PROCESS DESCRIPTION AND MONITORING

96) Provide further details of process flow diagrams within the Plant Site Area showing the location(s) and details of increased productivity and output measures expected in achieving a production rate of 1.9 million tonnes per annum.

This diagram and explanatory table is provided in Figure 96.1.

97) Provide a map or maps which summarises the location and nature of the environmental monitoring network in and around the Plant Site and BRDA.

The following is a schedule of maps outlining the environmental monitoring network at AAL

Table 97.1: Schedule of maps

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Comment</th>
<th>Figure No.</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air</td>
<td>Extended dust gauge network submitted with IPCL Review July 2005</td>
<td>Fig. 97.1</td>
<td>Attached to this report</td>
</tr>
<tr>
<td>Air</td>
<td>Air Monitoring locations for EIS Baseline</td>
<td>Fig. 9.1</td>
<td>Volume 2 of the EIS</td>
</tr>
<tr>
<td>Air</td>
<td>Dust Monitoring locations for IPCL (Phase 1 BRDA)</td>
<td>Fig. 9.2</td>
<td>Volume 2 of the EIS</td>
</tr>
<tr>
<td>Air</td>
<td>Ambient Dust, Particulate and SO$_2$ Monitoring Locations</td>
<td>Fig. 9.3</td>
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</tr>
<tr>
<td>Surface Water</td>
<td>Surface Water Monitoring locations submitted with IPCL Review July 2005</td>
<td>Fig. 97.1</td>
<td>Attached to this report</td>
</tr>
<tr>
<td>Noise</td>
<td>Noise Monitoring Locations submitted with IPCL Review July 2005</td>
<td>Figure 97.2</td>
<td>Attached to this report</td>
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<tr>
<td>Groundwater</td>
<td>Groundwater monitoring locations (Plant area, Phase 1 and 2 BRDA)</td>
<td>Fig. 97.3</td>
<td>Attached to this report</td>
</tr>
<tr>
<td>Groundwater</td>
<td>Groundwater monitoring locations (Plant area and Phase 1 BRDA)</td>
<td>Fig. 15.1  and Fig. 15.2</td>
<td>Volume 2 of the EIS</td>
</tr>
</tbody>
</table>

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RESTORATION AND AFTERCARE

98) Clarify the source(s) of the water to be used in the sprinkler system proposed for the BRDA and whether any effects on emerging vegetation may arise.

The water used in the existing and proposed extension to the sprinkler network is treated waste water from the plant process waste water plant which complies in quality to the IPCL No. 562 Schedule 2(i) W1-1 for emission to the River Shannon. In the unlikely event that this water is not available for any reason, potable water can be used in the sprinkler network. However that would not be an environmentally sustainable use in the long term of a commodity resource purchased from LCC.

Sprinkler system should be advantageous to emerging vegetation as it will assist in the leaching of excessive salts in the amended substrate. Once vegetation is established the need for a sprinkler system on revegetated surfaces should not arise.

Currently some of the on site sprinklers used in the existing BRDA would have had some dispersion onto the existing trials plots of vegetation on the southern and south western sides of the exposed red mud surfaces and no adverse effects on plant growth have been detected on this thriving vegetation.

Under IPCL conditions 7.4.7 (xii) which deals with Waste Management Restoration and condition 14 Residuals Management and in accordance with a specific EPA Audit recommendation, AAL is currently constructing a trial plot cell at the north eastern side of the existing BRDA and within that trial plot cell all aspects concerning the sustainability of the BRDA restoration grassing and other vegetation as well as the surface water and leachate generation will be thoroughly researched. This will be undertaken by a team including a University of Limerick post doctorate scientist to ensure that the conditions necessary for sustainable vegetation post closure have been examined and that all related issues and risks are covered by our Residuals Management Plan to the satisfaction of the EPA.

99) Submit an assessment of the effects on vegetation of preferential drainage pathways, which may exist within the BRDA stacks.

This issue has been covered in Section 4 and Figure 5 and in particular section 4.5.1.2 of Appendix O of this Further Information Report. Localised shallow valleys occur in the Phase 1 BRDA which tend to be transient as they are formed by the interaction of two or more paste discharge points. The slopes of the valley floor where present are very shallow and typically less than 2%. At closure, there will be a number of broad shallow valleys formed.

