CHAPTER 7.
Amelioration Options for Rehabilitating Areas with Stockpiled Topsoil

7.1 INTRODUCTION

Inorganic fertilisers are more commonly used in mine rehabilitation in the Hunter Valley than organic fertilisers due to the costs and difficulty level of application associated with organic treatments. However, a number of research trials have been conducted on organic ameliorants that emphasised their potential use in mining rehabilitation (Phillips, 1994b; Parker and Grant, 2001). For example, Parker and Grant (2001) found that the application of biosolids in rehabilitation in the Hunter Valley open cut coal-mines has the potential to increase the growth of native and exotic grass species. The benefits of biosolids include a source of organic matter, a source of plant nutrients (e.g. nitrogen, phosphorus, potassium and micronutrients including boron, copper, iron, manganese and zinc), improvement to soil structure and acceleration of microbiological development (Tisdale *et al.* 1985; Phillips, 1994a).

While direct inoculation of legume seeds with microbes (i.e. *Rhizobium*) has been attempted in a number of rehabilitation programs in the Hunter Valley (Hannan and Gordon, 1996), most sites have relied on inoculation from topsoil. If topsoil is stockpiled and its inoculum potential decreases, direct inoculation may be required. Inoculation is required when high numbers of the appropriate microbe are not present in the soil and they must be introduced by adding them to the seed at sowing. This inoculated seed may also be pelleted by adding a protective layer of fine ground limestone to improve survival of the microbe that is important when sowing in direct contact with acid fertilisers (Gemell and McDonald, 2002). Biological inoculum has been trialled in the Hunter Valley only for legume seed. This process is expensive and the application of a thin layer of fresh topsoil may be a more cost effective technique that could be used as a biological ameliorant in rehabilitated areas receiving stockpiled topsoil. Where plant species are to be established quickly after reclamation, 5 cm of freshly stripped topsoil over re-spread, stored topsoil may act as a mycorrhizal inoculum (Thurber Consultants *et al.,* 1990). The addition of these ameliorants may improve stockpiled soil quality and allow larger stockpiles to be created as long as the appropriate amelioration takes place in the rehabilitation process.

The glasshouse trial (chapter 6) investigated management strategies that can be utilised once stockpiled topsoil is respread. All of the investigated ameliorants affected some of the chemical and biological parameters that were assessed. Organic fertiliser (biosolids) generally increased chemical parameters and some biological parameters to a greater extent than the inorganic treatment (DAP) indicating improvement to soil fertility. Addition of fresh topsoil increased some vegetation parameters but not microbial activity. These results were used to design a field trial where topsoil from the stockpile field trial (chapter 5) was spread in rehabilitated areas and exposed to various ameliorants. The objective of this chapter was to investigate the effects of different chemical (biosolids and di-ammonium phosphate) and biological ameliorants (fresh topsoil and liquid inoculum) on soil and vegetation characteristics of respread topsoil from stockpiles varying in age and height.

7.2 METHODOLOGY

7.2.1 Experimental Design and Treatments

The field trial was established at three mines in the Hunter Valley to evaluate the effectiveness of ameliorants on topsoil quality and plant productivity. At each site, the 2, 4 and 6 m stockpiles were spread 18 (April 2002) and 30 months (April 2003) after creation respectively (chapter 5) with three chemical and three biological ameliorant treatments applied over three replicates (Table 7.1). The experimental design involved 54 treatments at each site and a total of 486 plots (10 m x 10 m).

Table 7.1: Treatments for field rehabilitation trial.

Treatments	Total	Description		
Mines	3	Bengalla	Cheshunt	Mt Arthur Coal
Age (months)	2	18	30	-
Height (m)	3	2	4	6
Chemical ameliorants	3	Control	Organic fertiliser	Inorganic fertiliser
Biological ameliorants	3	Control	Liquid inoculum	Fresh topsoil
Replications	3	-	-	-
Total number of plots	486			

At Cheshunt and Mt Arthur Coal mines, the trial design was a large block of 90 m x 90 m involving a 90 m x 30 m plot for each stockpile height (2, 4 and 6 m), repeated for the two ages (18 and 30 month stockpile spreads; Figure 7.1; Appendix 7.1). Bengalla mine, on the other hand, developed a field design that was a large block of 270 m x 30 m involving a 90 m x 30 m plot repeated another two times horizontally across the slope, divided into three topsoil stockpile heights (2, 4 and 6 m; Figure 7.2). Within each of the 30 m x 30 m plots were nine 10 m x 10 m plots where the chemical and biological ameliorant treatments were applied (7.2.2). The ameliorants were applied in a strip-split plot design, an extension of the criss-cross design (Mead, 1988; Figure 7.1; Figure 7.2). To minimise confusion with terminology the rest of this chapter will reference the 18 month stockpiled topsoil as the 1st spread and the 30 month stockpiled topsoil as the 2nd spread.

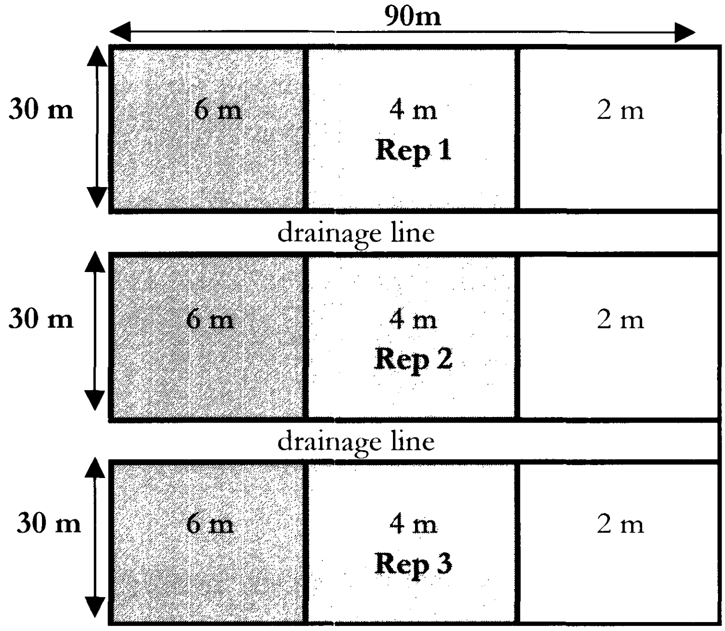

Figure 7.1: Example of stockpile height layout at Cheshunt mine site

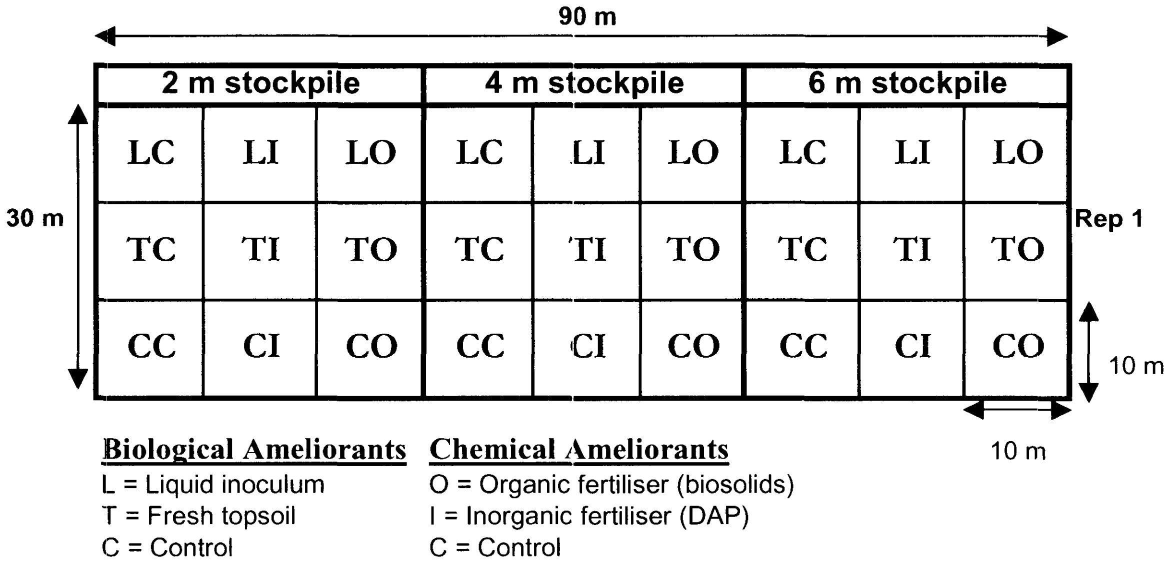

Figure 7.2: Strip-split plot design treatments in the field.

Sites at each mine had a similar slope (<10°) for the rehabilitation trial. Surveyors pegged out areas of different topsoil stockpile height treatments where the soil was to be spread. Each mine then spread the topsoil using their standard rehabilitation procedures. For the 1st spread at Bengalla, the topsoil was stripped from the stockpiles with a dozer, trucked to the site and later spread by dozer. For the 2nd spread, topsoil was stripped with a dozer, dumped close to the plot, reloaded onto small 4WD trucks and dumped onto the plot area, and later spread with a dozer. Mount Arthur Coal used scrapers for the spreading of the topsoil, while Cheshunt used a dozer and trucked it to the site, shaping and ripping with dozer tynes to a 250 mm depth (Figure 7.3 a,b).

a) b)

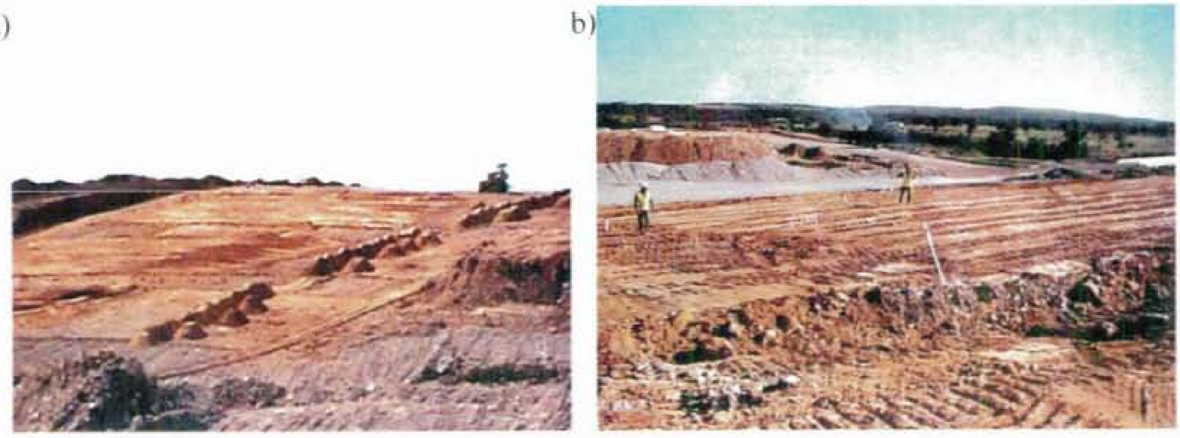

Figure 7.3: (a) Spreading of topsoil and (b) pegging out of plots at the Cheshunt mine.

7.2.2 Application of Ameliorants

The three chemical treatments were a control, inorganic and organic fertiliser. The inorganic treatment involved application by hand of 200 kg/ha of di-ammonium phosphate (DAP). The organic treatment involved application of biosolids, supplied by Hunter Water Corporation, delivered and dumped in a 'wet form' adjacent to the trial area. Prior to delivery at each mine, however, Hunter Water Corporation had conducted a soil analysis of biosolids application areas and biosolids nutrient and contaminant levels were classified (refer to Appendix 7.2). At all three mines, the application of biosolids to the rehabilitated areas was by a small dozer or tractor and a belt spreader, applied at 50 dry t/ha (equivalent to 250 wet t/ha - containing 21.4% solids, 3.33% N, 1.41% P; Figure 7.4 a-c).

a) b) c)

Figure 7.4: (a) Biosolids being put into the spreader, (b) spreading of biosolids on a rehabilitation site and (c) rehabilitated area following spreading (all at Cheshunt mine).

The three biological treatments were a control, liquid inoculum and fresh topsoil. A general liquid inoculum was developed based on legume species recorded in the glasshouse management trial (chapter 6) by the University of Newcastle (refer to Appendix 7.3 for inoculum development methodology). The liquid inoculum was applied using spray packs with a 1:10 concentration of the solution (Figure 7.5a-b).

The fresh topsoil was extracted near a creek bed (where possible) where the soil was of a moist nature and rich in organic matter. Soil was stripped and dumped adjacent to the rehabilitation areas and 130 kg per plot (where 1 m^3 = 1.3 t of soil) was applied to the individual plots. The fresh topsoil was applied by hand to create a thin layer of coverage (approximately at 1 mm thickness; Figure 7.6 a-c; see Appendix 7.4 for chemical and biological status of the fresh topsoil). For the 2nd spread at Cheshunt, fresh topsoil was distributed with a spreader.

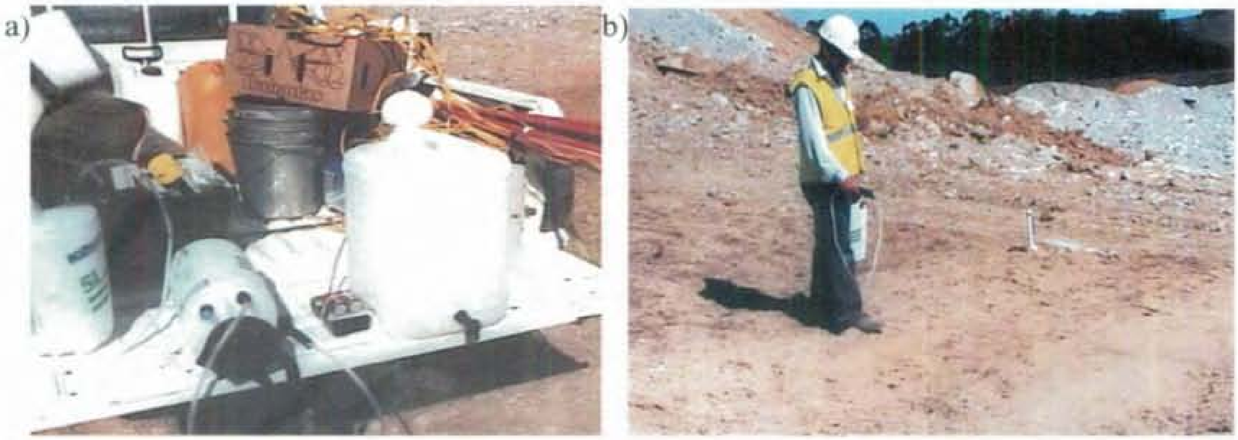

Figure 7.5: (a) Liquid inoculum being aerated and (b) spray application of inoculum in the field (at Cheshunt mine).

Figure 7.6: (a) Fresh topsoil collection by backhoe, (b) fresh topsoil bucket load and (c) manual spreading of fresh topsoil on plots (all at Cheshunt mine).

