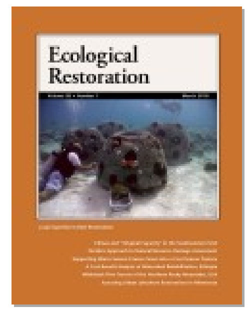
Rehabilitation of Red Mud Bauxite Wasteland in India (Belgaum, Karnataka)



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Ecological Restoration, Volume 28, Number 1, March 2010, pp. 12-14 (Article)

Published by University of Wisconsin Press

fall 1993, the trees' mean annual increase in height would be 28.0 cm/y over a period of nine growing seasons, fairly close to their mean annual increase in height of 25.9 cm/y during the study period. This growth rate is roughly comparable to rates reported for knobcone pines in the Santa Ana Mountains (Vogl 1973) and near San Luis Obispo (Keeley et al. 1999) but less than half that reported for a Mendocino County site receiving an average of 94 cm of rain per year (McCreary 2001).

For the Chamise Ridge stand, the ten-year fire return interval was too short to sustain its continued existence in that only one tree had produced even a few immature seed cones, which take two years to mature, by the end of the ninth growing season; and the fire at the end of the tenth growing season obliterated all signs of the stand. Nonetheless, others have reported that a fire return interval of as little as 14 years does not hamper recovery of knobcone stands (Minnich and Everett 2001), even though knobcone pines in the Santa Ana Mountains typically begin bearing seed cones only between 10 and 12 years of age (Vogl 1973). In other knobcone populations, trees as young as five or six years (Peattie 1950) or even two years (Keeley et al. 1999) may already produce seed cones. Nonetheless, given this species' great tolerance of harsh site conditions, good resistance to disease and insect attack, and rapid growth rate, it may be worth including in revegetation projects on harsh sites in its native range.

Acknowledgment

The author thanks the California Department of Water Resources for its support.

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Rehabilitation of Red Mud Bauxite Wasteland in India (Belgaum, Karnataka)

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Red mud is an insoluble waste material from the production of high-grade aluminum from bauxite. It is a highly alkaline mixture of fine metal oxides, and therefore the deposits of red mud pose number of environmental and health risks. The most common method for its disposal is storage in impounded dike deposits. The ecological rehabilitation of red mud residue deposits is complicated by many factors, including its hazardous nature, extremely high pH and salinity, poor water-holding capacity, and extremely low microbial activity (Krishna et al. 2005). Establishment of vegetation cover has rehabilitated the red mud residue in rare successful cases; however, the nutrient concentrations in vegetation tend to be low, which can be improved to some extent by addition of ameliorants such as gypsum and sewage sludge (Barrow 1982, Wong and Ho 1991). Gypsum is a calcium sulfate ($CaSO_4 \cdot 2H_2O$), and it reduces alkalinity via calcium carbonate ($CaCO_3$) formation and improves the structure of the substrate through the exchange of sodium for calcium, which help reduce pH as the calcium absorbs hydroxide ions. Red mud closely resembles alkali soil in its high pH and exchangeable sodium percentage and the associated physicochemical properties, and hence it is likely to react in a similar way to gypsum. Here, we present a pilot study at the aluminum refineries of Hindustan Aluminum Company Ltd. (HINDALCO), located in Belgaum, Karnataka, in southern India, which generate about 400,000 metric tons of bauxite waste per annum. The goal was to initiate a process of rehabilitation by establishing and sustaining vegetation growth and improving the physicochemical properties of the bauxite residue.

The rehabilitation attempt was preceded by nursery experiments from January to December 2002 involving 13 treatment combinations of soil amendments and inoculants and five tree and four grass or legume species. The selection of tree and grass species was driven by some of their favorable properties such as high tolerance of alkaline and saline soils, relatively fast growth rates, soil-binding properties, and ability to supply biomass to local people in the form of fuel wood and fodder (Sharma et al. 2004). The soil amendments were gypsum, farmyard manure (FYM), and vegetative dry dust in three different proportions. The FYM was used to enrich nutrient supply and to partially make up for the deficiency of zinc, while the vegetative dust, a mixed dry biomass of grasses, herbs, and trees, improved water retention and moisture-holding capacity and also provided micronutrients to the plants.

The inoculant treatments were a 2 × 2 factorial of bacteria and mycorrhizae. The 13th treatment was a control of just the red mud.

