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BIOLOGICAL RECLAMATION OF IRON ORE OVERBURDENS

S. Manivannan
A.K. Sikka
S. Priya Devi
J. Ashok Kumar
N.P. Singh
B.L. Manjunath

भाकृअनुप
ICAR

ICAR-Central Coastal Agricultural Research Institute
Old Goa - 403 402, Goa, India

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- **Dr. Narendra Pratap Singh**
  Director
  ICAR-Central Coastal Agricultural Research Institute
  Old Goa, Goa – 403 402
  www.ccari.res.in
  Fax : 0832 2285649
  Telephone : 0832 2284677, 2284678
  E.mail : director.ccari@icar.gov.in

Authors

- **S. Manivannan**
- **S. Priya Devi**
- **N.P. Singh**
- **A. K. Sikka**
- **J. Ashok Kumar**
- **B.L. Manjunath**

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ICAR-Central Coastal Agricultural Research Institute

(Indian Council of Agricultural Research)

Foreword

Iron ore production in India is contributing to more than seven per cent of the world production and ranking fourth in terms of quantity produced following China, Brazil and Australia. India ranks sixth in the world in terms of iron ore resources and is a leading producer and exporter after Brazil and Australia. Major iron ore resources are located in Jharkhand, Orissa, Chattisgarh, Karnataka and Goa. The balance iron ore resources are spread over the states of Maharashtra, Madhya Pradesh, Andhra Pradesh, Rajasthan, Uttar Pradesh and Assam. Goa is well known for its iron and manganese ores and contributing 70 % of India's iron ore export. Since decades, iron ore mining has been the backbone of Goan economy; the industry is instrumental in providing jobs, business, and livelihood and employment opportunities for Goans. However, one of the major problems associated with active mining operations is disposal of mining related wastes. The mining wastes so called over burdens dumped in open land consist of waste rock, overburden substrata ore and heavy metals. Stabilization of iron ore over burden is a major challenge to the mining industries.

ICAR – Central Coastal Agricultural Research Institute, Goa formerly known as ICAR Research Complex for Goa has conducted a pilot study to test various horticultural species for biological reclamation of iron ore overburdens. Eight horticultural species with three soil amendments have been tested. Soil erosion, nutrient build up in soil by cover crops and growth parameters of various horticultural species were monitored from 2002 to 2011.

I am glad that the ICAR - Central Coastal Agricultural Research Institute, Goa compiled the data collected over the period of 10 years and has come out with the recommendations for stabilization of iron ore overburdens. The suitable horticultural species and cover crops have been identified and recommended for biological reclamation of iron ore waste piles. I am confident that this technical bulletin will be of great help and guidance to the mining industries and policy makers of state and central governments in managing iron ore over burdens.

N. P. SINGH
DIRECTOR

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Preface

India is an important producer of iron ore in the world contributing to more than seven per cent of the production and ranking fourth in terms of quantity produced following China, Brazil and Australia. India ranks sixth in the world in terms of iron ore resources and is a leading producer and exporter after Brazil and Australia. India possesses total haematite resources of 14,630 million tonnes of which 7,004 million tonnes are reserves and 7,626 million tonnes are remaining resources. Major haematite resources are located mainly in Jharkhand, Orissa, Chattisgarh, Karnataka and Goa. The balance resources are spread over the states of Maharashtra, Madhya Pradesh, Andhra Pradesh, Rajasthan, Uttar Pradesh and Assam.

Goa is well known for its iron and manganese ores. Bauxite and laterite are the other minerals produced in the State. Iron and manganese ore belts extend from South-East to North-West of the State. Important iron ore deposits are located in Bicholim, Sanguem and Satari Talukas. Manganese ores are associated with iron ores and occur as pockets of various sizes in a form of concretionary pebbles in shales. Important manganese ore deposits are confined to the Southern and South- Eastern parts of Sanguem Taluka. The mining industry is the backbone of Goan economy which provides jobs, business, and livelihood and employment opportunities for Goans.

However, the major problems associated with active mining operations are air emissions release, ore dispersal during transportation and disposal of mining related wastes. The waste piles associated with mining operations consists of waste rocks, overburden substrata ore and heavy metals. The waste piles created are often unstable with a steep slope. Since, Goa experiences high rainfall with higher intensity, the combination of unstable piles and heavy rains leads to increased possibility of runoff. Many mines and their waste piles are located close to residences and agricultural field. The silt transported from the waste piles are being accumulated layer by layer in the adjacent agricultural fields making the land unsuitable for cultivation. Another major problem facing the iron ore industries is the waste material emerging from the excavation of ore does not allow vegetation to grow on the waste piles.

In order to explore the possibility of rehabilitation of iron ore overburdens, a study was conducted with various horticultural species and cover crops for their suitability in biological reclamation of iron ore overburdens. The objectives of the study are to develop the package of practices for biological reclamation of mine overburdens, to identify and evaluate the growth performance of various horticultural species with different soil amendments. The data collected during the study period was compiled, analyzed and reported in this technical bulletin.

Hope and look forward that this bulletin will be of immense use to the mining industries, policy makers of the state as well as central and state governments and farming communities to intervene and take appropriate steps to manage the iron ore overburdens in eco-friendly and environmentally sustainable way.

