Physico-chemical characterization of different age series sponge iron solid waste dumps with respect to reclamation

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ABSTRACT

Sponge iron solid waste dumps represent a distressed habitat and possess scare in the natural landscape of the area and such dumping sites therefore need urgent attention for their reclamation. Physico-chemical properties of 0, 1, 3 and 5 yrs old sponge iron solid waste dumps were analyzed. A comparative analysis of physical features of different age series sponge iron solid waste dumps revealed an improvement of textual (increase in clay and slit) and structural (decline in bulk density) properties along with the improvement in hydrological regime (water holding capacity and moisture content). pH of the different age series sponge iron solid waste dumps gradually shifted from alkaline range to the neutral range. The soil organic carbon, nitrogen and extractable phosphorous in the freshly laid dump was observed to be beyond the detection limit. However, with the increase in the age of the waste dumps, the carbon, nitrogen and phosphorous content showed progressive increase. C:N ratio was showing declining trend with increasing age of the waste dumps. Findings of the present study indicated the positive effect of soil supplementation and natural vegetation succession on the process of reclamation of the waste dump converting it into a natural ecosystem.

Key words: Sponge iron soil waste, physico-chemical characterization, derelict land, reclamation

1. Introduction

Sponge iron is a generic name of metallic product obtained through reduction of iron oxide in solid state, which is mostly used for steel manufacturing. The process of sponge iron making aims to remove oxygen from iron ore and when that occurs, the departing oxygen causes micro pores in the ore body, making it porous. The final product, when observed under a microscope, resembles a honeycomb structure and looking spongy in texture, hence the product is called “Sponge Iron” (APPCB, 2006). India has emerged as the world’s largest producer of sponge iron, accounting for 33% of the global production and the coal based sponge iron production contributes about 80% of the total capacity of the country (IBM, 2013). The availability of the principal raw materials like high grade iron ore and non-coking coal have created a favorable atmosphere for the development of sponge iron industry in the central eastern belt of India including the states of Odisha, West Bengal, Jharkhand and Chhattisgarh (Patra et al., 2008). From the coal based sponge iron industry huge amount of solid waste is generated in form of char, dust and accretion material (CPCB, 2007). Majority of the solid wastes are dumped on land which creates large areas of black calcareous derelict land that apart from reducing productivity, also reduce aesthetic value of the region (Roy et al., 2002). In developing country like India, reclamation of such derelict land is an urgent necessity.
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The knowledge about physico-chemical properties of soil is a pre-requisite for conceptual understanding of the reclamation process of any degraded land. Their analysis with respect to a time sequence can provide important information about the direction of change, which is very useful for formulation of an effective restoration strategy. Soil physicochemical properties such as pH, fertility, soil texture, aggregation, bulk density, compaction, water holding capacity, moisture content etc. are regulating factors for vegetation and microbial growth. Thus change in the physico-chemical properties with passage of time can be used as an effective parameter to assess the progress of reclamation (Bradshaw, 1996; Gairola and Soni, 2010). On the basis of such concept in the present study an attempt was made to analyze physiochemical properties of different age series sponge iron solid waste dumps were with respect to reclamation.

2. Materials and methods

2.1 Study site

The study was carried out in solid waste dumping site of Scans Steels limited, Sundragrah, Odisha. Geographical location of the area is between 20º11' North Latitude and 84º19' East Longitude. Altitude of the area is about 213m above the mean sea level. The area experiences tropical climate with three distinct seasons i.e. summer, rainy and winter. The mean annual rainfall in the area is 1422mm, 80% of which fall during rainy season. Mean air temperature of the area varies from 10ºC to 45ºC. The relative humidity fluctuates from minimum of 40% to maximum of 83%. In the sponge iron solid waste dumping site, accumulation of solid waste over years resulted in formation of different age series of dumps. For the present study freshly laid dump (D₀), 1 year (D₁), 3 year (D₃) and 5 year (D₅) old dumps were selected. Dump age is expressed as time since the establishment of dump in the site. During dumping of the solid waste, when the dump attains sufficient height, soil of the adjacent area is covered over the dump for stabilization. Thus, D₁, D₃ and D₅ were with soil cover, where as D₀ was without soil cover. A natural site adjacent to the waste dumping site was been taken as control site (C) for reference.

