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Revegetation of gold-processing residue storage areas in the eastern jarrah forest of south-west Western Australia.

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Summary

Gold-processing residue produced at Boddington Gold Mine and Hedges Gold Mine is deposited in valley impoundments known as Residue Storage Areas (RSAs). These areas will be rehabilitated as part of the mine closure plans, though the rehabilitation prescription requires amendments to overcome those properties of residue that are unfavourable for plant growth. Treatments, such as gypsum and spreading of topsoil and gravel, have been identified that may improve conditions for vegetation growth by alleviating or decreasing the alkaline, saline, and sodic properties of the residue and increasing its hydraulic conductivity. The effectiveness of these treatments is now being tested in a large field experiment involving the growth of plant species endemic to the surrounding jarrah forest, as well as known salt and waterlogging tolerant species. The background and establishment of this experiment is the subject of this paper.

Ten months after application, 30 tonne of gypsum/ha has contributed to a decrease in residue surface pH, salinity, and sodicity. Applying gravel in addition to topsoil has not improved plant vigour or foliage cover in relation to plots with 10 cm of topsoil only. Factors that are causing better growth in the topsoil only treatment and the persistence of the effect are currently under investigation.

Introduction

Gold is mined near Boddington in the eastern jarrah forest, 125 km south-west of Perth, Western Australia at Hedges Gold Mine (now inactive) and Boddington Gold Mine (still operating). The majority of gold ore is the oxide clay/saprolite material from the regolith approximately 15 to 60 metres in depth.

Gold-processing residue is a challenging material to revegetate as it is characterised by extreme chemical and physical conditions limiting soil biological processes and the growth of most plants. It generally has a very low hydraulic conductivity (2×10^{-2} m day^{-1}), and high pH (9-10), salinity (EC 1:5 3-4 dS m^{-1}), and sodicity (62 % Exchangeable Na) (Bell *et al.*, 1999). Unamended residue storage areas (RSAs) therefore tend to have dry, salt-crusted surfaces in summer, and in winter become waterlogged with water pooling in low lying areas (Ho *et al.*, 1999).

The results of research conducted by Murdoch University (Ho *et al.* 1999; Bell *et al.* 1999) were used to prepare a draft revegetation prescription, aimed at generating a sustainable ecosystem in the RSA. Two components of this prescription deemed essential were the addition of topsoil and/or gravel to provide a suitable medium for plant establishment; and the application of gypsum at a rate of 30-60 t/ha to decrease pH and sodicity, facilitate flocculation, and improve permeability and leaching of salts. This paper describes the next phase of research involving a large-scale field experiment aimed at investigating the effectiveness of these two prescription components in achieving vegetation establishment.

The field experiment is located on the north-west corner of the R4 RSA at Boddington Gold Mine (BGM), covering an area of approximately 5 hectares. Most of the residue in this part of the RSA was estimated to be less than 2 metres deep. The field site was established over the period January to September 1999, involving in sequence: initial site characterisation, application of treatments, cultivation, direct seeding, seedling transplanting and inorganic fertiliser application.

Site characterisation

In order to define the most appropriate arrangement of plots and treatments, variability in residue physical and chemical characteristics over the field area was defined. The physical and chemical characteristics examined included residue field texture, % water content, depth, critical shear strength, pH, and electrical conductivity (EC). The sampling programme included the top 50 cm of residue, with the most intensive sampling conducted in the top 10 cm. Depth and shear strength was measured using a Dynamic Cone Penetrometer (DCP), to a maximum depth of 2 m.

The field texture of the residue ranged from a loam (Northcote, 1979) up to a light clay. The majority of the surface residue (0-10cm depth) material had a field texture equating to silty clay loam. Field texture was influenced by proximity to previous discharge points, with the coarse sandy particles deposited closest to the discharge point. BGM's residue deposition strategy utilises alternating discharge points, therefore at a given location and depth, the residue texture will be dependent on proximity to a discharge point and its time of operation. At the surface (0-10cm depth) an area of loam corresponded with the known location of the last discharge point to operate.

The majority of residue pH (1:5 water) values were between 9.5 and 9.8 with the mean pH at 9.6. There were no significant spatial patterns or trends in pH of the surface residue over the site. The pH tended to be slightly higher at the surface compared to further down the residue profile. The pH values were consistent with previous studies of gold-processing residue from Hedges Gold Mine (HGM) and BGM (Bell *et al.*, 1999; Samaraweera *et al.*, 1993) which report pH values of 9.3 and 9.5, respectively.

EC (1:5 water) varied over the site but was commonly between 2.5 and 5 dS/m, with a mean of 4.0 dS/m. EC was significantly higher ($p<0.05$) at the residue surface and dropped quickly with depth (Table 1). Previous studies have recorded diverse EC values for the residue at BGM and HGM (Samaraweera *et al.*, 1993; Bell *et al.*, 1999). Residue salinity is affected by the length of drying time, time of year, water content, and the amount of rainfall that has leached through the residue. Surface residue EC was also generally lower closer to the RSA 'beach', compared to that of deeper locations. A possible explanation for this is the greater migration of salts to the surface in areas that have a greater depth of residue.

