considered to be a crucial component of soils that provide immunity for the plants growing in contaminated soils [12]. In addition to its role played in the provision of essential plant nutrients from the soil and saving the plants growing on dry soils, mycorrhizae help the plants to escape from heavy metal toxicities [12]. Numerous studies have been conducted collecting lead concentration data from both natural and contaminated soil on a range of scales. However, practical ways of transforming plant available soil Pb to unavailable forms have been paid little attention. Therefore, this study was done to investigate the effectiveness of using compost to control Pb toxicity in soils.

## II. MATERIAL AND METHODS

The area selected for the study is believed to be worsted affected by Pb contamination in soils [13]. Experimental area, Horton Plains, is the highest plateau of Sri Lanka between altitudes of 1,500 and 2,524m [14] 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 [15]. Temperatures are low, with an annual mean of 13°C, and ground frost is common in February [16]. 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 [15].

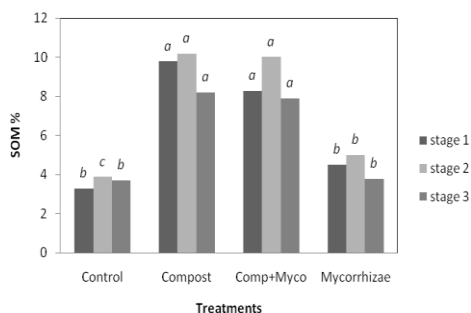
Twenty-four permanent plots of 20 m × 20 m were established to represent an affected area in the Horton Plain National Park. Randomized Complete Block Design (RCBD) was used with six replications. A sketch of the area and the experimental plots mapped using GPS (Global Positioning System) points with 20 cm accuracy. The indicator plant used to identify the response to soil Pb 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 residing in each plot. They were randomly selected from each sampling plot. 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. Lead in the soil samples was measured by wet ash method [17] and the extractants were analyzed for the above elements by Atomic Absorption Spectrophotometry [18]. Soil sampling was done three times and the samples were collected from 0.20m depth and 0.3m-0.5m away from each sapling. 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.

### III. RESULTS

The results shown here are based on the work done during the two-year study period in the Horton Plains National Park (HPNP), Sri Lanka. Average values of the parameters were used to compare the effect of different treatments.

#### 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 the four stages of sampling – e.g. Stage-1 ( $p < 0.001$ ), Stage- 2 ( $p < 0.001$ ), and Stage-3 ( $p < 0.001$ ) at the 0.2m depth.



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

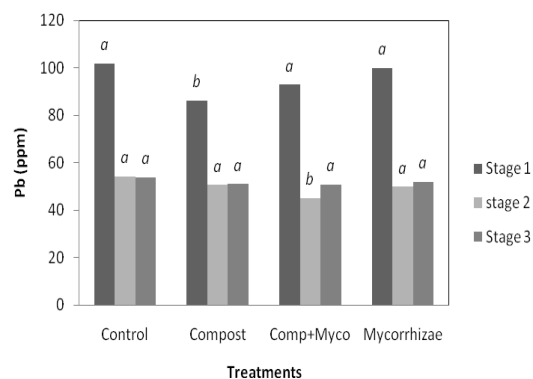
Fig.1. Status of SOM% among the treatments at three different stages of sampling in 0.2m depth

Treatments with mycorrhizae only and the control showed the lowest SOM at all three stages. Across different stages at 0.2m depth, the highest SOM content was exhibited in the Stage – 2 but the statistical analysis under  $\alpha$  level of 0.05, was not significant.

#### Lead in the soil

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

Differences among the treatments were observed in terms of soil Pb level in 0.2m depth during Season-1 ( $p=0.01$ ), -2 ( $p=0.004$ ) but there was no significant influence detected at Season-3 ( $p=0.79$ ) (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.



(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 three different stages of sampling in 0.2m depth.

#### Pb in the leaves

Results from foliar analysis indicated the entry of Pb into the plant bodies (see table I). When the levels of Pb in the soil were considered, plots treated with mycorrhizae showed lower values when compared to the values observed in the other plots. Even though this decline was not statistically significant ( $p = 0.075$ ) under  $\alpha$  level of 0.05, the results cannot be disregarded.

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

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

Standard error for the respective mean is given within brackets

### 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 II).

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

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

Standard error for the respective mean is given within brackets



Fig.3. A dead sapling of *Syzygium rotundifolium*

### Lead in the soil and death 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 (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 Pb in relation to the survival of *Syzygium rotundifolium* saplings was around 60ppm in the Horton Plains soil 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 [19].