2.2 Sample collection

Waste samples from different age series dump (D₀, D₁, D₃ & D₅) and soil from control site were collected by random sampling method from a depth of 0-15cm by digging pits (15 X 15 X 15 cm³). For each site, sub-samples were collected from five locations. These sub-samples were brought to the laboratory in sterilized polythene bags and mixed thoroughly to form a composite sample. After sorting out larger pieces of materials, the sample were subjected to sieving in 2mm mesh. Each of the composite samples was divided into three replicates for analysis.

2.3 Physicochemical characterization

Texture of the waste samples was determined by mechanical sieve method (Mishra, 1968) and bulk density (g/cm³) was estimated following the method prescribed in TSBF Handbook (Anderson and Ingram, 1992). The water holding capacity (%) was determined following the protocol proposed by Mishra (1968) and moisture content (%) was measured as the ratio of fresh weight to dry weight of soil expressed in percentage. pH was determined in (soil/water, 1:5) suspension with electronic digital pH meter. Soil organic carbon (mg/g soil) was estimated following titration method of Walkley and Black rapid titration method (Mishra,
1968), total nitrogen (µg/g soil) by Kjeldahl method (Jackson, 1958) and phosphorous (µg/g soil) content by following the protocol of Olsen et al., (1954).

3. Statistical analysis

The data from physic-chemical analyses were subjected to Analysis of Variance (ANOVA) to test whether the variations between different sites were significant or not. The simple correlation analysis between different parameters and age of the waste dumps were also conducted.

4. Results and Discussion

The data related to textural composition (sand, slit and clay percentage), bulk density, water holding capacity, moisture content and pH of waste samples collected from D₀, D₁, D₃ & D₅ and soil sample from control site was presented in Table 1. It was observed that among the waste dumps sand percentage was highest in D₀ and lowest in D₅ showing decreasing trend with increasing age of the waste dumps. The slit and clay percentage was found to be minimum in D₀ and maximum in D₅ showing increasing trend with increasing age of the waste dumps. The correlation between the clay (%) in different waste samples and the age of the waste dumps was noted to be significantly positive (r = 0.881, p < 0.05). Growth of the root and root exudates inform of organic acid stimulates the weather of coarse particle to finer particles like clay and slit (Vimmerstedt et al., 1989; Banerjee et al., 2000). Vegetation succession in the waste dumps (Kullu and Behera, 2011) could be a season for increased clay percentage as observed in different mine spoils (Jha and Singh, 1991, Dutta and Agrawal, 2002; Kujur and Patel, 2012). Besides, in D₁, D₃ and D₅ there was soil cover in the waste dumps, which also contributed to more percentage of clay in older dumps than in D₀ where there was no soil cover. In absence of vegetation clay particle are more prone to loss (Narain et al., 1990; Parr and Padendick, 1997) and vegetation cover on degraded barren land was reported to check the loss of clay particles (Wali, 1987; Jha and Singh, 1991). As an important particle for soil texture, clay contributes to soil structural stability (Van Veen et al., 1985; Gregorich et al., 1991). Thus, the gradual increase in the clay percentage indicated the development of soil structural stability, aggregation and developed resistance to the soil erosion with the increase in the age of the waste dumps.

Table 1: Textural composition, bulk density, water holding capacity, moisture content and pH of different age series waste dumps (D₀, D₁, D₃ and D₅) and control site (C).

<table>
<thead>
<tr>
<th>Parameters</th>
<th>D₀</th>
<th>D₁</th>
<th>D₃</th>
<th>D₅</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sand (%)</td>
<td>84.97±0.81</td>
<td>78.77±0.25</td>
<td>76.70±0.44</td>
<td>75.20±0.70</td>
<td>63.76±1.24</td>
</tr>
<tr>
<td>Slit(%)</td>
<td>8.13±0.61</td>
<td>11.53±0.31</td>
<td>12.80±0.20</td>
<td>13.57±0.50</td>
<td>15.89±0.59</td>
</tr>
<tr>
<td>Clay(%)</td>
<td>6.90±0.20</td>
<td>9.70±0.10</td>
<td>10.50±0.30</td>
<td>11.23±0.25</td>
<td>20.34±0.78</td>
</tr>
<tr>
<td>Bulk Density (g/cm³)</td>
<td>1.84±0.04</td>
<td>1.74±0.03</td>
<td>1.66±0.04</td>
<td>1.44±0.02</td>
<td>1.24±0.04</td>
</tr>
<tr>
<td>Water Holding Capacity (%)</td>
<td>21.92±1.61</td>
<td>26.44±1.03</td>
<td>28.79±0.55</td>
<td>32.72±0.75</td>
<td>43.24±0.97</td>
</tr>
<tr>
<td>Moisture content (%)</td>
<td>4.45±0.26</td>
<td>5.64±0.36</td>
<td>6.74±0.10</td>
<td>7.44±0.12</td>
<td>10.53±0.29</td>
</tr>
<tr>
<td>pH</td>
<td>9.13±0.12</td>
<td>8.24±0.21</td>
<td>7.81±0.12</td>
<td>7.28±0.20</td>
<td>6.57±0.21</td>
</tr>
</tbody>
</table>

