A COMPARISON OF VEGETATION DEVELOPMENT ON COARSE COAL REJECT AND REPLACED TOPSOIL ON AN OPEN-CUT COAL MINE IN CENTRAL QUEENSLAND, AUSTRALIA

by

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Abstract. In 1988, the University of Queensland commenced a research program at Curragh coal mine in the Bowen Basin of central Queensland to examine factors that would encourage the growth of a cover crop sufficient to control soil erosion, but not so competitive as to hinder the establishment of native species. Weed and grass growth from the soil seed store in replaced topsoil often has a negative impact on the establishment and survival of sown native tree and shrub species. In contrast, good establishment has been achieved using a surface mulch of coarse coal reject. Longer term data confirm the beneficial effect of coarse coal reject, with approximately 4500 trees/ha on coarse reject after 10 years compared to 300 trees/ha on replaced topsoil. The difference is attributed largely to the competitive effects of the dense ground cover on topsoil at initial establishment. However, there are two potential problems for the long-term sustainability of communities on coarse coal reject. Firstly, reject is very low in nutrients and microbial biomass, limiting the satisfactory development of nutrient cycling. Secondly, it is often saline and will be likely to continue to generate salt with weathering, raising concerns over the success of secondary recruitment. It is concluded that coarse coal reject can play a role in successful tree and shrub establishment and hence in increasing the diversity of post-mining ecosystems. However, careful management is required to avoid the use of saline materials, and strategies need to be explored to increase its biological activity.

Additional Key Words: rehabilitation, salinity, nutrient cycling, sustainability.

Introduction

The Curragh open-cut coal mine is located in central Queensland (23°30'S, 148°52'E) towards the southern end of the coal-rich Bowen Basin and approximately 200 km west of Rockhampton. Almost 70 Mt have been mined since operations began in 1983, with a current production of around 4 Mt/a. More than 600 ha have been rehabilitated since 1989. The rehabilitation program has emphasised the establishment a self-sustaining community with an upper storey of native trees and shrubs (mostly eucalypts and acacias) and a ground cover of exotic pasture grasses. In more recent years, however, there has been a growing interest in returning a significant portion of the mined land to native ecosystems, which in turn support native fauna.

In March 1988, a direct seeding field trial was commenced on reshaped dragline spoil. The trial was designed to examine the effects of cover crop seeding rate, fertiliser rate and substrate on, firstly, the establishment and growth of both cover crop and native tree and shrub species, and secondly, the response of native species establishment and growth to the competition from both the sown cover crop and volunteer weeds and grasses. A primary objective was the determination of a specific combination of inputs that would result in the development of cover sufficiently vigorous to protect the soil surface and control erosion, but not so competitive that the establishment of native species would be excessively hindered. The media and/or vegetative characteristics of this site have since been monitored on seven occasions, the most recent being in April 1998.

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It had previously been recognised that when topsoil was replaced on re-contoured spoil, competition from weed and grass species present within the soil seed store markedly reduced the establishment rate of native tree and shrub species. This is a fairly widespread problem throughout the Bowen Basin, but particularly in the soils available at Curragh. One option was to use herbicides and other management inputs to control the grass competition, and a second was to not use topsoil but sow directly into spoil. However, high sodicities and crust strengths were typical characteristics of some of these spoil materials. This would reduce establishment success and hence the value of spoil as a seedbed. A third option has been to use coarse coal reject as an alternative to topsoil for capping the spoil. There are observed establishment advantages (through its role in acting as a surface mulch to reduce the surface-sealing of the spoils) and defined cost advantages in using coarse coal reject. The material is cheaper than topsoil to source and apply and because it does not support the level of grass cover, also removes the need for the application of herbicides to control grass/weed competition for tree establishment. At a number of coal mines in the Hunter Valley of New South Wales, the use of coarse coal reject as a surface mulch on areas of reshaped spoil has proven to be beneficial for the establishment of trees by direct seeding. The mulch provides greater micro-relief and better sites for seed germination, as well as reducing crust formation and thus improving infiltration (Hannan and Gordon 1996).