A physical ameliorant, gypsum (calcium sulfate - $CaSO_4.2H_2O$ - 18% sulphur) was only applied at Mt Arthur Coal (MAC) at a rate of 5 t/ha due to the high clay content of the soils. This follows recommendations from the glasshouse trial (chapter 6). Contractors applied the gypsum using a truck or spreader before the chemical and biological ameliorants were applied (Figure 7.7 a-b). Bengalla and Cheshunt mines did not use gypsum as soil types on the mine lease and under current rehabilitation procedures indicated no need for this ameliorant technique to be used.

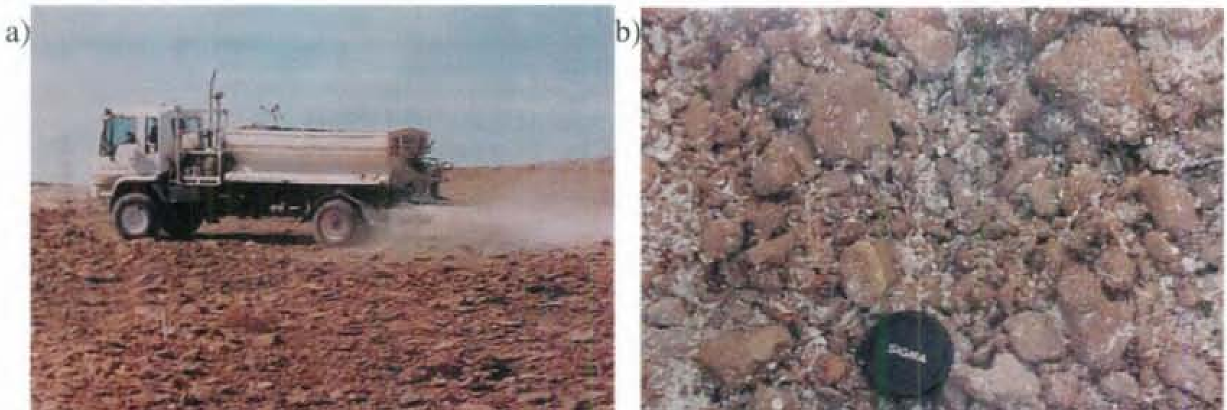

Figure 7.7: (a) Spreading machinery for gypsum and (b) close up of gypsum applied to the soil at Mt Arthur Coal mine.

7.2.3 Ripping and Seeding

Ripping operations utilised a dozer with a three-tyned ripper configuration, with the spacing between each tyne approximately 1.3 metres (Figure 7.8a-b). Ripping depth at Bengalla and Mt Arthur Coal mines following topsoiling and addition of ameliorants was a minimum of 300 mm, and 200 mm at Cheshunt. This was essential to establish a seedbed suitable for the direct seeding of native species by a seed hopper mounted at the rear of a dozer. Ripping occurred along the contour of the 10^{o} batter slopes and any associated bunds. Rocks greater than 200 mm, which may be brought to the surface following ripping, required removing and placing outside of the rehabilitation area.

All plots were seeded at a rate of 50-60 kg/ha following ripping (see Appendix 7.5 for seed mixes at each mine site). Cheshunt seed mix was inoculated with a limestone coating. Bengalla and Mt Arthur Coal mixed fertiliser with the seed (Granuloc and Starter 15, respectively). Poor pasture establishment occurred at Mt Arthur Coal following the first spread due to the lack of rainfall (see 7.2.5) and the area was re-seeded 12 months later.

a)

b)

Figure 7.8: (a) Ripping of the area and (b) seeding of the rehabilitation area at Cheshunt mine.

7.2.4 Soil and Vegetation Monitoring

Soil was collected 6 months after each establishment of the rehabilitation area (1st and 2nd spreads) from all 486 plots and analysed for chemical and biological parameters. In addition, soil was collected 18 months after the 1st spread for comparison of soil parameters across assessment time. Four soil samples within each plot were collected using hand trowels to a depth of 20 cm and were mixed in a bucket with a sub-sample of this collected in plastic bags for chemical analyses, while samples for biological analyses were sub-sampled and stored in 120 ml plastic containers. Soil for the biological analyses were stored in a portable insulated container in the field before being refrigerated at 4°C at the University of New England until they could be analysed. This maintained soil moisture and microbial activity. All plastic bag soil samples were dried at 40°C for two weeks at the University of New England. At Mt Arthur Coal, the 1st spread was compared to a direct return area of the same age, where five quadrats were used to collect soil samples to analyse chemical and biological parameters.

Once dry, the soil was sieved (<2 mm) and was transported to CSBP (Perth, Western Australia) for chemical analyses. Soil chemical properties measured were: pH (1:5 soil water), electrical conductivity, total organic C (loss on ignition converted to SOC), total N (Leco combustion, comparable to Kjeldahl digest), nitrate nitrogen (NO_3-N - 2M KCl), ammonium nitrogen (NH_4-N - 2M KCl), total P (Kjeldahl digest), available P (Bray), and where possible exchangeable cations (Ca, Na, K, Mg - NH_4Cl extract). Analytical techniques have been described in earlier chapters (see chapter 4 or 5). Microbial respiration in the soil from each site was measured using KOH incubation test and was carried out at the University of New England laboratories (see chapter 4).

In the centre of each 10 m x 10 m plot, a 1 m x 1 m quadrat was established and all plant species (native and non-native) were identified and their density and cover estimated. Vegetation monitoring was undertaken at 6, 12 and 18 months for the 1st spread and only at the 6 month assessment time for the 2nd spread. In addition, five 1 x 1 m quadrats were randomly located in the direct return area at Mt Arthur Coal as a comparison.

All above ground biomass (sown species and weeds) was collected in a 0.5 m x 0.5 m (0.25 m^2) quadrat from one random location in each of the 81 plots at the Cheshunt mine only, at the 18 month time assessment of the 1st spread and the 6 month assessment of the 2nd spread. Biomass was also collected in the direct return area at Mt Arthur Coal. Each vegetation sample was dried for 48 hours at 70°C and weighed to give total biomass.

7.2.5 Environmental Field Conditions

The trial was established in April 2002 and the final monitoring was undertaken in October 2003. Rainfall in the first seven months following establishment of the trial was below average (Figure 7.9). From May to October in 2002, the area received 31.6% of the long-term average for those months, compared to the year 2003 that received 51.6%. From November 2002 to April 2003, the area received 82% of the long-term average for those months. However, similar total rainfall data occurred for 2002 and 2003 (446.0 and 433.3 mm, respectively), compared to the long-term average total of 619.0 mm. The lack of rainfall following establishment of the trial in April 2002 had the greatest impact.

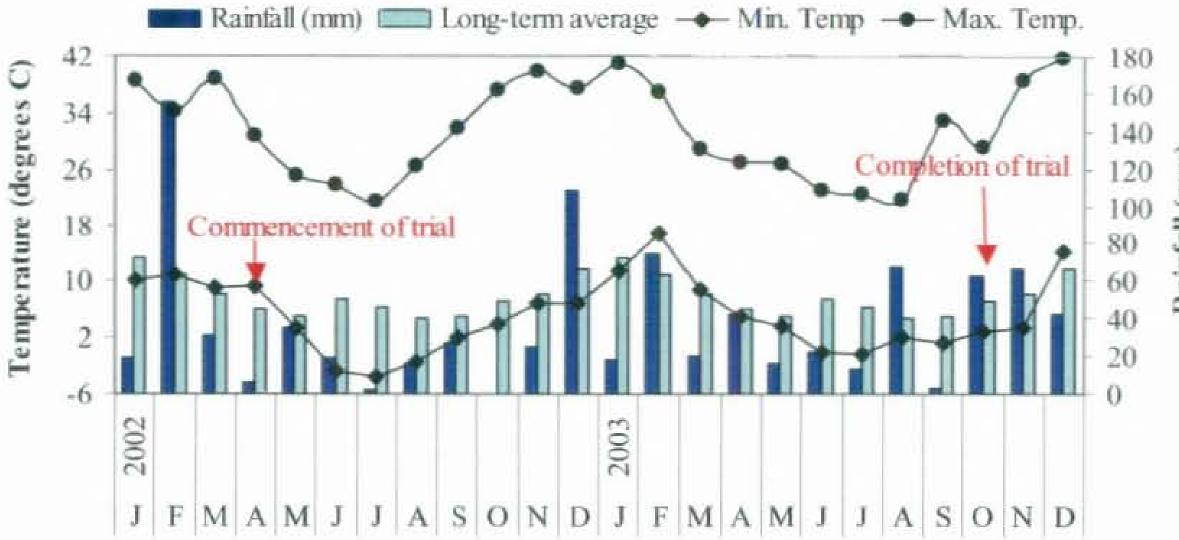

Figure 7.9: Average rainfall (mm) and temperature (°C) in 2002 and 2003 indicating commencement (April 2002) and completion (October 2003) of the rehabilitation trial.

7.2.6 Statistical Analyses

The data were first subjected to ordination to determine the most dominant factors across all chemical and biological parameters. Ordinations were carried out using Detrended Correspondence Analysis (DCA) in the CANOCO™ application. The ordinations used mean values of the three replicate samples taken from each rehabilitation plot. Data were range standardised prior to analysis.

Using the statistical program R (Inaka and Gentleman, 1996), a balanced pseudo-replication, strip-split plot design and model was developed and tested for each individual mine site. Two models were developed to assess the effects of stockpile height, age and ameliorants at the three mine sites, namely:

- Model 1 = compared the 1st and 2nd spreads of stockpiled topsoil, assessed 6 months after establishment at all three mines.
- Model 2 = examined the 1st spread of stockpiled topsoil, at 6 and 18 months after establishment at Cheshunt and Mt Arthur Coal mines.

Data used for ANOVA were initially tested for normality and equal variances and transformations using either square root or log were made where necessary. Arithmetic means rather than those predicted by the models were presented. Only significant one-way and two-way analyses were presented. Refer to Appendix 4.4 for units associated with physical, chemical and biological parameters measured. Post-hoc significance levels were determined by using contrasts in the ANOVA's. All biological count data underwent square root transformations. All unknown species were included for species richness data analyses, however, they were excluded from the native and non-native species classifications. Of the significant two-way interactions, only SOC, N, P, pH, microbial respiration and vegetation cover are presented because these parameters are seen as the most important to the assessment of the applied ameliorants. Although some patterns were significant at two or more mines, only a small number showed consistent patterns across the mines.

7.3 Results

7.3.1 Multivariate Analyses

When all sites and chemical and biological parameters were included, the Detrended Correspondence Analysis (DCA) showed that site was the most important factor explaining variation in the data set (Figure 7.10). The ordination separated Mt Arthur Coal to the left, Bengalla in the middle and Cheshunt to the right of the first axis. The ANOSIM for site between all soil parameters was significant (overall Global R=0.875, P<0.001). Consequently, all subsequent analyses were undertaken separately for each site. Age of soil at spreading (1st or 2nd) also significantly separated sites across axis 1 of the DCA ordination (Global R= 0.069, P<0.001; Figure 7.10).

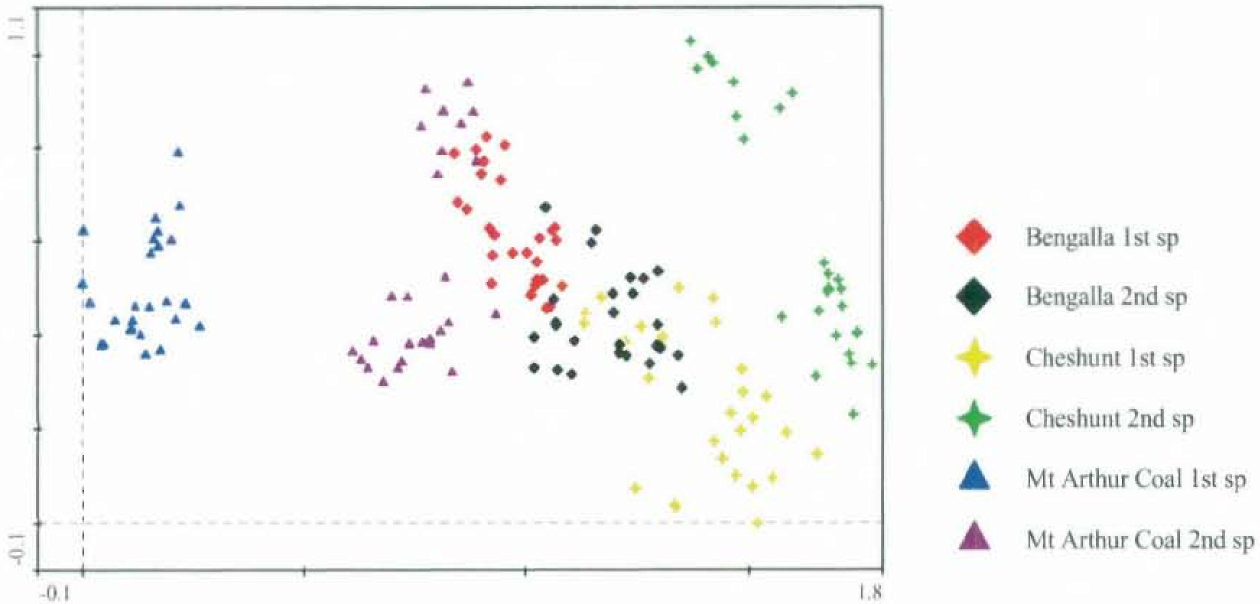

Figure 7.10: Detrended Correspondence Analysis (DCA) across all sites and spreads for all measured chemical and biological parameters.

7.3.2 Spread

A total of 42 chemical and biological soil parameters varied significantly with spread (18 or 30 months) across the three mine sites six months after establishment. Bengalla, Cheshunt and Mt Arthur Coal mines had 13, 13 and 16 significant parameters respectively. Results are presented separately below for each site.

Nine chemical and four biological parameters varied significantly with spread at Bengalla mine (Table 7.2). One chemical (available P) and three biological parameters (species richness, plant density and non-native species richness) increased significantly in the 2nd spread, while microbial respiration and all other chemical parameters were significantly higher in the 1st spread (Table 7.2).

Table 7.2: Summary table of comparison of means for significantly different chemical and biological parameters across spreads at Bengalla mine (***=P<0.001, **=P<0.01,*=P<0.05). Different letters refer to contrast tests to determine post-hoc significance, a: corresponds to the highest value.

Bengalla Parameter	**Spread 1st**	**2nd**	$F_{1,18}$	**P**
EC	0.28a	0.12b	155	***
Avail P	15.3b	22.4a	18.2	***
Total N	0.13a	0.08b	26.3	***
NO_3-N	84.9a	19.6b	256	***
Ca	7.84a	5.54b	24.4	***
Mg	2.75a	1.97b	13.9	**
Na	0.49a	0.33b	53.6	***
K	0.67a	0.44b	14.5	**
ECEC	11.7a	8.28b	22.9	***
Microbial Respiration	15.9a	12.2b	15.7	***
Species Richness	4.27b	6.30a	30.7	***
Plant Density	13.2b	53.1a	317	***
Non-native Species Richness	3.98b	6.00a	37.6	***

Ten chemical and three biological parameters varied significantly with spread at Cheshunt (Table 7.3). Four chemical parameters (K, available P, total P and N) and two biological parameters (plant density and vegetation cover) were significantly higher in levels following the 2nd spread. In comparison, seven chemical parameters exhibited higher levels in the 1st spread (Table 7.3).