The bulk density (g/cm³) was having highest value in D₀ and lowest in D₅, showing decreasing trend with increasing age of the waste dump. Bulk density of the control site was
found to be less than the waste dumps. Further analysis of variance (ANOVA) indicated that the bulk densities of different sites were observed to be statistically significant ($F = 204.687, p<0.001$). The bulk density and the age of the waste dump were found to be negatively correlated ($r = -0.984, p < 0.01$) and statistically significant. A decline in bulk density with the age of waste can be interpreted as a reduction in the soil compactness because of the development of soil micropore space (Brady, 1990). An increased level of clay fraction contributes to the development of soil micropore space that reduces the soil bulk density. Further vegetation cover on barren land is reported to reduce bulk density and soil compactness (Fisher, 1995). Findings of the present study could be explained by the fact that gradual increase in vegetation cover, accumulation of clay fraction and organic matter led to the development of soil micro-pore space that ultimately reduced the soil bulk density.

The water holding capacity (%) of $D_0$, $D_1$, $D_3$ and $D_5$ were recorded to be 21.92, 26.44, 28.79 and 32.72% respectively. It was having lowest value in $D_0$ and highest in $D_5$, showing increasing trend with increasing age of the waste dumps. In control site the water holding capacity was 43.24%, which was higher than the waste dumps. The analysis of variance (ANOVA) indicated that the water holding capacities of different sites were observed to be statistically significant at ($F = 178.279, p<0.001$). Further the relationship between water holding capacity and the age of the waste dump was positive correlated and statistically significant ($r = 0.972, p< 0.01$). Soil texture and organic matter content are the key components that determine soil water holding capacity (Haynes and Naidu, 1998; Leu et al., 2010; Vengadaramana and Jashothan, 2012). The positive correlation of water holding capacity with clay percentage and organic matter content in different age series mine spoil (Kujur and Patel, 2012; Maharana and Patel, 2013) which supported the findings of present study.

Annual average moisture content (%) in different age series waste dumps ranged from 4.45-7.44%, having lowest value in $D_0$ and highest in $D_5$ showing increasing trend with increasing age of the waste dumps. In control site the moisture content was 10.53%, which was higher than the waste dumps. The analysis of variance (ANOVA) indicated that the moisture content of different sites was observed to be statistically significant ($F = 257.693, p < 0.001$). The relationship between the moisture content and the age of the waste dump was positive correlated and statistically significant ($r = 0.954, p< 0.01$). The progressive improvement of the moisture content of the waste dumps with age of waste dumps could be due to the positive influence of the increasing vegetation cover on the waste dump, which prevented the loss of soil water through evaporation by not allowing direct exposure of soil surface to the incoming radiation (Lal, 1989; Reid and Bird, 1990).

pH of the waste dumps was recorded to be in alkaline range. The highest value of pH (9.13) was in $D_0$ and lowest (7.28) was in $D_5$, showing decreasing trend with increasing age of the waste dumps. In control soil pH was recorded to be 6.57. The analysis of variance (ANOVA) indicated that the pH of different sites was observed to be statistically significant at ($F = 91.23, p< 0.001$). The relationship between the pH and the age of the waste dump was negatively correlated and statistically significant ($r = -0.954, p < 0.05$). The alkaline pH of waste dumps was due to dolomite, which is one of the raw materials for sponge iron production. The residues of dolomite in form of CaO in the sponge iron solid waste resulted in high pH (Dwari et al., 2012). However with increasing age of the waste dumps there was gradual decline in the pH value. Organic matter is usually considered to lower soil pH by releasing $H^+$ associated with organic anions, by nitrification or by an increased cation exchange capacity and corresponding increase in exchangeable acidity (Helyar and Porter,
Physico-chemical characterization of different age series sponge iron solid waste dumps with respect to reclamation

1989; Bolan et al., 1991). Gradual leaching with time, mixing of waste with soil in the waste dumps (except D₀) and addition of organic matter by vegetation succession might have resulted in declining pH.