Surface run off after closure will be intercepted by a spiral drain system excavated into the red mud as described in the updated Residuals Management Plan, Appendix O. Thus, there will be no significant length of run off on the red mud surface.

The risk to vegetation will be in the early stages of its growth cycle but once established, the impact of surface water runoff on the vegetation will be less. Vegetation trials will be undertaken on the red mud as discussed in the Section 4.2 (Residuals Management Plan Appendix O) in specially constructed cells and an assessment of the effects on vegetation of surface runoff confined to a specific drainage pathway will be carried out.
100) Please provide details of scientific studies of successful restoration/re-vegetation projects at the Aughinish BRDA and/or similar facilities.

**Aughinish BRDA**

A series of field trials were established on rotavated, weathered red mud in autumn 1996. These trials included various organic amendments and grass mixtures. Findings from 3 years monitoring of these trials are summarised below:

- Topsoil (200 t/ha) was not an adequate amendment for year 1
- High rate Mushroom compost (200 t/ha) amendment was an effective organic amendment
- Low application rate of gypsum (300 kg/ha) did not appear to influence soil or plant properties
- Grass species *Holcus lanatus* (yorkshire fog) was a successful candidate for red mud revegetation
- Colonisation of plots by clovers was apparent after year 3
- By year 3 topsoil amendment was comparable to other treatments


To further investigate the establishment of native vegetation on red mud, a PhD study was initiated in 1998. The study was conducted at the Institute of Technology, Sligo and at Aughinish Alumina Ltd. Topics investigated within the study included, analysis of the residue, amendment of the residue, greenhouse trials to screen for suitable candidate species for growing on the residue. Greenhouse trials were followed by a two-year field study on the residue examining amended substrate quality, plant growth and performance. In addition to the production of a PhD thesis from the work carried out, findings from the study have been published in three separate peer reviewed journals. Details are indicated below.


**Abstract**

Aughinish Alumina Limited (AAL) have an obligation by terms of their Integrated Pollution Control Licence (IPCL) and Planning Permission to establish vegetation on the BRDA at their plant at Aughinish, Co. Limerick. High pH and high exchangeable sodium percentage are the main known factors limiting the establishment of vegetation on red mud. Gypsum addition has been known to assist in alleviating these problems in other countries. However, there is no experience or published information on red mud rehabilitation under Irish conditions.

Red mud with organic and inorganic waste-derived ameliorants as well as selected grassland species were examined under laboratory controlled environment conditions as well as in field plot trials. Also, in order that it would be economically achievable, the research utilised locally available waste products as the organic amendments.
Screening trials found that physical constraints severely limit plant germination and growth in red mud. Gypsum addition effectively lowers pH, exchangeable sodium percentage and the availability of Al and Fe in the mud. A strong relationship between pH, ESP and Al levels was also found. Gypsum addition increased germination percentages and plant growth for all species investigated.

Greenhouse trials demonstrated that organic wastes alone did not greatly improve conditions for plant growth but when used in conjunction with gypsum plant performances for all species investigated were significantly increased. There was a high mortality rate for grasses in non-gypsum treatments. An emerging trend of preferential iron uptake and calcium deficiency in non-gypsum treatments was found at pot screening stage. Species also displayed manganese and magnesium deficiencies.

Adverse chemical conditions in field trials were significantly reduced following physical and chemical improvement of the substrate. After one year's growth in the field trials at AAL, grasses had persisted in all treatments. Herbage analysis from the first years harvest showed some nutrient deficiencies and elevated sodium and iron levels, although gypsum amended plots displayed improved results. A decrease in essential elements, notable manganese, and an increase in iron and aluminium levels are attributed to the significant decrease in plant performance for all treatments in the second year's growing season.

Trials show that the establishment of vegetation directly on red mud is achievable when inhibitive parameters, notably pH and ESP levels, are sufficiently reduced and organic amendments added. However, a period of monitoring is recommended to assess if sustainable growth of herbage on the stacks is achievable.


