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Environmental Amelioration through *Pongamia pinnata* based Phytoremediation

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Abstract: ***The current trends of global warming are of great concern. It is estimated that an increase of 2.5% of global temperature would reduce agricultural productivity in USA by 6%; but by 38% in India (Sengupta 2013). Added to the problems of climate change leading to increasing temperatures, the world is facing the problems of soil deterioration due to pollution and mining activities. It is therefore necessary to come up with appropriate technologies involving tree species that are efficient in not only cutting down global warming and bring about perceptible levels of C sequestration; but also ameliorate the problem soils. Pongamia pinnata is one such species that is capable of carrying out the soil amelioration as well as enhancement of upper environment***

Keywords: Pongamia pinnata, phytoremediation

1. Introduction

The current trends of global warming are of great concern. It is estimated that an increase of 2.5% of global temperature would reduce agricultural productivity in USA by 6%; but by 38% in India (Sengupta 2013). Added to the problems of climate change leading to increasing temperatures, the world is facing the problems of soil deterioration due to pollution and mining activities. It is therefore necessary to come up with appropriate technologies involving tree species that are efficient in not only cutting down global warming and bring about perceptible levels of C sequestration; but also ameliorate the problem soils. *Pongamia pinnata (Karanj)* is one such species that is capable of carrying out the soil amelioration as well as enhancement of upper environment.

In recent years it has been convincingly shown that *Karanj* forms a dependable feed stock for biodiesel production in view of its consistent seed & oil yield and its wider adaptability to diverse agro-ecological situations.

Pongamia pinnata (Karanj) is an important component in afforestation programs, in view of high rate of survival and hardiness in withstanding vagaries of weather including soil aberrations. Considering its ease of maintenance, inclusive nature without any adverse effect on the surrounding vegetation, manurial value of its products, its ability to improve soil and consistent oilseed yield, *Karanj* tree is finding a niche in agroforestry programs too. *Karanj* is very amenable to intercropping with wide range of economically important annual and perennial plant species. This attribute of inclusiveness and amenability for intercropping puts *karanj* tree on top pedestal in agroforestry programs.

2. Soils with Heavy Metals

Heavy metals are generally defined as metals with relatively high densities, atomic weights, or atomic numbers. The earliest known metals—common metals such as iron, copper, and tin. Crops cultivated on soil with an elevated content of heavy metals typically present inhibited growth, reduced transpiration, chlorosis of leaves, limited germination of seeds and deformations of the root system. The effect induced by heavy metals is more pronounced in the early development of plants. Increased quantum of heavy metals in soil is observed to be associated with a low content of humic acids. The soils in addition to containing very high heavy metal levels (Cu, Cr, Mn, Ni, Pb, Zn), they are also characterized by a lack of clear horizonation, a relatively high pH, a high mineral and organic carbon contents, a low nitrogen level and a high C/N ratio. Heavy metals were poorly labile (i.e. not soluble in diluted CaCl2), indicating that their leaching under natural conditions was probably very low. (Remona et al 2005)

The soils contaminated with Pb are associated primarily with the carbonate and the Fe-Mn oxide phases of the soil samples. Cu was associated with carbonate, Fe-Mn oxide, and organic fractions of the soils. In one of the test soils (Soil A), SEM/EDX analyses showed the presence of roughly spherical isolated Pb-enriched particles (Prasad etal 1995).

Because of the potential hazards associated with the soils polluted with heavy metals it is becoming very difficult to propose conventional remediation techniques or new occupation plans. In many contaminated landfills, there is the risk of vertical heavy metal transfer both to the groundwater and to the above ground vegetation. (Remona et al 2005)

Despite the recalcitrant nature of the above kind of soils for conventional amelioration practices, there exists the possibility of their reclamation through phyto-remediation employing some efficient hyper accumulator trees such as *Pongamia pinnata. (*Prasad 2007)

Environmental Problems of Coal Mines

Ranked high in the record of environmentally degraded region, huge areas in the Raniganj and Jharia coalfield in India got degraded due to abandoned dumps, active mine surface and underground mines. In open cast mines, waste resources are usually stacked as huge dumps in the surroundings.

