CHAPTER 5.
Field Trials Investigating the Effect of Height, Age and Depth of Stockpiles on Soil Quality

5.1 Introduction

Topsoil may deteriorate in many ways during storage (Visser *et al.*, 1984a). Topsoil buried deep in a storage pile may become anaerobic and, as a consequence, physical, chemical and biological properties will undergo changes that may affect its quality for use in rehabilitation. Some examples of deterioration resulting from stockpiling includes soil structure decline, loss of organic matter and nutrients, deterioration of seeds, death of other plant propagules and significant reduction of populations of beneficial soil micro-organisms (EPA, 1995). 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 stripping and stockpiling results in a decline of structural attributes and an increase in extractable P and total N. They suggested that 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. The major objective of this chapter was to investigate the effect of stockpile age, height and depth on physical, chemical and biological aspects of the topsoil used for rehabilitating open cut coal mines in the Hunter Valley.

5.2 Methods

5.2.1 Stockpile Trial Location

Experimental topsoil stockpiles were constructed at three open cut coal mines in the Hunter Valley in August 2000. The three sites were Bengalla, Cheshunt and Mt Arthur Coal mines (Figure 2.1).

Bengalla mine

Bengalla mine is located in the upper Hunter Valley of New South Wales, west of Muswellbrook. The open cut mine lies on the north-western side of the Hunter River, 3 km west of Muswellbrook township (Figure 5.1). The pre-mining landuses consisted of dairy farms, beef cattle grazing, horse studs and cropping on the rich alluvial flats of the Hunter River. Four soil types exist on the mine site namely red duplex, yellow duplex, brown gradational and brown uniform soils. The current active mining area at Bengalla is not within the alluvial land area, which occurs on the southern portion of Bengalla's lease area. Two main vegetation associations existed pre-mining; an alluvial floodplain that was cleared and intensely farmed, and foothills and undulating grazing land containing native and exotic pastures and weed species with only scattered wooded areas (Envirosciences, 1993).

Figure 5.1: View of Bengalla mine, showing Muswellbrook in the background.

Cheshunt mine

Cheshunt mine is located in the Hunter coalfields approximately 15 km west of Singleton and lies to the west of the Hunter River at its junction with Wollombi Brook (Figure 5.2). The topography of the area is undulating, with elevations rising from 60 m in the Hunter River floodplain to 110 m in the southern part of the Cheshunt lease. The two major soil types occurring within the general South Cheshunt area are duplex soils and siliceous sands. These soil types are directly associated with the two major geological units in the area (alluvial and sedimentary bedrock units). The vegetation within the general South Cheshunt area includes large expanses of grassland, stands of regenerating woodland and a narrow band of riverine woodland along Wollombi Brook (Sinclair Knight and Mertz, 1997).

Figure 5.2: Aerial view of Cheshunt mine.

Mt Arthur Coal mine

Mt Arthur Coal is located 5 kilometres south of the township of Muswellbrook in the upper Hunter Valley within lands predominantly used for grazing prior to mine ownership (Figure 5.3). The soil texture within the site consists of a loamy sand to a medium clay consistency. The vegetation consists predominantly of pastoral grasslands typically found throughout the region, comprising native and exotic species, containing a high diversity of species and abundance of exotic weed species. Remnants of open forests of *Corymbia maculata* occur at Saddlers Creek and at Mt Arthur (Resource Planning Pty Limited, 1993).

Figure 5.3: View of McDonalds Pit from Mt Arthur at Mt Arthur Coal mine.

5.2.2 Trial Design

The survey of stockpiles conducted over 12 mines sites in the Hunter Valley (chapter 4) showed that 60% of stockpiles were greater than the current guideline of 3 m recommended by the Department of Planning, Infrastructure and Natural Resources (DIPNR, Appendix 4.1). Therefore, two heights greater and one lower than this critical limit were chosen, namely 2, 4 and 6 m. All three mine sites originally planned to construct two replicates of each of the three heights of stockpiles. However, due to time and logistical constraints, two replicates were constructed at Bengalla (Figure 5.4) and only one at Cheshunt and Mt Arthur Coal mines. Topsoil stripped and used for the stockpile trial at Bengalla mine was not located on the alluvial land. Cheshunt mine constructed a 6 m stockpile, with the 2 m and 4 m stockpiles constructed as a composite stockpile to act as a bund wall around the outside of the mining lease area (Figure 5.5). Mt Arthur Coal constructed one large composite stockpile, with the 6 m depth at one end, descending to the 2 m height at the other end (Figure 5.6). All stockpiles were trapezoidal in shape and were constructed with machinery typically used at that particular mine site (i.e. scrapers or dozers - Table 5.1).

a) b)

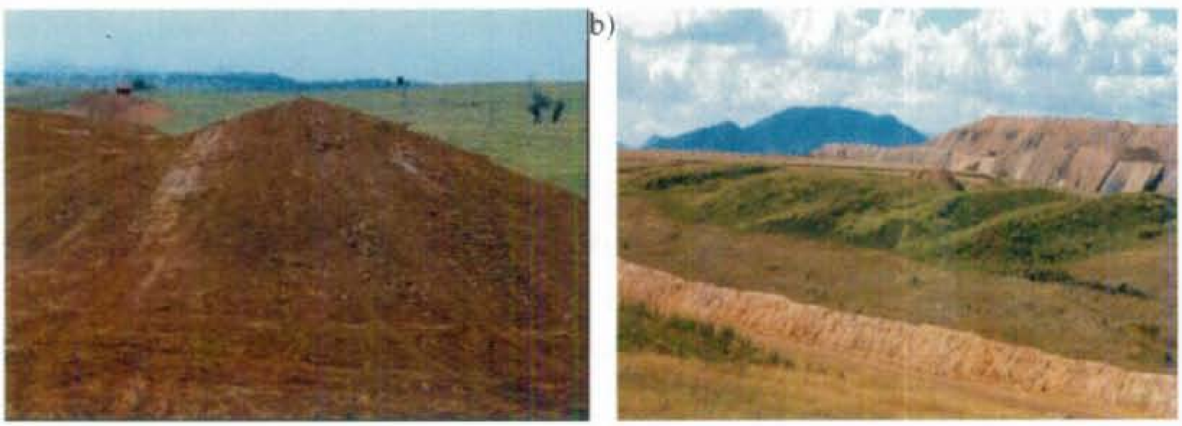


Figure 5.4: (a) Bengalla 4 m stockpile at 0 months, and (b) 2 and 4 m (left to right) stockpiles at 12 months.

Figure 5.5: (a) Cheshunt 4 m topsoil stockpile at 0 months and (b) 6 m stockpile at 18 months.

Figure 5.6: (a) Mt Arthur Coal 4 m topsoil stockpile at 0 months and (b) 6 m stockpile at 6 months.

Table 5.1: Summary of stockpile construction information.

Site	Height	Location	Equipment	Construction Date	Stripping Depth
Bengalla	2 m	Near Stockyards	Scraper	September, 2000	0-30 cm
	2 m	Near Stockyards	Scraper	September, 2000	0-30 cm
	4 m	Near Stockyards	Loader/r190 trucks	October, 2000	0-30 cm
	4 m	Near Stockyards	Loader/r190 trucks	October, 2000	0-30 cm
	6 m	Near 5 year dam	Loader/r190 trucks	August, 2000	0-30 cm
	6 m	Opp. erecting pad	Loader/r190 trucks	September, 2000	0-30 cm
Cheshunt	2 m	South Cheshunt	Scrapers/dozer	September, 2000	0-30 cm
	4 m	South Cheshunt	Scrapers/dozer	September, 2000	0-30 cm
	6 m	South Cheshunt	Scrapers/dozer	October, 2000	0-30 cm
Mt Arthur Coal	2 m	Saddlers Creek	Scrapers/dozer	September, 2000	0-50 cm
	4 m	Saddlers Creek	Scrapers/dozer	September, 2000	0-50 cm
	6 m	Saddlers Creek	Scrapers/dozer	September, 2000	0-50 cm

All topsoil stockpiles were seeded with each mine sites standard pasture mix (Table 5.2a-c). These mixtures were based on current guidelines produced by DIPNR for rehabilitation of mine sites in the Hunter Valley. Stockpiles were seeded in November after construction from August to October.