Within the context of the much larger experiment, this paper specifically reports the results of comparisons over time of vegetation success (with respect to native tree/shrub establishment and growth) on spoil cappings of topsoil and coarse coal reject. Data is also presented on temporal changes in the chemical properties throughout the two reconstructed profiles.

Background

Environment

The climate of the region is subtropical with a concentration of rainfall in the period November to March when 75% of the annual average of 625 mm is received. Early wet season rain is usually associated with thunderstorms leading to high spatial variability and high intensities. Temperatures also vary and heatwave conditions of 35–40°C are frequently experienced in the warmer months. Evaporation exceeds rainfall in every month of the year and annually by a factor of three.

The pre-mining terrain was mostly gently undulating plains and lowlands, with slopes in the range of 2–5%. The two main soil types on the lease area are cracking clays (brown and grey/black) and texture contrast soils, with the former occupying the greater area. Grazing was the main land use in the lease area, and only small remnants of the original brigalow (*Acacia harpophylla*) woodland communities remain on the mine site due to the clearing practices of the past.

Trial Design

The full details of trial establishment, treatments applied and plot layout are presented in Orr (1993). In summary, six native tree and shrub species (*Acacia aneura, Acacia saligna, Casuarina cristata, Corymbia citriodora, Eucalyptus camaldulensis,* and *Eucalyptus crebra)* were direct seeded (at a combined rate of 6.3 kg/ha) onto four media types, with further fertiliser and cover crop sowing rate treatments superimposed. The media types were bare spoil, spoil amended with gypsum (3 tonnes/ha), replaced topsoil at two depths (15 cm and 30 cm over spoil) and replaced coarse coal reject (7.5 cm over spoil). There were four replicate plots for each treatment combination, with each plot measuring 5 m x 5 m surrounded by a 1 m buffer strip. The treatments were replicated on two slopes (2% and 8%), but longer-term monitoring has been restricted to the former. The results reported here relate to the comparative responses of the developing vegetation communities on the coarse coal reject and replaced topsoil treatments only.

Sampling and Assessment Methods

The trial was established in March 1988, and assessments were conducted in June 1988, October 1988, July 1992, March 1993, July 1993, November 1995 and again in April 1998. The treatments sampled included both replaced depths of topsoil plus the coarse coal reject, superimposed on which were two cover crop (Rhodes grass – *Chloris gayana*) seeding rates (0 and 6 kg/ha) and two fertiliser rates (40 kgN/ha / 20 kgP/ha and 160 kgN/ha / 80 kgP/ha). The N was applied as ammonium nitrate and the P as single superphosphate. For most of the parameters referred to in this paper, the rate of fertiliser application at the time of trial establishment has had minimal impact on the outcomes. Therefore, unless specifically referred to, the data presented are either averages of both fertiliser treatments or solely that of the response at the 160 kgN/ha and 80 kgP/ha combination. The topsoil used in this trial was a brown clay, representative of the soil covering most of the lease. It had been stockpiled for approximately four years in a shallow grassed mound, having originated from an area of the lease that had previously been cleared of native woodland species and used as grazing pastures for a number of years. The coarse coal reject was taken from a dump where it had been stored for approximately six months.

On each sampling occasion, all trees and shrubs were identified and their height recorded. Ground cover was assessed using a sighting tube (point-intercept method) on a grid of 64 points (1 m x 1 m spacing) across each plot. Where yield was measured, four 0.5 m x 0.5 m quadrats were randomly selected within each plot, and all ground cover removed. The harvest from each plot was sorted into either species (in the case of the major grasses present) or categories (eg. broad-leaved weeds). Fresh weights were measured immediately and then subsamples taken for drying (60°C for 48 h) to allow conversion to oven-dry weight estimates.

In 1992 and 1995, 100 cm deep cores (two per plot) were collected using a 38 mm diameter coring tube and electric jackhammer. The cores were divided into intervals of 0–1 cm, 1–10 cm, and at 10 cm intervals thereafter. Since the spoil was capped with either soil or coarse coal reject, the depth increments were varied to coincide with the interface. Samples were air-dried, ground to <2 mm and analysed for pH and EC on 1:5 aqueous extracts. In the 1998 sampling, only the upper 10 cm was collected and analysed for pH and EC. At the time of trial establishment and again during the 1992 sampling, additional chemical properties of the surface 0–10 cm fraction were determined for the two media. These included organic C, nitrate-N, total N, mineralisable N, available P, sulfate-S, exchangeable cations (K, Ca, Mg and Na), chloride, copper, zinc, iron and manganese. Microbial biomass was also measured in the top 10 cm of the profile in 1992, 1995 and 1998. The samples were kept cool prior to biomass determinations using the incubation-extraction method of Amato and Ladd (1988).