Emissions of fly ash during combustion of coal, and huge quantities of ash generated from the boilers of coal-based power plants and industrial houses, are among the host of problems associated with the handling and use of coal. The emission of carbon dioxide and methane, which are important components of the `green-house gases' (GHGs) provoke global warming. Air pollution in coalmines is mainly due to the fugitive emission of particulate matter and gases, including methane, sulphur dioxide and oxides of nitrogen. The mining operations, such as drilling, blasting, movement of the heavy earth-moving machinery on haul roads; collection, transportation and handling of coal; and the screening, sizing and segregation units are the major sources of such emissions. Significant variations in the impact of opencast operations are identified, especially in relation to the potential for derelict land reclamation and the grade of agricultural land affected.

The major source of solid waste in a coalmine is the overburden. Segregation of the stones in the coal-handling plants and the coal breeze also contribute to the solid waste generation. The overburden-to-coal ratio in open-cast mining is about 2 m3/tonne of coal. The environmental degradation has affected especially the common property resources such as land and water on which depend the subsistence and well-being of the local community. Other problems associated with coal mining are overburden management, subsidence management; underground mine fire abatement, land degradation during mining activity, and its reclamation and compensatory re-forestation.

The land use pattern has been changed considerably over last three decades. The quality of restoration still has scope for improvements, such as reducing soil compaction and the subsequent management of the land by the farmer. In this context the efficient biological agent such as *Pongamia pinnata* (*Karanj)* has been found very effective in remediating not only overburden dumps, but also the upper environment due to the tree's marvellous carbon sequestration capacity (Prasad 2007 and Prasad 2013)

Efficient Tree Species for Environmental Amelioration

Pongamia pinnata or ***Mellettia pinnata*** or ***Pongamia glabra*** *or* ***Derris indica*** *(*2n=2x=22*)* is a tropical ever green fast growing leguminous tree, with glabrous, glossy and deciduous leaves. The tree is reported to be the hyper accumulator of heavy metals in the soil (Prasad 2007). The soils with *Pongamia* tree stands present favorable characteristics for crop growth,devoid of toxic elements including heavy metals. The tree is native to India and South Asia and also found in Oceania. The common names of the tree in English are **Pongam** and **Indianbeech**. In India there are several local names of the tree depending upon the region. Some of the local names are **Karanj** (Hindi), **Pungam (**Tamil), **Honge** (Kannada) **Panigrahi (**odissi) and **Gaanuga / Kaanuga** (Telugu). It is often planted as an ornamental and shade giving tree on roadside.

Pongamia is a medium-sized tree that generally attains a height of about 8.0 to 12.0 m and a trunk diameter of more than 50-75 cm. The bark is thin, grey to greyish-brown and yellow on the inside. The alternate, compound pinnate leaves of the tree consist of 5 or 7 leaflets, which are arranged in 2 or 3 pairs, and a single terminal leaflet. Pods are elliptical, 3-6 cm long and 2-3 cm wide, thick walled, and usually contain a single seed. However, at times two seeds per pod are also observed in some pods at low frequency. Seeds are 1.5–2.5 centimetres (0.59–0.98 in) long, flat, oblong, and light brown in colour. Seeds yield a non-edible oil and a cake is rich in protein.

*Karanj*tree thrives in areas having an annual rainfall ranging from 400 to 2500 mm. In its natural habitat, the maximum temperature exceeds 38^{o}C and the minimum can be as low as 1^{o}C.The root system of *karanj* is thick and well developed deep tap-root of 10m depth and a spread of lateral roots to around 9m. *Pongamia pinnata (Karanj)*is known for its ability to fix atmospheric Nitrogen in association with soil Rhizobia. Mature tree apart from its inherent drought resistance, can withstand water logging and slight frost. This species grows up to the elevations of 1200 m, but in the Himalayan foothills it is not found above 600 m. It can grow on most soil types ranging from rocky to sandy to clayey, including dry sands, toxic and saline soils.