From these experiments, we concluded that a combination of 55% red mud, 25% FYM, 15% gypsum, and 5% vegetative dry dust, inoculated with both bacteria and mycorrhizae, resulted in good responses from three tree species—kikar (*Acacia nilotica*), karanj (*Pongamia pinnata*), and vilayati babul (*Prosopis juliflora*)—while other two species—drek (*Melia azedarach*) and Israeli babul (*Acacia tortilis*)—did not survive in any of the treatment combinations. Among the grass species, para grass (*Brachiaria mutica*), signal grass (*B. decumbens*), and shrubby stylo grass (*Stylosanthes scabra*) performed well in the same treatment combination as the trees, along with sesban (*Sesbania sesban*), a legume species.

For the pilot-scale implementation, we selected an area of 1 ha from one of the two HINDALCO red mud ponds in January 2003. We collected seeds from the plantation of the Forestry Research Centre of The Energy and Resources Institute (TERI) in Gurgaon, Haryana, and sowed them in HINDALCO's existing nursery in the later half of March. At this stage, we replaced drek and Israeli babul with kala siris (*Albizia lebbeck*) and leucaena (*Leucaena leucocephala*), respectively. Earthwork in the middle of April divided the study area into four terraces. By the middle of May, a total of 795 pits (each 45 cm × 45 cm × 45 cm) were dug, keeping a distance of 4 m and 3 m between rows and pits, respectively. At the time of planting (end of May), the saplings were a little over two months old and had attained a height of 30–45 cm. Each pit was filled with 5 kg of gypsum, 7 kg of FYM, and 1.5 kg of dry vegetative dust at the time of planting. Thus, for entire pilot plot, we used approximately 4 T of gypsum, 6 T of FYM, and a little over 1 T of vegetative dry dust.

Grass and legume seeds were procured from Indian Grassland and Fodder Research Institute in Jhansi. However, seeds were not available for para grass, and therefore we procured root slips from local forest department's nursery. Grass and legume species were planted at 30 cm spacing between the rows. We ensured regular watering through sprinklers until monsoon started by later June so that each sapling received at least 1.5–2 L of water every day. Monitoring started immediately after tree planting (end of May 2003) and continued until April 2004 at intervals of every three to four months. Another round of monitoring occurred in February and November 2007.

The first year of monitoring showed average survival of 80% for tree saplings in all four terraces, which matched our observations during the nursery experiment. However, to our surprise, the survival percentage declined sharply to 30% by 2007 (Figure 1). Soil analysis revealed that the proportion of silt and clay decreased noticeably, pH values came down to seven and eight at different depths, and micronutrients and total bacterial biomass increased,

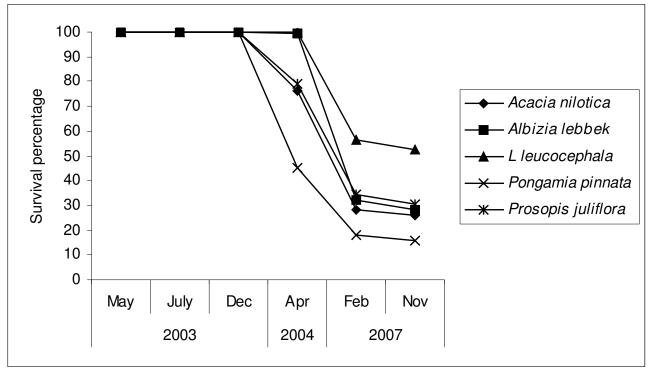

Figure 1. Percent survival of tree seedlings planted in red mud with soil amendments at a HINDALCO aluminum refinery in Belgaum, Karnataka, India.

thus improving the edaphic environment for the growth of vegetation (TERI 2008). In view of this, soil conditions are unlikely to be the reason for the reduced survival rate. However, we found that profuse growth of grass to an average height of nearly 2 m, severely limited the space for other plant species. Moreover, the abundant production of grass seeds provided ideal habitat for rodents and other burrowing animals to feed and inhabit the pilot site. These burrowing animals in turn destroyed the root zones of growing tree saplings, causing their mortality, according to field observations and discussions with the HINDALCO officials.

Leucaena experienced the greatest height gains, averaging 4.25 m in 2007, compared to 0.27 m in 2003. This was followed by karanj (from 0.19 m to 1.75 m), while kikar displayed the least growth (Figure 2a). Similarly, leucaena gained the largest diameters, going from 0.27 cm in 2003 to 14.75 cm in 2007. Vilayati babul (from 0.34 cm to 2.75 cm), kikar (from 0.75 cm to 2.25 cm), and kala siris (from 0.36 cm to 2.50 cm) also experienced good stem diameter growth, while karanj demonstrated the least growth (Figure 2b).