Authors

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Authors

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1.0 Introduction

Iron is the world's most commonly used steelmetals in which iron ore is the key ingredient, representing 95% of all metal used in a year. It is used primarily in structural engineering and maritime applications, automobiles and general industrial machinery applications. Iron ore mining is a high volume low margin business as the value of iron is significantly lower than base metals. It is highly capital intensive and requires significant investment in infrastructures and assets such as heavy machineries, transport vehicles, washing units, dumping yard *etc.*

1.1 Global scenario in Iron ore mining

The world reserve base of crude iron is estimated to be 170 billion tonnes (USGS Mineral commodity summary, 2014). USGS has also estimated that the world resources are estimated to exceed 800 billion tonnes of crude ore containing more than 230 billion tonnes of iron. Iron ore deposits are distributed in different regions of the world under varied geological conditions and in different geological formations. The top ten countries in the world in the order of their iron resources are the common-wealth of Independent States (erstwhile USSR), Australia, Canada, USA, Brazil, India, South Africa, China, Sweden and Venezuela(Table 1).

Table 1: World resources of iron ore by principal countries

Country	Mine Production (Mt)		Reserves (Mt)	
	2012	2013	Crude ore	Iron content
United States	54	52	6900	2100
Australia	521	530	35000	17000
Brazil	398	398	31000	16000
Canada	39	40	6300	2300
China	1310	1320	23000	7200
India	144	150	8100	5200
Iran	37	37	2500	1400
Kazakhstan	26	25	2500	900

Russia	105	102	25000	14000
South Africa	63	67	1000	650
Sweden	23	26	3500	2200
Ukraine	82	80	6500	2300
Venezuela	27	30	4000	2400
Other countries	96	88	14000	7100
World Total	**2930**	**2950**	**170000**	**81000**

Total production of iron ore in the world was 2.9 million tons in 2014. Ranking of iron ore producing countries was the Commonwealth of Independent States, China, Brazil, Australia, USA, India, Sweden, Canada, South Africa and Venezuela (Table 2). India stands at fourth position with a total iron ore production of 0.15 million tons.

Table 2: Iron ore production in top ten countries in the year 2014

Rank by sovereign State	Country	Iron ore production (000' tonnes)
1	China	1320000
2	Australia	530000
3	Brazil	398000
4	India	150000
5	Russia	102000
6	Ukraine	80000
7	South Africa	67000
8	United States	52000
9	Canada	42000
10	Iran	37000
	Total	**295000**

1.2 Indian Scenario

India is an important producer of iron ore in the world contributing more than 7 per cent of the production and ranking fourth in terms of quantity produced following China, Brazil and Australia. Iron ores are generally classified as haematite, magnetite, limonite and siderite. In India, iron ore mostly occurs as haematite or magnetite and the former is about 75% of the total. With recoverable reserves of 13,460 million tonnes, India ranks sixth in the world in terms iron ore resources and is a leading producer and exporter after Brazil and Australia. As per UNFC system as on 01.04.2005, India possesses total haematite resources of 14,630 million tonnes of which 7,004 million tonnes are reserves and 7,626 million tonnes are remaining resources. Major haematite resources are located mainly in Jharkhand (28%), Orissa (33%), Chattisgarh (19%), Karnataka (11%) and Goa (5%). The balance of 4 % resources is spread over the states of Maharashtra, Madhya Pradesh, Andhra Pradesh, Rajasthan, Uttar Pradesh and Assam.

The magnetite resources are placed at 10,619 million tonnes of which only 58 million tonnes constitute reserves. A major share of magnetite resources is located in Karnataka (74%), Andhra Pradesh (14%), Rajasthan (5 %), Tamil Nadu (5%) and Goa (2%). Assam, Jharkhand, Nagaland, Bihar, Madhya Pradesh and Maharashtra together account for a meagre share of magnetite resources. The most important magnetite deposits are located in Babubadan, Kudremukh, Bellary, Anadurga and Bangarkal areas of Karnataka, Goa, Ongole and Guntur district of Andhra Pradesh. The state wise recoverable reserves are shown in Table 3.

Table 3: State wise reserves of hematite and magnetite found in India (in million tonnes)

State	Recoverable Reserves		Total
	Haematite	Magnetite	
Andhra Pradesh	47	418	465
Bihar and Jharkhand	2967	5	2972
Goa	762	165	927
Karnataka	929	2518	3447
Kerala	-	35	35
Madhyapradesh and Chattisgarh	2045	-	2045
Maharashtra	176	-	176
Orissa	2667	-	2667
Rajasthan	9	1	10
Tamil Nadu	-	1	1
Total	**9602**	**3143**	**12745**

The Mining industry in India is a major economic activity which contributes significantly to the economy of India. The GDP contribution of the mining industry varies from 2.2 % to 2.5 % only but going by the GDP of the total industrial sector it contributes around 10 % to 11 %. The advance estimates of GDP for the first two quarters of the year 2013-14 from the mining and quarrying sector accounted for about 2.02% total GDP which is indicating a decrease of 1.47 % over that in the previous year. Indian mining industry provides job opportunities to around 700,000 individuals. India is the largest producer of sheet mica, the third largest producer of iron ore and the fifth largest producer of bauxite in the world.