Results

Tree and Shrub Density

The total density of the native trees and shrubs was significantly higher on the coarse coal reject than on topsoil, and remained so over time (Figure 1). Numbers of trees were often very low on replaced topsoil plots and those that were present were typically localised to plot margins where topsoil was prone to greater erosion and grass cover was less. Total tree and shrub densities declined with time on both topsoil and coarse coal reject treatments (Figure 1), although by seven years (1995), numbers had generally stabilised.

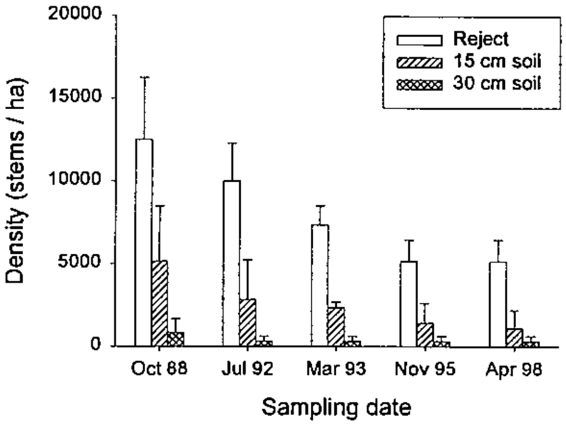

Figure 1. Total tree and shrub density over time in relation to the type of spoil capping material. Data are means and standard errors (bars) of four replicate plots per treatment, sown with a cover crop of Rhodes grass at 6 kg/ha and a fertiliser input equivalent to 160 kgN/ha and 80 kg P/ha.

The decline in total density was caused partly through the natural senescence of the relatively short-lived *Acacia saligna* (Figure 2). The second *Acacia* species sown, *A. aneura*, failed to establish in the trial at all initially. However, in recent years, a few specimens have been recorded in the coarse coal reject areas (mainly in plots outside the current monitoring program), an indication of the longevity of the seed and its ability to remain viable in the substrate.

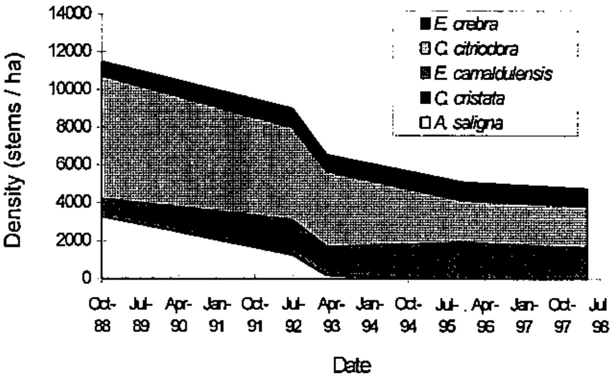

Figure 2. Changes over time in the mean densities of individual species growing on the spoil capped with coarse coal reject.

While *Corymbia citriodora* was the dominant tree species growing on the coarse coal reject initially, at ten years the relative proportions of the other two *Eucalyptus* species had increased. *Casuarina cristata* had comparatively much lower initial rates of establishment on the coarse coal reject than did the other species and it has remained a minor component of the canopy structure ever since.

Even after ten years, the initial effects of cover crop competition were still showing their impact, as evidenced by the significantly decreased density of trees and shrubs in the coarse coal reject plots originally sown with Rhodes grass (Figure 3).

