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RESEARCH ARTICLE

Screening of Plants for Phytoremediation of Lead (Pb) on soils contaminated with Fly Ash

***Nisha Dawle[1], P. V. Patil[1] and Deepa Panhekar[2]**

1. LIT, RTM Nagpur University, Nagpur, India
2. Department of Chemistry, Dr. Ambedkar College, Deeksha Bhoomi, Nagpur, India.

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Corresponding Author

Nisha Dawle

Abstract

Traces of Heavy metal are found in fly ash. Fly ash generation is on the rise because requirement of power is on the rise in the developing countries going for industrial development. In the last few decades, newer methods of fly ash managements have been tried. Some of the innovations are technology dependent. These are rarely sustainable and are costly too. Phytoremediation has been tried with much success. This process is beneficial due to two major reasons. It is sustainable and cost effective. Backfilling and reclamation is a major way of disposal of fly ash. Phytoremediation of Lead (Pb) by locally available plants growing in Nagpur region (Maharashtra,India) is explored in this work. The observations suggests us to believe that that *Vitex Negundo* is the most efficient phytoextractor amongst the plants chosen. However, *Cymbopogon Citratus* displayed a steady increase in absorption over the entire year of experimentation. *Cymbopogon citratus* is found abundantly in Nagpur region and requires very little attention and care. Thus, this specie could be used for further studies with microbial inoculations and amendments for hyperaccumulation.

Introduction

Heavy metal pollution owing to fly ash production poses a serious health hazard across the world (Chaney, 1984; Adriano, 2001; Jalal, 2006 and Lidsky, 2003), particularly in developing nations (Sinha, 2000). Owing to rising energy requirements, and paucity of alternative, economically viable and sustainable energy generation options, thermal power plants fired by coal from bulk of electrical power generation.

Coal deposits found in India are largely of low grade (largely bituminous and lignite) (Chikkatur, 2008), and hence contain excess amounts of fly ash heavy metal concentrations. Hence, heavy metal traces are found in unacceptable quantities in the fly ash spewed out by the ever-increasing number of TPS’s.

The coal-fired power plants produce 70-75% fly ash that contains traces of heavy metals that are difficult to manage, in spite of the fact that applications of fly ash have been found in cement and concrete industry to some extent (Singh, 2011). The need for disposal of larger quantities of through sustainable and ecologically viable (Adriano, 1980) and more environment friendly ways has gained increased importance over the decades as the above named applications still are likely to contaminate soil and habitat texture and soil fertility issues (Gupta, 2002 and Bush, 1999). Water bodies in low-lying areas are also prone to pollution by heavy metals and hence rendering them unfit for consumption, just as arable land tracts become infertile, owing to fly ash dispersion.

Plants, by virtue of active and passive absorption of metals, to the shoots, through roots, abet the metal circulation in food chain being consumed by grazing, and, or, by humans. As such, varying contents of different metals in fly ash, soil and climatic conditions have necessitated varying directions for research on bioaccumulation (Jambhulkar, 2009), phytoremediation (Henry, 2000 and Thomas, 2012) and rhizoremediation by vastly different species of flora and fauna, shrubs and trees (Yoon, 2006). In India, soil erosion is already a serious problem as stated in a study ranging from loss of top soil in 130.5 million hectare (ha) to terrain deformation in 16.4 hectare (ha) (Sharda, 2010 and Ahalya, 2003).

In conjunction with organic manure and microbial inoculants, fly ash can enhance plant biomass production from degraded soil (Maiti, 2006 and Schacklette, 1984). In a study, out of a consortium of 11 bacteria, a combination of two strains, viz.,*Paenibacillus macerans NBRFT5 + Bacillus pumilus NBRFT9 (c7)* inoculated in rhizosphere was found to enhance Pb accumulation by about 278%, Mn by 75%,Zn by 163%, Cr by 226%, and Ni by 414% (Kumari, 2011).