1.3 Iron ore status in Goa

Goa has the credit of having pioneered the exports of iron ore from India. Goa exports 70.08% of India's Iron Ore and 43.27 million tonnes (2011) of iron ore is being exported annually from Goa. A fair share of the country's iron ore deposits is available in Goa. Although of low iron content, the ore is made marketable by processing. Ore is exported in the form of lumps, fines and pellets. The proximity to a natural seaport with modern amenities adds to its advantages.The Goan mining industry contributes approximately 35 percent of the state's GDP. Mining as an industry attracts Rs. 17,000 crores in form of foreign exchange and brings Rs. 6,000 crores in form of direct revenues to the State and the Central government.Over the last few years, with a surge in demand from China, the industry has grown at a fanatic pace. This has led to a host of traders and fly-by-night operators who entered the industry with a short term profit motive and paid scant regard to accountability, sustainability, infrastructure and environmental concerns. This, to a great extent, has tarnished the image of iron ore mining in the state and brought disrepute to the entire industry. Since decades, mining has been the backbone of Goan economy; the industry is instrumental in providing jobs, business, and livelihood and employment opportunities for Goans.

Goa is well known for its iron and manganese ores. Bauxite and laterite are the other minerals produced in the State. Iron and manganese ore belts extend from South-East to North-West of the State. Important iron ore deposits are located in Bicholim, Sanguem and Satari talukas. Manganese ores are associated with iron ores and occur as pockets of various sizes in a form of concretionary pebbles in shales. Important manganese ore deposits are confined to the Southern and South- Eastern parts of Sanguem taluka. Bauxite occurs in North and South Goa.

1.4 Objectives and background of the study

There are some problems associated with active mining operations, such as air emissions release and ore dispersal during transportation. The major problems associated with iron ore mining in Goa start from the disposal of mining related wastes. The waste piles associated with mining operations consists of waste rock, overburden substrata ore and heavy metals. The metals of concern in Goan mine waste piles are primarily iron and manganese. In some cases, the wastes disposals are located away from the mine lease areas. This necessitates the transport of the mines waste in trucks from the mining areas to the waste disposal areas, leading to the dispersal of some waste during transportation further increasing exposures to neighbouring settlements.

The waste piles created are often unstable with a steep slope. Since, Goa experiences high rainfall with higher intensity, the combination of unstable piles and heavy rains leads to the increased possibility of runoff. Many mines and their waste piles are located close to residences and agricultural fields. The silt transported from the waste piles are being accumulated layer by layer in the adjacent agricultural fields and the land becomes unsuitable for cultivation. Another major problem faced by the Goa iron ore mines is that the waste material that emerge from the excavation of ore contains a type of material that does not allow vegetation to grow on the waste piles. Keeping in view rehabilitation of iron ore mine dumps, a study was conducted to test various horticultural crops for biological reclamation of iron ore overburdens with following objectives:

- Evaluate the growth performance of various horticultural crops under different soil amendments and identify suitable horticultural crops and soil amendment for biological reclamation of iron ore overburdens.
- Suggest suitable control measures for reduction of soil erosion in iron ore overburdens.

View of an open-mined site

2.0 Description of Study Area and Methodology

2.1. Study area

The field experimental study was conducted at one of the mine dumps of M/s. Sesa Goa Limited at Sonshi in South Goa.The mine dumps selected was having maximum of magniferrous clay with an area of 0.9 Ha.

2.2. Creation of mine dumps

Mining operations are being carried out by forming systematic benches on the hill top and along hill slopes and the pits are laterally extended in stages in all directions with increasing depths. In general, bench height and width are maintained at 7 m and 10 m respectively. The pit configurations are planned in such a way that the overall pits slopes remains at 30 degree or less with the horizontal. Sequence of mining operations involves systematic removal of lateritic overburden and mining lumpy ore zone followed by powdery ore zone. Soft laterite is removed by ripping and dozing. Drilling and blasting is practiced in hard laterite and lumpy ore zone wherever necessary. To extract a tonne of powdery ore, on an average 2.5 cu.m of overburden material is required to be removed. This overburden material which consists of laterite, lateritic clay, magniferrous clay and phyllites is dumped generally within the leasehold along the hill slopes, roadsides and valleys. In some cases, overburden material is being transported to dumping sites outside the leasehold area. Normally overburden dumps are upto 30 m height but mine operators have raised the height of dumps beyond 30 m due to non-availability of land.

2.3. Characteristics of dumps selected for the study

The iron ore formation of Goa belongs to the Dharwar super group which consists of four formations *viz,* Barcem formation, Sanvordem formation, Bicholim formation and Vageri formation. Out of these Bicholim formation is very important from commercial angle as it contains all the iron and manganese ore deposits of Goa. The Bicholim formation overlies the Sanvordem formation confirmable and it includes quartz-chlorite-amphibole schist, ferrigeneous pink phyllites, and bonded ferrugineous quartzites. The selected mine waste pile was created by dumping waste from Bicholim formation dominated by magniferrous clay content. The soils are rich in manganese (92.7 ppm) and iron (21.5 ppm) with low nitrogen (41.4 kg ha^{-1}), phosphorus (12.3 kg ha^{-1}) and potassium (78.4 kg ha^{-1}) levels. Soil pH was 5.6 with EC of 0.086 mmhos cm^{-1} with low organic carbon content (0.48 %). Copper and Zinc contents are absent in the dump selected for the study.