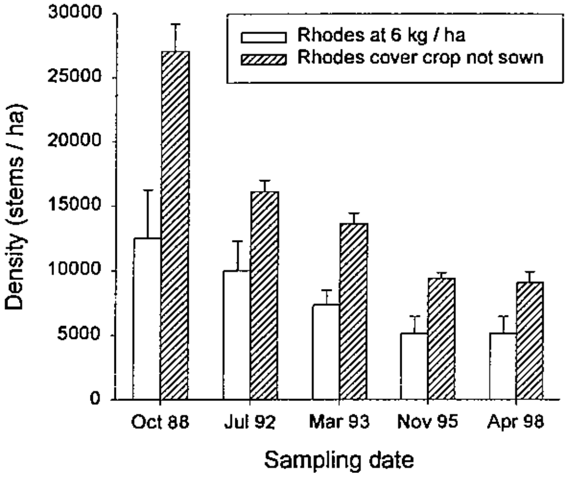

Figure 3. Effect of Rhodes grass seeded at 6 kg/ha on the densities of total trees and shrubs growing on spoil capped with coarse coal reject. Data are means and standard errors (bars) of four replicate plots per treatment, and fertiliser input equivalent to 160 kgN/ha and 80 kg P/ha.

Trees surviving after ten years were 2–5 m in height (data not shown), with *C. citriodora* generally higher than the other species in most treatments. Although uncommon in occurrence, the tallest eucalypts were found on the treatments with the deeper topsoil capping, but differences between the capping materials (and the depths thereof) were not statistically significant. As was the case for tree density, height growth on the coarse coal reject capping was greater in those treatments where a cover crop was not sown.

Ground Cover

Twelve weeks after trial establishment, 38 weed species were recorded in the replaced topsoil plots, and weed biomass exceeded that of the sown Rhodes grass by a factor of 10 (Orr 1993). At 30 weeks, similar yields of weed species and Rhodes grass were measured on the replaced topsoil (30 cm) plots (about 1t/ha of each). By 1992, however, more than 95% of the total ground cover biomass and projected cover was buffel grass (*Cenchrus ciliaris*). The higher drought tolerance of this species compared to Rhodes grass, and the high occurrence of the species in the surrounding environment apparently favoured its expansion and persistence. Grass yields averaged 9 t/ha on the topsoil plots and less than 0.5 t/ha on the coarse coal reject. In terms of cover *per se*, the average on the topsoil plots in 1992 was 70% and on the coarse coal reject plots, less than 7% (Figure 4).

By the time of the 1998 sampling, the percentage ground cover on replaced topsoil had remained very high (Figure 4), and was still comprised almost exclusively of buffel grass. While there was some fluctuation in the percentage cover on topsoil over time, presumably due to seasonal differences and drought conditions, the cover on coarse coal reject remained at less than 15% even after ten years.

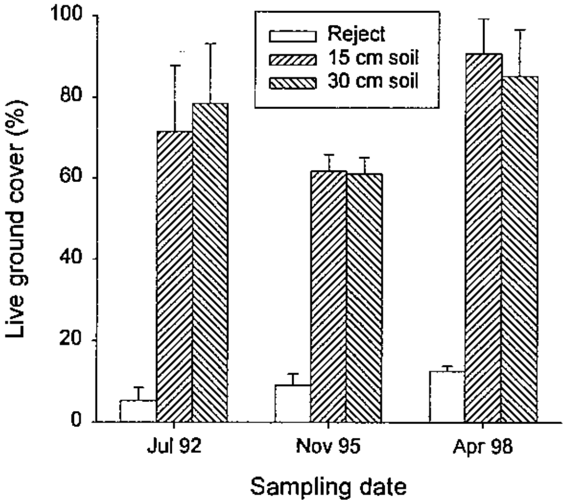

Figure 4. Live ground cover over time in relation to the type of spoil capping material. Data are means and standard errors (bars) of four replicate plots per treatment, sown with a cover crop of Rhodes grass at 6 kg/ha and a fertiliser input equivalent to 160 kgN/ha and 80 kg P/ha.

Media Characteristics

Results from a comprehensive chemical analysis of the upper 10 cm of the profiles from each of the treatments are presented in Table 1. The pH of the spoil itself averaged 9.4, the soil 8.6 and the coarse coal reject 5.8. Available P concentrations in the two capping materials were similar, and the 1998 analysis of P concentrations in the foliage of *C. citriodora* growing on coarse coal reject (approximately 0.08%) showed there had been little change over the previous six years. Sulfate levels in the coarse coal reject were high, and these were reflected in the higher EC values for this material.