*Karanj*is drought resistant tree; but can be grown under wide ranging climatic conditions too. Under scanty rainfall conditions of even less than 400mm, *Karanj*tree survives well and gives reasonable kernel and oil yield levels. It has been proved beyond doubt that *Karanj* forms a very promising feed stock for bio-diesel production due to its high and consistent oil yield (Prasad 2013)

Karanj tolerates all kinds of soil aberrations including high soil salinity, moderate alkalinity, soil toxicity, waterlogging and poor soil fertility (Orwa et al 2009). The tree can be grown on marginal soils and conditions of low rainfall (Duke 1981&1983). Nevertheless, it is advisable to get the soil analysed before planting*Karanj* in order to put in place a package of practices to enhance its kernel and oil yield.

Pogamia has been found to be superior in adaptability and seed and oil yield to other oil yielding shrubs/ trees like *Jatropha* (Prasad 2013).

Normal unselected *Pongamia* tree yields around 4 to 7 kg/tree after the 5th or 6th year of age. A genetically elite graft of *Pongamia (Karanj)* has an average higher yield potential of 80kg / tree / year from year-10, upto the fiftieth year of its productive life.

Elite Pongamia has been found to give superior pod an oil yields as indicated in the Table1 below:

Table 1: Pod and oil yield of elite *Pongamia (Karanj)*

Tree Age (yrs)→	3	4	5	6	7	8	9	10	11	12	13	14	15
Pod yield/ tree (kg)	7	15	30	45	58	67	77	89	100	110	120	135	150
Oil yield/ acre (Tons)	0.2	0.4	0.7	1.1	1.5	1.7	1.9	2.2	2.5	2.8	3.0	3.4	3.7

(Source: VAYUGRID 2014)

In terms of biodiesel, each tree produces 9 liters of biodiesel each year and over 500 liters over its life time.

Figure 1: *Pongamia pinnata* (*Karanj*) Tree (Elite genotype)

Figure 2: Pods and Seeds of *Pongamia pinnata (Karanj)*

Figure 3: Saplings ofelite *Pongamia pinnata (Karanj)* growing on problem (Cu) soil of Zambia (Warr 2018)

Phytoremediation of Problem Soils Using *Pongamia*:

Pongamia has been reported to be efficient in remediating problem soils containing heavy metals and other pollutants that impede plant growth (Prasad 2007, Tulod et al 2012 and Kumar et al 2017). The phytoremediation potential of *Karanj* has been examined in few comparative studies; in pot experiments, on coal mine spoil, fly-ash amended soils and on landfill wastes (Pandey 2017).

Total concentrations of copper in growing media declined as a result of plant uptake (Shirbate and Malode 2012). The addition of Vesicular-Arbuscular Mycorrhiza (VAM) and zeolite improved growth and therefore total uptake (Tulod et al 2012).Selective compartmentalisation indicates the highest concentrations of copper are in roots, seed coat, leaves, shoots (1220ppm to 26ppm respectively) (Kumar et al 2009). The on-going *Pongamia* plantation in Zambia planted during November 2016 is the first to provide evidence of phytoremediation by virtue of excellent tree survival and seed production on disused copper tailings facilities (Warr 2018).

Warr (2018) has shown how genetically elite *Pongamia* (*Karanj)* could be used reclaim mine overburdens of copper mine zones in Zambia and render them suitable for crop growth.

Following are the mechanisms involved in phytoremediation (Etim 2012)

Phytoextraction is also called phyto-accumulation, refers to the uptake and translocation of metal and chemical contaminants in the soil by plant roots in the above ground portions of the plants. Certain plants, called hyper-accumulators, absorb unusually large amounts of metals in comparison to other plants.