2.4. Climate and Rainfall

The general climate of the area is mainly tropical and is influenced to a large extent by the conditions in the Arabian Sea. There are four seasons, *viz.* winter (December to February), summer or pre-monsoon (March to May), monsoon (June to September) and post monsoon (October to November). The climate is characterized by high humidity and less extremes of temperature. The temperature varies between 20°C to 33°C. The study area experiences varying rainfall from 3200 mm to over 3800 mm per annum.

2.5. Methodology

The selected area of 0.9 ha was equally divided into four blocks and the following treatments refer to the amendment of rhizosphere imposed.

T1-Lateritic soil + Mine reject soil (1:1)

T2-Farm Yard Manure + Mine reject soil (1:1)

T3-Pressmud + Mine reject soil (1:1)

T4-Mine reject soil alone (control)

View of the iron overburdens before rehabilitation

In each treatment planting of cashew grafts (Vengurla 4), Mango (Ratnagiri Alphonso) grafts, Jamun (Gokak-1), Kokum grafts (Konkan Amurta), jackfruit (Firm type), Tamarind (SMG - 4) and local seedlings of Aonla and Neem was taken up with onset of monsoon in a spacing of 6 m X 6m. Contour staggered trenches with the dimensions of 2 m x 0.5 m X 0.5 m at 4 m vertical interval. *Stylosanthes hamata* grass and mucuna seeds were sown as cover crop in between the tree plants uniformly in all the treatments. The survival percentage and crop growth parameters of Cashew, Mango, Jamun, Kokum, Jackfruit, Tamarind, Aonla and Neem were monitored for the period of 8 years from 2002 to 2009. Silt reduction through silt trapping units was observed for the period of three years from 2002 to 2004. Effect of various soil amendments and cover crop on nutrient status was periodically monitored at every 3 years interval for 9 years period from 2002 to 2011. The collected data were analyzed and conclusions and recommendations were drawn. Combined package and practices for biological reclamation of mine overburdens have been developed.

3.0 Results and Discussion

The quantitative impacts of different soil amendments on survival percent and growth parameters of Cashew, Mango, Jamun, Jack Fruit, Kokum, Anola, Tamarind and Neem and nutrient build up are reported and discussed.

3.1 Survival percent

The survival percentage of all the crops planted were monitored and furnished in Table 4. Maximum survival of 100 percent was recorded with Laterite soil + Mine Reject Soil (T1) for all the crops followed by 100 percent survival in five crops (Cashew, Mango, Jamun, Anola and Tamarind) under the treatment namely pressmud and mine reject soil. Poor survival of Kokum (33%), Neem (30%) and Jack fruit (22%) was recorded under control plot where there is no soil amendment. Overall, Cashew, Mango, Jamun, Anola and Tamarind survived well in all the treatments.

Table 4. Survival percent of various crops in mine waste piles under different soil amendments

Name of the Crop / Treatment	Survival Percent			
	T1 (Laterite + Mine Reject Soil)	T2 (FYM + Mine reject soil)	T3 (Pressmud + Mine reject soil)	T4 (Control- Mine Reject Soil alone)
Cashew	100	100	100	100
Mango	100	100	100	90
Jamun	100	100	100	100
Jack Fruit	100	50	66	22
Kokum	100	55	87	33
Anola	100	88	100	88
Tamarind	100	75	100	100
Neem	100	66	33	30

3.2 Growth parameters

The growth parameters *viz.* height, girth, primary and secondary branches under different soil amendments were recorded at one year interval till 6/8 years after the date of plantation. Growth parameters of Aonla, Cashew, Jack fruit, Jamun, Kokum, Mango, Neem and Tamarind are reported and discussed as below:

3.2.1 Aonla

Growth parameters of Aonla are furnished in Table 5 and it was found that the maximum height (565 cm) and girth (52.9 cm) was achieved by Laterite soil amendment followed by 525 cm height and 53 cm girth in farm yard manure amendment against lowest height (340 cm) in control plot of during 8 years after planting. Similarly, maximum numbers of branches (52 nos) was achieved by laterite soil followed by farm yard manure (45 nos) against lowest number of branches (16 nos) in control plot during sixth year after planting. It was noted that variations within the treatment was in increasing trend up to fifth year and in reducing trend afterwards show that soil amendment was more effective up to fifth years period.




Establishment of Aonla in Iron Ore Overburdens

Table 5. Growth parameters of Aonla as affected by different soil amendments in iron ore mine overburdens

Treatment	1 YAP	2 YAP	3 YAP	4 YAP	5 YAP	6 YAP	7 YAP	8 YAP
Height (cm)								
T_1 (Laterite soil)	71	183	190	288	400	480	530	565
T_2 (FYM)	73	146	193	264	395	430	475	525
T_3 (Press mud)	112	175	208	246	288	340	375	410
T_4 (Control)	68	98	101	145	187	250	310	340
CV (0.05%)	26	25	28	27	32	27	23	23
Girth (cm)								
T_1 (Laterite soil)	1.4	4.2	9.0	15.3	23.0	30.3	38.5	52.9
T_2 (FYM)	0.9	3.3	7.3	14.0	22.0	29.4	36.2	48.6
T_3 (Press mud)	0.9	3.0	7.0	12.0	18.0	25.0	32.2	40.5
T_4 (Control)	0.8	2.9	4.3	10.0	14.0	19.2	23.5	28.0
CV (0.05%)	27.1	17.7	28.2	18.1	21.4	19.5	20.3	25.8
Number of Branches								
T_1 (Laterite soil)	4	9	16	22	35	52	-	-
T_2 (FYM)	3	8	14	19	28	45	-	-
T_3 (Press mud)	4	9	13	18	26	42	-	-
T_4 (Control)	2	4	8	14	22	35	-	-
CV (0.05%)	4	26	25	13	13	16	-	-

