Infiltration and erosion potential on reclaimed bauxite mine lands in Jamaica

Potentiel d'infiltration et d'érosion sur des terres restaurées de mines de bauxite en Jamaïque

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\textbf{Introduction}

Earthy bauxite (aluminum ore) deposits cover over 20\% of Jamaica’s surface area (Lyew-Ayee and Stewart, 1982). Bauxite deposits occur primarily as surface infillings of irregularly shaped karst depressions. Before mining, bauxite soils in Jamaica are deep, friable, and contain few rock fragments. The pH is 5.5 to 6.5, there is generally 60\% or more low activity clay, and mineralogy is dominated by gibbsite and iron oxides. In the USDA taxonomy system (Soil Survey Staff, 1994) deep bauxite soils are in the clayey, gibbsitic, isohyperthermic family. Most bauxite soils are classified as Rhodic or Typic Eutrodoxes.

Since there is little or no overburden, mining is done by the open pit method (Jamaica Bauxite Institute, 1992). About 30 cm of topsoil is scraped off and stockpiled near the mine site before bauxite is extracted down to the underlying limestone bedrock. The bedrock is often dramatically undulating, and areas narrower than 3 meters are not mined. When mining is complete, piles of limestone rubble mixed with bauxite are used to fill in the lowest areas in the pit. Then the topsoil is spread back over the whole disturbed area and grass is usually planted (Morgan and Stevens, 1979; Jamaica Bauxite Institute, 1992). Reclaimed soils are shallower, have weaker structure, and exhibit higher bulk density, pH (6.5 to 8.0), and limestone fragment content than pre-mined soils. Reclaimed bauxite soils could be classified as Typic or Lithic Udarents depending on the depth to bedrock.

“The relationship between bauxite and agriculture was inevitably a competitive one” (Stone, 1975) because the bauxite deposits are also the best agricultural soils. There is a shortage of arable land in Jamaica, and there is great interest in using post-mined bauxite lands for agriculture (Thomas, 1973). The post-mined soils are too shallow for tree crops, but they have been used successfully for pasture and some vegetable and root crops. Proper soil management is essential (Coke et al., 1987) because “the problems of soil erosion and water conservation are further aggravated and assume even greater proportions on restored mined-out bauxite lands” (Thomas, 1973). But, proper management practices for post-mined bauxite lands are not necessarily the
same as those for unmined soils. In order to facilitate the productive agricultural use of mined out bauxite lands, research is needed to help determine what crops and what practices work best (Coke et al., 1987). Since water retention and soil erosion are concerns on post-mined bauxite lands, an evaluation of these properties would be helpful in determining best management practices. The purpose of this study was to compare infiltration and erosion potentials for reclaimed bauxite mine soils of different ages and pre-mined soils with and without grass cover.

Study Area and Site Selection

The study area is located in west-central Jamaica in Manchester Parish near the city of Mandeville. This area has been and will continue to be mined extensively for bauxite by Alcan Jamaica Company. Elevation in the study area ranges from about 450 to 650 m. The natural terrain is hilly, often with shallower soils on steep sideslopes and deeper soils in valleys. The deep soils in the valleys represent the commercial bauxite deposits. After mining and reclamation, the terrain is usually steeper and has a much higher percentage of shallow soils.

Mean annual precipitation in the study area ranges from 1700 to 2200 mm and mean annual potential evapotranspiration ranges from 1200 to 1400 mm. Since precipitation exceeds evapotranspiration, the soil moisture regime is udic. Rainfall distribution is bimodal, with the driest period from December through February and another dry period during June and July. Mean annual air temperature is about 22 °C, with a difference of less than 5 °C between average daily winter and summer temperatures. Thus, the soil temperature regime is isohyperthermic (Ahmad, 1966; Ahmed 1990).

Three post-mined sites of varying ages of reclamation were used for this study done in the summer of 1996. These sites, named for the towns they are adjacent to, were reclaimed (reshaped and covered with topsoil) and restored (revegetated with grass) in the following years:

- Trinity - reclaimed in 1992, restored in 1994
- Russell Place - reclaimed and restored around 1980
- Battersea - reclaimed and restored around 1970

A pre-mined site near Martins Hill was used for comparison to soils of the post-mined sites.