Table 5.2: Seed mix applied to stockpiles in the field trial across the three mine sites. Note: Cheshunt mine used inoculated legumes with lime coating.

a) Bengalla

Species	Seeding rate (kg/ha)
Couch grass (hulled) (*Cynadon dactylon*)	5
Millet-Japanese (*Echinochloa esculenta*)	2
Kikuyu grass (*Pennisetum clandestinum*)	5
Lucerne (*Medicago sativa*)	5
Rhodes grass-Pioneer (*Chloris gayana*)	10
Subterranean clover (*Trifolium subterraneum*)	3
Total	**30**

b) Cheshunt

Species	Seeding rate (kg/ha)
Lucerne-Aurora (*Medicago sativa)*	4
Couch grass (hulled) (*Cynadon dactylon*)	3
Green panic (*Panicum maximum*)	3
White clover-Haifa (*Trifolium repens*)	3
Kikuyu grass-Whittet (*Pennisetum clandestinum)*	4
Paspalum (*Paspalum dilatatum*)	3
Subterranean clover-Seaton Park (*Trifolium subterraneum)*	4
Barrel medic-Sephi (*Medicago truncatula*)	3
Millet-Shirrohie (cover crop) (*Echinochloa utilis*)	10
Rye grass-Wimmera (*Lolium rigidum*)	5
Total	**42**

c) Mt Arthur Coal

Species	Seeding rate (kg/ha)
Lucerne-Aurora *(Medicago sativa)*	7
Couch grass (unhulled) (*Cynadon dactylon*)	10
Green panic (*Panicum maximum*)	4
White clover-Haifa (*Trifolium repens*)	3
Kangaroo grass (*Themada australis*)	4
Kikuyu grass-Whittet (*Pennisetum clandestinum)*	3
Ryecorn (*Secale cereale*)	6
Subterranean clover-Seaton park (*Trifolium subterraneum)*	4
Barrel medic-Sephi (*Medicago truncatula*)	2
Rye grass-Wimmera (*Lolium rigidum*)	6
Total	**49**

5.2.3 Field Sampling

Initial soil samples were collected prior to the stripping of the topsoil from unmined areas (Figure 5.7). Ten random soil samples were collected at each mine site using a soil auger to a depth of 20 cm. Each soil sample (~ 1 kg) collected for physical and chemical analyses was placed in a plastic bag, while samples for biological analyses were stored in 120 ml plastic containers (Figure 5.8). 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 were analysed.

Figure 5.7: Collection of initial samples at Bengalla mine site.

Figure 5.8: Soil collected for chemical analyses from the Cheshunt 6 m stockpile.

After the construction of the stockpiles, soil samples were collected at 0, 6, 12, 18 and 30 months from 3-6 depths within the stockpile depending on stockpile height (Table 5.3). A total of 144 soil samples were collected from the three mine sites at the 6 and 12 month age intervals, while only 129 soil samples were collected at the 0 month age because only one of the 6 m stockpiles at Bengalla could be sampled. Only 108 soil samples were collected at the 18 and 30 month age intervals due to the early spreading of some of the topsoil for the rehabilitation field trial (see chapter 7). At each assessment, three randomly selected sites on each stockpile were sampled with a truck-mounted hydraulic soil sampler with a stainless steel coring tube (known as a push tube, Figure 5.9). Initially, the soil was augured to the required depth, followed by the insertion of a 50 mm diameter soil corer that hydraulically extracted soil samples (Figure 5.10). This method was chosen as sampling at depth was required and the samples obtained from corers have more soil structure preserved than augered samples (Aldrick, 1988). Soils were collected and stored as previously outlined (see 4.2.2).

Table 5.3: Sampling depths in the three stockpile height treatments

Height (m)	2	4	6
Depth of sampling (cm)	0-30	0-30	0-30
	80-110	80-110	80-110
	160-190	160-190	160-190
	-	340-370	340-370
	-	-	520-550

Figure 5.9: Truck-mounted soil corer at Cheshunt mine collecting 6 m stockpile samples.

a) b)

Figure 5.10: Truck-mounted soil corer (a) showing auger head and (b) push tube interchange capabilities.

For each stockpile at each mine site, vegetation cover was assessed at 6, 12, 18 and 30 months after establishment, from five randomly selected but permanently marked 1 x 1 m quadrats (Figure 5.11). Total cover of individual species was recorded as a percentage and plant samples were taken for identification.

Figure 5.11: Vegetation monitoring using a 1 m by 1 m quadrat.

Soil temperature for the 18 to 30 month assessments were recorded with data loggers in one of the 2, 4 and 6 m stockpiles at Bengalla mine with two replicates per stockpile. Twelve thermocouples were positioned at 0, 50, 100, 200, 300 and 500 cm depths (depending on stockpile height) down holes made with the truck-mounted soil corer and backfilled with soil (Figure 5.12). Each logger was programmed to record average temperatures every hour and was downloaded onto a computer every month with the help of site environmental staff. However, some problems occurred on specific stockpiles, due to mechanical problems with the data loggers, so results were not equally collected across all three stockpile heights.

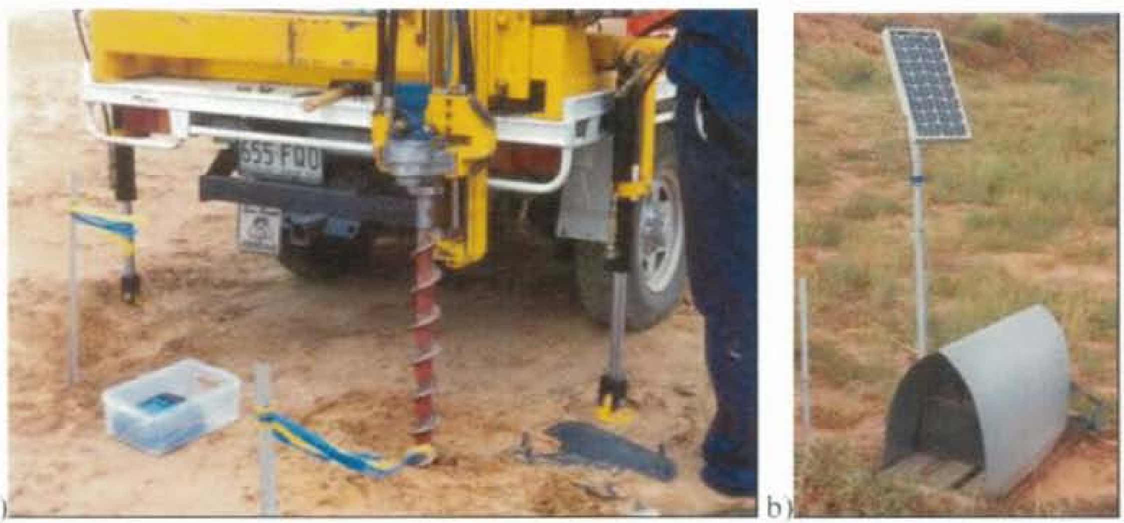
a) 

Figure 5.12: (a) Close up of auger drilling a hole for the data logger in a 6 m stockpile and (b) data logger location at the 6 m stockpile at Bengalla mine.