Aonla as a component of completely established ecosystem

3.2.2 Cashew

Growth parameters of Cashew are furnished in Table 6 and it was found that the maximum height (485 cm) and girth (78.6 cm) was achieved by FYM amendment followed by 460 cm height and 70 cm girth in laterite soil amendment against lowest height (345 cm) in control plot of during 8 years after planting. Similarly, maximum numbers of branches (72 nos) was achieved by FYM followed by laterite soil (69 nos) against lowest number of branches (56 nos) in control plot during six years after planting. It was noted that variations within the treatment was in increasing trend up to fourth year and in reducing trend afterwards shows that soil amendment was more effective up to four years period.

Establishment of Cashew in Iron Ore Overburdens

Table 6. Growth parameters of Cashew as affected by different soil amendments in iron ore mine overburdens

Treatment	1 YAP	2 YAP	3 YAP	4 YAP	5 YAP	6 YAP	7 YAP	8 YAP
Height (cm)								
T_1 (Laterite soil)	59	69	74	203	254	320	395	460
T_2 (FYM)	48	96	116	263	307	340	415	485
T_3 (Press mud)	61	89	105	256	282	315	370	410
T_4 (Control)	42	69	78	199	207	240	295	345
CV (0.05%)	17	17	22	15	16	14	14	15
Girth (cm)								
T_1 (Laterite soil)	1.9	7.0	11.9	18.2	25.1	37.5	52.1	70.2
T_2 (FYM)	1.9	9.8	13.3	26.4	29.9	40.2	56.2	78.6
T_3 (Press mud)	1.6	10.0	12.6	27.9	24.2	33.6	40.5	58.2
T_4 (Control)	1.4	6.6	10.6	17.0	22.2	28.5	36.8	53.8
CV (0.05%)	14.4	21.5	9.5	24.9	12.9	14.5	19.9	17.3
Number of Branches								
T_1 (Laterite soil)	2	6	19	35	52	69	-	-
T_2 (FYM)	2	8	22	37	55	72	-	-
T_3 (Press mud)	3	5	14	32	48	61	-	-
T_4 (Control)	1	3	11	26	41	56	-	-
CV (0.05%)	39	37	30	15	12	11	-	-

Cashew as a component of completely established ecosystem

3.2.3 Jack fruit

Growth parameters of Jack fruit are furnished in Table 7 and it was found that the maximum height (410 cm) and numbers of branches (57 nos) was achieved by FYM amendment followed by 395 cm height and 52 branches in laterite soil amendment against lowest height (310 cm) in control plot during 8th year after planting. However, maximum girth of 72 cm was observed in laterite soil amendment. Similarly, maximum numbers of branches (57 no) was achieved by FYM followed by laterite soil (52 no) against lowest number of branches (39 no) in control plot during six years after planting. It was noted that variations within the treatment was in increasing trend up to fourth year and in reducing trend afterwards shows that soil amendment was more effective up to four years period.

Table 7. Growth parameters of Jack Fruit as affected by different soil amendments in iron ore mine overburdens

Treatment	1 YAP	2 YAP	3 YAP	4 YAP	5 YAP	6 YAP	7 YAP	8 YAP
Height (cm)								
T_1 (Laterite soil)	41	86	126	182	235	285	340	395
T_2 (FYM)	63	120	132	190	246	310	360	410
T_3 (Press mud)	40	85	123	160	205	245	290	350
T_4 (Control)	36	80	105	145	198	220	260	310
CV (0.05%)	27	20	10	12	10	15	15	12
Girth (cm)								
T_1 (Laterite soil)	2.0	12.4	15.6	25.6	35.8	48.2	59.6	72.3
T_2 (FYM)	1.5	10.8	14.3	24.3	34.2	46.5	55.3	69.8
T_3 (Press mud)	1.3	8.5	13.6	19.6	29.6	37.9	49.8	56.9
T_4 (Control)	1.4	6.0	10.3	14.9	21.3	32.5	40.2	50.3
CV (0.05%)	20.1	29.6	16.8	23.1	21.5	17.9	16.3	16.8
Number of Branches								
T_1 (Laterite soil)	3	8	14	22	35	52	-	-
T_2 (FYM)	3	9	19	26	39	57	-	-
T_3 (Press mud)	3	6	12	21	32	47	-	-
T_4 (Control)	3	5	11	19	29	39	-	-
CV (0.05%)	4	26	25	13	13	16	-	-

Growth of Jack fruit in Iron Ore Overburdens

Jackfruit as a component of completely established ecosystem

3.2.4 Jamun

Growth parameters of Jamun are furnished in Table 8 and it was found that the maximum height (450 cm) and girth (65 cm) was achieved by FYM amendment followed by 390 cm height and 58 cm girth in laterite soil amendment against lowest height (350 cm) in control plot during 8 years after planting. Similarly, maximum numbers of branches (73 no) was achieved by FYM followed by laterite soil (69 no) against lowest number of branches (54 no) in control plot during six years after planting.