Table 1. Mean values for a range of chemical properties of the surface (0–10 cm) material from the soil and coarse coal reject plots in July 1992. Samples from the two soil treatments have been combined.

Measurement	Units	Extractant	Soil	Coal reject
pH		1:5 H_2O	8.6	5.8
EC	dS/m	1:5 H_2O	0.11	1.41
Organic C	%		2.47	5.86
Organic N	%		0.20	0.34
NO_3-N	mg/kg	1:5 H_2O	1.0	0.6
Mineralisable N	mg/kg		33.7	7.7
SO_4-S	mg/kg	0.01M $Ca(H_2PO_4)_2$	11	1738
P	mg/kg	0.5M $NaHCO_3$	22	25
K	cmol(+)/kg	1M NH_4OAc	1.36	0.21
Ca	cmol(+)/kg	1M NH_4OAc	28.4	19.4
Mg	cmol(+)/kg	1M NH_4OAc	7.8	2.7
Na	cmol(+)/kg	1M NH_4OAc	0.34	0.06
Cl	mg/kg	1:5 H_2O	9	5
Cu	mg/kg	0.005M DTPA	1.3	1.9
Zn	mg/kg	0.005M DTPA	0.7	1.9
Mn	mg/kg	0.005M DTPA	1.8	25.0
Fe	mg/kg	0.005M DTPA	5.6	50.0

The soil had 2.5% organic C and as would be expected, the concentration in the reject was high, albeit not in a form that was of nutritional benefit to the plants. The coarse coal reject also had a higher nitrogen content than the soil, but because very little of it was mineralisable, the potential of this substrate to supply N to the vegetation is greatly reduced.

In the 1998 sampling, the surface 10 cm was collected and pH and ECs were compared with samples from the equivalent depth in the previous collections (Table 2). The surface values indicate fluctuating conditions but a general persistence of original differences between media, notably the high salt load in coarse coal reject. However, surface characteristics are subject to short-term variability, and sampling results are partly dependent on timing in relation to climatic conditions, particularly rainfall. They therefore have a limited ability to detect changes due to treatment effects. The salt and pH profiles for the 30 cm replaced topsoil had not changed markedly over time (Figure 5), and similarly for the shallower topsoil depth (data not shown). However, this was not the case for the coarse reject treatment (Figure 6). Under this treatment, leaching of salts from the weathering coarse reject appeared to have contributed to an increase in EC in the spoil below, to a depth of approximately 50 cm. A feature of the 1995 samples is the high variability in readings for the upper 50 cm of the profile, indicating that the process of salinisation is not uniform across the plots. At the same time, there was a drop in pH at the reject/spoil interface and in the upper 20 cm of the underlying spoil.

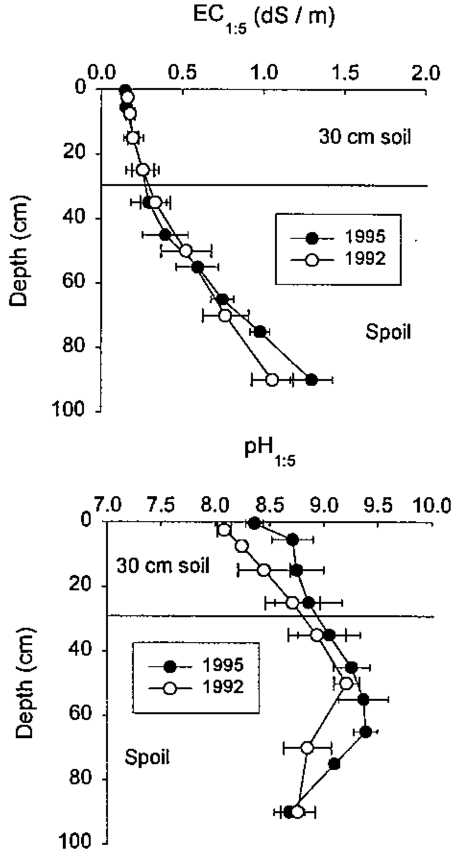

Figure 5. Salt and pH profiles for the 30 cm capping depth of topsoil over spoil in 1992 and 1995. The bars represent standard errors of the means of eight cores per treatment (two cores from each of four replicate plots). The horizontal line indicates the approximate topsoil/spoil interface.