Abstract

Aughinish Alumina Ltd. annually produces approximately 1.5M tonnes of alumina, 1.05M tonnes red mud and 0.15M tonnes of process sand residue. The residues which are stored in the Bauxite Residue Disposal Area are susceptible to wind erosion in a plant closure scenario. Establishment of vegetation on the residues is an attractive desirable method of suppressing dust generation. However, there are constraints in achieving vegetation growth on the residues due to the inherent high pH and sodium levels. The present study examined the use of gypsum and thermally dried sewage sludge as amendments for establishing the clover species *Trifolium pratense* on a red mud/process sand mix. Gypsum was applied to plots at rates of 0 and 3\% (w/w) with both treatments receiving thermally dried sludge at 35\% hha. Gypsum amendment improved chemical conditions of the substrate and increased plant yield. Plant tissue analysis indicated adequate levels for Ca and Mg but a deficiency of Mn. High Fe and Na levels were also recorded. Results demonstrate that growth of clover on red mud is possible with the addition of dried sludge and without the addition of gypsum. However, future monitoring is recommended to determine if the absence of gypsum will have a deleterious effect.


Abstract

Although the treatments for overcoming the high pH and exchangeable sodium percentage (ESP) of bauxite residue are well known, there is little information on long-term nutrient management of vegetation after rehabilitation. The present study examined the chemical and physical amendment of fine fraction residue (red mud) at the Aughinish Alumina Ltd. Bayer Plant, Ireland followed by a two-year field investigation. Gypsum and sewage sludge were incorporated into the residue and amended...
mud sown with *Lolium perenne* and *Holcus lanatus*. Aerial portions were harvested and nutrient composition determined annually for the first two years growth. Amended substrate was low in manganese and magnesium. After year one herbage contained adequate calcium levels, but there were deficiencies for nitrogen, manganese, potassium and magnesium. Sodium levels were not considered excessive and levels declined further in year two. Levels for nitrogen, calcium, manganese, magnesium, phosphorous and potassium were also reduced in the second year. As levels were already deficient in year one the further decreases suggest severe nutrient shortage in the residue substrate. For long-term success of revegetation of bauxite residue, even after gypsum and organic amendment, the deficiencies of nutrients in the substrate must be overcome.


**Abstract**

Establishment of vegetation on residues produced from the bauxite refining process is a beneficial part of their environmental management. Of the two fractions produced in the refining, the coarse fraction has greater efficiency in the leaching of excess salts and alkalinity. However, these same properties can result in increased loss of nutrients and low water-holding capacity. The current study investigated the use of mixing coarse fraction residue with fine fraction residue, at two different application rates (10% and 25%), with and without the use of gypsum as an ameliorant, for re-vegetation of the residue with *Trifolium pratense*. Optimum plant growth was observed in treatments that had also received gypsum amendment, with higher plant biomass, Mn nutrition and lower Al and Fe concentration. However, use of process sand at the higher application rate (25%) promoted lower levels of soluble Al and Fe and exchangeable Na in the substrate and, consequently, lower plant uptake of Na. Results indicate that co-disposal of the coarse fraction sand at 25% w/w with fine fraction residue can improve the substrate and, therefore, plant uptake and growth. Further monitoring is recommended to determine the effect of the absence of gypsum and other nutrient sources on plant growth.

**Current Research**

AAL is currently undertaking a 3-year field study on a trial area of the BRDA. Improvement and weathering of the residue deposited therein constitutes the initial project within the study. Once vegetation trials have been established a series of sub-projects will investigate soil parameters, nutrient status of the residue and vegetation thereon. The vegetation-residue system will also be used to investigate and determine levels of nutrient elements as well as levels of potentially toxic elements. Data obtained from representative surface residue and herbage samples taken over the course of the 3-year study will be analysed and this information used to determine key parameters for assessing performance of the emerging vegetation system.

This project aims to assess:

i) Mechanisms for amendment of alkaline red mud to promote plant growth

ii) Factors influencing the long-term growth of vegetation on amended bauxite residue

iii) Transfer of nutrients and other elements to plant tissues

IV) Measurement of key parameters for determining quality of vegetation systems and trends within same.
Other BRDA’s

In the course of conducting literature searches for the above study all available relevant publications on bauxite residue were reviewed. In addition, where possible, in-house company reports on aspects of bauxite residue were obtained and examined.

Findings from published papers on rehabilitation and revegetation of bauxite residues (red mud) were used in the development of methodologies for the studies on the Aughinish BRDA.

Relevant publications on bauxite residue rehabilitation and revegetation (other than Aughinish BRDA) and the accompanying abstracts are listed below. In many cases, meetings have been held with authors of the publications and issues on red mud (bauxite residue) rehabilitation discussed.