This paper is in furtherance of all above observations and deductions to open up possibilities of narrowing down on locally available plants (Dana, 2011) and encourage further exploration of ecologically sustainable remediation practices. This study aims to find the different, viable and local plant species, capable of translocation of Lead (Pb) aggregated over a whole year. It was envisaged that over a year, the plants would weather different climatic conditions. Hence, provide an insight to identify the ones that could, be picked out for hyperaccumulation by inoculating them with microorganisms. The study was carried out in pots, translocation was studied, and analyses have been presented in this paper.

Material and Methods

Study area

Twin Locations of Koradi Thermal Power Station, Koradi (Latitude 21° 14′ 55″ N., Longitude 79° 5' 55" E.), Khaperkheda Thermal Power Station, Khaperkheda.,(Latitude 21° 16′ 27″ N., Longitude 79° 6' 48" E.), within 5 Kms. of each other near Nagpur, (Maharashtra, India) were selected for the study owing to following reasons:

a) There are power plants with continually expanding capacities, owing to large scope of horizontal growth. That there is a proliferation of coal mines in these regions is also an important reason for choosing this area.
b) Large tracts of land that have not been irrigated for considerable period of time has rendered them as dumping pits for all types of wastes of these TPS'S. Continuous dumping of fly ash, laden with heavy metal traces has contaminated and polluted these areas as well as large populated areas around them (Maiti, 2006 and Ahalya, 2003) to an extent where they have become a serious health hazard. Air, soil and water contamination are rising to alarming levels and need immediate attention towards long term, sustainable and eco-friendly remediation.
c) Most of the preliminary studies had pointed out the efficacy of phyto-extraction observed in locally abundant shrubs and plants. Plants species were selected on:
    - Their capacity to withstand local ambient climatic conditions of wide temperature fluctuations;
    - Easy availability and their obvious capacity to absorb and bioremediation of heavy metal contents, at virtually no cost (Economic Consideration), and
    - The optimal full growth period of the chosen species was 12-16 months.
d) The amount, insolubility factor of Lead (Pb), and toxicity have attracted our attention the most (Pacyna, 1995), amongst the many metal traces found in the soil samples of the dumping sites.

A comparative study of Lead (Pb) uptake by plants (Yoon, 2006), and remediation of ash contaminated soil, thereby helping the cause of sustainable and affordable ways to offset the damaging effects of fly ash has been attempted and presented in this paper.

Preparation of soil

Garden Soil (GS) was selected from areas of garden where soil was treated equally (Pennock, 2007; Carter, 2008 and Sahoo, 2011). The surface was cleared of all debris, stones, rocks, twigs and dried leaves. Samples were taken by shoveling a feet or so deep uniformly from each patch (of the sixteen equally marked out areas). Tree root zones, wherever present were dug an additional 6 inches. Any possibility of fertilizer contamination/traces were eliminated by collecting soil samples between the rows of plantations. Areas with different fill soils were added in equal ratios to acquire a homogenous mixture.

All lumps were then broken down to get a coarse, granular feel, like the rest of the soil. The soil, thus collected, was spread out in a sparse, equitable layer, exposed to the sun, for a week, thus drying it naturally. All soil piles were churned thoroughly using spades and hand shovels from all sides to achieve maximum possible uniformity. This assorted soil sampled from different parts of the garden was crushed manually, care being taken to avoid reaching a powdered form.

Since four different species were to be observed for lead uptake and compared thereafter, eight different cardboard boxes were each filled with a pint or two of the preparation. One set (for four different plants, viz., *Vetiveria zizanioides, Vitex negundo, Catharanthus roseus* and *Cymbopogon citratus*) was marked out for pure Garden Soil, the other set was marked for GS added with the Fly-Ash (FA) added in equal amounts (GS:FA::1:1) to each box separately and thoroughly mixed. This was then labeled and marked. Six such sets were replicated to measure the average lead uptake achieved, considering the fact that each plant may behave differently. All anomalies (standard deviations, errors during readings and upkeep of plants), had to be taken into account. We took six readings to incorporate the effect of possible vagaries of nature therein and a more acceptable, studied observation be obtained that could be standardized fairly.