5.2.4 Soil Analyses

Soil samples were analysed for physical, chemical and biological attributes as outlined in sections 4.2.3-4.2.5. A commercial laboratory (CSBP Futurefarm) conducted the 18 and 30 month stockpile assessments for all soil tests (with the fine earth fraction, < 2 mm) as previously outlined, with the following exceptions. Total P and N methods were different from those methods used at the University laboratory, but were comparable. Total P was determined on an auto analyser after Keldjhal digestion (concentrated sulfuric acid - Rayment and Higginson, 1992). To determine total N, soil samples were combusted at 950°C in oxygen using a Leco FP-428 Nitrogen Analyser (Searle, 1984).

5.2.5 Statistical Analyses

The data were first subjected to ordination techniques to determine the most dominant factors across all physical, chemical and biological parameters. Ordinations were carried out using Detrended Correspondence Analysis (DCA) in the CANOCO™ application. The ordinations used mean values for the three replicate samples taken from each stockpile. Data were range standardised prior to analysis. Analysis of Similarity (ANOSIM) of the 20 soil parameters was conducted with the Bray-Curtis similarity matrices using the PRIMER 5 application, using a maximum of 10,000 permutations to determine if there were significant differences between stockpile factors of age, height and depth (Anderson, 2001).

The 30 unmined soil samples (referred to as initial) collected from the three mines were tested against the 0 month assessment by one-way ANOVA to determine changes that occurred from the process of creating the stockpiles. Tukey's multiple range test was used as the post-hoc test to compare the means of the different variables when the ANOVA was significant.

A linear mixed effects model was developed for each sampling period for each mine with fixed effects consisting of height, depth and age, and random components were replicates within stockpiles. This model allowed determination of possible correlations in the data (i.e. repeated measures).

Three models were developed to assess different combinations of stockpile height and sampling depth over time namely:

- Model 1 = Three common sampling depths (0-30, 80-110 and 160-190 cm) for the 2, 4 and 6 m stockpile heights (Table 5.3);
- Model 2 = Depth was classified as upper, middle and lower positions (Table 5.4) across the three height treatments; and

- Model 3 = All five depths for the 6 m stockpile were analysed separately for depth and age.

The two sets of Bengalla results were pooled together and analysed as one set, so sites could be compared to each other. Within each model, diagnostic plots were used to assess the quality of the models. Natural log (log or log+1) or square root transformations were used where they improved the normality or aided in the reduction of the residual spread for all soil parameters. A modified t-test was used to determine pot-hoc significance. All biological count data for topsoil seed stores (species richness and seed density) refers to per sample results and were square root transformed. All unknown species were included for species richness data analyses, however, when broken into origin, the unknown species were eliminated. A comparison of Akaikes Information Criteria (AIC) between successive models helped determine the most appropriate final model for the individual soil parameters (Venables and Ripley, 2000). All analyses were conducted using the 'R' program (Inaka and Gentleman, 1996) with the NLME package (Pinheiro and Bates, 2000).

Table 5.4: Classification of depths (cm) for analyses of each stockpile height.

Class	2 m	4 m	6 m
Upper	0-30	0-30	0-30
Middle	80-110	160-190	160-190
Lower	160-190	340-370	520-550

Main effect characteristics (age, depth and height of stockpile) and associated two-way interactions were analysed by selected depths (model 2). Age was significant for the majority of parameters in model 3, however, they were not presented as age had already been considered in the earlier models. The focus of model 3 was to show the depth responses in the largest stockpiles. Age by depth interactions for model 3 were only significant for a small number of soil parameters occurring across two or more mine sites and were not presented. Arithmetic means rather than those predicted by the models are presented. Refer to Appendix 4.4 for units associated with physical, chemical and biological parameters measured. Only significant results were presented for the main effects and the two-way interactions of the soil parameters. Of the significant two-way interactions, only SOC, N, P, microbial respiration and topsoil seed store parameters were presented as these were seen as the most important to assess stockpile height and age. Three-way analyses were undertaken, but were not presented, as they were not considered ecologically meaningful. Mt Arthur Coal physical analyses were excluded due to sample preparation problems because of the high clay content of the soil. In addition, for Bengalla and Cheshunt mines, only the fine earth (< 2 mm) physical analyses are presented due to sampling problems with the gravel fractions in the soil. The silt, sand and clay fractions do not add up to 100% as the gravel fraction was calculated but not presented.

To summarise the soil temperature data, the data logger information downloaded from the two replicate holes in each stockpile height were pooled and averaged per 24 hours to give a daily mean at the individual depths. Depth was classified as upper, middle and lower across the three height treatments to give a balanced design (Table 5.4). Where the data collected were not a complete 24 hour set, they were not used and any data deemed questionable were deleted (three consecutive blanks, zero, 99.9, too high).

The topsoil seed store (species, density and origin) and vegetation data (species and percentage cover) were subjected to ordination techniques to determine the most dominant stockpile factors (mine, age, height and depth) across biological parameters. The ordinations (undertaken using the same techniques as described above) used mean values for the replicate samples taken from each stockpile. Where required, data were range standardised prior to analysis. The establishment of vegetation cover on the stockpiles of different heights over time was subjected to one-way ANOVA.

5.3 RESULTS

5.3.1 Initial Compared to 0 month Samples

Of the physical properties of topsoil collected from unmined areas (initial soil) at the three mines, particle size analysis indicated that topsoil collected from the Bengalla mine contained a small proportion of coarse and fine sand, giving it an international texture class of loam, while Cheshunt mine had a larger proportion of coarse and fine sand, with a texture class of loamy sand (Table 5.5). In contrast, Mt Arthur Coal mine contained a higher proportion of clay giving it an international texture class of clay loam.

The chemical and biological properties of topsoil prior to stripping differed across the three mine sites (Table 5.6). Nonetheless, most parameters at all sites were regarded as adequate when compared to recommended levels, with the exception of available P, SOC and NO_3-N being low, and K being high. Comparison of the initial and 0 month samples from the constructed stockpiles showed that significant soil changes occurred as a result of the stripping of topsoil and construction of the stockpile itself. When data were pooled across the three mine sites, four chemical, two biological and one physical parameter showed a significant difference resulting from the construction of stockpiles. All parameters, except for available P and sand, decreased across all sites (Table 5.7). Potassium and total N showed the greatest deterioration (59 and 69% respectively), while available P showed a significant increase (69%) as a result of stockpile construction.

Of the 18 physical, chemical and biological parameters investigated, six, 10 and five, changed significantly at Bengalla, Cheshunt and Mt Arthur Coal respectively, as a result of the construction of the stockpiles (Table 5.8). At Bengalla mine, three chemical and one biological parameter decreased out of the six significant parameters. Cheshunt mine had seven chemical out of 10 significant parameters that decreased (Table 5.8). At Mt Arthur Coal, total N and K decreased while the other parameters increased. Total N and K decreased at all three sites (60, 65 and 91% and 55, 62 and 57% respectively), while SOC decreased at two sites. There were no other consistent patterns across sites for parameter changes following stockpiling.

Table 5.5: Particle size analysis of initial topsoil samples (of the fine fraction <2 mm) across the three Hunter Valley mines. Source: McDonald and Isbell, 1990.

Mine site	Bengalla	Cheshunt	Mt Arthur Coal
Coarse Sand %	32	24	11
Fine Sand %	29	49	42
Silt %	19	15	19
Clay %	19	12	29
International texture class	Loam	Loamy sand	Clay loam

Table 5.6: Chemical and biological properties of the initial soil samples collected from the three mine sites, compared to recommended levels. Recommended levels modified from Charman and Murphy (2000) and Peverill *et al.* (1999).