Table 7.3: Summary table of comparison of means for significantly different chemical and biological parameters across spreads at Cheshunt mine (***=P<0.001, **=P<0.01,*=P<0.05). Different letters refer to contrast tests to determine post-hoc significance, a: corresponds to the highest value.

Cheshunt Parameter	**Spread 1st**	**2nd**	$F_{1,18}$	**P**
pH	6.31a	5.99b	116	***
Avail P	12.2b	25.7a	90.3	***
Total P	112b	218a	81.3	***
Total N	0.02b	0.04a	29.7	***
NO_3-N	10.01a	8.07b	44.8	***
NH_4-N	24.9a	8.27b	159	***
Mg	0.60a	0.42b	51.6	***
Na	0.13a	0.05b	102	***
K	0.20b	0.25a	109	***
ECEC	2.12a	1.98b	9.03	***
Microbial Respiration	10.02a	7.12b	16.6	***
Plant Density	34.7b	39.2a	6.73	*
Vegetation Cover	27.3b	70.5a	212	***

Ten chemical and six biological parameters varied significantly with spread at Mt Arthur Coal (Table 7.4). One chemical parameter (NO_3-N) and five biological parameters (species richness, plant density, vegetation cover, native and non-native species richness) exhibited significantly higher levels following the 2nd spread. In contrast, nine chemical parameters and one biological parameter (microbial respiration) had higher levels in the 1st spread (Table 7.4).

Table 7.4: Summary table of comparison of means for significantly different chemical and biological parameters across spreads at Mt Arthur Coal mine (***=P<0.001, **=P<0.01,*=P<0.05). Different letters refer to contrast tests to determine post-hoc significance, a: corresponds to the highest value.

Mt Arthur Coal	Spread			
Parameter	**1st**	**2nd**	$F_{1,18}$	**P**
pH	7.26a	6.78b	52.7	***
EC	1.45a	1.13b	21.5	***
Avail P	48.3a	37.6b	18.0	***
NO_3-N	21.9b	46.8a	81.2	***
NH_4-N	200a	33.7b	236	***
Ca	37.3a	14.1b	128	***
Mg	7.08a	5.45b	104	***
Na	1.17a	0.94b	15.5	***
K	0.55a	0.39b	487	***
ECEC	46.1a	20.9b	198	***
Microbial Respiration	20.5a	18.0b	4.52	*
Species Richness	4.81b	6.24a	23.4	***
Plant Density	54.7b	61.3a	6.22	*
Vegetation Cover	5.92b	58.3a	472	***
Native Species Richness	0.12b	0.53a	28.8	***
Non-native Species Richness	4.72b	5.54a	10.2	**

7.3.3 Stockpile Height

A total of five chemical or biological soil parameters varied significantly with height of the stockpiles across the three mine sites. Mt Arthur Coal mine had three significant parameters, while Bengalla and Cheshunt had only one (Table 7.5). One chemical parameter at Bengalla (Na) and one biological parameter at Cheshunt (native species richness) had higher levels in the 2 m stockpile height, decreasing as stockpile height increased. At Mt Arthur Coal, pH and NO_3-N exhibited increasing levels towards the 6 m stockpile height. Potassium at Mt Arthur Coal had higher levels for both the 2 and 6 m stockpile heights (Table 7.5).

Table 7.5: Summary table of comparison of means for significantly different chemical and biological parameters across stockpile height (m) at all mines (***=P<0.001, **=P<0.01,*=P<0.05). Different letters refer to contrast tests to determine post-hoc significance, a: corresponds to the highest value.

Bengalla	**Stockpile Height (m)**				
Parameter	**2**	**4**	**6**	$F_{2,6}$	**P**
Na	0.49a	0.40b	0.34c	6.38	*
Cheshunt	**2**	**4**	**6**	$F_{2,6}$	**P**
Native Species Richness	0.31a	0.28a	0.06b	5.98	*
Mt Arthur Coal	**2**	**4**	**6**	$F_{2,6}$	**P**
pH	6.80c	6.98b	7.30a	39.6	***
K	0.48a	0.45b	0.48a	6.46	*
NO_3-N	30.7b	32.3b	40.1a	5.26	*

7.3.4 Chemical Ameliorants

Chemical amelioration treatments had the highest number of significant parameters at all three mines, with a total of 45. Mt Arthur Coal, Cheshunt and Bengalla mine had 17, 16 and 12 significant parameters respectively. Results are presented separately below for each site.

Twelve parameters were significantly different at Bengalla mine across the chemical ameliorants, with eight chemical parameters and three biological parameters exhibiting higher levels with the organic treatments (Table 7.6). In contrast, pH was higher in the control and inorganic treatment.

Table 7.6: Summary table of comparison of means for significantly different chemical and biological parameters across stockpile age (months) at Bengalla mine (***=P<0.001, **=P<0.01,*=P<0.05). Different letters refer to contrast tests to determine post-hoc significance, a: corresponds to the highest value.

Bengalla	**Chemical Treatments**				
Parameter	**Control**	**Inorganic**	**Organic**	$F_{2,12}$	**P**
pH	6.93a	6.88a	6.62b	33.01	***
EC	0.15c	0.15b	0.30a	186	***
Avail P	10.9c	20.3b	25.3a	59.4	***
Total P	248c	276b	427a	89.1	***
Total N	0.10b	0.09b	0.13a	63.8	***
NO_3-N	33.6b	38.7b	84.6a	25.4	***
NH_4-N	13.2c	20.1b	42.4a	82.2	***
Ca	6.62b	6.36b	7.09a	7.85	**
ECEC	9.89b	9.54b	10.61a	6.58	*
Microbial Respiration	12.4b	11.5b	18.3a	47.3	***
Species Richness	4.98b	5.11b	5.76a	5.55	*
Non-native Species Richness	4.81b	4.72b	5.43a	5.30	*

Sixteen parameters were significantly different at Cheshunt mine across the chemical treatments (Table 7.7). The pH levels were higher in the control treatment, while K exhibited higher levels in the control and organic treatments. The remaining chemical and biological parameters exhibited higher levels in the organic treatment.

Table 7.7: Summary table of comparison of means for significantly different chemical and biological parameters across chemical treatments at Cheshunt mine (***=P<0.001, **=P<0.01,*=P<0.05). Different letters refer to contrast tests to determine post-hoc significance, a: corresponds to the highest value.

Cheshunt	Chemical Treatments				
Parameter	**Control**	**Inorganic**	**Organic**	$F_{2,12}$	**P**
pH	6.30a	6.26a	5.88b	46.9	***
EC	0.03b	0.03b	0.18a	355	***
SOC	0.44b	0.41b	0.66a	8.30	**
Avail P	4.82c	22.7b	29.4a	292	***
Total P	87c	111b	296a	137	***
Total N	0.02b	0.02b	0.04a	34.9	***
NO_3-N	3.22b	3.44b	20.5a	88.8	***
NH_4-N	3.69c	9.35b	36.8a	334	***
Ca	1.04b	0.98c	1.69a	133	***
Mg	0.49b	0.46b	0.57a	34.9	***
Na	0.09b	0.08b	0.10a	9.25	**
K	0.23a	0.21b	0.23a	6.55	*
ECEC	1.84b	1.73b	2.58a	105	***
Microbial Respiration	6.10b	6.62b	12.9a	23.0	***
Plant Density	35.5b	34.7b	40.7a	8.67	**
Vegetation Cover	39.0c	49.2b	58.4a	49.8	***

Seventeen chemical and biological parameters exhibited significant differences across chemical treatments at Mt Arthur Coal (Table 7.8). Two chemical parameters (Ca and ECEC) exhibited significantly higher levels for the control treatment and three chemical parameters (pH, Mg and total N) exhibited higher levels for the inorganic treatments. The remaining chemical and biological parameters exhibited higher levels in the organic treatment (Table 7.8).

Table 7.8: Summary table of comparison of means for significantly different chemical and biological parameters across chemical treatments at Mt Arthur Coal mine (***=P<0.001, **=P<0.01,*=P<0.05). Different letters refer to contrast tests to determine post-hoc significance, a: corresponds to the highest value.

Mt Arthur Coal	Chemical Treatments				
Parameter	**Control**	**Inorganic**	**Organic**	$F_{2,12}$	**P**
pH	7.07b	7.18a	6.82c	24.7	***
EC	1.31a	1.18b	1.39a	10.3	**
SOC	1.58c	1.80b	2.71a	50.4	***
Avail P	29.1c	43.7b	56.1a	128	***
Total P	312b	348b	1671a	349	***
Total N	0.09b	0.09b	0.26a	377	***
NO_3-N	18.5c	27.9b	56.7a	58.6	***
NH_4-N	87.6c	103b	160a	35.2	***
Ca	26.9a	24.6c	25.5b	4.12	*
Mg	6.37a	6.44a	5.98b	5.18	*
K	0.44b	0.45b	0.51a	15.5	***
ECEC	34.8a	32.6c	33.0b	4.18	*
Microbial Respiration	15.4c	16.9b	25.5a	109	***
Species Richness	5.13b	5.78a	5.69a	6.28	*
Vegetation Cover	23.2c	30.7b	42.3a	91.9	***
Native Species Richness	0.31b	0.39a	0.19c	4.15	*
Non-native Species Richness	4.74b	5.20a	5.35a	6.58	*

7.3.5 Biological Ameliorants

Five chemical or biological soil parameters varied significantly with biological treatments across the three mine sites. Mt Arthur Coal and Bengalla mine had two significant parameters, while Cheshunt had only one (Table 7.9). One chemical parameter (NO_3-N) and two biological parameters (species richness and non-native species richness) had higher levels with the addition of the fresh topsoil biological treatment at Bengalla and Mt Arthur Coal mines respectively. In contrast, one biological parameter (microbial respiration) at Bengalla exhibited higher levels for the control. In addition, total N at Cheshunt mine had higher levels for both the fresh topsoil and liquid inoculum biological treatments (Table 7.9).

Table 7.9: Summary table of comparison of means for significantly different chemical and biological parameters across biological treatments at all mines (***=P<0.001, **=P<0.01,*=P<0.05). Different letters refer to contrast tests to determine post-hoc significance, a: corresponds to the highest value.

Bengalla		**Biological Treatments**			
Parameter	**Control**	**Liquid Inoculum**	**Fresh Topsoil**	**$F_{2,12}$**	**P**
NO_3-N	52.8b	47.8c	56.2a	6.32	*
Microbial Respiration	15.4a	13.4b	13.3b	7.44	**
Cheshunt	**Control**	**Liquid Inoculum**	**Fresh Topsoil**	**$F_{2,12}$**	**P**
Total N	0.02b	0.03a	0.03a	12.7	**
Mt Arthur Coal	**Control**	**Liquid Inoculum**	**Fresh Topsoil**	**$F_{2,12}$**	**P**
Species Richness	5.26b	5.26b	6.07a	5.06	*
Non-native Species Richness	4.89b	4.72b	5.69a	5.75	*

7.3.6 Assessment Time

Between the 6 and 18 months assessment times for the 1st spread, seven parameters differed significantly at Cheshunt and five at Mt Arthur Coal (Table 7.10). At Cheshunt mine, three chemical parameters (EC, NO_3-N and NH_4-N) and plant density exhibited significantly higher levels at the 6 month assessment. In contrast, three biological parameters (species richness, vegetation cover and native species richness) exhibited higher levels at the 18 month assessment. Of the five biological parameters significant at Mt Arthur Coal, all exhibited higher levels at the 18 month assessment for the 1st spread (Table 7.10).

Table 7.10: Summary table of comparison of means for significantly different chemical and biological parameters across the time assessments for the 1st spread at both mines (***=P<0.001, **=P<0.01,*=P<0.05). Different letters refer to contrast tests to determine post-hoc significance, a: corresponds to the highest value.

Cheshunt	**Assessment Time (months)**			
Parameter	**6**	**18**	$F_{1,18}$	**P**
EC	0.07a	0.04b	65.4	***
NO_3-N	10.0a	3.49b	195	***
NH_4-N	24.9a	3.74b	429	***
Species Richness	5.44b	6.09a	7.14	*
Plant Density	34.7a	24.8b	16.5	***
Vegetation Cover	27.3b	70.9a	175	***
Native Species Richness	0.25b	0.73a	52.3	***
Mt Arthur Coal	**6**	**18**	$F_{1,18}$	**P**
Species Richness	4.81b	7.75a	90.4	***
Plant Density	54.7b	89.3a	30.4	***
Vegetation Cover	5.86b	64.8a	1647	***
Native Species Richness	0.07b	0.88a	66.5	***
Non-native Species Richness	4.67b	6.75a	39.1	***

7.3.7 Interactions between Spread and Chemical Ameliorants

Due to large number of significant interactions, only the chemical soil parameters most influenced by the application of the ameliorants (SOC, N and P, pH, microbial respiration and vegetation cover) will be discussed in more detail in all of the following sections (refer to Appendix 7.6 for a summary table of two-way interactions). Significant two-way interactions between spread and chemical ameliorants were recorded for seven chemical parameters and one biological parameter. At both Cheshunt and Mt Arthur Coal mines, pH levels decreased in the organic amendment of the 2nd spread ($F_{2,36}$=60.4, P<0.0001; $F_{2,36}$=20.2, P<0.0001, respectively, Figure 7.11a). Higher SOC levels were exhibited in the organic ameliorant of the 2nd spread for Mt Arthur Coal ($F_{2,36}$=26.4, P<0.0001; Figure 7.11b). Vegetation cover at Mt Arthur Coal exhibited a greater increase in the inorganic and organic treatments for the 2nd spread ($F_{2,36}$=20.8, P<0.0001; Figure 7.11c).