It has become common knowledge that Lead being insoluble in water has been found on the top soil frequently in residential areas next to industries that use lead in any form. The most disconcerting effect of this lead contaminated soil has been found on children, and therefore, phyto-extraction of lead has gained utmost importance over most other remedial measures. Working along the lines explains the need to estimate Lead uptake as accurately as possible.

The samples being prepared were filled in pots that were sealed at the bottom thereby eliminating the possibility of Lead run-off. It was envisaged that, locally available plants, that grow with minimal or even if left to themselves and having good accumulating capabilities needed to be studied for a sustained period. It was also important, in view of the fact that fly ash generation is and will be generated in huge amounts, that the phytoaccumulators have a good rate of growth. Four plants, with already noted capabilities were observed for a period of twelve months and comparative Lead (Pb) uptake was noted with regard to amount of absorption, peaking duration and their easy availability in the region.

Result and Discussion

The results of the experiments have been tabulated and comparisons drawn as elucidated in the graphs drawn. The results are summarized along two lines. The first set is a plant-specific, percentage comparison chart in Garden Soil/ Soil (GS) and Garden Soil / Soil + Fly ash (GS+FA) separately. The second set brings out the comparison of rates of absorption in GS as against GS+FA of each plant to study the stagnation periods individually.

One, the relative rate of mean concentration of Lead (Pb) absorption in 0-3 months, 3-6 months, and then 6-12 months was calculated progressively. The analysis of soil samples taken at the beginning (0 month) and at the end of 3^{rd}, 6^{th} and 12^{th} months. The results have been tabulated and hence illustrated in respective graphs to bring out the best period during which the said plants absorb most amount of Lead. Secondly, a superimposed graph illustrates the comparison of Lead uptake capability.

From Figure 1 (a) and 1 (b), we can safely infer that, the mean concentration of Lead (Pb) absorption improved after the 3^{rd} month. It started tapering off equally fast during the following period (both in GS as well as GS+ FA environment), leading us to an insight of the absorption behavior of the plant in comparison with what had been absorbed and also to the rate of absorption in comparison with the available, phytoextractable Lead present in the soil. *Vitex Negundo* seems to be the most efficient phytoextractor amongst the plants chosen followed by *Catharanthus Roseus* and *Vetiveria Zizanioides*.