Soil Parameter	Recommended	Bengalla	Cheshunt	Mt Arthur Coal
pH	5.5-7.5	5.92 moderate	7.01 moderate	6.74 moderate
EC	< 1.5 ds/m	0.03 moderate	0.02 moderate	0.05 moderate
SOC	> 2%	1.33 low	0.72 low	1.33 low
Ca	2-18 cmol(+)/kg	5.61 moderate	2.53 moderate	5.53 moderate
Mg	0.6-1 cmol(+)/kg	1.38 moderate	1.12 moderate	4.44 moderate
K	0.05-1 cmol(+)/kg	1.51 high	1.24 high	1.53 high
Na	0.0005-0.05 cmol(+)/kg	0.11 moderate	0.91 moderate	1.83 moderate
ECEC	cmol(+)/kg	9.5 n/a	5.8 n/a	13.21 n/a
Avail P	4-20 mg/kg	1.83 low	0.87 low	2.09 low
Total P	200-1500 mg/kg	259 moderate	200 moderate	184 low
Total N	0.05-0.3%	0.17 moderate	0.11 moderate	0.20 moderate
NO_3-N	20 mg/kg	10.8 low	3.61 low	12.4 low
NH_4-N	mg/kg	20.1 n/a	10.6 n/a	20.6 n/a
Microbial Respiration	mg/kg	18.9 n/a	5.79 n/a	16.9 n/a

Table 5.7: Initial versus 0 month samples for significant physical, chemical and biological parameters across mine sites (*** = P<0.001, ** = P<0.01, * = P<0.05). Different letters refer to significantly different values determined from Tukeys post-hoc test, a: corresponds to the highest value. Percentage change arrows indicate an increase (↑) or decrease (↓) from the initial to 0 month assessment.

Across all mine sites	Initial	0 months	$F_{1,61}$	P	% Change
SOC	1.14a	0.71b	15.1	***	38↓
K	1.43a	0.61b	177	***	59↓
Total N	0.16a	0.05b	36.6	***	69↓
Avail P	1.59b	5.10a	6.37	*	69↑
Sand	41.4b	51.8a	4.53	*	20↑
Microbial Respiration	13.9a	9.03b	8.23	**	36↓
Species Richness	3.23a	2.01b	4.25	*	38↓

Table 5.8: Initial versus 0 month samples for significant physical, chemical and biological parameters for the three individual mine sites (*** = P<0.001, ** = P<0.01, * = P<0.05). Different letters refer to significantly different values determined from Tukeys post-hoc test, a: corresponds to the highest value. Percentage change arrows indicate an increase (↑) or decrease (↓) from the initial to 0 month assessment.

Parameter Bengalla	Initial	0 months	$F_{1,23}$	P	% Change
pH	5.98b	6.73a	25.5	***	11↑
EC	0.03b	0.05a	6.37	*	40↑
SOC	1.34a	0.77b	33.5	***	43↓
K	1.56a	0.62b	127	***	62↓
Total N	0.17a	0.06b	33.5	***	65↓
Microbial Respiration	18.9a	9.22b	16.5	***	51↓
Cheshunt	**Initial**	**0 months**	$F_{1,17}$	**P**	**% Change**
SOC	0.73a	0.25b	33.3	***	66↓
K	1.32a	0.51b	42.6	***	59↓
Mg	0.63a	0.21b	10.2	**	59↓
Ca	2.49a	1.03b	60.9	***	62↓
ECEC	6.12a	3.31b	163	***	45↓
NO_3-N	0.37b	0.82a	13.4	**	55↑
Total N	0.11a	0.01b	36.9	***	91↓
Avail P	0.88b	10.1a	8.68	**	91↑
Total P	200a	131b	12.7	**	35↓
Sand	49.9b	75.8a	53.3	***	34↑
Mt Arthur Coal	**Initial**	**0 months**	$F_{1,17}$	**P**	**% Change**
Ca	5.53b	13.8a	30.3	***	60↑
K	1.52a	0.69b	39.8	***	55↓
Mg	2.32b	4.01a	13.6	**	42↑
ECEC	12.8b	23.1a	20.0	***	45↑
Total N	0.20a	0.08b	7.44	*	60↓

5.3.2 Multivariate Analyses

When all sites and all parameters were included, the Detrended Correspondence Analysis (DCA) showed that site was the most important factor explaining variation in the dataset (Figure 5.13). The ordination separated stockpiles into Bengalla bottom left, Cheshunt to the top left and Mt Arthur Coal to the right of the first axis. Investigation of the soil parameters controlling the observed site pattern (Figure 5.14), indicated that Bengalla had higher levels of topsoil seed stores, total P, total N and K, Cheshunt mine had higher levels of sand, NO_3-N and available P, while Mt Arthur Coal had higher levels of exchangeable cations, SOC and microbial respiration.

The ANOSIM between all physical, chemical and biological parameters across the three mine sites was significant (overall Global R = 0.473, P<0.001). Consequently, all subsequent analyses were undertaken separately for each site, with data pooled for the two Bengalla replicates. Time of sampling (age) also exhibited a significant ANOSIM (Global R = 0.283, P<0.001), but these patterns are further emphasised when each site was analysed separately.

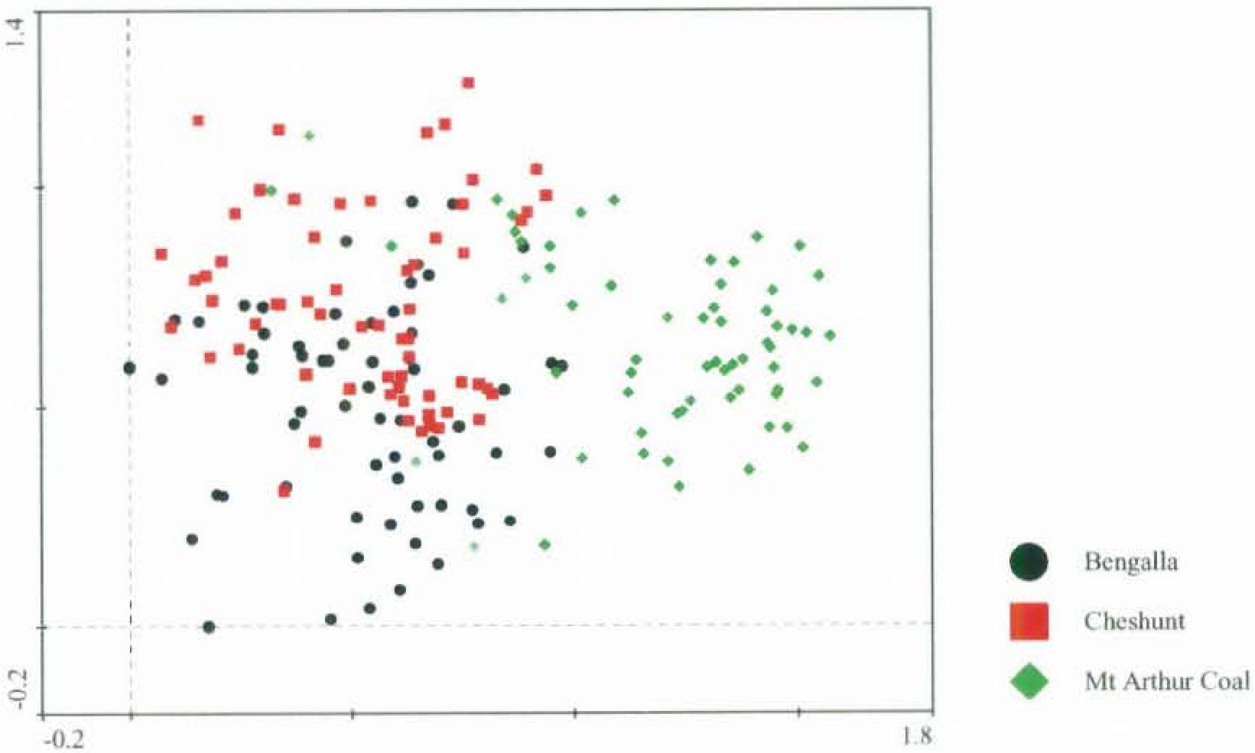


Figure 5.13: Detrended Correspondence Analysis (DCA) across all sites for mean physical, chemical and biological parameters.