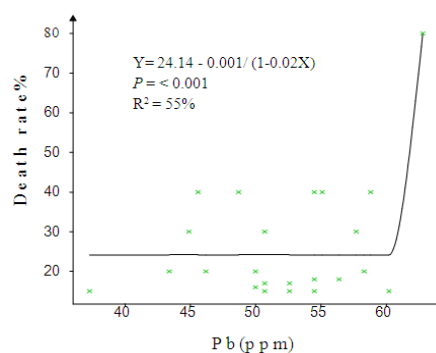


Fig.4. Pb concentrations in the soil Vs Death rate of saplings

### 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 5).

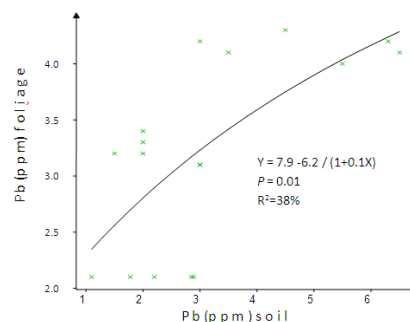


Fig.5. Pb concentrations in soils Vs Pb concentrations in foliage.

### 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 the decline of Pb with the increasing SOM level seems to be linear by linear (Figure 6). 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., [20]).

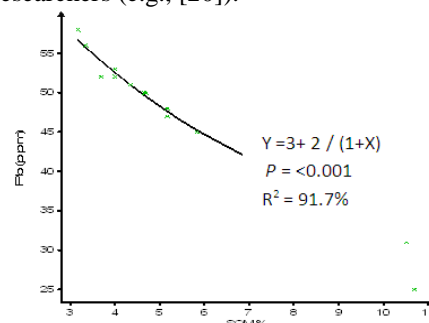


Fig.6. Soil organic matter Vs Pb in the soil at four different stages

### 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 by maintaining SOM level somewhere above 4%, the death rate of the saplings could be reduced significantly (see figure 7).

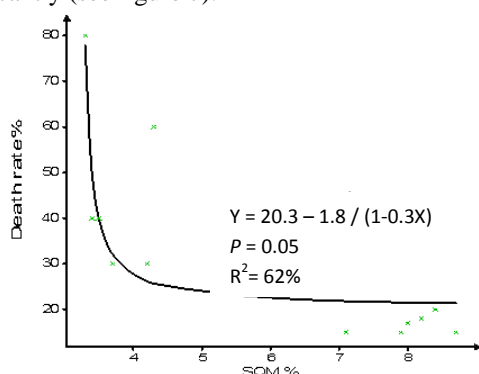


Fig.7. Soil organic matter content in the soil vs Death rate of saplings

## IV. DISCUSSION

Deterioration of the level and the quality of soil organic matter in terms of humic substances appears to have influenced on the development of Pb toxicity. The death of plants may be linked with dozens of reasons which include Pb toxicity as well. Effect of the treatments consisted of SOM justify the argument. One of the most important fractions of SOM, the humic substances, is highly effective in neutralizing the effects of toxic substances (e.g. Pb) in the soil [20]. The lower the level of SOM, the higher the level of plant available soil Pb and therefore, the enrichment of soils in affected areas with quality organic matter with standard levels of humic substances could be recommended to control Pb toxicity in the soil. This argument is backed by the death rate of the saplings where the results show 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 [21]. Even the smallest amount of Pb may impose severe damages on plant's metabolism leading to death. Lead (Pb) at toxic levels has been identified as an agent causing damages on plants' respiratory mechanism in particular. [19]. Burning diesel, gasoline and lubricants releases Pb to the atmosphere. Additionally, the frictions in 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. Following pioneer studies, Pb is subjected to long-range atmospheric transportation to a greater extent [22] where Pb can be transported for a

distance greater than 120km [23]. Status of air pollution in Kandy, Sri Lanka a city that is located in middle of the country has been documented by [24]. Therefore, it is very unlikely that the rain falling onto the area is free from Pb. Hence, during rainy period, continuous addition of Pb to the soil with rain may be anticipated.

When the levels of Pb in the soil are considered, plots treated with mycorrhizae showed lower values than the values observed in the other plots. Even though this decline is not statistically significant under the  $\alpha$  level 0.05, the results cannot be ignored. Mycorrhizae significantly increase the absorption of various elements from the soil including heavy metals such as Pb [25]. Therefore, it could be assumed that mycorrhizae are responsible for reduction of Pb in the soil treated with mycorrhizae. Mycorrhiza is considered to be a crucial component of soils that provide immunity for the plants growing in contaminated soils [12]. Therefore, mycorrhizal treatment may have been effective in increasing the tolerability of plants growing in contaminated soils with Pb.