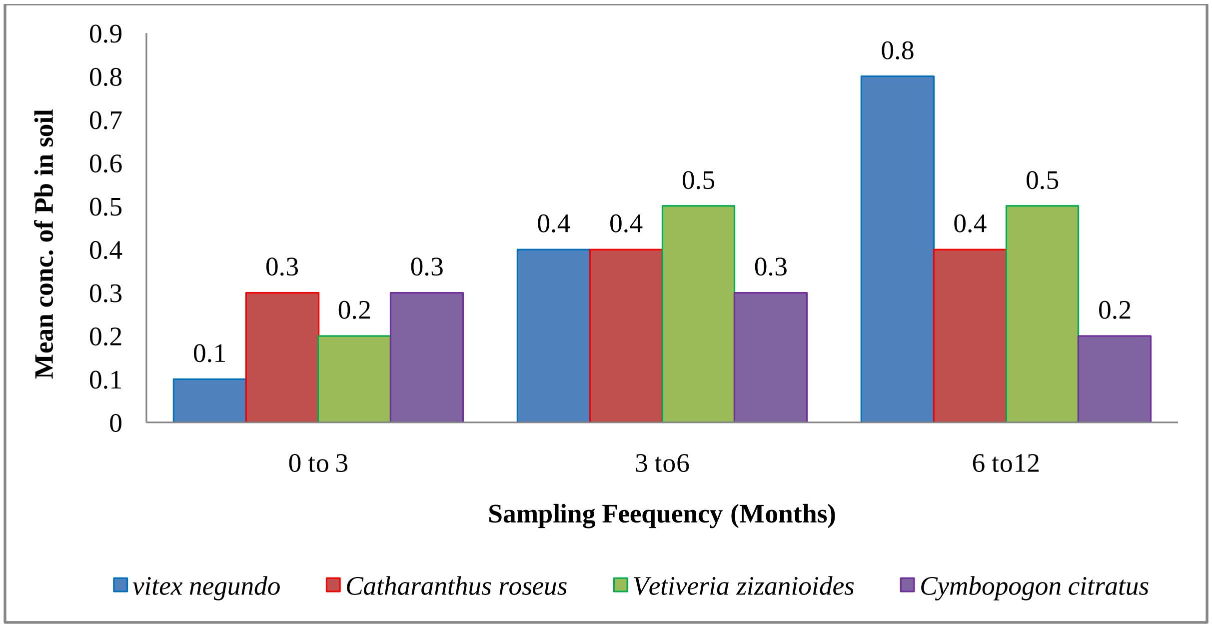


Fig. 1(a) Mean concentration of Lead (Pb) in soil absorbed in Vitex Negundo,Catharanthus Roseus, Vetiveria Zizanioides, Cymbopogon Citratus in soil.

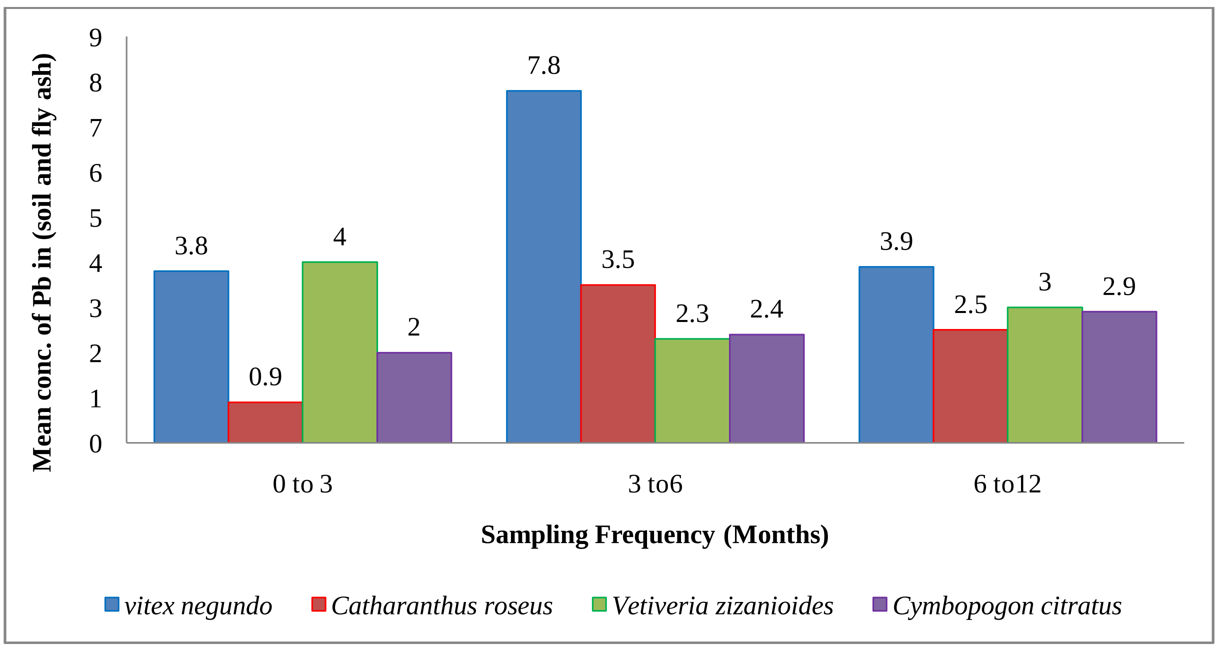


Fig. 1(b) Mean concentration of lead in soil and fly ash absorbed in Vitex Negundo,Catharanthus Roseus, Vetiveria Zizanioides, Cymbopogon Citratus in soil and fly ash.

Compared to *Vitex Negundo*, *Catharanthus Roseus* exhibited a more relaxed slide off in absorption rate, meaning, quantitatively, better absorption throughout the 12 months cycle. This suggests us to believe that *Catharanthus Roseus* might be a better choice over a longer duration. Since the pot studies were under controlled conditions, these results can form a basis for more detailed analysis with a longer period, enabling to conclusively ascertain the absorption (or absorption rate) vs. life cycle of the two species.