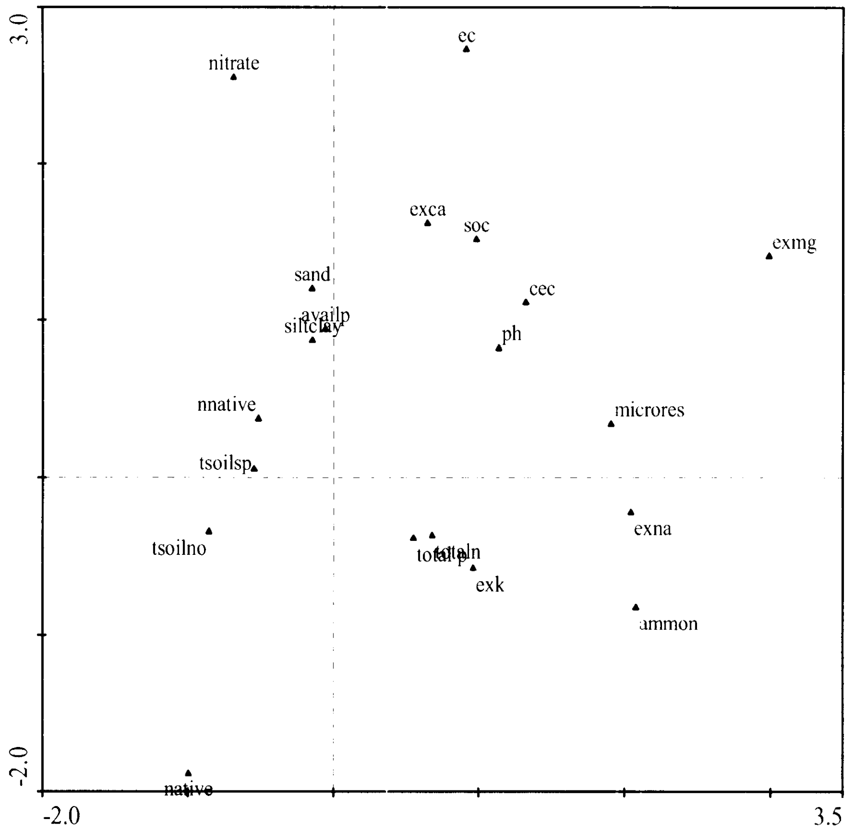


Figure 5.14: Ordination (DCA) of physical, chemical and biological parameters measured over all three mine sites. Refer to Appendix 4.4 for meaning of soil parameters abbreviated codes.

Within each site (Bengalla, Cheshunt and Mt Arthur Coal), the major grouping on the DCA related to age (0, 6, 12, 18 or 30 months), with all three ANOSIMs for age being significant (Global R = 0.314, $P<0.001$; Global R = 0.793, $P<0.001$; Global R = 0.595, $P<0.001$; respectively; Figure 5.15a-c). The separation of the age assessments for Bengalla mine can be explained by investigating soil parameters NO_3-N, sand and topsoil seed stores that showed an increase over time from the bottom left to the top right of axis 1, moving away from the initial assessment time (Figure 5.16a). A greater spread at Cheshunt mine of age assessments represents greater variation of soil parameters. Increased variation within the assessment times can be explained by the soil parameters topsoil seed stores, available P, EC and NO_3-N increasing over time from the top left axis to the bottom right axis, moving again further away from the initial assessment time (Figure 5.16b). Mt Arthur Coal was relatively homogenous, but separates from the initial assessment over time. Sites are moving from the bottom right axis to the top left axis overtime as a result of increases in NO_3-N, EC, sand, and silt and clay (Figure 5.16c).

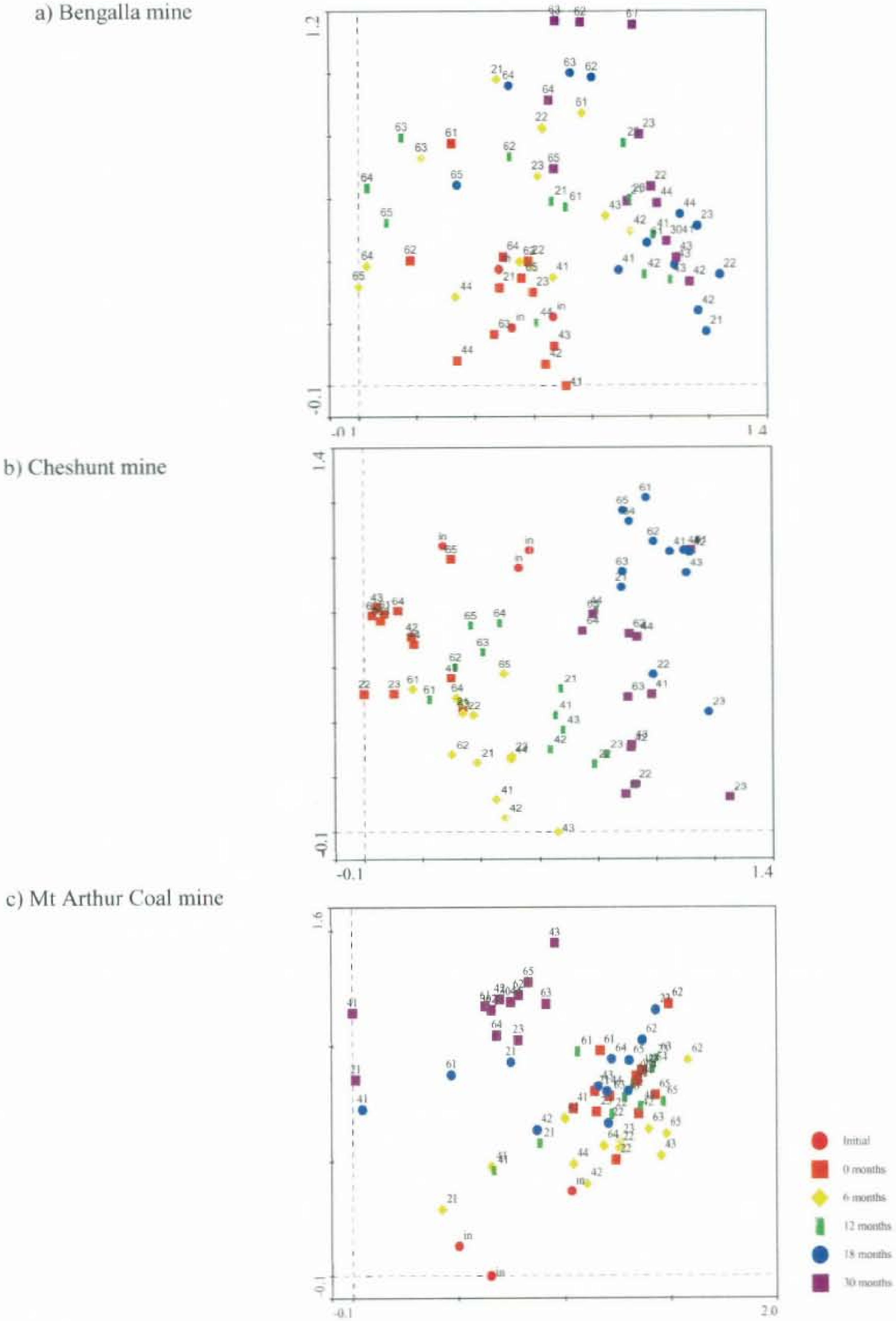


Figure 5.15: Detrended Correspondence Analysis (DCA) across all sites for mean physical, chemical, and biological parameters. Labels refer to height (2 = 2 m, 4 = 4 m and 6 = 6 m) and depth (1 = 0-30 cm, 2 = 80-110 cm, 3 = 160-190 cm, 4 = 340 -370 cm and 5 = 520-550 cm).