Growth of Jamun in Iron ore Overburdens

Jamun as a component of completely established ecosystem

Table 8. Growth parameters of Jamun as affected by different soil amendments in iron ore mine overburdens

Treatment	1 YAP	2 YAP	3 YAP	4 YAP	5 YAP	6 YAP	7 YAP	8 YAP
Height (cm)								
T_1 (Laterite soil)	64	78	124	204	268	310	350	390
T_2 (FYM)	64	77	114	215	289	318	370	450
T_3 (Press mud)	64	79	107	226	258	295	330	370
T_4 (Control)	61	76	86	181	228	290	310	350
CV (0.05%)	2	2	15	9	10	4	8	11
Girth (cm)								
T_1 (Laterite soil)	1.9	5.4	11.6	17.3	25.6	36.5	48.9	58.5
T_2 (FYM)	1.8	7.4	12.6	20.8	29.2	38.9	52.2	65.3
T_3 (Press mud)	2.0	5.4	11.6	18.9	24.3	34.2	48.7	56.9
T_4 (Control)	1.7	4.4	9.6	16.5	22.5	28.5	39.9	52.0
CV (0.05%)	7.0	22.3	11.1	10.3	11.2	12.9	11.1	9.4
Number of Branches								
T_1 (Laterite soil)	4.2	12	25	40	52	69	-	-
T_2 (FYM)	5.3	14	29	45	59	73	-	-
T_3 (Press mud)	4.4	11	22	37	48	62	-	-
T_4 (Control)	4	10	17	29	41	54	-	-
CV (0.05%)	13	15	22	18	15	13	-	-

3.2.5 Kokum

Growth parameters of kokum are furnished in Table 9 and it was found that the maximum height (250 cm) and girth (55 cm) was achieved by FYM amendment followed by 220 cm height and 49 cm girth in laterite soil amendment against lowest height (189 cm) in control plot during 8 years after planting. However, maximum numbers of branches (24 no) was achieved by laterite soil followed by FYM (22 no) against lowest number of branches (14 no) in control plot during six years after planting. Overall, kokum establishment in mine overburdens was poor due to its inherent slow growing nature.


Kokum as a component of completely established ecosystem

Table 9. Growth parameters of Kokum as affected by different soil amendments in iron ore mine overburdens

Treatment	1 YAP	2 YAP	3 YAP	4 YAP	5 YAP	6 YAP	7 YAP	8 YAP
Height (cm)								
T_1 (Laterite soil)	50	55	66	95	125	140	165	220
T_2 (FYM)	57	63	75	102	132	155	195	250
T_3 (Press mud)	52	58	63	89	118	136	159	198
T_4 (Control)	51	53	60	85	110	132	160	189
CV (0.05%)	2	2	15	9	10	4	8	11
Girth (cm)								
T_1 (Laterite soil)	1.0	2.1	3.3	13.9	23.9	30.3	37.5	48.9
T_2 (FYM)	1.1	2.1	3.6	15.0	25.0	32.6	40.6	55.3
T_3 (Press mud)	0.9	2.0	2.9	14.9	22.9	29.8	35.9	45.6
T_4 (Control)	0.9	1.5	2.6	10.0	20.0	25.6	32.8	41.2
CV (0.05%)	9.8	14.9	14.2	17.5	9.3	9.9	8.9	12.4
Number of Branches								
T_1 (Laterite soil)	3	8	12	16	22	24	-	-
T_2 (FYM)	3	6	9	14	19	22	-	-
T_3 (Press mud)	2	4	7	11	15	17	-	-
T_4 (Control)	2	3	4	7	12	14	-	-
CV (0.05%)	21	42	42	33	26	24	-	-

3.2.6 Mango

Growth parameters of Mango are furnished in Table 10 and it was found that the maximum height (400 cm) and numbers of branches (52 no) was achieved by laterite soil amendment followed by 360 cm height and 47 branches in FYM amendment against lowest height (253 cm) in control plot during 8 years after planting. However, maximum girth of 76 cm was observed in laterite soil amendment.

Establishment of Mango in Iron ore overburdens

Mango as a component of completely established ecosystem

Table 10. Growth parameters of Mango as affected by different soil amendments in iron ore mine overburdens

Treatment	1 YAP	2 YAP	3 YAP	4 YAP	5 YAP	6 YAP	7 YAP	8 YAP
Height (cm)								
T_1 (Laterite soil)	115	127	142	208	245	290	340	400
T_2 (FYM)	80	106	125	206	210	265	310	360
T_3 (Press mud)	65	88	110	152	162	195	250	290
T_4 (Control)	62	78	101	142	152	178	232	253
CV (0.05%)	2	2	15	9	10	4	8	11
Girth (cm)								
T_1 (Laterite soil)	2.5	8.2	14.3	22.3	28.3	36.8	49.8	68.5
T_2 (FYM)	2.2	11.0	17.0	23.6	30.6	39.8	56.8	75.8
T_3 (Press mud)	1.6	8.4	13.3	21.0	26.0	34.5	52.9	65.9
T_4 (Control)	2.1	7.7	11.6	20.3	23.5	29.8	35.9	50.8
CV (0.05%)	17.8	16.8	16.1	6.7	11.2	12.0	18.6	16.1
Number of Branches								
T_1 (Laterite soil)	4.4	8	13	24	38	52	-	-
T_2 (FYM)	3.3	5.3	11	21	34	47	-	-
T_3 (Press mud)	3	7	10	18	29	41	-	-
T_4 (Control)	2.5	5	7	14	22	34	-	-
CV (0.05%)	24	22	24	22	22	18	-	-