Table 2. Surface (0–10 cm) pH and electrical conductivity (EC) of each capping material at three sampling times (July 1992, November 1995 and April 1998). Values are the means from four replicate plots and the two fertiliser rates have been combined.

Spoil capping	pH (1:5 H_2O)			EC (1:5 H_2O) dS/m		
	1992	1995	1998	1992	1995	1998
15 cm soil	8.7	8.5	7.7	0.11	0.15	0.09
30 cm soil	8.6	8.7	8.1	0.11	0.16	0.09
Coal reject	5.8	5.8	6.0	1.41	1.75	1.18

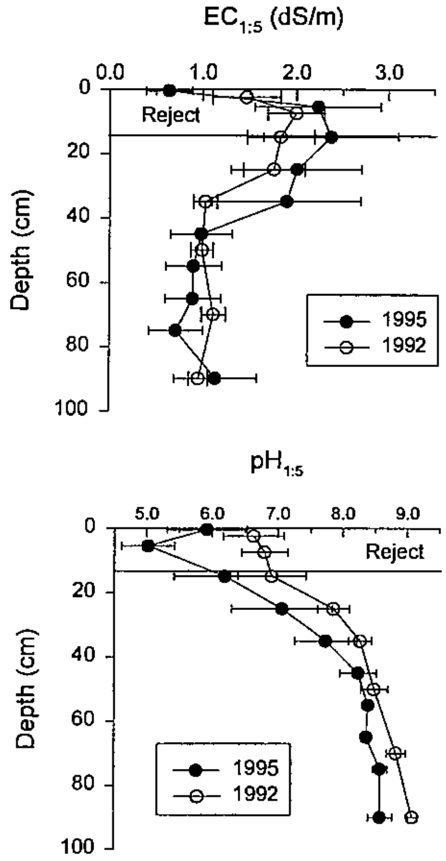

Figure 6. Salt and pH profiles for the spoil capped with coarse coal reject in July 1992 and November 1995. The bars represent standard errors of the means of eight cores per treatment (two cores from each of four replicate plots). The horizontal line indicates the approximate depth of the coarse coal reject.

Microbial Biomass

Soil microbial biomass was significantly higher in topsoil compared to coarse coal reject (Figure 7). Microbial biomass was unaffected by the rate of fertiliser application and the data presented are averages across all rates. In topsoil, levels were significantly higher at the 1995 sampling when compared to the 1998 collection, but the latter were at similar levels to those reported for samples taken in 1993, suggesting possible seasonal effects.

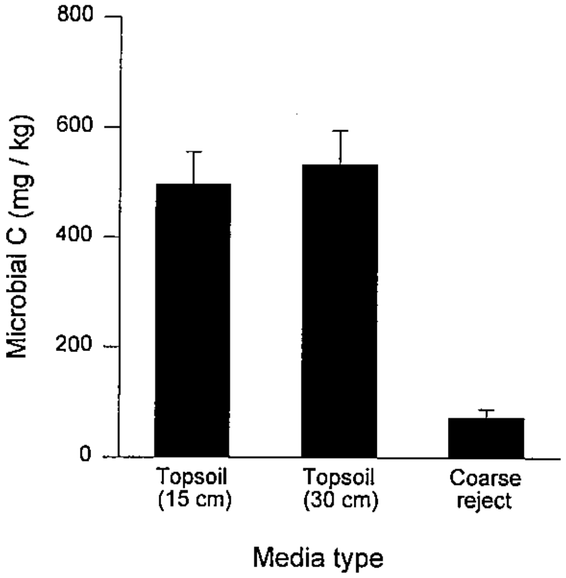

Figure 7. Soil microbial biomass in the surface 10 cm of the different capping materials. Data presented are the means and standard errors (bars) of combined results from two samplings in 1995 and 1998.