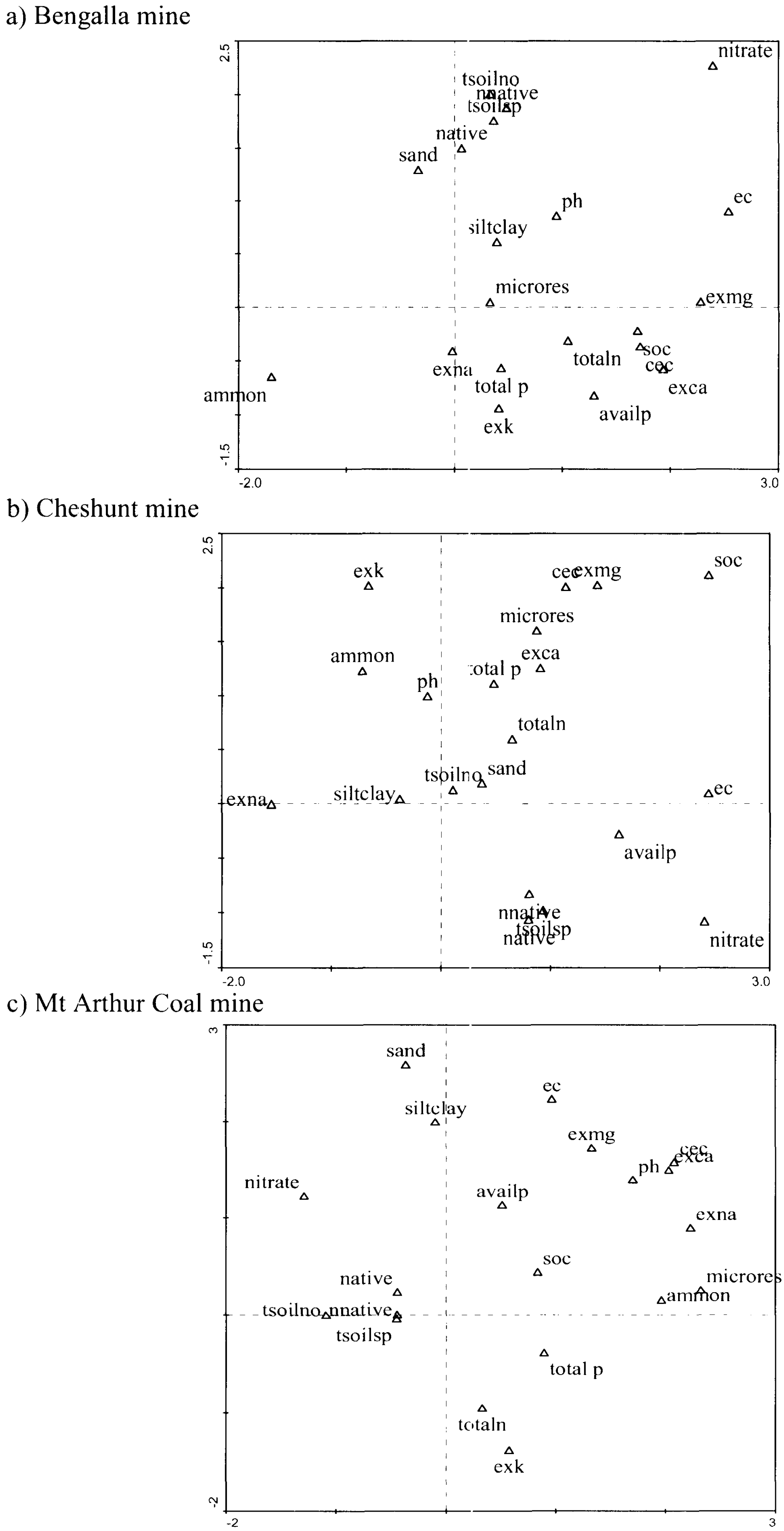


Figure 5.16: Ordinations (DCA) of physical, chemical and biological parameters measured over all individual mine sites. Refer to Appendix 4.4 for abbreviated soil parameter codes.

5.3.3 Summary of Age, Height, and Depth Across Sites

Of the two physical, 13 chemical and five biological parameters tested across the three stockpile attributes (age, height and depth) at each of three mine sites (one-way ANOVA-180 tests), 54 were significant for age, 31 were significant for height and 29 were significant for depth (Table 5.9). Bengalla exhibited the highest number of significant tests (42), followed by Cheshunt mine (37) and Mt Arthur Coal (35). Of the two-way ANOVAs, 19 parameters indicated a significant interaction between height and age, 15 for age and depth and 11 for height and depth. The one and two-way results will be discussed in more detail in the following sections (age, height and depth).

5.3.4 Age

Age of the stockpile (0, 6, 12, 18 and 30 months) had the greatest number of significant parameters at all three mine sites. A total of 54 physical, chemical and biological parameters were significant with age of the stockpiles across the three sites. Bengalla, Cheshunt and Mt Arthur Coal mines had 20, 19 and 15 significant parameters respectively. Results are presented separately below for each site.

Table 5.9: Summary of height, depth and age one and two way analyses across 20 physical, chemical and biological parameters, *** = P<0.0001, ** = P<0.01, * = P<0.05, blank = non-significant, n/a = not applicable, H*D = height by depth, H*A = height by age, D*A = depth by age.

Parameters	Bengalla						Cheshunt						Mt Arthur Coal						
	Height	Depth	Age	H*D	H*A	D*A	Height	Depth	Age	H*D	H*A	D*A	Height	Depth	Age	H*D	H*A	D*A	Total (/18)
Sand	*	**	**		**	***		***	***	*	*	***	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	**10**
Silt and Clay	**	**	***	**	***		*		***		***	*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	**9**
pH	***		***	**	***		*		***	*	***	*	**	***		*		**	**13**
EC	***	**	***	*	***	**		*	***	**	**	***	**	***	***	*		**	**16**
SOC	***		***		***	**			***		***		*				***		**8**
Total N	**		*		***	**			***		***				**				**7**
NO_3-N		**	***	*	***	**	**	***	***	*	***	***	*	***	***	*	**	***	**17**
NH_4-N	***	***	***	**	**	*	**	***	***	***	***	***		***	***				**14**
Total P	***		***		***	*		*	***	**	***			*	***		**		**11**
Avail P	**		**		**		**	**	***	***	***	**			***				**10**
K	**	*	***	**	***		**		***		***			*	***	**		**	**12**
Na	***		***	*	***	**			***	*	***			*	***	*	**	**	**13**
Ca	***		**	*	**	**		*	***		***		*	**	***			***	**12**
Mg	**		***	**	***	**			***		***						*	**	**9**
ECEC	**		*		***	***			***		**		*	**	***			***	**10**
Microbial Respiration	*	**	***		*	**	*							**	***				**8**
Species Richness			***		*		*		***					**	***				**6**
Seed Density			***		*			*	***		***			**	***				**7**
Native Species Richness			***				**		***					**	*				**5**
Non-native Species Richness			***		**		**		**		*			**	***				**7**
TOTAL (/20)	**15**	**7**	**20**	**9**	**19**	**12**	**10**	**8**	**19**	**8**	**17**	**7**	**6**	**14**	**15**	**5**	**5**	**8**	**204**

Bengalla mine

All measured parameters varied significantly with age of stockpiles at Bengalla mine (Table 5.10). Two chemical parameters (total P and Na) and three biological parameters (microbial respiration, seed density and native species richness) decreased significantly from 6 to 12 months. In contrast, five chemical parameters (K, Ca, Mg, EC and ECEC) and two physical parameters (sand, and silt and clay) increased from 6 to 12 months. Three biological parameters (microbial respiration, species richness and native species richness) and NH_4–N had significantly higher values at the 6 month assessment (Table 5.10). In comparison, seed density and non-native species richness were significantly higher in the 6 and 30 month age intervals. Higher pH values were recorded at 6 months, increasing significantly from the 0 month assessment. In addition, higher available P values were recorded at 0 and 30 months.