Rhizofiltration is the adsorption of soil and groundwater contaminants onto, or into, plant roots. Rhizofiltration is similar to phytoextraction, but the plants are used primarily to address contaminated groundwater rather than soil.

Phytostabilization is the use of certain plant species to immobilize contaminants in the soil and groundwater through absorption and accumulation by roots, or precipitation of the contaminants within the root zone of the plants. This process reduces the mobility of the contaminants and prevents migration into the groundwater or air and reduces the bioavailability and thus entry into the food chain.

Phytovolatilization is the uptake and transpiration of a contaminant by a plant, with release of the contaminant, or a modified form of the contaminant, into the atmosphere.

Phytodegradation: This is also referred to as phyto-transformation. It involves the degradation of complex organic molecules to simple molecules or the incorporation of these molecules into plant tissues. When the phytodegradation mechanism is at work, contaminants are broken down after they have been taken up by the plant. As with phytoextraction and phytovolatilization, plant uptakegener generally occurs only when the contaminants' solubility and hydrophobicity fall into a certainacceptable range.

Rhizodegradation refers to the breakdown of contaminants within the plant rhizosphere. It is believed to be carried out by bacteria or other microorganisms whose numbers typically flourish in the rhizosphere. Microorganisms may be so prevalent in the rhizosphere because the plant exudes sugars, amino acids, enzymes, and other compounds that can stimulate bacterial growth. The roots also provide additional surface area for microbes to grow on and a pathway for oxygen transfer from the environment. The localized nature of rhizodegradation means that it is primarily useful in contaminated soil, and it has been investigated and found to have at least some successes in treating a wide variety of mostly organic chemicals, including petroleum hydrocarbons, polycyclic aromatichydrocarbons (PAHs), chlorinated solvents, pesticides, polychlorinated biphenyls (PCBs), benzene, toluene, ethylbenzene, and xylenes (EPA, 2000). It can also be seen as plant-assisted bioremediation, the stimulation of microbial and fungal degradation by release of exudates/enzymes into the root zone (Zhuang et al., 2005).

Symbiotic Nitrogen Fixation by *Pongamia*: *Pongamia (Karanj*) produces its own nitrogen through Symbiotic Nitrogen Fixation, thereby displacing approximately $200 / ha/year of nitrates applied as compound fertiliser (Elevitch and Wilkinson, 1999). Soils under *Pongamia* stands of +15 years' age accumulate almost 1100 to 1300 kg of Nitrogen per hectare per annum, apart from enhancing the soil organic matter and consequent positive soil biological activity **(**Elevitch and Wilkinson, 1999).

Table 2: Soil Analysis Data
(Vayugrid 2014)

Parameter	Under *Pongamia* (6yr old trees)	Adjoining Barren soil
pH	6.5	6.7
Bulk density	4.75	4.87
Oxidisable C	1.6	0.45
Organic matter	3.27	1.16
N	0.091	0.027
P	0.0093	0.0030
K	0.086	0.032

The impoverished gravelly soil in Mahboobnagar district of Telangana State in India under six years' old trees of *Pongamia (Karanj)* exhibited marked improvements not only soil organic matter and Nitrogen, but also in other plant nutrients viz., Phosphorous and Potash.

According to Samuel et al (2013) nodule number in legumes is controlled by a systemic regulation loop called AON (Autoregulation of Nodulation), in which nodule primordia signal the leaf to produce an inhibitor blocking further meristem proliferation. Thus nodules are usually found on the upper regions of a legume's root system.