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## REFERENCES

- [1] S. D. Sithole, Moyo, N. and J. Macheke, An assessment of lead pollution of vehicle emissions along selected roadways in Harare (Zimbabwe). *Intern. J. Environ. Anal. Chan.* 1993, 53: 1-12.
- [2] F. Monacci, and R. Bargali, Barium and other metals as indicator of vehicle emissions. *Water Air Soil Pollut.* 1997, 100: 89-98
- [3] B.E. Davies, "Lead". In *Heavy in soils*, B.J. Alloway, Ed. London: Blackie Academic professional, 1995, pp. 206-223.
- [4] A. Kabata-Pendias, H. Pendias, Trace elements in soils and plants. 2nd ed. CRC Press, Boca Raton Ann Arbor, London, 1992
- [5] D.C. Adriano, "Trace elements in terrestrial environments" in *Biogeochemistry, bioavailability, and risks of metals*. 2nd ed. New York: Springer-Verlag, 2001.
- [6] C. Angehrn-Bettinazzi, L. Thoni, J. Hertz, An attempt to evaluate some factors affecting the heavy metal accumulation in a forest stand. *Int. J. Environ. Anal. Chem.* 1989, 35: 69-79.
- [7] A. Datta, S.K. Sanyal, S. Saha, A study of natural and synthetic humic acids and their complexing ability towards cadmium. *Plant Soil*, 2001, 235: 115-125.
- [8] D.V. Ladonin, S.E. Margolina, Interaction between humic acids and heavy metals. *Eurasian Soil Sci*, 1997, 30: 710-715.
- [9] V.P. Evangelou, M. Marsi, Composition and metal ion complexation behavior of humic fractions derived from corn tissue. *Plant Soil*, 2001, 229: 13-24.
- [10] M. Arias, M.T. Barral, J.C. Mejuto, Enhancement of copper and cadmium adsorption on kaolin by the presence of humic acids. *Chemosphere*, 2002, 48: 1081-1088.

- [11] M. Halim, P. Conte, A. Piccolo, *Potential availability of heavy metals to phytoextraction from contaminated soils induced by exogenous humic substances*. *Chemosphere*, 2003, 52: 265-275.
- [12] A. Gaur, A. Adholeya, Prospects of arbuscular mycorrhizal fungi in phytoremediation of heavy metal contaminated soils. *Current Science*, 2004, 86: 528 – 534.
- [13] P.N. Ranasinghe, C.B. Dissanayake, D.V.N. Samarasinghe, R. Galappatti, The relationship between soil Geochemistry and Dieback of montane forests in Sri Lanka – A case study, *Environmental Geology*, 2006.
- [14] T.C. Whitmore, *Tropical Rain Forests of the Far East*. Claredon Press, Oxford, 1984.
- [15] R.A. Wijewansa, Horton Plains: a plea for preservation. *Loris*, 1983, 16: 188-191.
- [16] K.H.G. Silva de, Aspects of the ecology and conservation of Sri Lanka's endemic freshwater shrimp *Caridina singhalensis*. *Biological Conservation*, 1982, 24: 219-231.
- [17] USEPA, Method 3050B. Acid digestion of sediments, sludges and soils. Revision 2, 1996.
- [18] E. Dale, H. Norman, "Atomic absorption and flame emission spectrometry" in *Methods of Soil Analysis*, Page, 2nd ed. Vol. 2, A. L. Miller, R.H. Keeney, D.R., Eds. Madison, WI, USA : Agronomy 9, American Society of Agronomy, Inc, 1982, pp. 13-27.
- [19] A.B. Pahlsson, Toxicity of heavy metals (Zn, Cu, Cd, Pb) to Vascular Plants. *Water Air Soil Poll*, 1989, 47: 287-319.
- [20] J. Drozd, S.S. Gonet, N. Sensei, J. Weber, I. Pavasaras, *Complexation of Europium by an Aquatic Fulvic Acid: Iron as a Competing Ion*. The Role of Humic Substances in the Ecosystems and in Environmental protection, Wroclaw, Poland, 1997.
- [21] A. Kloke, Orientierungsdaten für tolerierbare gesamtgehalte einiger elemente in kulturboden mitt. *VDLUFA*, 1980, H.1-3: 9-11.
- [22] E. Steinnes, J.P. Rambaek, J.E. Hanssen, Large scale multi-element survey of atmospheric deposition using naturally growing moss as biomonitor. *Chemosphere*, 1992, 35:735-752.
- [23] M.F. Billett, E.A. Fitzpatrick, M.S. Cresser, Long term changes in the Cu, Pb and Zn content of forest soil organic horizons from North – East Scotland, 1991, *Water Air Soil Poll*, 59: 179-191.
- [24] C.B. Dissanayake, J.M. Niwas, S.V.R. Weerasooriya, Heavy metal pollution of the mid-canal of Kandy: an environmental case study from Sri Lanka. *Environ Res*, 1987, 42 (1): 24-35.
- [25] L. Weissenhorn, C. Leyval, J. Berthelin, Bioavailability of heavy metals and abundance of arbuscular mycorrhiza in soil polluted by atmospheric deposition from a smelter. *Biol. Fert. Soils*, 1995, 19: 22-28.



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