Table 5.10: Summary table of comparison of means for significantly different physical, chemical and biological parameters across stockpile ages (months) at Bengalla mine (*** = P<0.001, ** = P<0.01, * = P<0.05). Different letters refer to modified t-tests to determine post-hoc significance, a: corresponds to the highest value. Percentage change arrows indicate an increase (↑) or decrease (↓) from the 0 to 30 month ages.

Bengalla Parameters	**Age (months) 0**	**6**	**12**	**18**	**30**	**$F_{4,117}$**	**P**	**% Change**
Sand	56.9b	57.4b	62.3a	56.4b	52.8bc	4.58	**	7↓
Silt and Clay	7.27a	4.79b	6.90a	4.34b	4.18b	9.93	***	42↓
pH	6.76c	7.26b	7.12b	7.50a	7.25b	13.2	***	7↑
EC	0.06c	0.05c	0.09b	0.11ab	0.12a	57.8	***	50↑
SOC	0.84b	0.79bc	0.75c	1.09a	0.86b	23.3	***	2↑
Total N	0.07b	0.07b	0.06b	0.06b	0.08a	3.42	*	13↑
NO_3-N	0.84d	9.89b	6.45c	11.2a	13.6a	146	***	94↑
NH_4-N	18.6a	19.4a	15.4b	4.78c	5.57c	111	***	70↓
Total P	222a	222a	148c	145c	170b	119	***	23↓
Avail P	3.15ab	2.16c	2.29bc	2.62ab	3.24a	5.14	**	3↑
K	0.50b	0.50b	0.63a	0.50b	0.48b	16.3	***	0
Na	1.11a	1.26a	0.52c	0.66b	0.49c	201	***	56↓
Ca	5.97bc	5.39c	6.74a	5.45bc	6.27ab	6.61	**	5↑
Mg	1.74b	1.66b	2.08a	2.19a	2.03ab	12.1	***	14↑
ECEC	9.31ab	8.80b	9.94a	8.96ab	9.28ab	3.22	*	0
Microbial Respiration	11.5b	15.7a	10.9b	12.1b	10.6b	12.4	***	8↓
Species Richness	2.33b	5.04a	3.28b	1.74c	4.00b	26.5	***	42↑
Seed Density	6.29b	11.9a	5.23b	3.85c	11.2a	24.4	***	44↑
Native Species Richness	0.78b	1.72a	0.91b	0.85b	0.81b	9.75	***	4↑
Non-native Species Richness	1.60c	3.11a	2.23b	0.89c	3.19a	16.1	***	50↑

Cheshunt mine

Two physical, 13 chemical and four biological parameters (Table 5.11) varied significantly with age of stockpiles at Cheshunt (Table 5.11). Two physical (silt and clay, and sand) and one chemical parameter (K) exhibited significantly higher levels at 0 and 12 months. In comparison, two chemical parameters (total N and NO_3-N) had significantly higher levels at 6 months. Total P had higher values at the 0 month interval, decreasing at 6 to 12 months, then increasing again at 18 and 30 months. In comparison, two chemical parameters (EC and Ca) exhibited higher levels in the 12 and 30 month age intervals, increasing from 0 to 12 months. Three biological parameters (species richness, native species richness and non-native species richness) had higher levels at 6, 12 and 18 months, with an increase from 0 to 6 months. In comparison, Na exhibited significantly higher concentrations at 0 and 6 months, with a decrease in concentration from 6 to 12 months (Table 5.11).

Table 5.11: Summary table of comparison of means for significantly different physical, chemical and biological parameters across stockpile ages (months) at Cheshunt mine (*** = P<0.001, ** = P<0.01, * = P<0.05). Different letters refer to modified t-tests to determine post-hoc significance, a: corresponds to the highest value. Percentage change arrows indicate an increase (↑) or decrease (↓) from the 0 to 30 month ages.

Cheshunt	**Age (months)**							**%**
Parameters	**0**	**6**	**12**	**18**	**30**	$F_{4,72}$	**P**	**Change**
Sand	77.2b	70.2c	83.5a	67.2c	68.2c	25.5	***	12↓
Silt and Clay	8.29a	3.48b	7.79a	3.63b	3.72b	55.0	***	55↓
pH	6.88a	6.49b	6.56b	6.20c	6.00d	24.4	***	13↓
EC	0.01c	0.02c	0.04a	0.03b	0.04a	81.0	***	75↑
SOC	0.25d	0.24d	0.29c	0.56a	0.43b	55.3	***	42↑
Total N	0.02c	0.05a	0.03b	0.02c	0.04ab	20.9	***	50↑
NO_3-N	0.72d	13.57a	8.46c	8.96bc	11.3ab	244	***	94↑
NH_4-N	10.5a	9.56a	9.82a	2.89b	2.15b	213	***	80↓
Total P	126a	91.4c	82.4c	101b	116a	21.5	***	8↓
Avail P	4.25bc	3.72c	2.36d	4.40ab	6.22a	31.9	***	32↑
K	0.60a	0.36b	0.52a	0.30b	0.34b	11.5	***	43↓
Na	0.92a	0.97a	0.13b	0.12b	0.04c	864	***	96↓
Ca	1.12cd	1.08d	1.63a	1.27bc	1.36b	26.6	***	18↑
Mg	0.50bc	0.45c	0.65b	0.82a	0.49bc	22.3	***	0
ECEC	3.14b	2.87b	2.93b	5.27a	2.23c	95.9	***	30↓
Species Richness	1.56b	4.44a	3.81a	1.96b	3.56a	13.9	***	56↑
Seed Density	16.9b	12.4b	28.6a	5.63c	15.7b	19.3	***	7↓
Native Species Richness	0.22d	3.00a	1.96a	0.74c	1.33b	32.2	***	84↑
Non-native Species Richness	1.30bc	2.33a	1.93ab	1.22c	2.22ab	3.95	**	41↑

Mt Arthur Coal mine

Ten chemical and five biological parameters varied significantly with age (0, 6, 12, 18 or 30 months) of stockpiles at Mt Arthur Coal (Table 5.12). Two chemical parameters (total P and Na) exhibited significantly higher levels at 0 and 6 months with a large decrease at 12, 18 and 30 months. In contrast, three chemical parameters (K, Ca and ECEC) had significantly higher levels at the 12 month age interval, and one chemical (total N) and one biological parameter (native species richness) were significantly higher at 6 months (Table 5.12). Ammonium-N exhibited higher levels at 6 and 12 months. Two chemical parameters (EC and NO_3-N) and three biological parameters (species richness, seed density and non-native species richness) exhibited significantly higher values at the 30 months age interval, with the majority of the biological parameters increasing from 0 to 6 and 18 to 30 months, while decreasing from 6 to 12 and 12 to 18 months (Table 5.12). Microbial respiration had a peak with levels at the 12 and 18 months age intervals. In contrast, available P was higher at 0 months, decreasing at 6 and 12 months and increasing at 18 and 30 months.

Table 5.12: Summary table of comparison of means for significantly different chemical and biological parameters across stockpile ages (months) at Mt Arthur Coal mine (*** = P<0.001, ** = P<0.01, * = P<0.05). Different letters refer to modified t-tests to determine post-hoc significance, a: corresponds to the highest value. Percentage change arrows indicate an increase (↑) or decrease (↓) from the 0 to 30 month ages.