Monitoring showed increased density of signal grass (15 to 37 tufts/m²) and para grass (9 to 47 tufts/m²), indicating their tolerance of adverse soil conditions. On the other hand, shrubby stylo grass was not observed in 2007, and sesban declined from 43 to 16 individuals/m² during the same period. All of the surviving grasses increased substantially in height, from 60.8 cm to 175 cm for signal grass, 101 cm to 179 cm for para grass, and 153 cm to 245 cm for sesban.

In 2007, we also observed other plant species such as a climber, locally known as ban kakari (*Momordica* spp.), clitoria grass (*Clitoria* spp.), and a few other edible crops such as tomato (*Lycopersicon esculentum*), beans (*Phaseolus* spp.) and finger millet (*Eleusine coracana*). We believe that birds have helped disperse these species. Laboratory tests of edible species indicated all toxicity parameters well within the permissible limit. The extensive growth of these species and presence of a few faunal species, such as reptiles

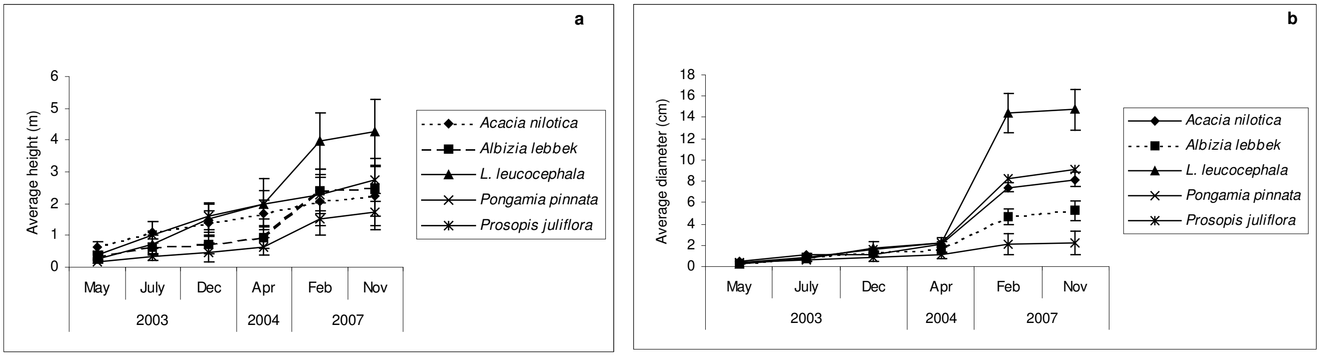

Figure 2. Patterns of growth in tree seedlings planted in red mud with soil amendments at a HINDALCO aluminum refinery in Belgaum, Karnataka, India: a) mean (± SE) height; and b) mean (± SE) girth.

(garden lizard) and small mammals (rabbits, squirrels, and shrews), not only confirmed the improving soil quality but also indicate that ecological recovery was underway.

One of the important aspects of the rehabilitation was the transfer of technological knowledge to HINDALCO. Ecological rehabilitation of the 1 ha pilot plot was followed by its replication and scaling up by HINDALCO in another 4 ha area of the same red mud pond in the following year with more than 60% survival of the planted trees (TERI 2008).

The use of plantations for restoration and reclamation of damaged tropical lands has been described by many authors (e.g., Rao and Tak 2002), but there are not many examples with red mud. The results presented here, however, sufficiently indicate the possibility of treating red mud deposits in an environmentally sound and cost-effective manner. The rehabilitation methods adopted in this pilot program are in line with the findings of Wong and Ho (1991), suggesting the use of gypsum to improve the physical properties of red mud.

Successful establishment and growth of plantations depend largely on correct species selection, soil-working methods (pit sizes, trenches, etc.), planting techniques, and other management practices suited to local edaphic and climatic conditions, including maximizing rainwater utilization and minimizing the salt concentration in the active root zone of young through leaching processes. In the case of red mud, suitable soil amendments are required, commonly gypsum and iron pyrites. Spot treatment only at the planting site is adequate to make the operation cost effective. Furthermore, soil treatment should reach deeper zones and not be confined to only the upper 10–15 cm. Scaling up of the pilot at the present site and replication in another site by HINDALCO in eastern India indicate interest in an economically viable and environmentally acceptable solution for treating large volumes of red mud deposits.

Acknowledgment

The authors are grateful to HINDALCO, Belgaum, Karnataka, India for financial and logistical support.

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Restoring Nutrient Capture in Forest Herbaceous Layers of the Midwest (Iowa)

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Much of the natural land cover in the American Midwest has been altered to support intensive agricultural production. One unintended consequence has been