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Soil factors affecting revegetation success on nickel waste dumps

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Abstract

The primary objective of this research was to investigate the constraints for successful mine waste dump revegetation at the Bulong Nickel Operation (BNO) in the arid *Eucalyptus* woodlands of the Eastern Goldfields of Western Australia. The chemical properties of two waste dump substrates (overburden) and one sub-soil at BNO were investigated to determine the nature of the material and its suitability for growth of two local species, the legume, *Acacia acuminata* ssp. burkittii and the salt tolerant blue bush, *Maireana pyramidata*.

The most serious constraint affecting successful plant growth on the waste dumps at BNO was the inhospitable nature of the overburden used to construct the dumps. *Maireana* tolerated the sodicity and salinity of the waste dump substrate but grew poorly especially on one of the substrates that contained very high levels of 0.01 M $CaCl_2$-extractable Ni. Many *Acacia* plants died on this substrate. The difficulty with growing plants satisfactorily in the pot experiment suggested that the establishment of sustainable ecosystems capable of restoring arid landscape function would be difficult on these materials. Current rehabilitation plans envisage the creation of waste dumps using this material and placing a 15-cm layer of topsoil over the top as a seedbed for germination and plant growth. In the short term the spread of topsoil will aid plant establishment however once plant roots penetrate sodic, high Ni waste dump material it is possible that only salt tolerant and Ni tolerant species will persist. Further research is required to investigate the effect of gypsum and organic matter on the physical properties of the material and the subsequent effect on plant growth. However, it is strongly recommended that systematic characterisation of the sub-soils and overburden materials at BNO be undertaken to determine if more benign substrates can be identified in the mine waste steam and used for revegetation.

Introduction

Overburden is one of the main waste materials from open-cut mining. It comprises either regolith or waste rock or both and is usually generated in substantial quantities. Special waste dumps are constructed to contain this material followed by revegetation of the upper and outer wall surfaces to create a stable landform. In many parts of the arid zone of WA, regolith overburden is characterised by high levels of salinity and or sodicity (Bell *et al.* 1995; Osborne *et al.* 1996). In addition on base metal mines, the overburden though containing insufficient ore for processing, may still contain significant levels of the minerals of interest. In other cases, sulfide minerals in the overburden from base metal and precious metal mines requires special handling strategies to avoid acid mine drainage. Thus waste dumps embrace a range of difficult constraints to revegetation. Systematic research is required to identify and overcome these constraints.

The chemical properties of two waste dump substrates derived from overburden and one sub-soil at BNO were investigated to determine the nature of the material and its suitability for growth of the legume, *Acacia acuminata* ssp. burkittii and the salt tolerant blue bush, *Maireana pyramidata*.

Materials and methods

Mining for nickel ore has commenced in several pits at the BNO, about 30 km east of Kalgoorlie. Topsoil (0-10 cm depth) was sampled in summer from a 1 ha woodland site in an unmined area near the Mints stockpile. Sub-soil was sampled from 100 cm depth in an alluvial channel near the Albion pit. Samples were also collected (0-10 cm) from waste dumps of overburden material from the Albion and Mt Lyall pits. Samples were analysed by CSBP and the Government Chemical laboratories (DTPA and $CaCl_2$ extractable Ni only) for chemical properties as described by Rayment and Higginson (1992).

Two kg (topsoil) or 1.7 kg (sub-soil and overburden) portions of sieved substrates (< 2 mm) were placed in pots lined with plastic bags. A thin layer of topsoil (10 cm) collected from the same site as the substrate was placed over the sub-soil and overburden materials to create a better seedbed for seed germination. Soils were either unfertilised or treated with complete basal fertiliser at rates taken from Jasper *et al.* (1988). Nutrients were mixed in the top 5 cm of the substrate. Pots were placed in temperature-controlled water baths at 25 °C, and substrates watered to 95 % field capacity. After 1 week, 10 seeds of *Acacia acuminata* ssp. burkittii and *Maireana pyramidata* were sown per pot. *A. acuminata* seeds were immersed in water which had been bought to the boil to break hard seededness before sowing. *M. pyramidata* fruit were debracted before sowing. Seed had been collected from within 100 km of Kalgoorlie. Soils were watered daily to 95 % field capacity. Alkathene beads were placed on the surface of substrates to reduce evaporation from the surface and reduce soil temperature. Plants were thinned after 2 weeks to two *A. acuminata* and three *M pyramidata*. After 6 and 10 weeks growth, *M pyramidata* and *A. acuminata* , respectively were harvested. Shoot dry matter and root fresh weight were recorded.

Results and Discussion

Most substrates available for revegetation at Bulong including topsoil, sub-soil and overburden were alkaline (Table 1). The Albion overburden was the only exception but this material was only mildly acidic. Whereas topsoil was non-sodic, sub soils and overburden were highly sodic (Purdie 1998) and some of the materials also contained high levels of exchangeable Mg which may exacerbate a tendency to dispersiveness. Exchangeable Ca levels varied greatly among the substrates with very low levels in the Albion overburden. The Albion sub-soil and overburden had the highest electrical conductivity and were marginally saline for most plants (Purdie 1998).

Low levels of Colwell-extractabl;e P was found in all the substrates (Purdie 1998), especially in the sub-soil and overburden materials (Table 1). By contrast, NO_3- N was low in topsoil and Mt Lyall overburden but quite high in the Albion sub-soil and overburden. Levels of other essential elements (K, S, Ca, Cu, Mn, Zn, Fe) were all more than adequate for plant growth although levels of S in topsoil and Cu in Mt Lyall overburden were marginal (Table 1: data not shown for K, Mn, Zn, Fe).