Materials and Methods

A free standing, drip type rainfall simulator was used to measure runoff and erosion rates on grassed and tilled microwatersheds. The rainfall simulator was just under two meters tall. It delivered rain at about 3/4 terminal velocity at a rate of 165 mm/hr on an area of about 0.5 m². Metal rings and triangular pans were installed and sealed with silicone cement to form microwatersheds (about 0.33 m²) on eight grassed replicates and eight tilled replicates at each of the four sites. Runoff was measured by weighing water that flowed out of the triangular pan at the bottom of each microwatershed. The raindrop-producing module, microwatershed installation, and runoff measuring system were similar to those of Blackburn, et al. (1974). Tilled replicates were small plots tilled by hand and raked smooth. For grassed replicates, grass (primarily Cynodon nlemfuensis and Brachiaria spp.) was trimmed to a height of 30 cm. Slope of the microwatersheds was generally near 20 %, but it ranged from 15 to 25 %.
In order to begin the rainfall simulator measurements with soil moisture contents near field capacity, on the afternoon before the rainfall simulator was run at each site microwatersheds and the areas just outside them (for a total area of .65 m$^2$) were wet up by hand spraying with 6 cm of water and then covered with plastic tarpaulins. The next morning another 3 cm of water was sprayed on. Immediately before running the rainfall simulator at each microwatershed, soil samples were taken at two depths (0 to 5 and 5 to 10 cm) just outside the microwatershed to determine starting soil moisture content. The rainfall simulator was run at each microwatershed for one hour with measurements of runoff every five minutes. The amount of runoff was subtracted from the amount of water delivered at 165 mm/hr to determine infiltration rate at each five minute interval. A 250 ml sample of runoff water was taken to a laboratory for analysis of total suspended solids in order to assess erosion potential at different sites under tilled and grassed conditions. The next day all the grass (including the mat) was cut from each grassed replicate and air dried and weighed. Several soil profile descriptions were made at each site from back hoe pits in order to calibrate morphological properties with differences in infiltration rates and sediment loss determinations.

Results and Discussion

Figures 1 and 2 depict mean values for the eight replicates run at each site with error bars representing ± one standard deviation. All readings were taken at the same 5 minute intervals, but graphs are offset slightly to better display the error bars. Letters to the right of the graphs indicate significant differences in terminal (60 minute) infiltration rates with $p<.05$ based on randomization tests. The test statistic used was the absolute difference in study site means, and significance was determined by comparison with a null distribution of 500 random assignments of study site. Figure 1 shows that infiltration for tilled plots was highest at Martins Hill (the unmined site) and decreased with decreasing age of reclamation for the mined sites. Error bars indicate that the variation was generally greater on the reclaimed sites than on the unmined site, reflecting the higher spatial variability of reclaimed soils. The terminal infiltration rates were significantly different except between Russell Place and Battersea, due primarily to the high variation at Russell Place.
Figure 2 shows that the ranking of sites for the grassed plots is nearly reversed that of the tilled plots, probably because the thick grass mats at Martins Hill (unmined) and Battersea (reclaimed and planted in grass over 25 years) restricted infiltration. Grass samples indicated that the average weights of grass and grass mat at Martins Hill and Battersea were about 40% higher than the weights for Russell Place (reclaimed and planted in grass over 15 years) and Trinity (reclaimed 4 years, planted in grass 2 years). On grassed plots terminal infiltration rates were significantly different between all three reclaimed sites. Martins Hill was only significantly different from Trinity. In many instances on the grassed plots, infiltration rates decreased and then increased slightly with time rather than just decreasing. The late increase in infiltration rates probably coincided with saturation of the grass mat so it became less of a barrier to infiltration. At Battersea and Martins Hill infiltration rates were higher on the tilled plots than on grassed plots, while for Trinity and Russell Place infiltration rates were higher on the grassed plots. These differences between tilled and grassed treatments were all significantly different with p<.05 based on randomization tests described above. The treatment and study site differences were due to variations in grass mat thickness as well as soil structure. Unmined bauxite soils have strong granular structure and are friable despite a high clay content. Recently reclaimed soils are compacted and have large blocky structural units (imported from the deep bauxite deposits) commonly admixed with the stockpiled topsoil. After decades under grass, the blocks begin to disaggregate into smaller units and granular structure slowly forms.
The coefficient of variation was used to calculate the number of replicates needed to estimate mean terminal infiltration rates (Wilding and Drees, 1983) (Table 1). Number of replicates needed ranged from 10 to 25 for the tilled plots and from 3 to 30 for the grassed plots, reflecting the greater variability on grassed plots.