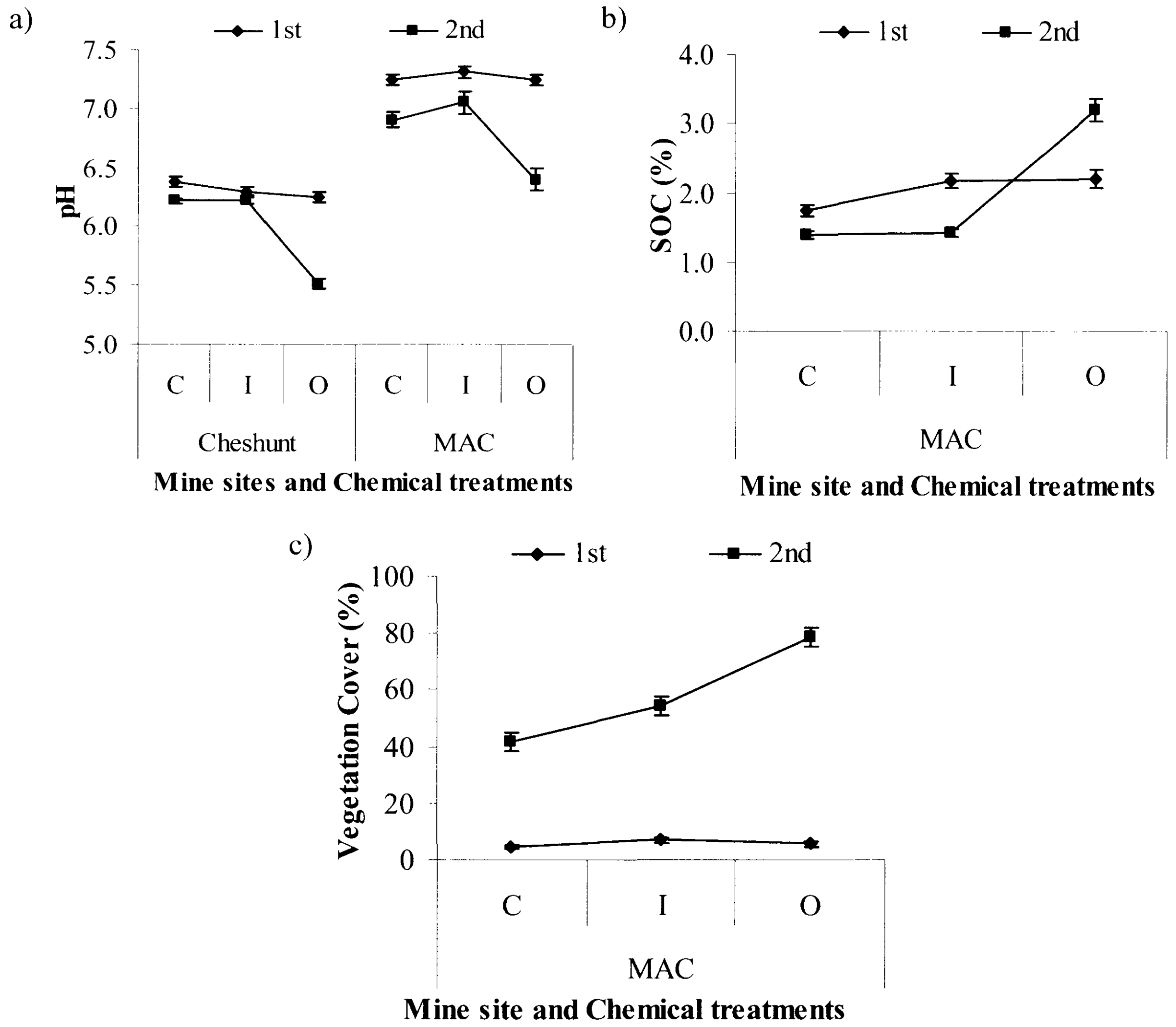

Figure 7.11: Interactions between spread and chemical treatments for (a) pH, (b) SOC and (c) vegetation cover (Mean +/- Standard Error of the Mean). Note: pH scale starts at 5 to emphasise treatment differences.

Available P displayed a different pattern at each mine. Bengalla exhibited a higher level for the inorganic amendment of the 2nd spread ($F_{2,36}$=13.5, P<0.0001; Figure 7.12a). In contrast, Cheshunt and Mt Arthur Coal exhibited an increase in the organic amendment of the 2nd spread ($F_{2,36}$=36.3, P<0.0001; $F_{2,36}$=37.7, P<0.0001, respectively).

Total P and N showed a similar pattern at Cheshunt and Mt Arthur Coal mine sites, with the 2nd spread having significantly higher levels for the organic treatments (total P, $F_{2,36}$=72.8, P<0.0001; $F_{2,36}$=34.7, P<0.0001, respectively - total N, $F_{2,36}$=13.9, P<0.0001; $F_{2,36}$=14.8, P<0.0001, respectively; Figure 7.12b-c).

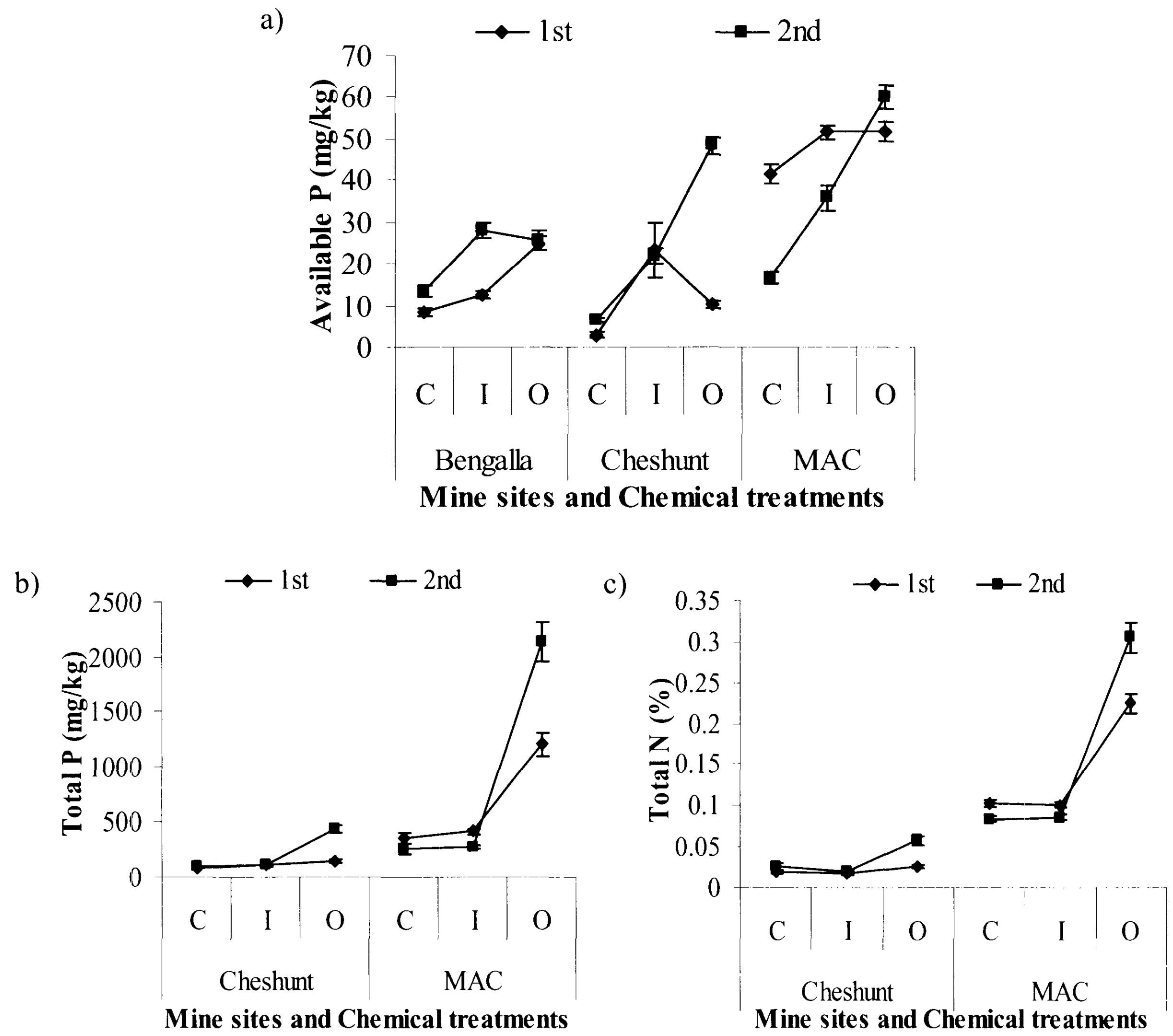

Figure 7.12: Interaction between spread and chemical treatments for (a) available P, (b) total P and (c) total N across the mine sites (Mean +/- Standard Error of the Mean).

Nitrate-N at Bengalla mine was significantly higher in levels for the 1st spread for the organic chemical treatment ($F_{2,36}$=24.8, P<0.0001; Figure 7.13a). In contrast, Cheshunt exhibited higher levels in the control and inorganic treatments for the 1st spread, however the 2nd spread exhibited higher levels for the organic treatment ($F_{2,36}$=14.8, P<0.0001; Figure 7.13a). Ammonium-N levels at Bengalla and Cheshunt mines were significantly greater in the 1st spread with the organic amendment ($F_{2,36}$=100, P<0.0001; $F_{2,36}$=151, P<0.0001, respectively; Figure 7.13b). In addition, Mt Arthur Coal exhibited the same pattern, however NH_4-N was significantly greater in all chemical treatments for the 1st spread ($F_{2,36}$=22.8, P<0.0001; Figure 7.13b).

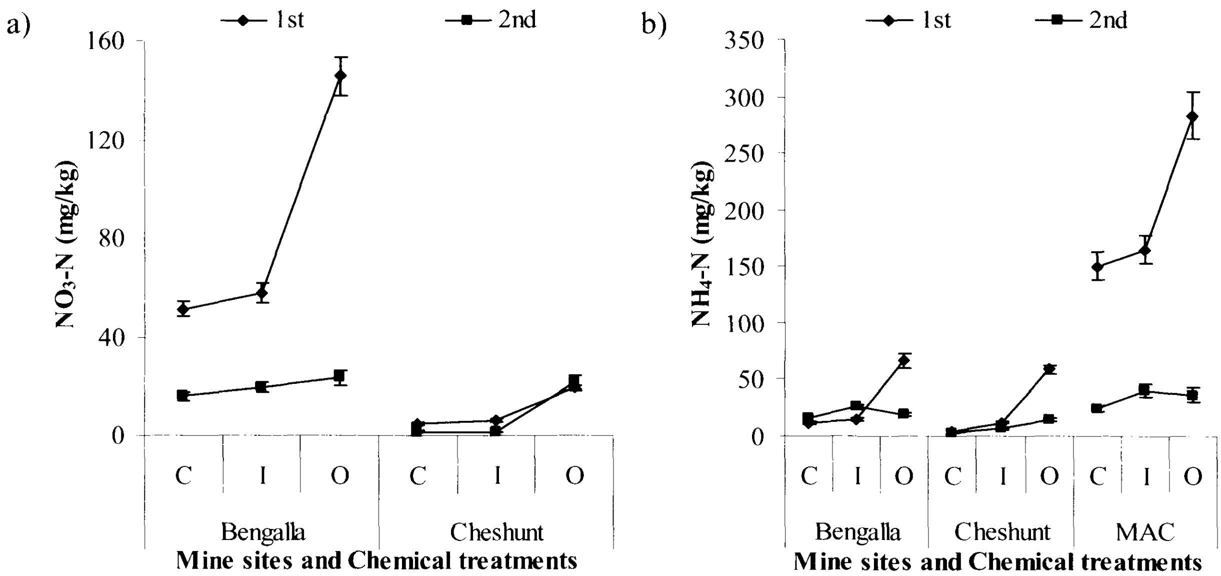

Figure 7.13: Interaction between spreads and chemical treatments for (a) NO_3-N and (b) NH_4-N (Mean +/- Standard Error of the Mean).

7.3.8 Interactions between Stockpile Height and Chemical Ameliorants

Two-way interactions for stockpile height and chemical treatments were recorded for one chemical and two biological parameters. At Bengalla mine, pH decreased in soil from the 2 to the 4 m stockpiles across all chemical treatments, with the organic treatment exhibiting less of a decrease from the 2 to the 4 m height ($F_{4,12}$=5.08, P=0.013; Figure 7.14a). Microbial respiration at Bengalla was greater in the organic treatment of soil from the 2 and 6 m heights compared to the 4 m stockpile ($F_{4,12}$=3.68, P=0.035; Figure 7.14b). Vegetation cover at Cheshunt mine increased with increasing stockpile height for the inorganic and organic treatments, but decreased in the control ($F_{4,12}$=12.1, P<0.0001; Figure 7.14c). At Mt Arthur Coal, vegetation cover was higher for all heights in the organic treatment, while the inorganic treatments exhibited higher levels for soil from the 2 and 6 m stockpiles ($F_{4,12}$=3.50, P=0.041; Figure 7.14c).

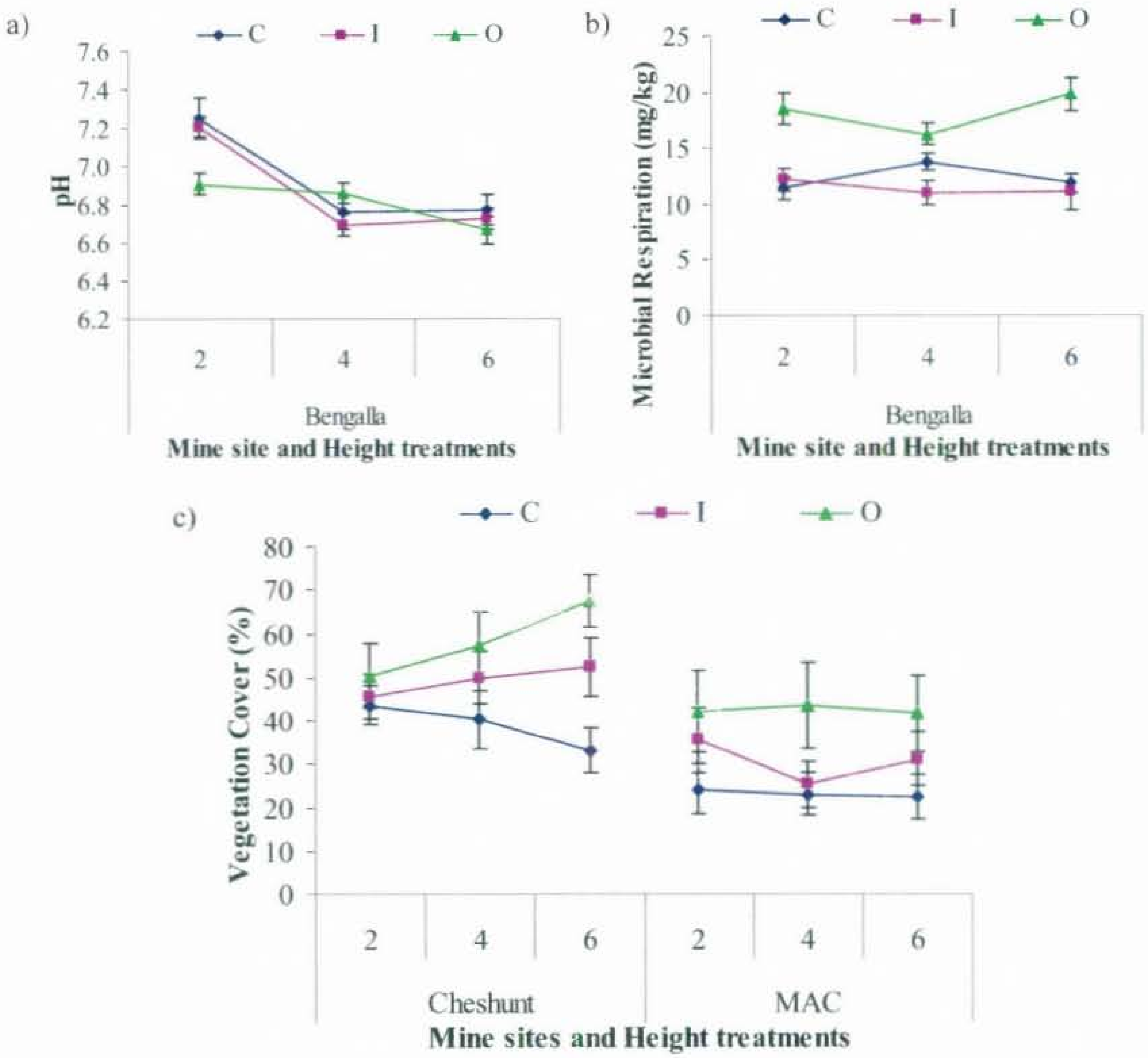

Figure 7.14: Interactions between stockpile height and chemical treatments for (a) pH, (b) microbial respiration and (c) vegetation cover (Mean +/- Standard Error of the Mean). Note: pH scale starts at 6.2 to emphasise treatment differences.