Vetiveria Zizanioides, on the other hand shows a decreasing rate in the beginning followed by a gradually increasing rate after the 6th month, thereby leading us to infer that these need to be left for a longer period of observation to ascertain the inclination of absorbing tendencies as well as the time frame after which stagnation is reached.

The following graphs shows Pb concentration absorption quantities in ppm as found directly from AAS (Atomic Absorption Spectrophotometer) (Model: GBC 906AA), ICP-OES (Inductively Coupled Plasma Optical Emission Spectra) (Model: Thermo Fisher scientific, IRIS Intrepid II XDL) and XRF (X-ray Fluorescence) (Model: PHILIPS Magix PW 2403,Panalytical,holland).

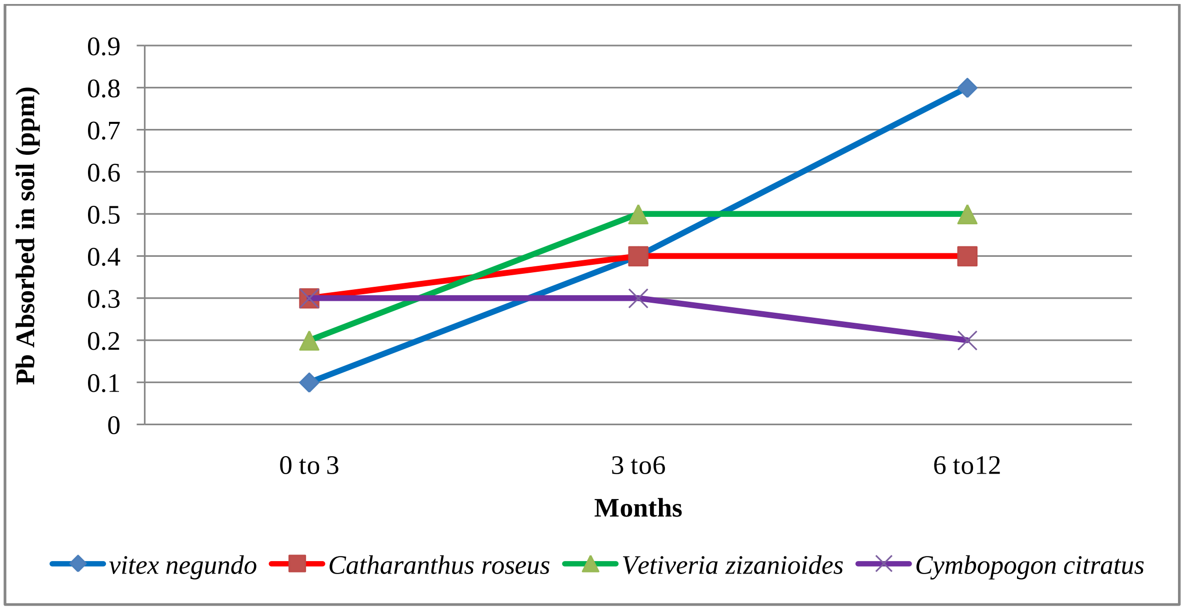


Fig 2(a) Comparison of Vitex Negundo,Catharanthus Roseus, Vetiveria Zizanioides, in soil in ppm.

