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Role of soil covers in establishment of vegetation on gold oxide refining residues☆

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ABSTRACT

Revegetation of ore refining residue may be limited by the physical and chemical constraints of the material, necessitating the use of soil covers and ameliorants to improve conditions for plant growth. The aim of this study was to establish the depth of soil cover needed to establish vegetation on saline, sodic, alkaline residue in a mediterranean climate, Western Australia. The effects of three soil covers (10 cm topsoil plus nil, 15 or 30 cm of gravel-rich subsoil (referred to as gravel), on the residue) compared to no cover, of residue ameliorants (broadcast gypsum or compost), and the influence of shrinkage-cracks on plant density, species richness, leaf stress symptoms and root abundance were examined in a 2-year field experiment. Seedling density on topsoil covers, recruited from the topsoil seedbank and broadcast seeding, was 10-fold higher than that on bare residue. Live canopy cover with topsoil-only over residue was consistently higher than with topsoil over gravel. Plant roots preferentially grew along the faces of the vertical shrinkage-cracks, as well as fine horizontal cracks and through coarser textured residue strata and had greatest abundance and depth in residue covered by topsoil-only. However, seedling density and species richness declined with topsoil-only cover compared to the thicker cover treatments in the second year. Leaf symptoms from salt damage developed in plants established with topsoil-only on residue. Increasing gypsum broadcast on residue from 30 to 60 t ha^{-1} increased root abundance and penetration, but had no effect on seedling density. We conclude that the 10 cm cover of topsoil-only, while potentially cheaper to establish, and providing greater initial vigour and vegetation cover, had diminished species diversity after 2 years relative to thicker covers. By contrast the thicker cover (10 cm topsoil plus 15–30 cm gravel) slowed initial growth, but combined with 60 t gypsum ha^{-1} broadcast on the residue, resulted in the most diverse plant community and most vigorous root growth on saline gold oxide processing residue.

1. Introduction

Restoration following mining usually establishes vegetative cover as a means of stabilising the disturbed substrates (Carolina and Belén, 2005). Successful ecological restoration depends on the establishment, growth, and reproduction of plants within the target community (Gillespie and Allen, 2004). Direct seeding, applying topsoil containing a seed bank, or transplanting seedlings have marked catalytic effects on forest development (succession) on severely degraded sites relative to unplanted sites (Parrotta and Knowles, 2001). However, constraints in the substrate may severely hamper restoration (Bell, 2013).

The revegetation of ore refining residues (or 'tailings') frequently encounters a complex of soil constraints such as acidity, salinity, insufficient nutrient supply, metal toxicity, low water holding capacity due to the coarse texture and poor structure (Dollhopf, 1998; Jones et al., 2010; Komnitsas et al., 2010). The constraints, which vary among types of residues, are often ameliorated by topsoil and ameliorant treatments such as fertilizer, lime, organic manure, gypsum and cultivation (Bell, 2013). Past research has centred on revegetation of ore refining residues such as red mud (bauxite refinery residues), and metal-mining residues (Wong and Ho, 1994; Wilden et al., 2001; Carolina and Belén, 2005). Gold-processing residue is characterised by extreme chemical and physical conditions likely to limit both soil biological processes and the growth of most plants. The gold

☆ A preliminary account of the results were presented in McGrath et al. (2003).
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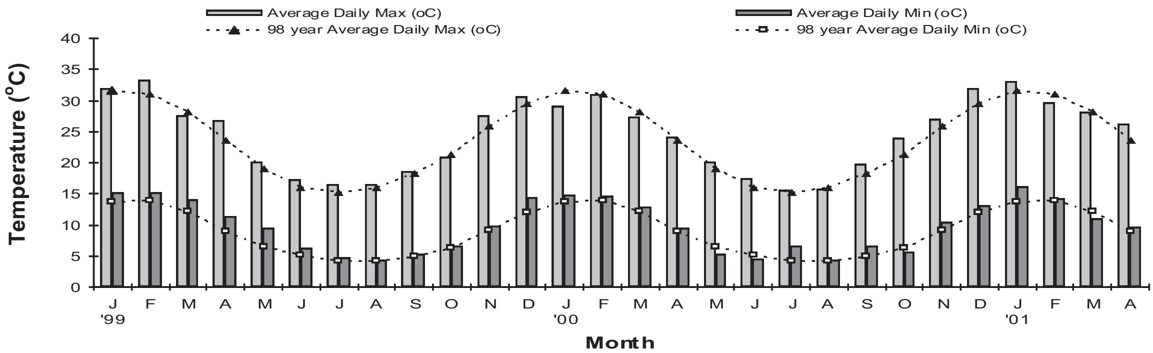

Fig. 1. Average monthly maximum and minimum temperatures for Wandering (25 km E-NE of Newmont Boddington Gold mine) from January 1999 to April 2001. Averages for last 98 years shown as continuous lines (Bureau of Meterology, 2001).

refining residue from regolith ore has very low hydraulic conductivity (2×10^{-2} m day^{-1}), high pH (9–10), high salinity ($EC_{1:5}$ 3–4 dS m^{-1}), and extreme sodicity (62% exchangeable Na) (Bell et al., 1999). Unamended residue storage areas (RSA) therefore tend to have dry, salt-crusted surfaces in summer, and in winter become waterlogged with water pooling in low lying areas (Rayner et al., 1996).