7.3.9 Interactions between Spread and Stockpile Height

Nitrate-N levels at Bengalla mine were higher in the 1st spread and increased with stockpile height. In contrast, NO_3-N decreased with increasing height in the 2nd spread ($F_{2,18}$=11.6, P<0.001; Figure 7.15a). At Cheshunt mine, the 2nd spread had higher levels of NO_3-N in the 6 m stockpile height ($F_{2,18}$=3.61, P=0.048; Figure 7.15a). In contrast to NO_3-N, NH_4-N at Cheshunt mine exhibited higher levels for the 1st spread, decreasing with increasing height, while in the 2nd spread NH_4-N increased with height ($F_{2,18}$=3.95, P=0.037; Figure 7.15b). Total N at Cheshunt mine exhibited higher levels in the 2nd spread for soil sourced from the 2 and 6 m stockpiles ($F_{2,18}$=5.89, P=0.011; Figure 7.15c).

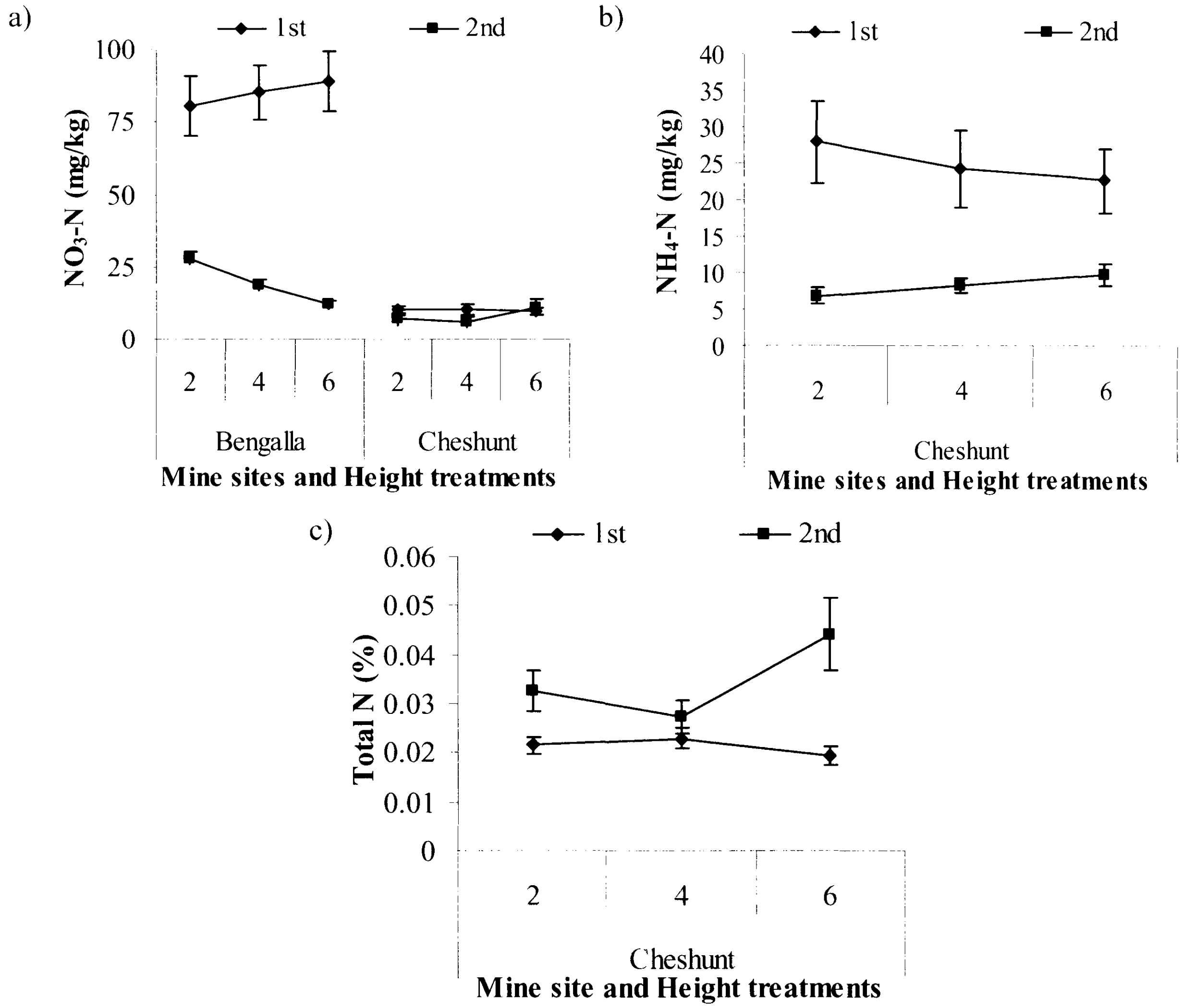

Figure 7.15: Interaction between spread and stockpile height for (a) NO_3-N, (b) NH_4-N and (c) total N (Mean +/- Standard Error of the Mean).

7.3.10 Interactions between Stockpile Height and Biological Ameliorants

Total N at Cheshunt mine exhibited higher levels for the liquid inoculum biological treatment in soil from the 2 and 6 m stockpiles, with the fresh topsoil treatment exhibiting higher levels in the 6 m height ($F_{4,12}$=6.35, P=0.006; Figure 7.16a). Vegetation cover was higher for the liquid inoculum biological treatment in soil from the 6 m stockpile, with the fresh topsoil treatment displaying higher levels in the 4 m height ($F_{4,12}$=4.69, P=0.016; Figure 7.16b).

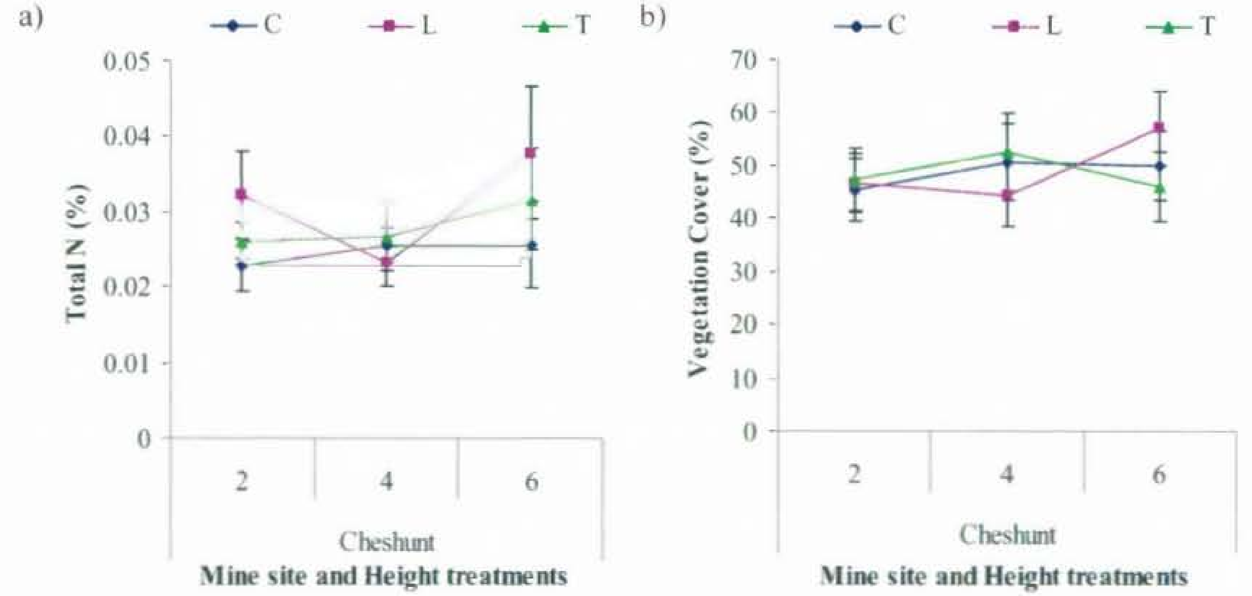

Figure 7.16: Interaction between stockpile height and biological treatments for (a) total N and (b) vegetation cover (Mean +/- Standard Error of the Mean).

7.3.11 Interactions between Biological and Chemical Ameliorants

At Bengalla mine, pH was higher in the control than the two biological treatments for the chemical control and inorganic chemical treatments while this pattern was reversed for the organic treatment ($F_{4,24}$=3.12, P=0.033; Figure 7.17a). Total P at Cheshunt mine was greater in the organic chemical treatment with the liquid inoculum treatment exhibiting maximal levels ($F_{4,24}$=4.78, P=0.006; Figure 7.17b).

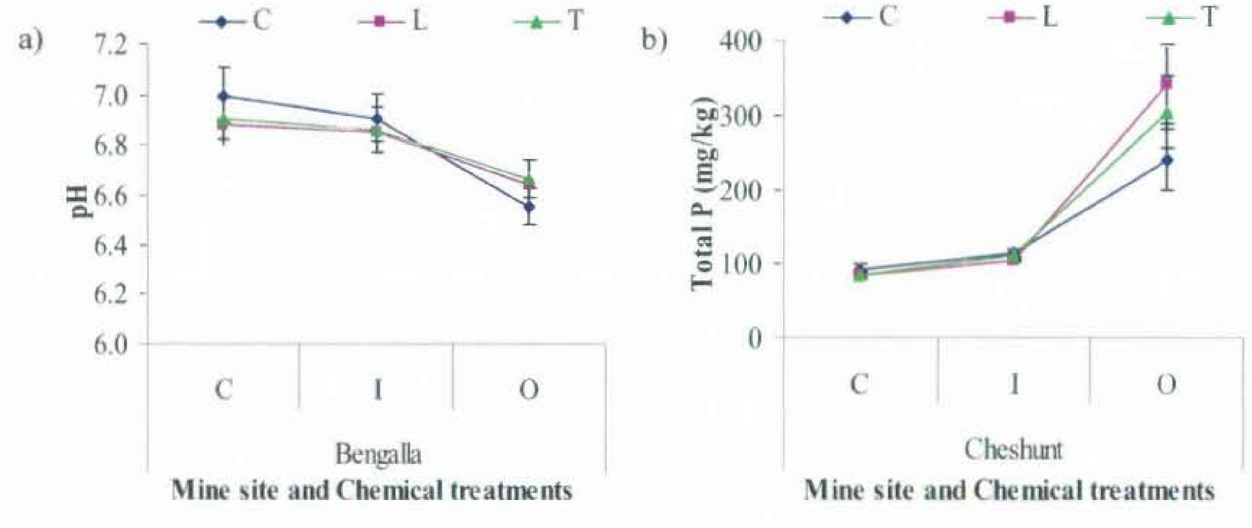

Figure 7.17: Interaction between chemical and biological treatments for (a) pH and (b) total P (Mean +/- Standard Error of the Mean). Note: pH scale starts at 6 to emphasise treatment differences.

7.3.12 Interactions between Assessment Time and Chemical Ameliorants

Ammonium-N was significantly higher in the organic chemical treatment at 6 compared to 18 months ($F_{2,36}$=151, P<0.0001, Figure 7.18a). Available P in the 18 month assessment increased across the chemical treatments, while levels were higher in the inorganic than the organic treatment in the 6 month assessment ($F_{2,36}$=29.4, P<0.0001; Figure 7.18b). The pattern for total P was similar to available P, although levels in the inorganic treatment at 6 months were lower ($F_{2,36}$=18.3, P<0.0001; Figure 7.18c). Microbial respiration in the control chemical treatment was greater at 6 than 18 months in the 1st spread of stockpiled topsoil, while the opposite pattern was observed in the inorganic and organic treatments ($F_{2,36}$=3.35, P=0.046; Figure 7.18d).

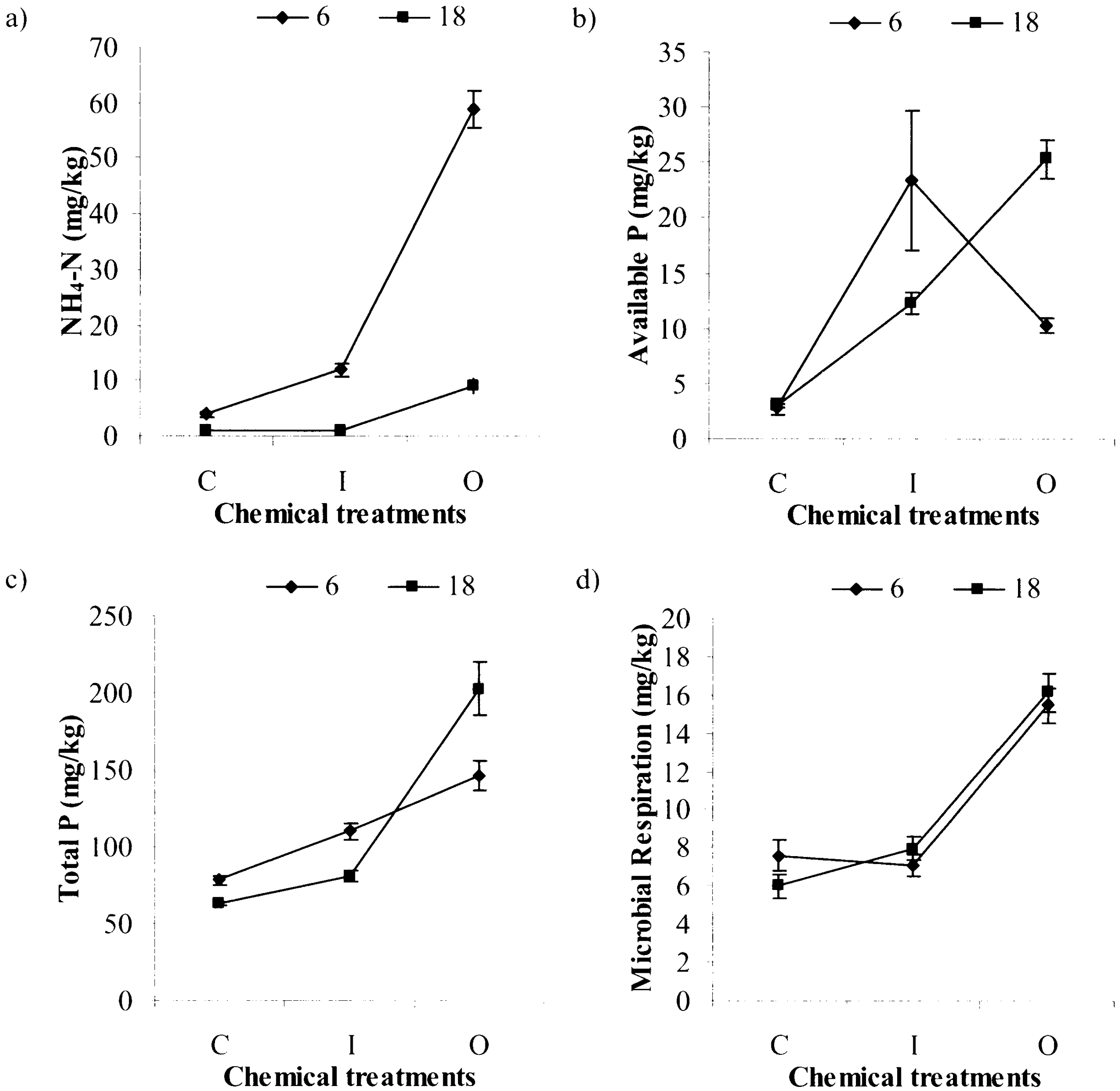

Figure 7.18: Interaction between assessment time and chemical treatments at Cheshunt mine for (a) NH_4-N, (b) available P, (c) total P and (d) microbial respiration (Mean +/- Standard Error of the Mean).