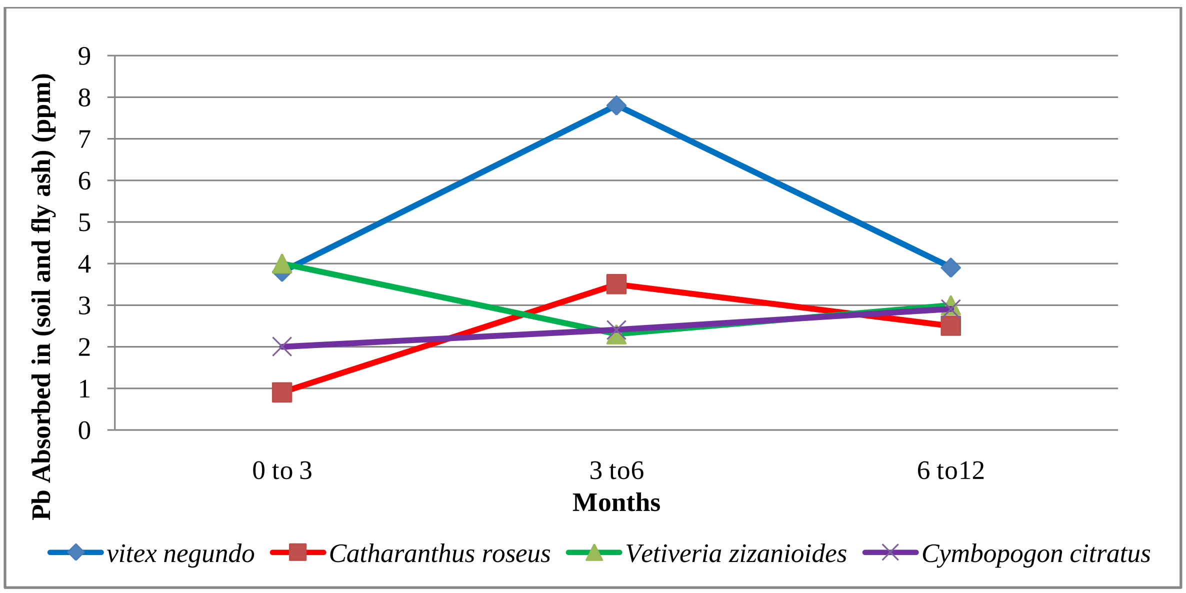
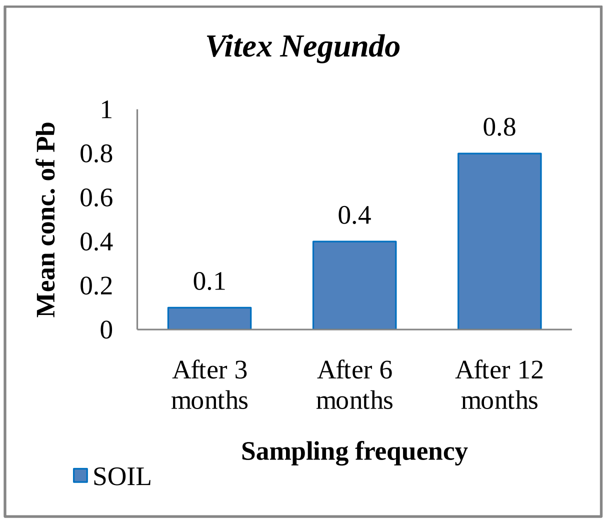


Fig 2(b) Comparison of Vitex Negundo,Catharanthus Roseus, Vetiveria Zizanioides, Cymbopogon Citratus in soil and fly ash in ppm.

As opposed to all above plants, *Cymbopogon Citratus* displayed a steady increase in absorption over the entire year of experimentation/observation, and the ease with which it is found and stands the vagaries of nature suggests us to an interesting, if vastly divergent behavioral trends.

The graphs depicts, the rate and quantity of absorption depends, to a large extent on the quantity of available Lead initially, and then, that the rate of absorption goes down, indicating that comparative uptake is set-off by the amount of Lead present in the plants. Further investigation is thus, necessitated.

For purposes of study of relative comparison of absorption tendencies in GS Versus GS+FA, graphs of respective plants have been drawn and the discussions thereof, towards conclusive as well as further lines of studies needed have been incorporated.