Discussion

Most of the decline in total tree and shrub density on the coarse coal reject is associated with the senescence of the *Acacia* species, and as such is to some extent a natural and expected trend. There will also be some natural thinning of the remaining eucalypts as competition between individuals increases with increasing tree size, and a continuing decline would therefore also be expected into the future. After 10 years, densities are still very high in relation to mature eucalypt woodlands in the region (200–400 trees/ha; Burrows and Burrows 1992), giving some confidence that pre-mining tree and shrub densities are achievable.

There is currently very little evidence of secondary recruitment of any of the eucalypt species on the coarse coal reject, or indeed the topsoil. Several of the trees have seeded, discounting the possibility of immaturity of the population. On topsoil, the persistent and dense ground cover of buffel grass is likely to provide an ongoing competitive barrier to recruitment, as happened during the early stages of trial establishment, and the lack of new seedlings is not surprising. On the coarse coal reject, however, the extent of cover is far less, suggesting that other factors may be important. One of the chemical characteristics of this material is that as weathering proceeds, salts are generated, in this experiment resulting in increased salinity at approximately 5–50 cm depth between 1992 and 1995 (Figure 6). Analysis of cores more recently sampled is required to determine whether the process is continuing, but the poor ground cover on coarse coal reject even after 10 years, suggests that salinity could be impacting on the success of the second generation of tree establishment. More recent observations and experiments on younger areas of established vegetation on coarse coal reject, however, have been more positive, with at least some *Acacia* species colonising onto pre-existing areas of this substrate.

One of the other key issues associated with establishing vegetation on non-soil media is whether the material has the capacity to supply nutrients for long-term sustainability. Soil organic matter includes part of the living biomass of the soil (animal, plant and microbial) as well as non-living decomposing organic residues. The dynamics of this soil component is recognised as one of the key processes regulating ecosystem sustainability through its effects on soil physical and chemical characteristics, microbial activity and nutrient supply (Woomer *et al.* 1994). This is a critical component virtually absent in coarse coal reject, at least initially. Microbial biomass, the active component of soil organic matter which includes bacteria, fungi, actinomycetes, protozoa, algae and microfauna (Jenkinson and Ladd 1981, Sparling 1985), is very low in the coarse coal reject and shows little improvement over time. It plays an important role in biogeochemical cycling of plant nutrients and soil structure development (Schnurer et al. 1985, Tate 1985). Given that the microbial populations and activities are crucial to decomposition processes, this finding raises the issue of nutrient supply and cycling for ecosystem sustainability. The potential exists that the cycling of essential plant nutrients may be limited, and if this situation continued, the result could be an ecologically unstable community that would require on-going inputs to ensure its survival. In order to comprehensively address these issues, a litter decomposition experiment was instigated and a survey conducted of the mesofauna, one of the facilitators of litter breakdown. These current studies are comparing rates of litter breakdown in communities established on coal reject and on replaced topsoil, determining the dynamics and release of nutrient elements from decomposing litter on the two substrates, and relating these findings to the chemical and biological properties of each substrate.

Notwithstanding the above considerations, many (although not all) of the other areas across the mine where coarse coal reject has been applied are, like the 1988 trial, supporting successfully established and healthy plants. The identifiable reasons for such improved tree and shrub establishment are the promotion of higher infiltration rates (cf. spoil) and the reduction in grass competition (cf. soil). Additional studies at the mine have been designed to provide further quantitative information on the advantages and disadvantages of using coarse coal reject as a spoil capping. Attention is focussed on the impacts of coarse coal rejects on native ecosystem development and future sustainability, and the assessment of potential impacts on the chemical and physical properties of the underlying media and on groundwater and runoff water quality.

The need for ongoing research was further stimulated by the fact that not all coarse coal reject areas were becoming as saline as others, and thus an attempt has been made to determine the variability in the properties of the coarse coal reject as it leaves the coal preparation plant. Samples from across the strike length of the mine and from each of the three seams from which coal is recovered have been collected. Since the coal quality varies markedly throughout the deposit, ranging from high quality coking coal to domestic steaming coal, it is therefore likely that the type and properties of the reject material could likewise vary considerably. It is possible that some of the reject material, properly managed in terms of replacement depth and organic matter and biological inputs, could prove to be a successful substrate for the longer term sustainability of the reconstructed native ecosystems.

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