As expected, surface residue was slightly drier than underlying layers, which increased progressively in water content with depth. All values were still high, with the surface averaging 19.5 % w/w water and the underlying residue with an average of 22 %. Variability in water content was caused by different texture at similar depths across the experimental area. The field capacity of the residue increased with increasing clay and silt content.

The primary purpose of measuring critical shear strength and residue depth was to assess residue trafficability for earthmoving equipment. Examination of the relationship between the shear strength values and residue field texture, moisture content, and depth are currently under investigation.

Table 1: Chemical analyses of topsoil, gravel and gold-processing residue.

Attribute	Topsoil	Gravel	Surface residue[1] (Jan 99)	Treated surface residue[2] (Feb 00)	Deeper residue[3] (Jan 99)
Conductivity (dS/m)	0.038	0.070	4.50	0.71	0.74
pH ($CaCl_2$)	5.4	5.8	9.0	8.4	8.2
pH (H_2O)	6.5	6.4	9.4	8.6	8.6
Nitrate N (mg/kg)	2	2	27	7	13
Ammonium N (mg/kg)	8	6	1	1	3
Total Nitrogen (%)	0.16	0.09	0.03	0.02	0.04
Colwell P (mg/kg)	3	3	9	7	6
Colwell K (mg/kg)	83	46	512	471	504
S (mg/kg)	15.2	66.4	517	259	306
Organic C (%)	1.62	0.87	0.14	0.13	0.13
Reactive Fe (mg/kg)	1939	1454	494	520	511
Exchangeable Cations					
Ca (cmol(+)/kg)	2.48	2.20	0.92	3.12	1.01
Mg (cmol(+)/kg)	0.85	0.71	0.78	0.91	1.00
Na (cmol(+)/kg)	0.26	0.18	24.08	3.04	8.13
K (cmol(+)/kg)	0.22	0.12	0.19	0.12	0.17
Trace Elements					
EDTA Fe (mg/kg)	214	125	16.6	16.9	33.7
EDTA Cu (mg/kg)	0.76	0.62	26.0	25.7	21.6
EDTA Zn (mg/kg)	0.3	0.40	1.15	2.47	1.36
EDTA Mn (mg/kg)	11.3	8.00	1.40	3.20	4.60

[1] Surface residue was from the top 10 cm of the profile.
[2] Same locations as surface residue in Jan 99. Treated with 30 t gypsum/ha in March 99.
[3] Deeper residue was from between 20 and 30 cm below the surface.

Experimental design and establishment

The main treatments being examined, are three depths of gravel overlying the residue that had been treated with a broadcast application of 30 tonnes of gypsum per hectare (Table 2). The treatments are replicated four times in a randomised block design, with the blocks based on the site characterisation results as described in Table 3. All plots subsequently received a surface application of 10 cm topsoil (Figure 1).

Table 2: Summary of treatments investigated in field experiments.

Treatment	Gypsum (tonnes/ha)	Topsoil depth (cm)	Gravel depth (cm)
1	30	10	0
2	30	10	15
3	30	10	30

Table 3: Summary of characteristics that define blocks in field experiment.

Block number	Properties of residue in blocks
1	Gradual increase in depth of residue away from beach compared to Blocks 2, 3, and 4. Generally higher EC compared to those blocks.
2	Mostly clay loam.
3	Finer surface material than Block 2, mostly silty clay loam.
4	Finer surface material than Block 3, large amount of residue is classed as light clay. Cracks in surface much deeper than other areas.

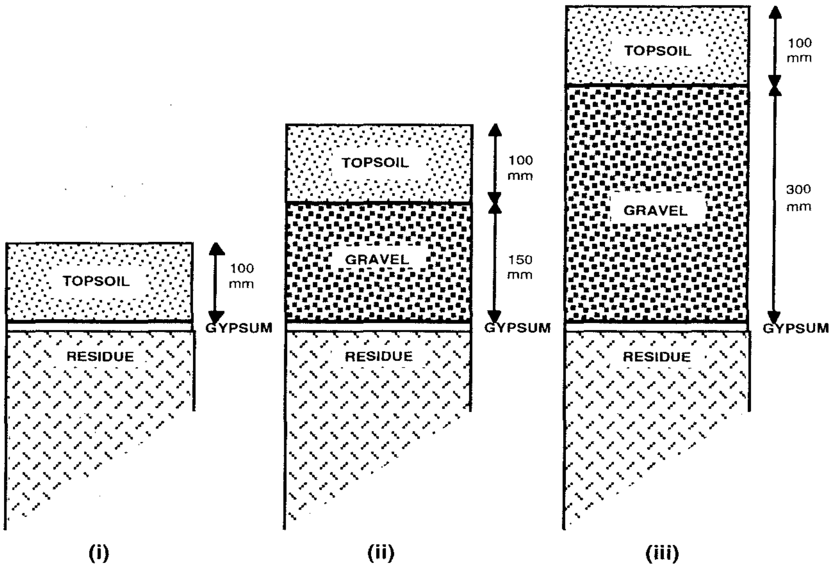

Figure 1: Cross-section of three different topsoil/gravel treatments showing location of gypsum layer, corresponding to treatments described in Table 1 as follows: (i) Treatment 1; (ii) Treatment 2; and (iii) Treatment 3.