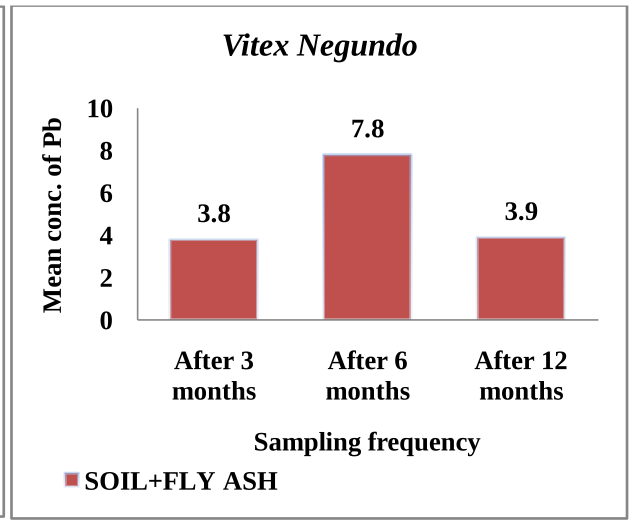
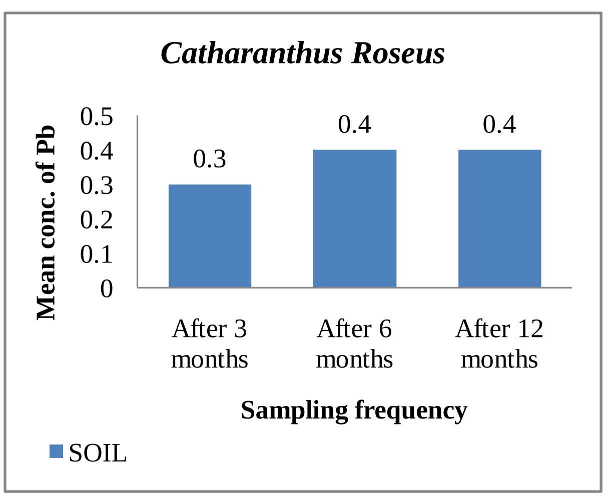


Fig 3(a)i **Fig 3(a)ii**

Lead absorbed in ppm by Vitex Negundo in soil [Fig 3(a) i] and in fly ash [Fig 3(a) ii].



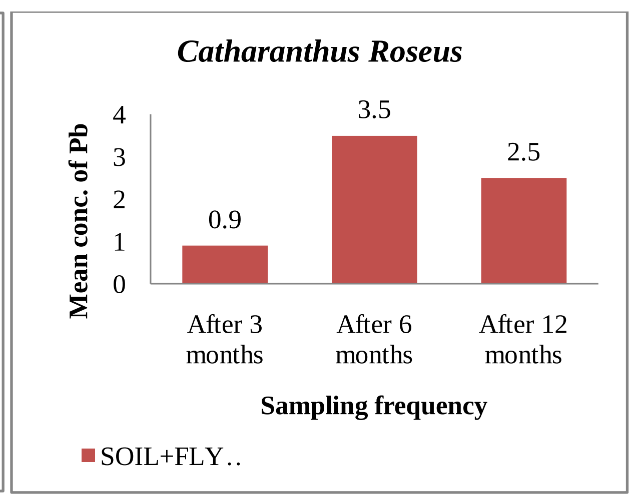
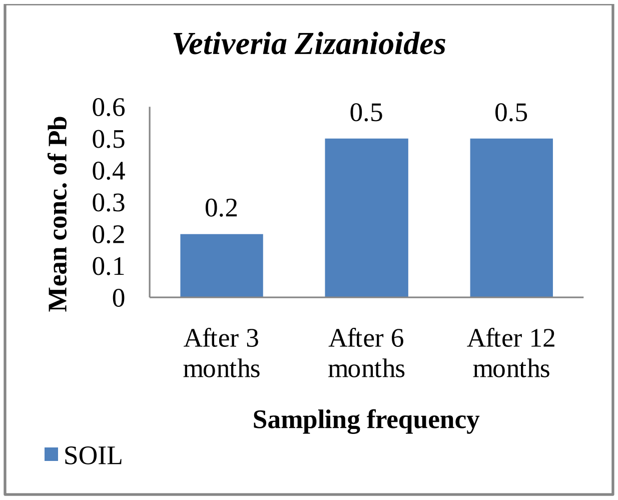


Fig 3(b)i **Fig 3(b)ii**

Lead absorbed in ppm by Catharanthus Roseus in soil [Fig 3(b) i] and in fly ash [Fig 3(b) ii].