3.2.7 Neem

Growth parameters of Neem are furnished in Table 11 and it was found that the maximum height (510 cm) and number of branches (41 no) was achieved by laterite soil amendment followed by 495 cm height and 38 branches in FYM amendment against lowest height (420 cm- 8 YAP) and number of branches (26 no) in control plot (6 years after planting). However, maximum girth (62 cm) was achieved by FYM followed by laterite soil (57 cm) against lowest girth (45 cm) in control plot during eight years after planting. Even though, the height of neem increased through the years, the branch establishment was very poor and unsatisfactory.

Growth of Neem in Iron Ore Overburdens

Neem as a component of completely established ecosystem

Table 11. Growth parameters of Neem as affected by different soil amendments in iron ore mine overburdens

Treatment	1 YAP	2 YAP	3 YAP	4 YAP	5 YAP	6 YAP	7 YAP	8 YAP
Height (cm)								
T_1 (Laterite soil)	92	196	236	343	389	420	465	510
T_2 (FYM)	47	161	226	320	362	410	460	495
T_3 (Press mud)	47	154	211	270	320	368	410	472
T_4 (Control)	42	130	173	250	295	329	375	420
CV (0.05%)	41	17	13	14	12	11	10	8
Girth (cm)								
T_1 (Laterite soil)	1.1	6.8	10.6	19.6	25.9	33.9	42.6	56.9
T_2 (FYM)	1.2	8.3	13.5	22.3	28.3	35.6	44.8	62.3
T_3 (Press mud)	0.5	7.0	12.6	21.0	26.5	32.9	40.2	52.3
T_4 (Control)	0.5	6.0	8.0	15.6	23.6	28.5	36.8	44.7
CV (0.05%)	45.8	13.6	21.8	14.8	7.4	9.3	8.3	13.8
Number of Branches								
T_1 (Laterite soil)	4	9	17	24	35	41	-	-
T_2 (FYM)	1	7	14	19	30	38	-	-
T_3 (Press mud)	2	5	10	16	25	35	-	-
T_4 (Control)	2	3	7	11	18	26	-	-
CV (0.05%)	44	45	37	31	27	19	-	-

3.2.8 Tamarind

Growth parameters of Tamarind are furnished in Table 12 and it was found that the maximum height (440 cm) and number of branches (62 no) was achieved by FYM amendment followed by 395 cm height and 56 branches in laterite soil amendment against lowest height (342 cm- 8 YAP) and number of branches (34 no) in control plot (6 years after planting). However, maximum girth (63 cm) was achieved by FYM followed by laterite soil (59 cm) against lowest girth (45 cm) in control plot during eight years after planting. It was observed that growth of tamarind was slow during initial period and then it increased after fifth year.

Growth of Tamarind in Iron Ore over Burdens

Table 12. Growth parameters of Tamarind as affected by different soil amendments in iron ore mine overburdens

Treatment	1 YAP	2 YAP	3 YAP	4 YAP	5 YAP	6 YAP	7 YAP	8 YAP
Height (cm)								
T_1 (Laterite soil)	47	95	123	158	254	295	340	395
T_2 (FYM)	49	156	192	210	306	350	385	440
T_3 (Press mud)	49	99	130	170	254	298	326	380
T_4 (Control)	34	53	68	146	195	259	297	342
CV (0.05%)	16	42	40	16	18	12	11	10
Girth (cm)								
T_1 (Laterite soil)	1.3	8.1	14.0	21.6	27.9	35.5	50.1	62.7
T_2 (FYM)	0.9	7.8	12.0	17.9	27.0	34.0	48.7	58.9
T_3 (Press mud)	1.3	8.6	10.3	19.3	24.5	33.2	45.8	52.9
T_4 (Control)	1.0	3.2	5.3	10.3	16.5	22.8	29.5	44.8
CV (0.05%)	18.3	36.2	35.8	28.3	21.6	18.5	21.9	14.2

Number of Branches								
T_1 (Laterite soil)	3	5	14	25	41	56	-	-
T_2 (FYM)	3	9	18	31	48	62	-	-
T_3 (Press mud)	3	8	12	21	35	48	-	-
T_4 (Control)	2	4	10	16	25	34	-	-
CV (0.05%)	8	38	25	27	26	24	-	-

Growth parameters of Aonla, Mango and Neem were maximum in the treatment of laterite mixture followed by farm yard manure. Highest growth observations on Cashew, Jack Fruit, Jamun, Kokum and Tamarind were recorded in the mixture of Farm Yard Manure, followed by laterite and pressmud. Overall, laterite or farm yard manure mixture performed better than pressmud for enhancing growth parameters.