Abstract

Revegetation of red mud can be difficult without chemical or organic ameliorant for red mud. A greenhouse experiment was conducted to examine the short-term effect of a commercial peat moss-shrimp wastes compost on the growth of pucinellia (Pucinellia distans L.) in a bauxite residue (red mud) from the Alcan’s Vaudreuil alumina refinery at Jonquière (Quebec), Canada. Characterisation of the red mud revealed that the residue was strongly alkaline (pH_{eq}=14) and contained soluble salts (EC_{eq} = 10.3 dS m^{-1}), soluble Na (2743 mg L^{-1}), soluble Al (275 mg L^{-1}) and low levels of plant-available nutrients. Red mud components included approximately 40.4% Fe, 18.3% Al, 13.4% Si, 7.5% Ti, 6.7% Na and 3.5% Ca expressed as oxides. Hematite (α-Fe_{2}O_{3}) was the main mineral in the red mud. The results of the revegetation study have shown that compost amendment treatments affected pH values, salinity, organic carbon and DTPA-extractable Al contents compared to the control. The highest rate (45%) of compost reduced the pH to about 9.3. The dry weight yield of pucinellia increased as the percentage of compost in the red mud increased. However, survival and plant growth were very poor when the compost was applied at 18 and 23% rates. The critical substrate pH value for pucinellia growth was between 9.5 and 9.7. In general, the leachates from the compost amended red mud are slightly more concentrated with respect to Al, compared with the unamended red mud (control).


Abstract

Distichlis spicata var. stricta (desert saltgrass), Sporobolus airoides (alkali sacaton, Agropyron smithii (western wheatgrass), and A. elongatum (tall wheatgrass), alkaline-tolerant grasses of the western United States, were tested as species to colonize and cover red mud (bauxite residue) with a minimum use of soil amendments. A gradient in red mud texture at a residue impoundment (coarse at edge to fine in the centre) located in Mobile, Ala., was correlated with soil pH that ranged from 9.15 (coarse) to 11.9 (fine). Saturation-extract Na concentrations ranged from 394 – 4,900 mg/L and Al concentrations from 4.3 to 1,004 mg/L. Exchangeable Na percentage ranged from 52.6 to 91.1. Without amelioration red mud impoundments lacking subsurface drainage remain unvegetated indefinitely. Sewage sludge additions to red mud (2cm on surface, or 1:2 by volume) produced significantly greater growth compared with red mud controls with D. spicata var. stricta, A. elongatum, and S. airoides in greenhouse pot experiments. Other organic amendments (wheat straw, paper pulp waste, glucose, and pine needles) and complete nutrient additions failed to produce a consistent response. Sewage sludge caused similar growth increases with D. spicata var. stricta in field experiments on drained red
mud lakes. Sewage sludge may increase growth via several mechanisms: (i) lowering red mud pH, (ii) adding macro- and micro- nutrients, (iii) increasing nutrient availability through chelation, and (iv) lowering potential Al toxicity.


**Abstract**

Bauxite residue sand, even though a poor substrate for plant growth because of very high pH, salinity and sodicity, is required to be revegetated. Manganese deficiency is observed in residue-grown plants because broadcast applications of manganese fertiliser to the surface of residue deposits have a low residual value. In a laboratory experiment, manganese (as MnSO₄) was added to fresh and 4-year-old residue sand and a sequential fractionation procedure performed at 0, 1, 4, 8 and 24 h and 6, 14, 21, 43, 73, 103 and 130 d. Extraction with DTPA estimated plant-available Mn, while sequential fractionation with various extractants yielded the following fractions: readily soluble [Ca(NO₃)₂]; weakly adsorbed [CaDTPA-B₄O⁷]; carbonate-bound [HNO₃]; and oxide-bound [NH₄OH·HCl]. Residual Mn was calculated as a difference between the sum of all these forms and total Mn in residue sand. Transformation of manganese from the initially dominant readily soluble form to the less-available forms was very rapid (< 24 h). A change to fertilisation strategies is required if better efficiency of manganese application and uptake is to be achieved for plants growing on bauxite residue.