7.3.13 Interaction between Assessment Time and Biological Ameliorants

Species richness was significantly higher in the control and biological treatment at the 18 month assessment ($F_{2,18}$=7.26, P=0.004; Figure 7.19).

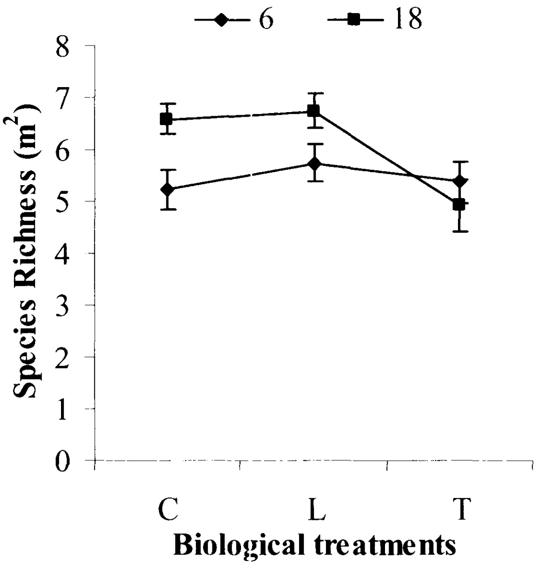

Figure 7.19: Interaction between assessment time and biological treatments at Cheshunt mine for species richness (Mean +/- Standard Error of the Mean).

7.3.14 Biomass

For the 1st spread assessed at 18 months, biomass was significantly greater in the fresh topsoil biological treatment ($F_{2,12}$=3.91, P=0.048; Figure 7.20a). For both the 1st and 2nd spreads, biomass increased in a linear trend across the chemical treatments, but levels were much greater following the 2nd spread ($F_{2,12}$=15.6, $P<0.0001$ and $F_{2,12}$=23.7, $P<0.0001$, respectively, Figure 7.20b).

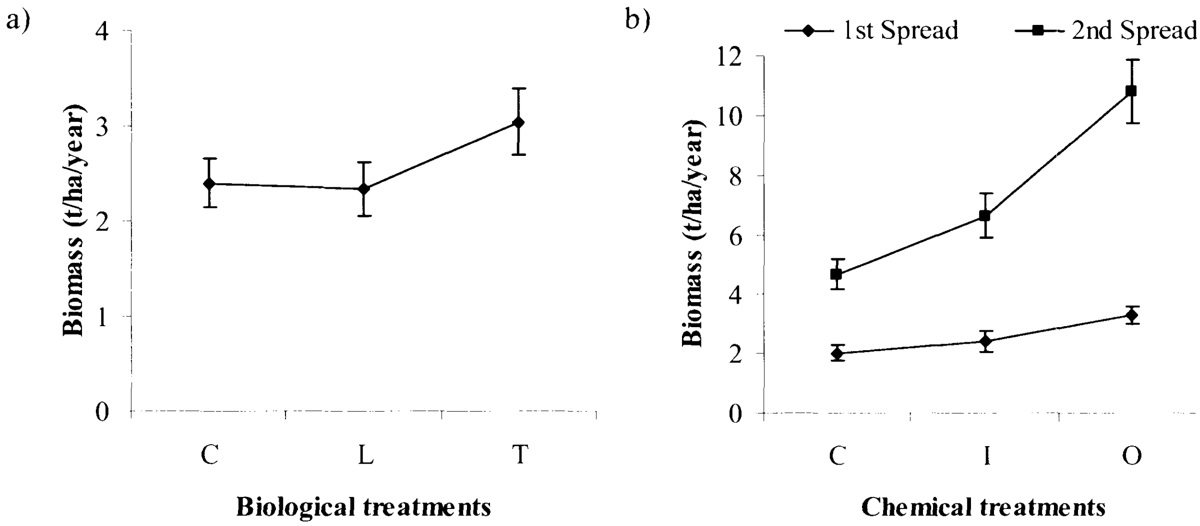

Figure 7.20: Biomass (t/ha/year) at Cheshunt mine across (a) different biological treatments for the 1st spread, and (b) chemical treatments for the 1st and 2nd spread.

7.3.15 Direct Return

All chemical parameters were higher in levels for the direct return area at Mt Arthur Coal, when compared to the 1st spread at Cheshunt mine. Vegetation cover and native species richness were greater in the direct return area than the 1st spread of stockpiled soil at Mt Arthur Coal, assessed 18 months after establishment. In contrast, non-native species richness was higher in the 1st spread topsoil, with levels of species richness and seed density similar. Seed density, vegetation cover and native species richness were also higher in the direct return area when compared to the Cheshunt 1st spread, while Cheshunt had higher levels for species richness and non-native species richness. However, biomass production was similar for both sites, whereas microbial respiration was higher in levels for the direct return area.

Table 7.11. Mean biological and chemical parameters of a direct return area (18 months old) at Mt Arthur Coal compared to the 1st spread parameters at Mt Arthur Coal and Cheshunt mines (where possible). n/a = not available.

Parameter	Recommended	Direct return Mt Arthur Coal	1st spread Cheshunt	1st spread Mt Arthur Coal
Species Richness	n/a	6.60	6.89	7.00
Plant Density	n/a	59.0	26.3	62.0
Vegetation Cover	n/a	82.0	66.6	59.8
Native Species Richness	n/a	2.00	0.89	0.56
Non-Native Species Richness	n/a	4.60	6.00	6.78
Biomass production	n/a	2.15	2.17	-
Microbial Respiration	n/a	19.8 n/a	5.77 n/a	-
SOC	>2%	1.65 moderate	0.28 low	-
Avail P	4-20 mg/kg	3.26 low	2.65	-
Total P	200-1500 mg/kg	296 moderate	63.6 low	-
Total N	0.05-0.30%	0.12 moderate	0.01 low	-
NH_4-N	mg/kg	7.17 n/a	1.00 n/a	-
NO_3-N	>20 mg/kg	24.7 moderate	1.00 low	-

7.4 Discussion

In the rehabilitation field trial, the ordinations showed that site was the most important factor affecting the chemical and biological parameters. This is consistent with the results of the stockpile field trial (chapter 5), indicating that soil type may be a more important consideration for rehabilitation options than stockpiling.

7.4.1 Spread

The majority of vegetation characteristics in 6 month old rehabilitation were greater following the 2nd spread (30 month old stockpiled soil) than the 1st spread (18 month old stockpiled soil). This is opposite to the expected pattern if deterioration during stockpiling was a major influencing factor. It appears that the increased rainfall from May to October 2003 compared to 2002 has had a greater impact on the vegetation characteristics of the rehabilitated areas than the period of time that the soil was stockpiled. Techniques used to establish and maintain vegetation on rehabilitated areas depend on factors such as climate, properties of the reconstructed landscape and the post-mining landuse (Bell, 1996). Revegetation programs need to be planned to evaluate and determine the risk factors involved and this requires rainfall and temperature data, moisture balance information and seed availability (Johnston, 2000). Pasture establishment in the climate of the Hunter Valley favours warm season pasture species due to the more reliable rainfall pattern in late summer and autumn making conditions suitable for seeds to germinate and survive (EPA 1995; Hannan and Gordon, 1996). The timing of seeding and sufficient first year rainfall is extremely important for successful revegetation on open cut coal mines in the Hunter Valley.

The majority of soil chemical parameters had greater levels in the 1st than the 2nd spread, indicating that rainfall could have caused a decrease in nutrient levels following leaching or increased plant uptake resulting from better vegetation establishment following the 2nd spread. For example, at both Bengalla and Cheshunt mines, NO_3-N levels were lower following the 2nd spread due to the increased rainfall resulting in leaching through the root zone in the loam and loamy sand soils at these sites. In contrast, total N at Cheshunt was significantly greater in the 2nd spread as a result of better vegetation establishment following increased rainfall. However, available N at the 2nd spread did not increase probably because the environmental conditions were not suitable for mineralisation to occur (Strong and Mason, 1999). Outputs of nutrients from the soil occur by weathering, volatilisation or by leaching (Helyar and Price, 1999). Higher levels of total and available P following the 2nd spread indicated that the increased rainfall had created suitable soil moisture conditions to enable the mineralisation of P. Many factors such as soil temperature, pH and moisture content affect the total amount of P mineralisation into the inorganic form for plant uptake (Glendinning, 2000). Most P moves in the soil by the slow process of diffusion, which relies on soil moisture, and is reduced under dry conditions (Glendinning, 2000).

Only three chemical parameters changed significantly from the 6 to the 18 month assessment times of the 1st spread of stockpiled topsoil. Nitrate-N, NH_4-N and EC decreased over time at Cheshunt. The conversion of NH_4-N into NO_3-N in soils under aerobic conditions and leaching of NO_3-N into sub-soil layers (inaccessible to plant roots) is controlled largely by rainfall and temperature (Strong and Mason, 1999). Increased rainfall in 2003 led to decreases in NO_3-N and NH_4-N due to better plant growth and increased leaching. This is supported by the recorded increases in vegetation cover and species richness over time (see Figure 7.10).

The majority of the significant interactions between spread and chemical ameliorants were related to the differential rainfall between the two spreads. For example, the 2nd spread had lower pH levels in the organic amendment. The higher rainfall led to increased leaching of organic acids from the biosolids leading to reduced pH levels. However, the observed lowered pH levels are unlikely to inhibit plant growth (Seaker and Sopper, 1988). The majority of overburden in the Hunter Valley is alkaline (8-8.5; Hannan and Gordon, 1996) and biosolids application may be a useful tool to help reduce pH levels.

Nitrate-N, NH_4-N and total N exhibited significant interactions between spread and stockpile height. The factors explaining these patterns were similar to those proposed for the one-way analyses. For example, NO_3-N levels were higher following the 1st spread of the soil from the 6 m stockpiles and the 2nd spread of the 2 m stockpiles at Bengalla mine. This is the result of the increased rainfall following the 2nd spread leading to leaching of NO_3-N. Furthermore, NO_3-N was higher following the 1st spread due lower rainfall, and the soil mixing and oxidisation that occurred during spreading.

7.4.2 Stockpile Height

The majority of chemical and biological soil parameters were not affected by the height to which soil had been stockpiled. This indicates that the low levels of deterioration that occur during stockpiling are rectified through soil mixing during handling or oxidation following exposure to aerobic conditions. However, NO_3-N was higher in soil spread from the 6 m stockpile height at Mt Arthur Coal, while native species richness had higher levels in the 2 and 4 m stockpile height. Nitrate-N may not have been as mobile in the taller stockpiles at Mt Arthur Coal due to the higher clay content soils. Usually NO_3-N is highly mobile in soils moving freely in soil water, particularly in sandy and free-draining soils, under high rainfall conditions allowing leaching though the soil profile (Glendinning, 2000). In contrast, higher native species richness levels for shorter stockpiles suggests the aerobic nature of these stockpiles can be a beneficial factor for the survival of seeds allowing increased establishment in rehabilitated areas. Elliott and Veness (1985) focussed on dimensions of stockpiles and found that broad and shallow stockpiles provide the best conditions for seed banks, vegetative material and aerobic organisms to survive.

Higher levels of microbial respiration for soil sourced from the 2 and 6 m stockpiles were recorded for the organic treatment. Nutrients are slowly released from biosolids compared to rapid release from inorganic fertiliser (Phillips, 1994a). The high organic matter content of biosolids help bind the soil together and improves the soils water holding capacity, allowing nutrients to be slowly released and providing ideal conditions for developing microbial communities (Ross *et al.*, 1991). Biosolids application has the potential to increase microbial respiration in rehabilitation areas.

7.4.3 Chemical Ameliorants

The majority of chemical and biological soil parameters had greater levels in the organic than the inorganic chemical treatment. The addition of biosolids led to a significant increase in total N (31-65%), NO_3-N (51-83%), NH_4-N (53-75%), SOC (50-72%), total and available P (35-79% and 19-23%, respectively). However, 105 times more total N (3,562 kg/ha compared to 34 kg/ha) and 31 times more total P (1,507 kg/ha compared to 48 kg/ha) were applied in the biosolids compared to the inorganic fertiliser that led to the observed significant increases in total and available N and P. Nonetheless, nutrients supplied in biosolids are generally in the organic form and are slowly released over time through the process of mineralisation. In contrast, fertilisers such as DAP provide N and P in the inorganic form so nutrients that are highly mobile and are not taken up rapidly (e.g. NO_3-N) may be lost through leaching, particularly at high application rates. Biosolids application can enhance mineralisation increasing available N as NH_4-N and NO_3-N, with a C: N ratio of 8-14 (Salt *et al.*, 1995). The benefits of biosolids include a source of organic matter and plant nutrients, improvement to soil structure, accelerated development of microbial communities and improved water holding capacity (Tisdale *et al.*, 1985; Voos and Sabey, 1987; Chang *et al.*, 1992; Phillips, 1994a).

Increased microbial respiration levels in the biosolids treatment at all three mines is indicative of increased organic carbon and water holding capacity promoting microbial activity. Sopper (1993) estimated that the re-establishment of microfauna and microflora populations could be attained in two years with the application of biosolids compared to 15 years in conventionally reclaimed coal mine spoil. Application of biosolids or other organic amendments (green waste or compost) in rehabilitated areas that receive stockpiled topsoil should be encouraged as this treatment improves chemical and biological soil properties essential for nutrient cycling.

Biomass and vegetation cover were greater in the organic compared to the inorganic treatment. Phillips (1994b) found that the application of biosolids at Rixs Creek mine, Singleton (NSW), increased grass yield by 125% compared to normal rehabilitation practices. Increased vegetation cover is often associated with increased plant biomass, which is highly desirable in the revegetation of mines to minimise surface erosion. Parker and Grant (2001) investigated the effect on native and introduced grasses of different biosolids application rates to topsoil and overburden samples collected from open cut coal mines in the Hunter Valley. They found that increasing the rate of biosolids application increased ground cover, however introduced grasses exhibited higher rates of emergence than the native species. Non-native species richness was generally significantly higher in the biosolids treatment. If biosolids are not composted for a period of time, they can act as a source for weeds due to survival of seeds through sewage treatment and composting (Phillips, 1994a). The organic treatment contained a greater number of weed species, producing a large biomass that may out compete some native species. The control of weed species must be considered when applying biosolids broad scale in mining rehabilitation.