The topsoil and gravel materials (Table 1) removed from the floor of the RSA before residue deposition has been stockpiled separately for approximately 10 years. The topsoil is a sandy gravel soil with some organic matter, while the gravel is made up of principally ferruginous gravel, and sand.

The plots were cultivated and seeded in May 1999, and 8 month old nursery grown seedlings transplanted in mid-July 1999. The seed mix was a blend of species known to occur in the jarrah forest that surrounds BGM and HGM, together with selected salt and waterlogging tolerant Australian native species. The seedlings were selected species from the seed mix list, and were included to allow early observations of plant survival and vigour on the treatments. Inorganic fertiliser was broadcast in late August 1999 (Table 4). Monthly assessments of vegetation commenced in August 1999 and were conducted up to March 2000.

Table 4: Constituents and rate of inorganic fertiliser application, 28th August 1999.

Fertiliser Constituents	Target Application Rate (kg/ha)
Urea	150
Super phosphate with Cu Mo Zn	400
Superphosphate	400
Muriate of Potash	60
$MnSO_4$	24
TOTAL	1034

Preliminary observations

There was a decrease in surface residue pH and salinity from late January 1999, prior to gypsum spreading, to early February 2000 (Table 1). Exchangeable Na in the residue decreased greatly between 1999 and 2000 from 24 to 3 cmol(+)/kg, while exchangeable Ca increased from 0.9 to 3.1 cmol(+)/kg. These changes in chemical attributes have been attributed to gypsum decreasing pH, and dissolved Ca replacing Na on soil exchange sites thereby decreasing clay dispersion and encouraging the leaching of salts through the profile.

It was hypothesised that with increasing depth of substrate overlying the residue, survival and vigour of plants established in plots would be higher. It was anticipated that a deeper substrate would provide a larger zone for roots to grow in before reaching the residue, which was thought to be adverse to plant growth compared to the topsoil and/or gravel overlying it. Waterlogging in winter and drought in summer were expected to be less on deeper treatments.

A quantitative assessment in March 2000, found that plants growing on 10 cm topsoil only (Treatment 1) were the most vigorous compared to those on treatments with a gravel layer overlying the residue in addition to 10cm of topsoil (Treatments 2 and 3). Mean vigour, % cover, and seedling heights were all significantly higher ($p<0.05$) for Treatment 1 plots compared to Treatments 2 and 3. There were no differences between Treatments 2 and 3.

Preliminary excavations conducted in April 2000 found that plant roots are growing in the residue, but are growing preferentially in cracks or in layers of coarser residue (clay loam and loam). Further excavations may be scheduled in early 2001 to further investigate root growth in the residue.

Discussion

Current research is investigating possible causes of improved plant growth in the topsoil only treatment (Treatment 1). Three factors have been identified as the possible cause(s) of this response.

> The majority of residue at or near the surface (0-50cm depth) had a gravimetric water content of around 20%, even in mid-summer, although actual plant available water content has yet to be determined. The gravel layer, with a much lower field capacity dries out more in summer. Therefore if plant roots can access water held in the underlying residue they will fare much better than plants in thicker gravel treatments, where roots must grow further to reach the residue. This factor is being investigated

using soil water measurements, in the field and laboratory, together with plant water status assessment (water potential, stomatal conductance).

Gravel has lower concentrations of essential nutrients and trace elements, such as nitrate N, K, Zn, and Cu, than residue (Table 3). Complexes containing N, provided by the refining process, may be a potential nutrient source for plant growth. Plant roots would reach the residue faster and in greater abundance in Treatment 1, and hence may be getting more nutrients, enhancing growth. A comparison of gravel and residue chemical analyses, and nutrient analyses of plants are being used to investigate this factor.

A third possible cause for poorer growth with gravel is that there are fewer macropores for air and water movement in the gravel layer. This reflects heavy trafficking during spreading and the relatively low finer soil fraction in the gravel matrix. As a result, root exploration may be inhibited and plant growth on these treatments depressed. Field excavations, and a glasshouse experiment simulating compaction of the gravel layer, are being used to determine if this is a significant factor.

To assess these hypotheses, it must first be determined if there are differences in root growth between treatments, and determine if there is a penalty for plants with comparatively fewer roots penetrating into residue. Both hypotheses 1 and 2 depend on the concept that plant growth will be disadvantaged if none or only some of their roots reach residue. If either of these two factors are causing the enhanced growth in the no gravel treatment, it is possible that the effect is only short term. When more roots in the thicker treatments reach the residue, plant growth may respond and therefore these initial effects may not be noticeable after several years. It is also noted that the vegetation established at the field site has not yet experienced a full winter, therefore future vegetation assessments are required to determine the persistence of the observations.

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