**Abstract**

Successful revegetation of bauxite residue sand (BRS) requires large inputs of nutrients such as manganese (Mn), yet Mn deficiency is still encountered, raising doubts about sustainable revegetation of BRS disposal areas. The application of deep placement of Mn, a measure common in agriculture, was examined as a method for improving productivity and sustainability when lucerne (*Medicago sativa* L.) is used as a species for BRS revegetation. In pots containing BRS, Mn was banded at 2.5-, 10- and 20-cm depths at rates of 10, 20 and 50 µg g⁻¹ BRS. Two lucerne genotypes used were Salado, a Mn-deficiency-tolerant variety, and Sirosal, a Mn-deficiency-sensitive variety. Banding at 10-cm depth produced the best shoot growth of Sirosal at each Mn rate. Greatest shoot growth in Salado was found at 2.5-, 10- and 20-cm depths for 10, 20 and 50 µg Mn g⁻¹ BRS, respectively. Deep banding 20 µg Mn g⁻¹ BRS at 10-cm depth significantly increased lucerne growth compared with mixing through the profile. Banding at 20 cm produced Mn deficiency symptoms in lucerne during early growth, but symptoms were alleviated when sufficient amounts of roots proliferated in the banding zone. Dissolution and movement of Mn away from the fertiliser band were also investigated. In pots without plants, water throughput from watering twice weekly to 110% field capacity had no effect on the amount of extractable Mn at distances more than 1 cm away from the original Mn band position. Whilst not only providing a more effective supply of Mn for BRS revegetation over one growth period, deep-banding of adequate rates of Mn may also result in a longer residual value, reducing the need for frequent broadcast applications.

Introduction

Alcoa World Aluminium Australia operates two bauxite mines and three bauxite refineries in southwest Australia. Approximately 15 M tones of bauxite processing residue (residue sand, and fines (red mud)) is produced annually, as a result of refining 26 M tones of bauxite. These residue products are stored in impoundments at each of the refineries. The residue sand is used specifically to construct batters, drainage layers in the impoundments, and as a final layer on areas to be rehabilitated. Both residue fractions, are highly alkaline, as a result of the bauxite refining process.

A long-term objective for the residue impoundments is to create a stable, aesthetically-acceptable landform, capable of sustaining a range of land-uses compatible with those in the surrounding districts. Establishing vegetation on the residue impoundments is important for several reasons, which include;

- enhanced physical stability of the external sloping batter;
- reduced dust generation and wind erosion;
- to maximize uptake of soil moisture from rainfall and thus minimize any potential deep drainage of soil water and associated alkalinity, or a rise in the water table;
- improved aesthetics of the impoundment landforms, and
- demonstration to the community of the capacity of the material to support productive growth.

Native vegetation and a range of agricultural land uses have been successfully established in pasture and dryland pasture. Since the establishment of these demonstration areas in 1995, an overall strategy for rehabilitation of the residue has been adopted in which the native species are established, after initial cropping with agricultural species. Almost all of this rehabilitation is occurring on sloping batters surrounding the impoundments. These residue surfaces generally have a slope of 10° (1 in 6).

Several constraints associated with the residue material must be overcome for successful plant establishment. The most important of these include:

- alkalinity, which may directly affect plant roots and indirectly affect nutrient availability;
- hard-setting and or cementation, which may potentially constrain root growth;
- absence of organic matter, and biological activity.


Abstract

Rehabilitation of bauxite residues needs to be sustainable in the long-term. Establishment of pools of soil carbon and nutrients is important to sustainability, and in this research we measured soil carbon and nutrients in residue sand sown to a range of annual and perennial crops, with each receiving rates of poultry manure and inorganic fertilizers.

Poultry manure was the most important initial influence on the levels of soil C. Beyond this immediate effect, all vegetation types contributed to soil C accumulation at similar rates, with around 10 t/ha of soil C accumulating after 5 years. Adequate chemical fertility was achieved in surface layers through

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application of gypsum and nutrients, and higher rates had no consequent effect on soil C accumulation. Reductions in soil pH achieved by the initial amendments was best maintained under high initial inputs of organic and inorganic nutrients.


**Summary**

Excess soluble salts (EC 30 to 48 mS cm⁻¹), high alkalinity (pH 9.2 to 11.0) and potentially toxic levels of sodium (ESP 49 to 88 per cent) were characteristic of fly ash and bauxite wastes (“red sand” and “red mud”) from the Gladstone alumina refinery. In red sand, N and P levels were extremely low and Zn and Mn marginal; extremely low levels of N and P and a marginal amount of Zn were measured in the red mud. Fly ash was characterized by a potentially toxic level of B and deficiency levels of N and Zn.