Table 1. Number of replicates needed to estimate mean terminal infiltration rates ± 10% with a 95% confidence interval

<table>
<thead>
<tr>
<th></th>
<th>Trinity</th>
<th>Russell Place</th>
<th>Battersea</th>
<th>Martins Hill</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tilled</td>
<td>13</td>
<td>25</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Grassed</td>
<td>3</td>
<td>23</td>
<td>27</td>
<td>30</td>
</tr>
</tbody>
</table>

It was hoped that the pre-wetting procedure would produce a uniform soil moisture content for all replicates at all sites. However, different sites retained moisture at different levels, and variation in the starting soil moisture content occurred between and within sites (Table 2). In general, Martins Hill had the highest and Russell Place had the lowest starting soil moisture content. So, the differences in structure between soils that were unmined, recently reclaimed, and reclaimed and in grass for decades affected moisture retention as well as infiltration. For the tilled plots, where Martins Hill had the highest infiltration rate, the differences in infiltration rates between sites would likely have been even greater if moisture content had been the same for all sites. For grassed sites, however, the differences in infiltration rates might have been less if moisture contents had been nearly uniform, although the grass mat variation would still likely confound the results.
Table 2. Average starting soil moisture content (%)

<table>
<thead>
<tr>
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<tbody>
<tr>
<td>Tilled</td>
<td>31</td>
<td>25</td>
<td>40</td>
<td>45</td>
</tr>
<tr>
<td>Grassed</td>
<td>34</td>
<td>26</td>
<td>53</td>
<td>62</td>
</tr>
</tbody>
</table>

Analysis of suspended solids in runoff indicated, not surprisingly, that there was much higher erosion on the tilled plots than on the grassed plots for the post-mined sites (Table 3). The Martins Hill site (unmined) had considerably lower erosion on the tilled plots than the post-mined sites. Also, Battersea had significantly lower erosion on the tilled plots than the more recently reclaimed post-mined sites, suggesting that age of reclamation and establishment of long term grass cover may be an important factor. The values for erosion presented in Table 3 are helpful for relative comparisons, but they can not be used to determine erosion on a watershed scale. Extrapolating from very small plots to field or watershed scale could dramatically overestimate erosion. Runoff and sediment that moves overland off of a 0.33m$^2$ microwatershed may be entrained within the large watershed and not contribute to downstream sediment loads.

Table 3. Average sediment loss (g/m$^2$) after one hour of 165 mm/hr rain

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<thead>
<tr>
<th></th>
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<th>Russell Place</th>
<th>Battersea</th>
<th>Martins Hill</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tilled</td>
<td>210</td>
<td>321</td>
<td>87</td>
<td>11</td>
</tr>
<tr>
<td>Grassed</td>
<td>2</td>
<td>12</td>
<td>22</td>
<td>16</td>
</tr>
</tbody>
</table>

Conclusions

Infiltration and erosion were affected by grass cover and age of reclamation of post-mined bauxite soils in Jamaica. Infiltration and water retention were higher and sediment loss was lower on tilled post-mined soils that had been reclaimed and planted in grass for several decades. This was probably due to the improvement in structure fostered by the grass cover. At all post-mined sites erosion was significantly higher on tilled plots than on grassed plots, suggesting that erosion might be a serious concern in removing grass cover to plant crops on post-mined bauxite soils with shallow topsoil.

References


Keywords : surface mine reclamation, bauxite mine soils, rainfall simulator
Mots clés : restauration des mines en surface, sols de mines de bauxite, simulation de pluie