7.4.4 Biological Ameliorants

The addition of fresh topsoil significantly increased biomass (21%), NO_3-N (6%), total N (33%) and species richness (13%), although it also led to a significant decrease in microbial respiration (13%) and an increase in non-native species richness (14%). Total N increased due to the higher N content of the fresh topsoil even though it was applied at a low rate (see Appendix 7.3). The addition of fresh topsoil provided a good source of viable seeds that led to greater species richness in rehabilitated areas, while also contributing additional weed species. The benefits of freshly placed topsoil can assist species diversity, high growth rates and plant production levels, microflora populations, low levels of bulk density in the plant root zone, balanced pool of nutrients and high levels of stored organic matter (Elliott and Reynolds, 2000). However, compared to the application of biosolids, the addition of fresh soil over the top of stockpiled topsoil on a broad scale is unlikely to be a cost effective rehabilitation strategy. The microbial inoculum, while a more cost effective technique, did not lead to an increase in the majority of measured chemical and biological parameters. The potential benefits of inoculation programs include increased uptake of N, P, K and S, increased N_2 fixation, increased root longevity, drought tolerance and resistance to extreme temperatures (Killham, 1994). The microbial inoculum is not recommended for use without further refinement of the procedure.

Total P was higher with biosolids amelioration for all biological treatments, with maximal levels recorded following application of the liquid inoculum. In pasture soils, the amount of organic P is positively correlated with the organic matter content of the soil, including from 20-80% of the total P content (MacLeod and Lockwood, 1997). The addition of biosolids supplied a large amount of organic matter that was mineralised by microbes contained in the liquid inoculum to an inorganic form that was available for plant uptake. A key factor in the success and survival of a highly specific inoculum is the level of moisture at which the cells are maintained (Gemell and McDonald, 2002). The addition of biosolids also increased the water holding capacity of the soil that assisted in maximising the activity of microbes contained in the inoculum.

Most biological parameters were greater in rehabilitated areas at Mt Arthur Coal that received fresh compared to stockpiled topsoil at 18 months of age. The replacement of fresh topsoil is important in native ecosystems in providing the most economical and reliable means of re-establishing the species richness of these communities (Koch and Ward, 1994). Investigation of seed in topsoil prior to mining and throughout rehabilitation procedures following bauxite mining in Western Australia showed that fewer seeds were lost when topsoil was directly returned to rehabilitation sites rather than being stockpiled (Koch *et al.,* 1996). This emphasises the importance of encouraging direct return of topsoil in native and pasture ecosystem rehabilitation because all chemical and biological soil parameters were higher in fresh compared to stockpiled topsoil.

7.4.5 Limitations of the Trial

During the establishment of the field rehabilitation trial, a number of difficulties were encountered relating to the consistent application of treatments across the three mine sites. This led to different mine sites having minor differences in their treatments that may have limited the comparability of results across the sites. These factors are discussed below:

- Mt Arthur Coal used gypsum on the rehabilitated areas to improve soil structure, water infiltration, aeration and seedling emergence on its clay loam topsoil; hence the calcium and ECEC levels were higher for all treatments at this site.
- Higher N and P levels at Bengalla and Mt Arthur Coal in all treatments were probably related to the application of additional inorganic fertiliser (Granuloc or Starter 15) and seed to the entire trial area following low initial establishment rates.
- The application of fresh topsoil to only 1 mm depth by hand cannot be undertaken by mining machinery and is therefore not operationally feasible at any site. Fresh topsoil was not applied at a higher rate because machinery was not available and hand application was too time consuming.
- Mining operations caused experimental sacrifice to some treatments within the rehabilitated area at Bengalla and Mt Arthur Coal for the 1st spread.
- Due to the lack of rainfall for the 1st spread at Mt Arthur Coal, the rehabilitated area was re-ripped and sown when the 2nd spread sites were established causing the 18 month assessment of chemical parameters for the 1st spread to be abandoned.

7.5 Conclusions

The objective of this chapter was to investigate the effects of different chemical and biological amelioration techniques on two different stockpile attributes (age and height) by monitoring soil and vegetation characteristics of rehabilitated areas. The trial encompassed a range of soil types across the three mine sites (loamy sand, loam and clay loam), and a range of soil qualities relating to age and height of stockpiles producing results that are applicable to other mines in the Hunter Valley. Increased rainfall following the 2nd compared to the 1st spread influenced the quality of the rehabilitation more than the age of the stockpiled soil (18 versus 30 months). Height of stockpiles had little influence on the chemical or biological quality of the soil in the rehabilitation areas, suggesting those soil qualities that did deteriorate with an increase in stockpile height (see chapter 5) can be rectified by soil mixing and oxidation during the spreading process.

Application of biosolids increased chemical (e.g. total and available N and P) and some biological (e.g. biomass, microbial respiration and cover) soil parameters to a greater extent than inorganic fertiliser (DAP), supporting the results from the glasshouse trial. Application of biosolids or other organic amendments (e.g. green waste or compost) in rehabilitated areas that receive stockpiled topsoil should be encouraged as this treatment improves the physical, chemical and biological properties of soil. Addition of fresh topsoil as a biological ameliorant does not seem justified, as this treatment did not significantly increase microbial respiration, although the majority of other biological measures did increase. Nonetheless, direct return rather than stockpiling of topsoil should be undertaken wherever possible as soil quality parameters (e.g. SOC, N, P and vegetation parameters) in rehabilitated areas receiving fresh soil were greater than those that received stockpiled topsoil. The microbial liquid inoculum, while a more cost effective technique for reintroducing biological soil activity, did not increase the majority of the biological parameters and, at this stage, is not recommended for use without further refinement. The inherent quality of topsoil prior to stockpiling was important when considering the addition of ameliorants after respreading. Poorer quality soils may require greater amelioration regardless of their stockpiling status.

CHAPTER 8.
Topsoil Management Recommendations

This chapter summarises the results of the four experimental chapters in relation to the specific objectives outlined in each chapter. A height by age matrix was constructed to synthesise measured chemical and biological parameters for the stockpile experimental chapter. This information was then used to make recommendations for the management of topsoil stockpiles and the rehabilitation of open cut coal mines in the Hunter Valley, while also identifying areas requiring further research.

8.1 SUMMARY

The major objective of this study was to examine the effect of increasing stockpile heights and age on the physical, chemical and biological components of topsoil used for rehabilitating open cut coal mines in the Hunter Valley, New South Wales. The major findings have been summarised below in relation to the identified specific objectives.

8.1.1 Preliminary Surveys of Topsoil Stockpiles in the Hunter Valley Compared to Practices in the Bowen Basin

- An assessment of 25 topsoil stockpiles in the Hunter Valley exemplified the differences in soil types across mine sites ranging from loamy sand to clay loam (Figure 8.1).
- Topsoil stockpiles in the Hunter Valley were younger, taller but were of lower volume than those in the Bowen Basin, indicating the unique nature of topsoil management in the Hunter Valley.
- Height and age of stockpiles did not significantly affect the majority of physical, chemical and biological characteristics investigated.
- Higher levels of NO_3-N, NH_4-N and exchangeable cations were recorded at 1 m compared to the surface depth, indicative of leaching.
- Microbial respiration was positively correlated with vegetation cover.
- Microbial respiration was maximal in moderately aged stockpiles and subsequently decreased in older stockpiles as the anaerobic zone became more extensive.

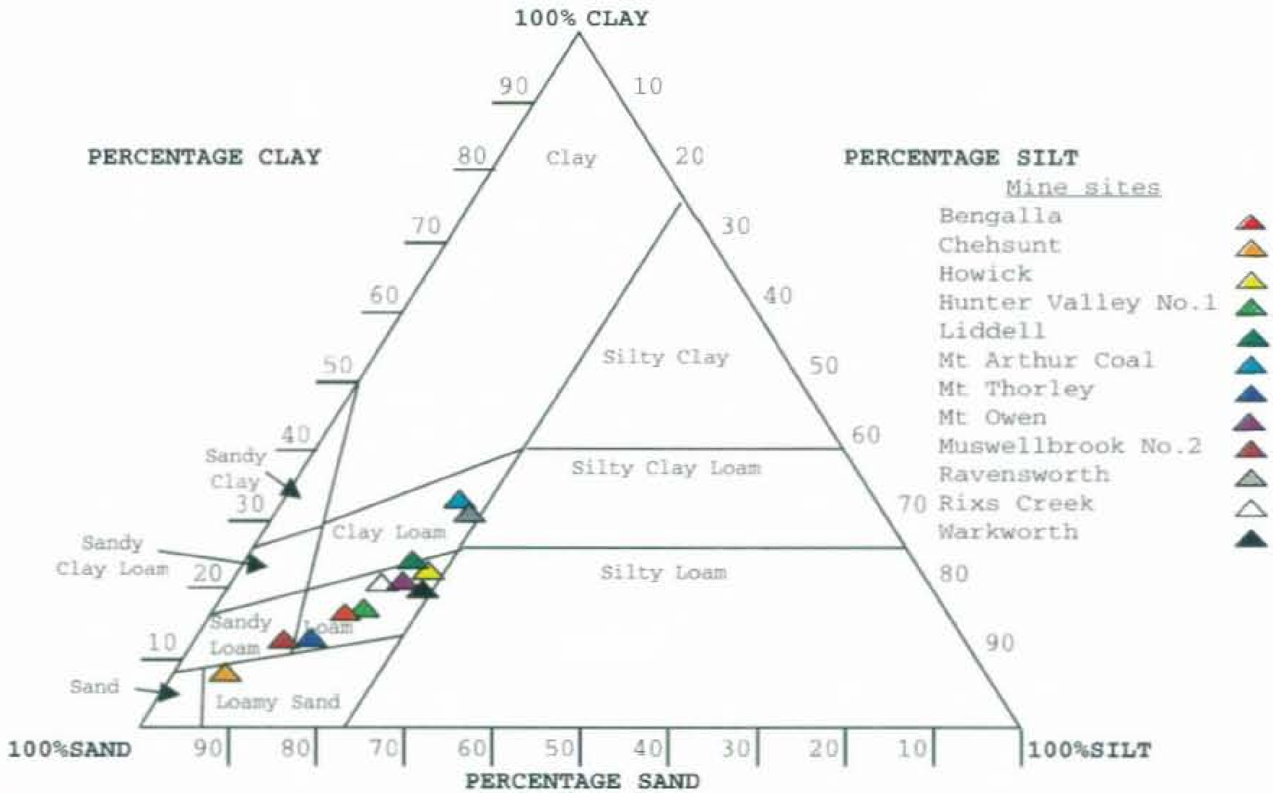

Figure 8.1: Triangular texture diagram based on international fractions from the particle size analysis from the 12 mine sites sampled in chapter 4 (methods from Day, 1965, after Charman and Murphy 2000). If multiple stockpiles were sampled at a site, the values were averaged.

8.1.2 Field Trial Investigating the Effect of Height and Age of Stockpiles on Soil Quality

- Handling soil with heavy machinery, prior to stockpiling, led to significant deterioration (up to 50%) across a range of soil chemical and biological parameters, indicating that deterioration of soil quality is rapid and initially independent of stockpiling.
- Age of stockpiles was the most significant factor affecting soil parameters across all three mine sites.
- The response of microbial respiration to age of stockpiles was dependent on soil type, with increases over time in the clay loam probably indicating better water holding capacity during drought conditions.
- Species richness and seed density in the topsoil seed store increased over time as vegetation established and set seed.
- Non-native species richness increased with stockpile age with maximal values indicative of seasonal changes in dominant vegetation.
- The 2 m stockpiles had greater levels of SOC and NO_3-N indicating maintenance of soil quality, while NH_4-N was greater in the 6 m stockpile due to ammonification occurring under anaerobic conditions.

- Nitrate-N, NH_4-N, EC, available P and some exchangeable cations increased with depth as a result of leaching, although an accumulation at the base of the taller stockpiles meant that nutrients were not lost completely.
- Microbial respiration increased with depth indicative of mineralisation of organic matter within the stockpile.
- Temperature increased at depth, particular in the taller stockpile, potentially indicating the formation of anaerobic zones at depth.
- Deterioration of soil quality during stockpiling was greater for the clay loam soils at Mt Arthur Coal, compared to the loam and sandy loam soils at Bengalla and Cheshunt respectively.
- Compared to the initial large deterioration resulting from handling by heavy machinery, stockpiling only led to minor decreases in soil quality, although taller and older stockpiles did record the greatest decrease.

8.1.3 Glasshouse Management Trial to Propose Practical Ameliorative Measures to Address Topsoil Degradation following Stockpiling

- All ameliorants affected some of the chemical and biological soil parameters that were assessed.
- Gypsum application increased many chemical parameters for mine sites with sodic or highly alkaline topsoil.
- Organic fertiliser (biosolids) generally increased chemical (e.g. total and available N and P) and biological (e.g. biomass and microbial respiration) parameters to a greater extent than the inorganic treatment (DAP).
- The addition of fresh topsoil increased plant biomass, species richness and vegetation cover, but not microbial respiration.
- The results from the glasshouse trial were utilised in the design of the field trial (8.1.4).

8.1.4 Rehabilitation Field Trial to Investigate the Effects of Different Chemical and Biological Ameliorants on Stockpiled Soil Quality

- Wherever possible, stockpiling should be avoided and direct return of topsoil should be undertaken as soil quality parameters in rehabilitated areas receiving fresh soil generally increased compared to sites receiving stockpiled topsoil.

- Increased rainfall following the second compared to the first spread influenced the quality of the rehabilitation more than the age of the stockpiled soil (18 versus 30 months).
- Height of stockpiles had little influence on the chemical or biological quality of the soil in the rehabilitation areas, suggesting those soil qualities that did deteriorate with an increase in stockpile height can be rectified by soil mixing and oxidation during the spreading process.
- Application of biosolids increased chemical (e.g. total and available N and P) and some biological (e.g. biomass, microbial respiration and cover) soil parameters to a greater extent than the inorganic fertiliser (DAP), supporting the results from the glasshouse trial.
- When rehabilitating areas with stockpiled topsoil, the application of biosolids or other organic amendments (e.g. green waste or compost) should be encouraged.
- Addition of fresh topsoil as a biological ameliorant did not significantly increase microbial respiration, however the majority of other biological measures did increase. The shallow depth to which the fresh soil was spread may have influenced this result.
- The microbial liquid inoculum, while a more cost effective technique for reintroducing biological soil activity, did not increase the majority of the biological parameters and is not recommended for use without further refinement.
- The inherent quality of topsoil prior to stockpiling was important when considering the addition of ameliorants after respreading. Poorer quality soils may require greater amelioration regardless of their stockpiling status.