The physical limitations of low water holding capacity of red sand and susceptibility of fly ash to wind erosion were reduced by mixing the wastes. Excess soluble salts in the fly ash-red sand mixtures were effectively removed by leaching without an accompanying decrease in the saturated hydraulic conductivities of the solids. Following the reduction in salinity, the pH values of the wastes remained high (8.4 to 9.6). Incubation of the ash and sand with NH₄NO₃, superphosphate, FeSO₄·7H₂O, FeS₂ and S for up to ten weeks demonstrated that FeSO₄·7H₂O was the most effective acidulant in the short term. Reduction of the excessive exchangeable sodium percentages in ash (49 per cent) and sand (88 per cent) to levels tolerable to plant growth was achieved by leaching and acidification.


**Summary**

In the absence of chemical limitations, the emergence and yield of Rhodes grass (*Chloris gayana*) on a 20 per cent fly ash : 80 per cent red sand mix were higher than those on fly ash or red sand alone or on the other mixes investigated. The poor emergence and yield in the red sand was attributed to the medium's low available water capacity and low unsaturated hydraulic conductivity. Mixtures containing from 40 per cent to 100 per cent fly ash were characterised by very low air contents at field capacity and were susceptible to water-logging. The extremely poor emergence and low yields observed in the mixtures containing 40 per cent and 60 per cent fly ash were considered to be due to high mechanical resistance to root ramification in addition to lack of aeration.

In the absence of the limitations of excess salinity, alkalinity and sodicity, deficiencies of nitrogen and phosphorous were the major restrictions to the growth of Rhodes grass on fly ash, red sand and a 20 per cent fly ash : 80 per cent red sand mix. Manganese was also limiting in the red sand, and boron was slightly deficient in fly ash, but these deficiencies were not present in the ash:sand mix.

In a nitrogen (NH₄NO₃) by phosphorous (Ca(H₂PO₄)·2H₂O) interaction trial on fly ash and red sand, maximum yields of Rhodes grass were obtained with 100 kg N ha⁻¹ (red sand) to 200 kg N ha⁻¹ (fly ash) and 400 kg P ha⁻¹. The severe yield depression which occurred at nitrogen rates greater than 200 kg ha⁻¹ on both wastes was attributed to NH₄⁺ toxicity aggravated by the dearth of nitrifying bacteria and wastes' low cation exchange capacities.

Abstract

The poor soil structure and low hydraulic conductivity of fine bauxite refining residue (red mud) from alumina production are the major factors hindering its revegetation. Red mud, disposed of by the dry stacking-method, was amended with gypsum (38.5 and 77 t/ha) and sewage sludge (38.5, 77, and 144 t/ha) to evaluate their effects on soil physical properties in a field experiment. Sewage sludge amendment significantly reduced bulk density (25%) and particle density (9%), and increased the total porosity of red mud (8%). Both sewage sludge and gypsum contributed to the increase in hydraulic conductivity of red mud (from 1.3 to 24 x 10-5 m/s) after one growing season. Plant cover percentage and dry weight yield of *Agropyron elongatum* increased with an increase in gypsum and sewage sludge amendment. Plant growth did not significantly affect soil physical properties, but the enhanced growth was due to improved soil structure and hydraulic conductivity. An application of 77 t/ha gypsum and 144 t/ha sewage sludge exerted the maximum effect on soil physical properties of red mud and should ensure the initial establishment of plants.