For many residues, a capping barrier is applied to restrict the entry of water and plant roots into the toxic underlying substrate (e.g. Gilfedder and Lottermoser, 2008). Generally, the objective is to place a compacted capping over the residue that minimises the infiltration of water or penetration of roots. By contrast, Zhang et al. (2001) found that with a cover of at least 8 cm of topsoil placed directly on Pb/Zn tailings, plant establishment was feasible without a barrier to root penetration into the residue. There is very little information regarding the need for covers on saline gold oxide refining residue for revegetation.

Placement of soil covers after surface treatment of gold oxide refining residue with gypsum was effective in ameliorating physical and chemical constraints (Ni et al., 2014). At the RSA of Newmont Boddington Gold (NBG), the $EC_{1:5}$ was found to decline substantially (from 4.5–5.0 to about 1.0 dS m^{-1}) in the residue surface (0–10 cm), measured after the first season's rainfall, following surface application of gypsum and cover with topsoil and gravel. Surface residue pH also decreased from 9.0 to 8.0, and exchangeable Na percentage (ESP) decreased dramatically. Conversely, the salinity of the cover materials, which was initially very low ($EC_{1:5}$ 0.04–0.07 dS m^{-1}), increased to $EC_{1:5}$ 0.40–0.45 dS m^{-1} in the first 10 cm above the residue in the second summer season following placement indicating migration of salts into the cover materials. This was mitigated by provision of the gravel layer between the topsoil and residue, with ESP in topsoil not increasing where there was a 15 or 30 cm gravel layer separating it from residue compared with an increase from 17 to 70% in topsoil placed directly on the residue surface (i.e. with no gravel). Increasing gypsum from 30 to 60 t ha^{-1} did not contribute to further decrease in residue surface pH, salinity, or sodicity. Most nutrient elements did not differ with gypsum rate and compost amendment except for S, on account of the high gypsum rate, and extractable P and Mn, which were elevated by compost (Ni et al., 2014). Based on these improvements of chemical properties, we hypothesized that gravel cover placed between residue and topsoil will contribute to higher vigor vegetation because of lower EC and ESP in topsoil, and 60 t of gypsum ha^{-1} will have a similar effect on plant growth as 30 t ha^{-1}, while compost may improve vigor of vegetation by elevating supply of nutrients, particularly P and Mn.

In this study, the aim was to examine: (1) the effect of a layer of gravel cover separating topsoil from residue and its thickness on plant emergence and seedling growth; (2) the benefit of doubling broadcast gypsum from 30 to 60 t ha^{-1} for plant growth; (3) the effect of compost on plant growth; and (4) whether shrinkage-cracks in residue or layers of coarse residue had measurable effects on plant growth. To address these aims, the effects of topsoil or no topsoil (bare residue), gravel cover thickness (0, 15, 30 cm), gypsum rates (30 and 60 t ha^{-1}), compost application (0, 50 m^3 ha^{-1}) and shrinkage-cracks in the residue on plant emergence, seedling density, plant survival, plant vigour, live cover, height, species richness and diversity, and root abundance were examined over two years.

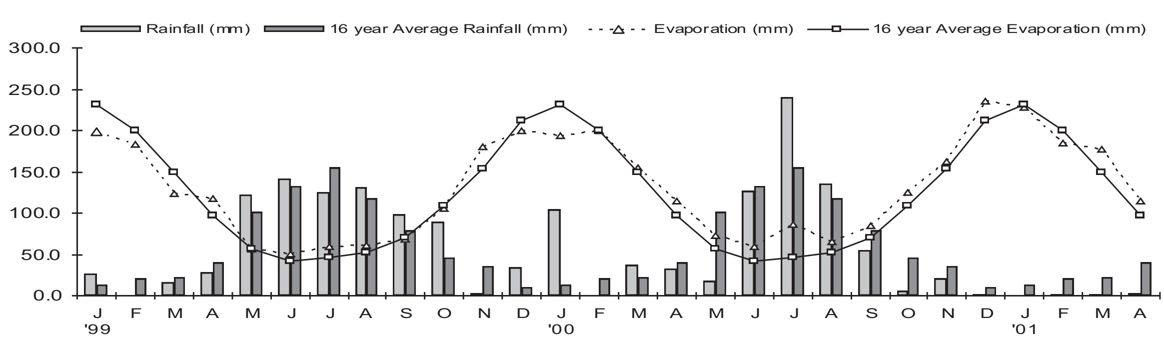

Fig. 2. Average monthly rainfall and pan evaporation for Newmonth Boddington Gold mine from January 1999 to April 2001. Averages for last 16 years are also shown (Bureau of Meterology, 2001).