Table 1. Chemical properties of topsoil (0-10 cm), sub-soil (100 cm depth) and overburden substrates from Bulong Nickel Operation.

	Topsoil	Albion sub-soil	Albion overburden	Mt Lyall overburden
Exch Mg (cmol/kg)	6	16	25	5
Exch Ca (cmol/kg)	13.0	14.8	1.66	0.31
Exch Na (cmol/kg)	0.6	25	24	9
ESP (%)	2.7	45	47	61
Electrical conductivity (1:5)(dS/m)	0.04	0.53	0.34	0.19
pH ($CaCl_2$)	7.4	7.5	5.9	8.2
NO_3-N (mg/kg)	4	22	67	7
Organic C (g/kg)	15	5	3	0.4
Colwell P (mg/kg)	7	3	2	3
DTPA Ni (mg/kg)	11	Nd	97	0.1
EDTA Cu (mg/kg)	4.6	2.8	1.7	0.3
Extractable S (mg/kg)	7.3	730	900	220

Nd- not determined

In unfertilised sub-soil and overburden, growth of both species was strongly depressed compared to that in the topsoil (Table 2). *A. acuminata* failed to respond to fertiliser application in any of the substrates. In the sub-soil and overburden, this was linked to leaf necrosis on old leaves resembling a salt toxicity, and significant plant mortality. This suggests that the sodicity of the sub-soil and overburden was the major constraint to Acacia growth and survival possibly by causing excessive sodium uptake. However, the substrates in the pot experiment also had poor physical properties due to sodicity which may have impeded root growth and function.

Maireana responded strongly to fertiliser on topsoil (Table 2). On Albion sub-soil and Mt Lyall overburden, shoot fresh weight responded to fertiliser but growth was depressed compared to that on topsoil, and besides plants were still relatively stunted in appearance and pale. On Albion overburden, shoot fresh weight failed to respond to fertiliser and plants were stunted with yellowish older leaves. The poor growth of *M. pyramidata* on the Albion overburden the and lack of response to fertiliser is unlikely to be due to the salinity of the material since Maireana is a halophyte and none to the EC values were high enough to limit growth of a halophyte (Purdie 1998). It cannot be attributed to sodicity since this was higher on Albion sub-soil and Mt Lyall overburden where growth was responsive to fertiliser.

The very high levels of DTPA extractable Ni and high levels of $CaCl_2$ extractable Ni (20 mg/kg *vs* 0.5 mg /kg in Mt Lyall overburden and topsoil) are the most likely factor accounting for poor growth of *M. pyramidata* on Albion overburden. Bergmann (1992) suggests that total nickel concentration of 100 mg Ni/kg soil is toxic to dwarf beans and oats. Bergmann (1992) also reports that Ni added to the soil at as low as 2.5 mg Ni/kg soil is toxic under acid soil conditions (pH 4.7), whereas at pH 6.2, plants tolerate up to 75 mg Ni applied/kg soil.

General Discussion

The most serious constraint for successful revegetation of the waste dumps at BNO is the inhospitable nature of some of the overburden used to construct the dumps. *Maireana* tolerated the sodicity and salinity of the Albion waste dump substrate but still grew poorly: Many of the *Acacia* plants died on these substrates. The difficulty with growing plants satisfactorily in the pot experiment suggested that the establishment of sustainable ecosystems capable of restoring arid landscape function would be difficult on these materials. Current rehabilitation plans envisage the creation of waste dumps using this material and placing a 15-cm layer of topsoil over the top as a seedbed for germination and plant growth. In the short term the spread of topsoil will aid plant establishment however once plant roots penetrate the sodic waste dump material it is possible that only salt tolerant halophytes will persist. Clearly this strategy needs re-examination.

Table 2. Effect of fertiliser application on shoot fresh weight of Maireana pyramidata and *Acacia acuminata* on topsoil, sub-soil and overburden materials. The fertiliser treatment had no significant effect on shoot fresh weight of *A. acuminata* so only the main effects for substrates is presented.

	Topsoil	Albion sub-soil	Albion overburden	M t Lyall overburden
M. pyramidata				
Unfertilised	1.8	0.1	0.1	0.2
Fertilised	3.3	2.2	0.5	2.2
LSD 0.05 = 0.7				
A. acuminata				
Main effect	0.99	0.19	0.16	0.22
LSD 0.05 = 0.06				

Options available to revegetate the sodic, saline waste dumps would be:

- direct seeding with a high rate of salt tolerant halophytes (Osborne *et al.* 1996). However, it is unclear whether this approach would be adequate for restoring landscape function and establishing nutrient cycles;
- the use of gypsum and organic matter to ameliorate the poor physical structure of the sodic waste dump material.

Further research is required to investigate the effect of gypsum and organic matter on the physical properties of the material and the subsequent effect on plant growth. The gypsum responsiveness of the sodic substrates can be tested using laboratory tests and pot experiments. However, field evaluation of the short and long term effectiveness of gypsum and organic matter needs to be conducted at BNO since this will depend on rainfall distribution, pore size distribution of the material and effectiveness of incorporation of these amendments.

However, it is most important that research be undertaken into the characterisation of the sub-soils and overburden materials at BNO to determine if more benign substrates can be identified within the overburden and sub-soil materials in the mine waste steam. Capping or layering the more benign materials over the top of the sodic waste dump may be the answer to sustainable revegetation.

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