8.2 Synthesis

8.2.1 Stockpile Age and Height

A stockpile age (0 to 30 months) by height (2, 4 and 6 m) standardised matrix was constructed based on the results of the stockpile field trial (chapter 5) to provide an overall assessment of the effect of stockpiling soil at different heights for varying periods of time on soil quality (Table 8.1). The initial values were collected from unmined sites prior to soil stripping. The three investigated mine sites are presented separately because soil type affected the response to stockpiling. Chemical fertility was determined by the addition of standardised results of SOC, NO_3-N, NH_4-N, available P, and total P and N. Ammonium-N values were standardised differently with the higher values receiving the lowest standardised values as high NH_4-N levels were indicative of anaerobic conditions. The biological measure was calculated from microbial respiration, topsoil species richness and seed density. The higher the standardised value, the better the soil quality. Averaged values for chemical and biological parameters across stockpile age and height have been re-standardised.

At all three mine sites, average soil qualities increased with increasing stockpile age. At Bengalla mine, maximal values were recorded at 6, 18 and 30 months while at Cheshunt mine values were highest at 12 and 30 months (Table 8.1a-b). Bengalla and Cheshunt mines exhibited higher soil quality values in the 2 and 4 m stockpile heights compared to the 6 m stockpile. In contrast, Mt Arthur Coal recorded lower values across all stockpile heights, with the 2 m stockpile only 8-9% greater than the 4 and 6 m heights (Table 8.1c). It is important to note that these results are pertinent to soil that has been stripped from pasture areas and subsequently stockpiled; they should not be extrapolated to mines trying to rehabilitate diverse native ecosystems.

Table 8.1: Height by age matrix based on standardised chemical and biological parameters (chapter 5) for (a) Bengalla, (b) Cheshunt and (c) Mt Arthur Coal. Shading relates to recommended amelioration (chapter 7) with no amelioration (white), organic chemical amelioration (orange), and organic chemical and biological amelioration (pink). Biological amelioration refers to the addition of fresh topsoil applied in strips.

a)

No Amelioration	Chemical Ameliorant	Chemical + Biological Ameliorant

Bengalla Parameters	2 m	4 m	6 m	Average
Chemical fertility	48			
Biological	98			
Initial average	**100**			
Chemical fertility	44	28	10	
Biological	24	16	32	
0 mths average	**38**	**19**	**17**	**25**
Chemical fertility	38	38	21	
Biological	100	57	59	
6 mths average	**94**	**59**	**48**	**67**
Chemical fertility	47	43	0	
Biological	35	30	20	
12 mths average	**49**	**42**	**0**	**30**
Chemical fertility	72	100	43	
Biological	4	26	0	
18 mths average	**44**	**84**	**18**	**49**
Chemical fertility	78	87	52	
Biological	66	42	23	
30 mths average	**98**	**86**	**44**	**76**
Average	**65**	**58**	**25**	

No Amelioration	Chemical Ameliorant	Chemical + Biological Ameliorant

b)

Cheshunt Parameters	2 m	4 m	6 m	Average
Chemical fertility	74			
Biological	80			
Initial average	**82**			
Chemical fertility	35	37	34	
Biological	0	45	58	
0 mths average	**0**	**32**	**39**	**24**
Chemical fertility	58	63	32	
Biological	68	64	55	
6 mths average	**63**	**63**	**36**	**54**
Chemical fertility	63	51	0	
Biological	100	100	77	
12 mths average	**88**	**80**	**29**	**66**
Chemical fertility	83	80	68	
Biological	64	9	39	
18 mths average	**77**	**38**	**50**	**55**
Chemical fertility	100	91	66	
Biological	79	89	53	
30 mths average	**99**	**100**	**58**	**86**
Average	**65**	**63**	**43**	

c)

Mt Arthur Coal Parameters	2 m	4 m	6 m	Average
Chemical fertility	86			
Biological	100			
Initial average	**100**			
Chemical fertility	86	86	84	
Biological	23	18	0	
0 mths average	**45**	**43**	**28**	**39**
Chemical fertility	18	34	35	
Biological	92	60	36	
6 mths average	**46**	**34**	**19**	**33**
Chemical fertility	22	0	40	
Biological	44	44	39	
12 mths average	**15**	**0**	**25**	**13**
Chemical fertility	58	73	88	
Biological	38	50	44	
18 mths average	**36**	**56**	**62**	**51**
Chemical fertility	94	100	85	
Biological	86	36	45	
30 mths average	**96**	**65**	**60**	**74**
Average	**48**	**40**	**39**	

The preliminary stockpile survey (chapter 4) indicated that over 50% of the topsoil stockpiles in the Hunter Valley were between 2 and 4 m in height, with 60% being greater than the 3 m Department of Infrastructure, Planning and Natural Resources (DIPNR) guideline. The mean height of topsoil stockpiles in the Hunter Valley was 3.8 m with a range from 1 to 9.5 m, with

16% being greater than 6 m in height. The chosen stockpile heights of 2, 4 and 6 m are therefore representative of the majority of stockpiles in the Hunter Valley. Stockpile age ranged up to 10 years old, with a mean of 3.2 years, with approximately 30% less than one year old. However, a large proportion of topsoil was stockpiled for long periods of time. The stockpile field trial was monitored for 30 months (2.5 years) and does not, therefore, cover the majority of stockpiles in relation to age. However, temporal patterns have emerged in the first 2.5 years, although further monitoring may be required.

8.2.2 Rehabilitating Stockpiled Topsoil

The lower values in the stockpile height and age matrix are indicative of poorer soil quality. The glasshouse (chapter 6) and field (chapter 7) rehabilitation trials demonstrated that this deterioration could be relatively easily rectified by the addition of chemical and biological ameliorants when the stockpiled soil is re-spread in rehabilitated areas. Organic chemical amelioration was recommended for soil stockpiled to a moderate height for a moderate period of time (Table 8.1). The cost of applying organic ameliorants was estimated at $1500-2000/ha (D. Pope pers. comm. 2003). Organic chemical and biological amelioration was recommended for soil stockpiled to greater heights for longer periods of time. The recommended biological amelioration is for fresh topsoil to be placed in strips on to areas rehabilitated with stockpiled soil. The cost of applying strips of fresh soil is dependent on the spacing and requires further research. For example, based on research undertaken in Western Australia using this technique (Grant *et al.* 2004), the estimated cost to strip topsoil to 30 cm and spread over 25% of the rehabilitated area at 10 cm depth is $625/ha (C. Grant pers. comm. 2004). The strips of fresh topsoil act as a source of seeds and microbes and maximise the utilisation of this important resource. Chemical and biological amelioration is recommended for the lowest quality soil as the organic treatment provides a carbon substrate in association with slowly released N and P, while the directly returned striped soil contributes seed and microbes. No amelioration was recommended for the 0 month soils even though the values are quite low because this does not represent a true stockpiling scenario.

8.3 MANAGEMENT RECOMMENDATIONS

Elliott and Veness (1985) conducted a study in the Hunter Valley on five stockpiles with a range from 0.6 to 3 m in height and concluded that stockpiling results in a decline of structural attributes and an increase in total P and N. They suggested improvements in the quality of topsoil can occur for up to two years in the upper 60 cm of a stockpile, and so recommended this depth as the optimum for topsoil storage. However, the DIPNR guidelines extrapolated from this research states that stockpiles should be constructed to a height of less than 3 m.

The following recommendations are based on direct outcomes of this research applicable to environmental management in open cut coal mines in the Hunter Valley.

- Soil can be stored in stockpiles greater than 3 m in height depending on the period of storage, the predominant soil type at the mine site and the level of amelioration undertaken in the rehabilitation process. These recommendations only relate to mine sites in the Hunter Valley rehabilitating land to a pasture final landuse and should not be extrapolated to areas elsewhere in Australia where the rehabilitation objective is to return diverse native ecosystems.
- Mine sites that have soils with higher clay content should store topsoil in lower stockpiles for shorter periods of time than sites with sandier soils. Alternatively, these sites can store clay soils in taller stockpiles on the provision that they can increase the level of amelioration of rehabilitated areas that receive this stockpiled topsoil.
- The geometry of stockpile construction is important and it is better to create free-draining stockpiles to prevent anaerobic zones forming rather than trying to maintain nutrients at the base of the stockpile. Therefore, stockpiles should continue to be shaped to prevent erosion but encourage water runoff, without the loss of soil.
- Maintain seeding of stockpiles to reduce erosion and the loss of beneficial soil micro-organisms by rapidly establishing vegetation cover. The seed mix should contain deep-rooted species (e.g. Lucerne), nitrogen-fixing species (e.g. clovers and medics) and grasses (couch, panic, ryegrass etc.).
- Every mine in the Hunter Valley should instigate a topsoil management system to record information on all stockpiles located at each site. The database (see Appendix 8.1) should contain the stripping location, soil type (clay content or sand), stripping depth, machinery used for stripping, date of creation of stockpile, volume and dimensions of the stockpile, seeding mix, priority of use and be identified by a unique number.
- After construction, clearly identify stockpiles with signs to minimise further disturbances and display the date of construction and priority of use.
- Ammonium-N is recommended as an indicator in stockpile storage, as high levels can help determine if anaerobic zones are forming in the lower depths of stockpiles.
- When respreading soil, aerobic and anaerobic zones formed during stockpiling should be mixed to avoid concentrating or diluting various chemical or biological parameters.
- The machinery used to return stockpiled topsoil affects the level of mixing that can occur. For example, scrapers don't have the ability to mix stockpiled soil as well as trucks and loaders. However, when using scrapers, selective topsoil stockpile portions can be moved from the stockpile, containing relatively equal amounts from aerobic and anaerobic

zones. This technique is commonly used in bauxite mining rehabilitation in Western Australia (C. Grant pers. comm. 2004; Figure 8.2).

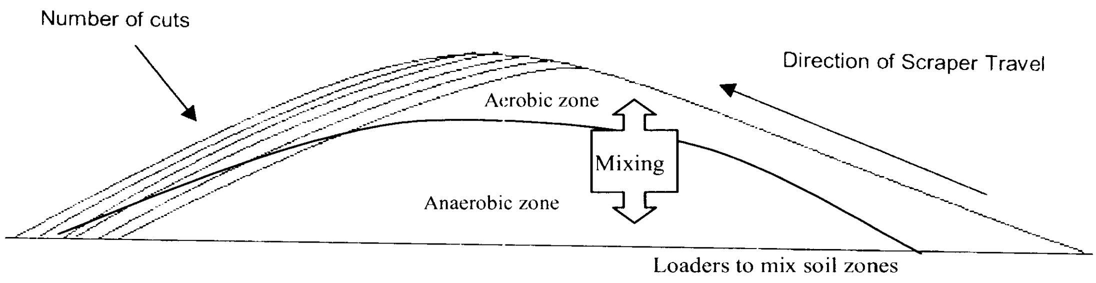

Figure 8.2: Correct method of reclaiming a stockpile using scrapers used to mix stockpiled topsoil when respreading (zones are after Harris *et al.,* 1989).

- Topsoil stored in taller and some older stockpiles will require the greatest level of amelioration when respread in rehabilitated areas (see Table 8.1).
- The additional amelioration required following longer storage of topsoil in larger stockpiles is justified if the increased cost of rehabilitation (i.e. application of biosolids at $1,500-2,000/ha; replacing strips of fresh topsoil at $625/ha) is outweighed by the cost saving in stockpiling soil to a greater height.
- Organic ameliorants (e.g. biosolids) are recommended for topsoil stockpiled to medium and larger heights for longer periods of time to provide nutrients, organic matter and contribute to soil stabilisation. However, the proliferation of weed species from biosolids needs to be closely monitored and other organic ameliorants may be more suitable (see 8.4).
- Based on current research within Australia (Grant *et al.* 2004), fresh topsoil should be applied in strips to a depth of 10 cm by scrapers (Figure 8.3), covering up to 25% of a rehabilitated area that receives soil that has been stockpiled to greater heights for longer periods of time (see Table 8.1), dependent on soil type. However, for the Hunter Valley further refinement on this technique may be justified with research carried out on the depth of application and the percent cover that is required to provide biological amelioration for effective vegetation establishment.
- Direct return should always be encouraged rather than stockpiling because this involves handling of the soil only once and avoids any further loss of soil quality that may occur during the stockpiling. Putting fresh soil in strips optimises the utilisation of this soil.
- Gypsum should be applied at mines with sodic soil at the rate of 5 t/ha, although specific soil testing should be undertaken to more precisely determine the application rate.

- Stockpiled soil should be spread on rehabilitated sites and seeded immediately to minimise the establishment of weed species through rapid establishment of native vegetation cover.

Figure 8.3: (A) Fresh topsoil applied in strips and (B) after the topsoil has been graded out at an Alcoa bauxite mine in Western Australia (Photo courtesy of Carl Grant). It should be noted however, that the rehabilitation objective in Alcoa bauxite mining is to return land to native ecosystems.

8.4 Further Research

A number of areas requiring further investigation have been identified throughout this project and these are listed below.

- The effect that constructing stockpiles with different machinery (e.g. scrapers versus loaders/trucks) has on soil quality should be investigated further. In the current study, different mines had different available machinery and, therefore, this effect could not be investigated independently.
- Further research into stockpile geometry could be undertaken and monitored to create the most effective free-draining stockpiles to prevent anaerobic zones forming.
- Where possible, continue monitoring the established stockpiles, as information greater than the 30 month time frame reported would add further robustness to the results and help confirm observed patterns and management recommendations.
- Applying fresh topsoil in strips on to rehabilitated stockpiled soil (see 8.3) should be investigated and monitored. This practice has been used previously with success in rehabilitated bauxite mines (Grant *et al.*, 2004). Refinement of this technique may be

needed for the Hunter Valley, investigating depth of return and the required percent cover of fresh soil.

- The application of other organic ameliorants as an alternative to biosolids should be assessed.
- Although the application of microbial inoculums was not beneficial in this study, further research should be undertaken to refine the process for the establishment of these mediums. This research is ongoing at the University of Newcastle.
- The management recommendations are based on results from the rehabilitation trial that was conducted at a relatively dry time in the Hunter Valley (refer to Figure 7.9). Some soil processes may have responded differently under different climatic conditions, therefore, further monitoring may identify some changes in soil processes.
- Continue monitoring the established rehabilitation trial to determine potential medium term impacts of stockpiling topsoil on the resulting quality of rehabilitated areas.

8.5 Conclusions

The major objective of this study was to examine the effect of increasing stockpile heights and age on the physical, chemical and biological components of topsoil used for rehabilitating open cut coal mines in the Hunter Valley, New South Wales. Compared to the initial large deterioration resulting from handling by heavy machinery in stripping and creating stockpiles, stockpiling to greater heights only led to minor decreases in soil quality. Greater deterioration of soil quality during stockpiling occurred for the clay loam soils at Mt Arthur Coal, compared to the loam and sandy loam soils at Bengalla and Cheshunt respectively. Nonetheless, deterioration during stockpiling was relatively easily rectified in the rehabilitation process. Topsoil stockpiles in the Hunter Valley can be constructed to a height greater than the DIPNR guideline of 3 m providing the mining company is prepared to accept and account for the costs of increased monitoring and soil amelioration prior to its use in the rehabilitation program.