Table 2: Organic Carbon, Total Nitrogen and Extractable Phosphorous content in waste samples of different age series waste dumps (D₀, D₁, D₃ and D₅) and in soil sample of control site (C).

<table>
<thead>
<tr>
<th>Parameters</th>
<th>D₀</th>
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<th>D₅</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Organic Carbon (mg/g soil)</td>
<td>ND*</td>
<td>1.88±0.21</td>
<td>2.43±0.25</td>
<td>3.86±0.54</td>
<td>13.83±0.70</td>
</tr>
<tr>
<td>Total Nitrogen (µg/g soil)</td>
<td>ND*</td>
<td>80.92±3.94</td>
<td>124.82±12.02</td>
<td>394.61±37.90</td>
<td>1536.36±43.18</td>
</tr>
<tr>
<td>Phosphorous (µg/g soil)</td>
<td>ND*</td>
<td>53.08±2.61</td>
<td>95.37±9.96</td>
<td>192.13±7.55</td>
<td>761.12±26.98</td>
</tr>
<tr>
<td>C:N</td>
<td>ND*</td>
<td>23.23</td>
<td>19.44</td>
<td>9.77</td>
<td>8.98</td>
</tr>
</tbody>
</table>

*Not detected

Organic carbon (mg/g soil), total nitrogen (µg/g soil) and NaHCO₃ extractable phosphorous (µg/g soil) content of D₀ was at non-detectable level, where as it was having minimum value in D₁ and maximum value in D₅, showing increasing trend with increasing age of the waste dumps (Table 2). In control soil the level of organic carbon, total nitrogen and NaHCO₃ extractable phosphorous were higher than the waste dumps. The analysis of variance (ANOVA) indicated that organic carbon (F = 719.34), total nitrogen (F = 2811.68) and phosphorous content (F =1621.88) of different sites were observed to be statistically significant at p<0.001. There was a positive correlation between age of the waste dumps and the organic carbon (r = 0.970), total nitrogen (r = 0.939) and extractable phosphorus (r = 0.986) content of different age series sponge iron solid waste dumps which was significant at p<0.01. In D₀ there was only solid waste freshly released from the industry which basically contained klin dust, iron residues, unburned coal and dolomite residues (Patra et al., 2008; Jena et al., 2008, Jena et al., 2012). Thus, organic carbon, total nitrogen and extractable phosphorous were not detected in D₀. However, in D₁, D₃ and D₅ there was soil cover from control site and also vegetation growth on the waste dumps.

The nutrients present on the control soil get mixed with the waste and input of litter from vegetation component resulted in increased level of organic carbon. There have been reports about the increase in the level of organic carbon along with the restoration of the degraded soil (Srivastava et al., 1989; Jha and Singh, 1991). With the increasing age of the waste dumps there was also increase in the number and diversity of the leguminous plants (Kullu and Behera, 2011) resulting in increased level of total nitrogen in the waste dumps. Besides, the establishment of mycorrhiza (Kullu and Behera, 2012) and activity of other phosphate solubulizing microbes in the waste dumps might have resulted in the increased level of extractable phosphorous. The ratio of organic carbon to total nitrogen (C:N ratio) was found to be maximum in the D₁ (23.23) and minimum in D₅ (9.77), showing decreasing trend with increasing age of the waste dumps. The decreasing trend of C:N ratio with increasing age of the waste dumps substantiated to the fact that there was relatively more accumulation of nitrogen than that of carbon.

Bandana Kul, Niranjan Behera
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5. Conclusion

From the inter comparison of physicochemical data of 0 to 5 years old sponge iron solid waste dumps it was revealed that with the increase in the age of the waste dumps there was amelioration of different physicochemical parameters of the waste dumps. This indicated that there is reclamation of the waste dumps due to soil supplementation and development of vegetation. Further comparison of 5 year old waste dump (D5) with that of the natural control site indicated a difference in between the two and this reflects that that the sponge iron solid waste dumps will take more time to reach to the state of natural site. In the present study it was observed that over a period of 5 years soil organic carbon was showed an annual increase of 772µg/g waste. The corresponding figure for nitrogen and phosphorous was 79 and 38.4µg/g waste respectively. This annual rate indicated the pace and progress of reclamation process in the sponge iron solid waste dump. If the pace is going to be sustained it will take 18 to 20 years to reach to the level of natural control site. The study in other way indicates the positive effect of soil supplementation and natural vegetation succession on the process of reclamation of the waste dump converting it into a natural ecosystem.

6. References


Physico-chemical characterization of different age series sponge iron solid waste dumps with respect to reclamation


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