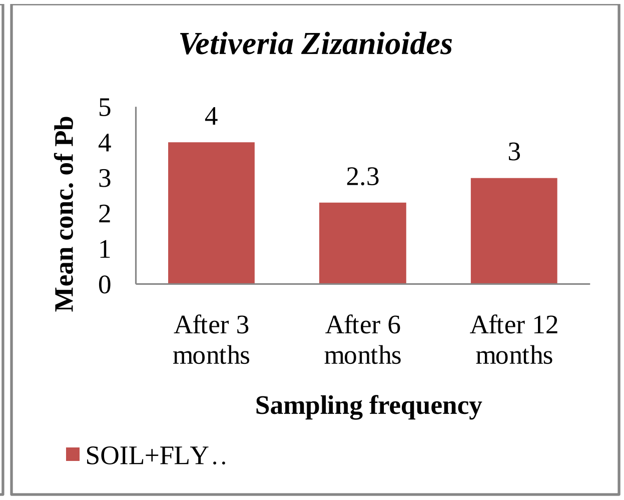
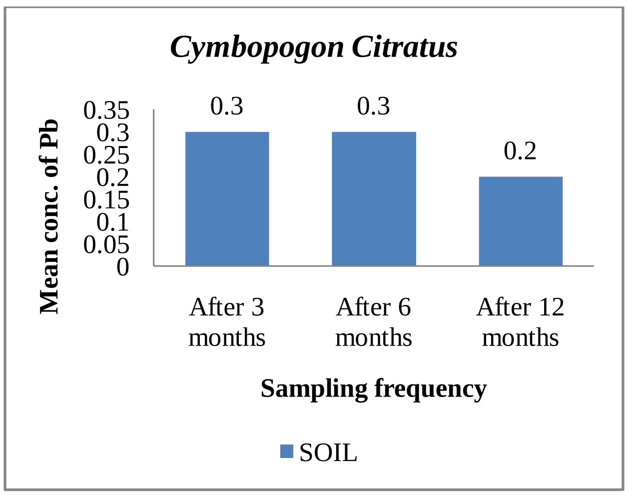


Fig 3(c)i **Fig 3(c)ii**

Lead absorbed in ppm by Vetiveria zizanioides in soil [Fig 3(c) i] and in fly ash [Fig 3(c) ii].



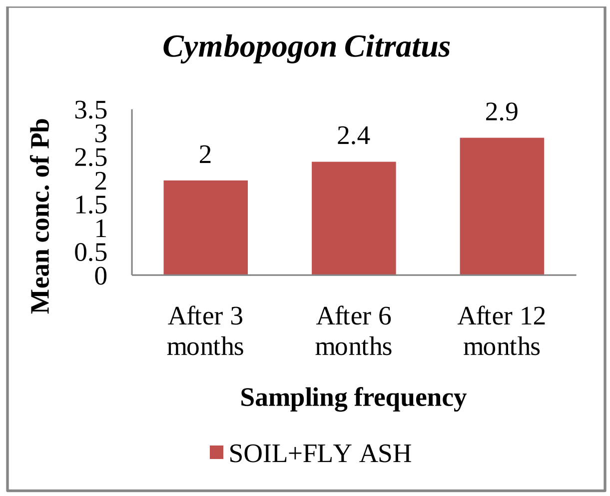


Fig 3(d)i **Fig 3(d)ii**

Lead absorbed in ppm by Cymbopogon Citratus in soil [Fig 3(d) i] and in fly ash [Fig 3(d) ii].

The fact that certain quantities of Lead (Pb) have been biosorbed was crosschecked with the study of Lead (Pb) content analysis after harvesting all four varieties of plant species that were planted in the pots with soil and (Soil & Fly ash).

Conclusion

The study indicated that Vitex Negundo and Cymbopogon Citratus possessed many beneficial characteristics to uptake Lead (Pb) from comtaminated soil. All the four varieties were tolerant and could grow in soil with high Lead concentration.The important implication of our findings is that vitex negundo is most efficient phytoextractor and can be used for phytoextraction on sites contaminated with high levels of heavy metals, particularly Lead (Pb).

Thus the finding emphasize on the need for checking these species for field trials (Fly ash dumps),and their utilisation for future studies with different ammendments and microbes.

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