Abstract

One major issue confronting the alumina industry is the disposal and management of residues generated from the refining process. They occupy huge areas of land that are devoid of vegetation and subject to wind and water erosion. Hence rehabilitation of red mud storage areas is a high priority for the industry. The major constraints in rehabilitation are the high alkalinity, salinity and sodicity of the fine residue (red mud). This paper describes a technique developed at Murdoch University aiming at direct revegetation of red mud aided with waste gypsum and sewage sludge. Gypsum amendment followed by 126mm of rainfall leaching significantly reduced the pH, EC, Na content and ESP of red mud. The reduced pH also significantly suppressed the availability of Al in red mud. The improved soil conditions significantly enhanced the seedling emergence and growth of *Agropyron elongatum* (Tall wheat grass) and *Cynodon dactylon* (Bermuda grass) in pots receiving ≥ 5% gypsum amendment with supply of fertilizer. Sewage sludge amendment gave an additional reduction in EC, Na and ESP for gypsum amended red mud. No evidence of any significant increases in heavy metal contents were observed in the leachate following sewage sludge amendment. Growth of *Agropyron* in sewage sludge and gypsum amended red mud was comparable to that of gypsum amended red mud without fertilizer. The results confirm that direct revegetation of red mud can be achieved by amending red mud with 8% waste gypsum and 16% sewage sludge but sufficient leaching following gypsum amendment and initial fertilization are required for initial plant establishment. The technique is cost effective and requires no expensive topsoil loading nor major earth moving.


Abstract

The disposal of fine bauxite refining residue (red mud) has occupied huge areas of land which remain derelict and subject to wind and water erosion. The major constraints in rehabilitation are the high alkalinity, salinity and sodicity of red mud. This paper describes a greenhouse study to evaluate the use of waste gypsum as ameliorants for red mud. Red mud was amended with gypsum at 0, 2, 5 and 8% (w/w) and its effect on the growth of two grass species, *Agropyron elongatum* (Tall wheat grass) and *Cynodon dactylon* (Bermuda grass), was evaluated. Gypsum amendment significantly reduced the pH, electrical conductivity (EC), and Na and Al content of red mud and provided a continuous
supply of Ca\(^{2+}\), which resulted in a lower soil exchangeable sodium percentage (ESP). The improved soil conditions at \(\geq 5\%\) gypsum amendment significantly increased seedling emergence and dry weight yields. The enhanced plant growth and seedling emergence show significant negative correlations with pH, Al and ESP of soil. Tissue analyses indicated that the availability of P, K, Mg and Ca also increased for \(\geq 5\%\) gypsum amended red mud, while Na and Fe were less available. Results from the present study indicated that waste gypsum is an effective ameliorant for red mud revegetation and no topsoil amendment is required.


Abstract

The rise in aluminium demand in the world has significantly increased the generation of bauxite residue which occupies huge areas of land worldwide. Direct revegetation of residue storage areas has been unsuccessful because of the high alkalinity and salinity, and poor nutrient contents of the fine residue (red mud). This paper describes glasshouse and field experiments evaluating the potential use of sewage sludge as an organic ameliorant for gypsum amended red mud. The growth of Agropyron elongatum in red mud receiving gypsum (0 and 38.5 t ha\(^{-1}\)) and sewage sludge (0, 38.5 and 77 t ha\(^{-1}\)) amendment was assessed in a glasshouse study. Leachate and soil analyses revealed that gypsum was effective in reducing the pH, EC and ESP of red mud, while sewage sludge gave additional reductions in EC, Na and ESP. No evidence of any significant increases in heavy metal contents were observed in the leachates following sewage sludge amendment. However, soil Al contents were more available in red mud receiving only sewage sludge treatment. Sewage sludge amendment significantly increased dry weight yield and provided sufficient nutrients for plant growth except K which was marginal. No heavy metal accumulation was observed in Agropyron. Following that, a field experiment was performed having red mud amended with sewage sludge (38.5, 77 and 154 t ha\(^{-1}\)) and gypsum (38.5 and 77 t ha\(^{-1}\)) to evaluate their effects on soil physical properties of red mud. Sewage sludge significantly reduced soil bulk density (25%) and particle density (9%) and increased the total porosity of red mud (8%). Hydraulic conductivity also increased from 1.5 to 23 \(\times 10^{-2}\) m s\(^{-1}\). Plant cover percentage and dry weight yield of Agropyron increased with an increase in gypsum and sewage sludge amendment. The results confirm that sewage sludge is effective in improving both soil structure and nutrient status of gypsum amended red mud. The use of sewage sludge for red mud revegetation provides not just an option for sludge disposal, but also a cost effective revegetation strategy for bauxite refining industry.

101) Supply details of environmental measures designed to deal with premature closure of the facility. This shall include an estimate of the cost of decommissioning, rendering safe the plant and restoration proposals in this event.

An update to the Residuals Management Plan was prepared by RPS Group in 2005 and submitted to the EPA as part of the IPCL review. This report is given in Appendix O.