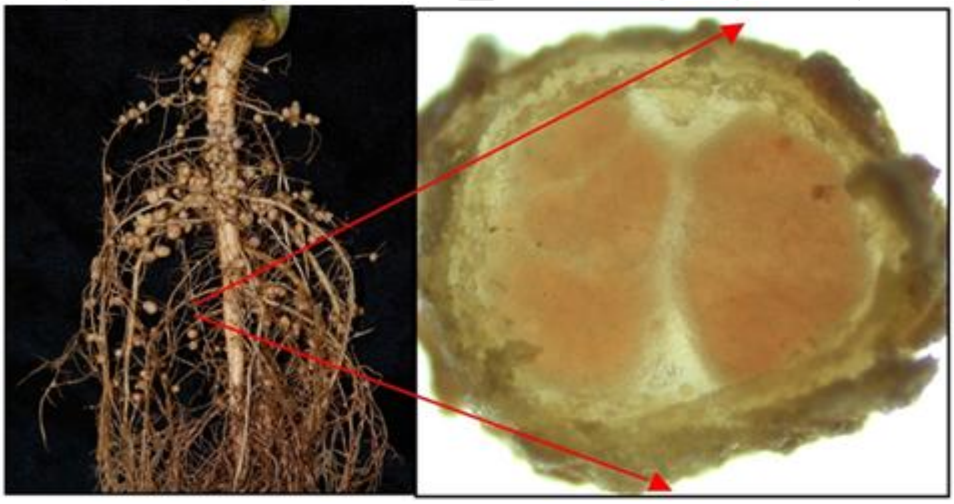

Figure 4: Rhizobial root nodules of *Pongamia pinnata* with section of a magnified root nodule showing rhizobial activity. (Source: Biswas et al 2013)

Prasad (2014 unpublished) working in the Barmer area Western Rajasthan desert in India, found poor sapling growth and lack of any nodulation on roots of elite grafts of *Pongamia*, since the desert soils were devoid of rhizobial population. Soil masses each of 25to 30 kg were collected from the root zones of old *Pongamia* tree populations elsewhere were used to fill up the pits of new plantations, which resulted in good root nodulation and enhanced growth of saplings. In other words, the microflora including rhizobia complex from the imported soil masses facilitated root nodulation leading to nitrogen. This resulted in the enhancement of microflora status of the desert soil too.

***Pongamia* (*Karanj*) as Carbon Sequestrator:**

The Carbon sequestration potential of *Pongamia pinnata (Karanj)* during the 10 to 15 years of its growth was found to be many folds higher than that of several other tree species. *Pongamia* was found to sequester around 45 to 50 kg of C per tree per annum as against 28 to 35 kg of Neem (*Azadirachta indica*), 23 to 26kg of Mahua (*Madhuca latifolia)* and 11 to 15 kg in respect of Tendu (*Diospyros* *melanoxylon)*. (Table 6) (Chaturvedi et al., 2011; Jesse More, 2009; Gupta, 2008; Kamarkar et al., 2012; Gera and Chauhan, 2010 and Reddy et al., 2009)

Table 3: Carbon sequestration by some popular tree species

Tree type	C sequestration / tree of 15yrs (kg)/ annum	C Sequestration (t)/ ha
Pongamia (*Pongamia pinnata)karanj*	45-50	23.5****
Tendu (*Diospyros melanoxylon)*	11-15	6.0***
Mahua (*Madhuca latifolia*)	23-26	8.5**
Neem (*Azadirachta indica*)	28-35	13.0*

C - sequestration by Neem is reported as 1.5 t/ha/yr from natural tree stands. The above figure of 13.0 was arrived, based on the population density (450/ha) that would be recommended for a regular plantation.

All the above values are for regular plantation model with appropriate tree densities per unit area.

** Tree density of 354 / ha
*** Tree population of 460/ha
**** Tree population of 500 / ha

A conservative estimate of carbon sequestration by *Pongamia* is as follows: A population of 200 trees of (aged 20 years) in an area of one acre can sequester (6118.2 kg) of Carbon.