3.3 Silt reduction

The effect of contour staggered trenches on reducing soil erosion was quantified and it is presented in Fig 1. It shows that the soil erosion was observed as 138 t ha^{-1} y^{-1} before excavation of trenches and planting and reduced to 18 t ha^{-1} y^{-1} after establishment of cover crop. Soil erosion was reduced to 86 % due to contour trenches and cover crops namely mucuna and *Stylosanthes hamato.*

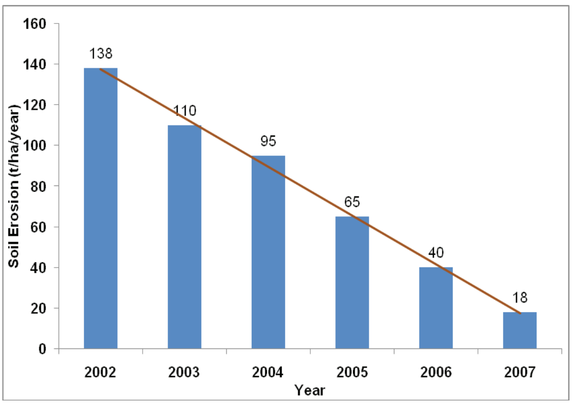

Fig 1. Impact of SCT and cover crops

Silt accumulated in trenches on soil erosion

3.4 Cover crop establishment and nutrients buildup

Stylosanthes hamato and mucuna seeds sown in between the tree plants were not established during first and second year. However, the seeds were germinated and established during third year after sowing. *Stylosanthes hamato* was established by covering 58 per cent of surface area whereas mucuna was able to cover only 10 per cent of area. *Stylosanthes hamato* proved to be a better cover crop for iron ore overburdens.

Soil nutrient enrichment was analyzed from the year 2002 at every three years interval up to 2011 and furnished in table 10. The major nutrients namely available nitrogen, phosphorus and potassium and organic carbon content was estimated. It shows that organic carbon content increased from 0.48 to 0.60 % over the period of nine years due to decomposition of cover crops and liter materials of horticultural crops. Available nitrogen has been increased from 41.4 to 75 kg ha^{-1} with marginal increase in available potassium from 78.4 to 105.0 kg ha^{-1}. However, there was no significant change in available phosphrous over nine years period.

Table 13. Effect of cover crops on soil nutrients in iron ore overburdens

Year	Organic carbon (%)	Nutrients (kg /ha)		
		N	P_2O_5	K_2O
2002	0.48	41.4	12.3	78.4
2005	0.50	42.5	12.0	80.5
2008	0.55	46.0	12.5	85.0
2011	0.60	75.0	13.5	105.0

3.5 Current status of rehabilitated overburdens in 2015

The plot in which the mine rejects were dumped looked barren, without any germ of life during 2002. Amendment of rhizosphere, followed by planting of different horticultural tree species and subsequent after care with irrigation has thrown life into the region. The initial establishment of cover crops has enhanced the soil nutrients and slow build-up of rejuvenation in the system, indeed aided by the bountiful monsoons in the state. Currently, the plot once barren and lifeless has turned into an eco-system bustling with ecological activities. The ground is completely covered with vegetation like grass and herbs. All the trees planted have completely grown-up and started bearing fruits. The grass cover has indeed encouraged movement of cattle into the system, which is voluntarily unchecked by the authorities. The excretal remains of cattle, goat *etc*. found throughout the plot, the bees, wasps and butterflies visiting the weed flowers, the chirping of birds on the evergreen trees, the enormous growth of vines on the shurbs and trees (especially

Re-established eco-system

which is otherwise a common sight in the Western Ghat eco-system) are evidential for a sustainable eco-system.

This Biological reclamation is a great step forward in setting a futuristic example for rejuvenating a mine reject dump or an Iron ore over burdens.



Vibrant flora and fauna as in a sustainable eco-system

4.0 Conclusions

Long term data generated through field experiments on evaluation of various horticultural crops for biological reclamation of iron ore overburdens were analyzed and following conclusions and recommendations were drawn.

- Biological reclamation through establishment of horticultural crops in iron ore overburden is one of the environmentally sustainable option for rehabilitation of iron ore overburdens.
- Soil amendment and excavation of staggered contour trenches are essentially required while planting horticultural crops in magniferrous clay iron ore over burdens.
- Cashew, Mango, Aonla, Jack fruit, Jamun, Kokum, Neem and Tamarind were evaluated with three types soil amendments namely laterite soil, farm yard manure and pressmud. Out of eight species evaluated, cashew, aonla, mango and jamun out performed in growth and canopy establishment compared to jack fruit, kokum, neem and tamarind.
- Aonla outperformed and attained maximum growth parameters with the laterite soil amendment with mine overburden soils. Cashew, Mango and Jamun attained better growth parameters with farm yard manure amendment with mine overburdens.
- *Stylosanthes hamato* was proved to be best cover crop for rehabilitation of iron ore overburdens as compared to mucuna.
- Staggered contour trenches and *Stylosanthes hamato* as cover crop reduced the soil erosion to the extent of 86 per cent.
- *Stylosanthes hamato* and litre materials generated from horticultural plants could increase the nutrient contents marginally in the iron ore overburdens in long term.
- Cashew, Mango, Aonla and Jamun are possible horticultural crops for biological reclamation of iron ore overburdens.
- Either laterite soil or farm yard manure in the ratio of 1:1 is recommended as soil amendment for planting horticultural crops in iron ore overburdens.
- Staggered contour trenches with the dimensions 2 m X 0.5 m X 0.5 m at 4 m vertical interval are recommended for controling soil erosion.

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