A 2006 study estimates that over the course of a 25-year period, one *Pongamia* tree has the potential to sequester 767 kg of carbon. The carbon sequestration ability of *Pongamia* was calculated for 3,600 trees planted in the Powerguda village In Adilabad district of Telangana State in India. Over the course of seven years, the trees are estimated to sequester 147 MT of carbon equivalent and yield about 51,000 kg of oil, resulting in a total value for the village of about $845. (http://www.responsibleagroinvestment.org/rai/sites/responsibleagroinvestment.org/files/Bioenergy%20Development%20%20Issues%20and%20Impacts%20for%20Poverty%20and%20natural%20resource%2)

Green Coal from *Pongamia*: Pod shells of *Pongamia pinnata (Karanj)* could be converted into briquettes (green coal) to be used as an efficient fuel in rural homes and as source of energy in rural zones. Density of the Briquettes is estimated to be 0.6819 g/ml with calorific value of 4052 cal/g.Each tree can produce about 0.1 kwh from the pod shells each year, which comes to almost 6kwh over its life time.

Table 4 given below shows the efficiency of the green coal as compared to the traditional black coal.

Table 4: A comparison of black coal and green coal

	Black Coal	Green Coal
	3800 - 5000	4500
Sulfur Content	0.5% - 1%	0%
Ash Content	35% - 45%	~0%

(Source: Vayugrid 2014)

Oil Yield and Profits:

- *Pongmia (Karanj)* is grown normally under unirrigated conditions, for which the recommended tree spacing is 5 m X 4 m.
- A tree population of 200 trees is recommended per acre under rain grown dry-land conditions.
- The average oil content under the conditions of dry-land plantation management varies from 35 % to 40%, the average oil content being 37%.
- The mean seed weight is 1.2 to 1.4 g/ seed. However, genotypes of *Pongamia* with 2.0 g of weight per seed are available.
- The average shelling percentage (pod to kernel ratio) is around 40%.
- The elite grafts of *Karanj* start yielding from the fourth year. The pod /kernel yield goes on increasing from the 5th year, as given the Table 1.
- The average kernel yield from a plantation of one acre of 8 to 15 years' age is around 9 to 10 tons.
- The corresponding oil yield @ 37% will be 3.7 tons /acre
- The bio-diesel yield / ha based on the above calculations will be around 4 (four) tons per acre
- ***Total cost of production/acre from the first year of planting up to the 10th yearis around Rs. 70,00/-*** Taking an average for one year; the value will be **Rs. 7,000/- per year per acre**. The major component of cost of production is in the first year towards the cost of the elite saplings (@ a Rs.100/-per plant)and for digging pits and planting operation (@R.50/- per pit/sapling)
- Profit in terms of kernel sale (@Rs.30/-per kg) shall be around Rs.26,000/- average per year per acre
- Profit interms of oil yield (price of oil @Rs.60/- per kg) will be around Rs.200,000/-per acre per year.
- The profit that would accrue from seed cake and briquettes (from pod shells) would be extra gains, which have not been included in this document.
- Biodiesel: The high cost of vegetable oils likely would push the biodiesel cost to over $1.00 (around Rs.70/-)per litre. Costs in a small plant would be about 10 cents per litre higher than the tallow cost.https://www.google.co.in/search?q=Price+of+biodiesel&rlz=1C1EKKP_enIN688IN688&oq=Price+of+biodiesel&aqs=chrome..69i59l2j69i57j0l3.10754j0j8&sourceid=chrome&ie=UTF-8)
- The current quoted price of biodiesel is around Rs.46/- to Rs. 50/- per litre, which is lower than the market price of *karanj* oil. In view of the above the profits from the production and sale of biodiesel in the case of *karanj* have not been included in this document.

3. Methodology

Pongamia (Karanj) based phytoremediation is non-destructive, in-situ technology, which employs establishment of elite *Pongamia* saplings (known to be hyper accumulators) forming a vegetative cover to bring about soil amelioration through the inherent mechanisms of Phyto-stabilization & Phyto-extraction for toxic or mine spoils.

Pongamia (*Karanj*) has been found effective in ameliorating various kind of soils including acidic soils, coal mine dumps with complex toxicity factors, soils with toxicity due to metallic ions of copper and Iron, gravelly soils with no organic matter, soils prone to erosion, soils with low water holding capacity, soils with petroleum pollution, soils posing problems for plant root development and soils with high degree of compaction and problems of bulk density.

The massive and prolific root network system of *Pongamia* acts like a powerful pump to suck out all toxic metallic components and other compounds and translocates them to above ground parts.

1. Pongamia roots continuously secrete compounds that promote growth and development of useful soil microflora such as Rhizobium & mycorrhiza that improve soil.
2. Photosynthetically fixed C is also secreted by roots and fixed in soil.

The Good network of surface root system of *Pongamia* with a lateral spread of 9 meters

Strong and deep tap root system reaching a depth of 10 meters.

By virtue of its well developed and dynamic root system it is soil remediator and its highly functional and efficient canopy makes it an environment cleaner

Genetically elite saplings of *Pongamia pinnata (Karanj)* shall form the key ingredient which shall be planted with a plant population density depending upon the specific physical soil characteristics and data of the soil analysis. The generally recommended plant population density is @ 500 plants saplings per hectare spaced at 5m x 4m. The size of the pit for planting etc shall be determined based on the soil type. The size of the planting-pit might range from 45 to 75 cubic cm.

The general problems associated with the degraded soils are as follows:

1. Compaction
2. Low water holding capacity
3. Deficiency of micro and macro nutrients
4. Associated rooting restrictions
5. Toxicity due to metallic ions and
6. Environmental degradation of Ecosystem

In order to formulate a sound and workable program of soil remediation the following data would be needed:

1. Soil pH
2. Soil organic carbon content (%)
3. ECe (ds/m)
5. Soil bulk density (kg/m3)
6. Exchangeable Sodium (Na) (%)
7. Cation Exchange Capacity (meq/ 100 g of soil) and
8. Calcium carbonate content of soil (%)

The general soil amendments, which need to be incorporated, before planting are as follows:

1. Decomposed wood chips
2. Poultry Manure / Animal or human wastes
3. Sawdust
4. Gypsum
4. Muriate of Potash
5. Rock Phosphate

[Quantities of each of the above shall be based on soil analysis data]

The above mentioned amendments are generally employed for problem-soils, but the kind, quality and quantity of amendments could vary much depending upon the soil analysis data of the site (s) in question.
Additionally some more amendments might be suggested based on the soil analysis data.

Complementing plant species:

An Annual like annual castor plant, which can complement *Pongamia (Karanj)* could be included in the interspaces between two rows of *Karanj* since castor possesses root system of 3m depth + 2m lateral spread.

- Castor is also known as efficient remediator for Fe, Cd, Cu,Pb etc., apart from being a carbon sequestrator.
- The root System of castor harnesses microflora known to be efficient in degrading micro-molecular pollutants.

Figure 5: CASTOR (*Ricinus communis)*

Post planting activities:

With effect from the second to third year following planting, soils samples shall be analysed periodically at quarterly intervals to study and assess the efficiency and effectiveness of the process of phytoremediation of the soils with reference to the toxic metallic ions.

Carbon sequestration activity would be estimated on the basis of total dry matter that gets accumulated periodically.

Expected Results:

- Enhancement of Soil Bio-activity
- Improvement of Soil Organic C
- Elimination of toxic metals through Phyto-extraction
- Amelioration of soil pH & physics.
- Cutting down Pollution
- Gaining Carbon Credits through C sequestration data.

The cost estimates and expenditure to be incurred in this regard shall be highly variable and depend upon various factors detailed above. Hence the cost estimates may be worked with the finalization of the actual project work.

Figure 6: Elite *Pongamia (Karanj*) growing on excavated toxic soil at Mahendra World City. Near Chennai (2012)

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