Mt Arthur Coal	Age (months)							%
Parameters	0	6	12	18	30	$F_{4,72}$	P	Change
EC	0.08c	0.07c	0.14b	0.15b	0.19a	64.6	***	58↑
Total N	0.08b	0.12a	0.10b	0.10ab	0.09b	5.35	**	11↑
NO_3-N	0.51c	5.99b	1.59c	8.44a	12.4a	94.6	***	96↑
NH_4-N	20.4b	32.1a	33.3a	21.6b	17.0c	14.6	***	17↓
Total P	174a	173a	98c	99c	119b	64.7	***	32↓
Avail P	1.30a	0.59b	0.77b	1.57a	1.40a	17.4	***	7↑
K	0.65c	0.77b	1.00a	0.57c	0.64c	49.8	***	2↓
Na	2.22a	2.23a	1.32b	1.28b	1.42b	18.4	***	36↓
Ca	11.9b	9.87cd	15.1a	9.37d	11.4bc	9.05	***	4↓
ECEC	21.3ab	18.9b	24.4a	15.6b	20.9ab	15.5	***	2↓
Microbial Respiration	14.0b	18.1a	19.4a	19.6a	11.7b	7.78	***	16↓
Species Richness	0.78c	2.26ab	1.41bc	1.19bc	2.41a	7.68	***	68↑
Seed Density	1.63c	5.56b	1.85c	2.74bc	10.6a	20.4	***	85↑
Native Species Richness	0.26b	0.74a	0.33b	0.52ab	0.48ab	3.08	*	46↑
Non-native Species Richness	0.52c	1.48b	1.00bc	0.67bc	1.93a	8.12	***	73↑

5.3.5 Height

A total of 31 physical, chemical and biological parameters varied significantly with height of the stockpiles across the three mine sites. Bengalla mine had 15 significant soil parameters, Cheshunt 10 and Mt Arthur Coal six.

Bengalla mine

Two physical, 12 chemical and one biological parameter varied significantly with height of stockpiles at Bengalla (Table 5.13). Eight chemical (pH, EC, SOC, total N, Ca, Mg and ECEC) and one biological parameter (microbial respiration) exhibited significantly higher levels in the shorter (2 m and 4 m) stockpiles. In comparison, NH_4-N exhibited significantly higher levels in the 4 m and 6 m heights. Three chemical parameters (total P, available P and K) had significantly higher levels in the 4 m stockpiles. Sodium, and silt and clay significantly decreased with increasing height of stockpiles, whereas sand increased as height increased (Table 5.13).

Table 5.13: Summary table of comparison of means for significantly different physical, chemical and biological parameters across stockpile heights (m) at Bengalla mine (*** = P<0.001, ** = P<0.01, * = P<0.05). Different letters refer to modified t-tests to determine post-hoc significance, a: corresponds to the highest value. Percentage change arrows indicate an increase (↑) or decrease (↓) from the 2 to 6 m heights.

Bengalla Parameters	**Height (m)** 2	4	6	$F_{2,15}$	**P**	**% Change**
Sand	54.9b	57.7ab	61.3a	5.11	*	10↑
Silt and Clay	7.57a	5.93a	3.37b	14.5	**	55↓
pH	7.28a	7.24a	6.86b	28.9	***	6↓
EC	0.10a	0.09a	0.05b	24.3	***	50↓
SOC	0.87b	0.93a	0.69c	24.7	***	21↓
Total N	0.07b	0.08a	0.06c	10.1	**	14↓
NH_4-N	9.29b	17.9a	16.4a	66.5	***	43↑
Total P	179b	212a	164b	51.4	***	8↓
Avail P	1.85b	4.17a	1.69b	11.9	**	9↓
K	0.52b	0.59a	0.47c	12.1	**	0
Na	1.09a	0.81b	0.63c	39.7	***	42↓
Ca	6.54a	7.34a	3.77b	63.3	***	42↓
Mg	2.22a	2.04a	1.37b	13.2	**	38↓
ECEC	10.4a	10.6a	6.46b	19.8	**	38↓
Microbial Respiration	12.6a	13.9a	10.5b	6.00	*	17↓

Cheshunt mine

One physical, five chemical and four biological parameters varied significantly with height of stockpiles at Cheshunt (Table 5.14). Two chemical (available P and NO_3-N), two biological (species richness and non-native species richness) and one physical parameter (silt and clay) decreased with increasing height. In contrast, two chemical (pH and K) and one biological parameter (microbial respiration) increased with stockpile height. Ammonium-N was significantly lower in the 4 m stockpile, while native species richness was significantly lower in the 6 m stockpile (Table 5.14).

Table 5.14: Summary table of comparison of means for significantly different physical, chemical and biological parameters across stockpile heights (m) at Cheshunt mine (*** = P<0.001, ** = P<0.01, * = P<0.05). Different letters refer to modified t-tests to determine post-hoc significance, a: corresponds to the highest value. Percentage change arrows indicate an increase (↑) or decrease (↓) from the 2 to 6 m heights.

Cheshunt Parameters	Height (m) 2	4	6	$F_{2,6}$	P	% Change
Silt and Clay	6.62a	5.22b	4.30b	7.67	*	35↓
pH	6.26b	6.30b	6.72a	6.25	*	6↑
NO_3-N	12.27a	9.39a	4.12b	50.3	**	66↓
NH_4-N	7.09b	4.66c	9.19a	51.6	**	23↑
Avail P	6.20a	3.80b	2.58b	22.1	**	58↓
K	0.33b	0.42b	0.52a	21.5	**	37↑
Microbial Respiration	5.60b	6.10b	8.86a	6.21	*	37↑
Species Richness	3.87a	3.20b	2.13c	9.99	*	45↓
Native Species Richness	1.60a	1.89a	0.87b	8.44	*	46↓
Non-native Species Richness	2.20a	1.93a	1.27b	8.13	*	42↓

Mt Arthur Coal mine

Six chemical parameters varied significantly with height of stockpiles at Mt Arthur Coal (Table 5.15). Three chemical parameters (pH, Ca and ECEC) had significantly higher levels in the 6 m stockpile. In comparison, NO_3-N had higher levels in the 2 m stockpile, decreasing with increasing stockpile height. Two chemical parameters (EC and SOC) had significantly lower levels in the 4 m stockpile height (Table 5.15).

Table 5.15: Summary table of comparison of means for significantly different chemical parameters across stockpile heights (m) at Mt Arthur Coal mine (*** = P<0.001, ** = P<0.01, * = P<0.05). Different letters refer to modified t-tests to determine post-hoc significance, a: corresponds to the highest value. Percentage change arrows indicate an increase (↑) or decrease (↓) from the 2 to 6 m heights.

Mt Arthur Coal Parameters	Height (m) 2	4	6	$F_{2,6}$	P	% Change
pH	7.37b	7.44b	7.89a	17.5	**	6↑
EC	0.13ab	0.12b	0.14a	18.0	**	7↑
SOC	1.29a	1.08b	1.18ab	5.80	*	9↓
NO_3-N	7.93a	6.39a	3.03b	9.59	*	62↓
Ca	10.4b	10.5b	13.6a	6.12	*	24↑
ECEC	18.8b	19.3ab	22.5a	5.61	*	16↑

5.3.6 Depth Across all Stockpile Heights

A total of 29 physical, chemical and biological parameters varied significantly with depth of soil upper, middle and lower) across the three sites. Mt Arthur Coal had 14 significant parameters, with Cheshunt eight and Bengalla seven.

Bengalla mine

Two physical, four chemical and one biological parameter varied significantly with depth of stockpiles at Bengalla mine (Table 5.16). Two physical (sand, and silt and clay), two chemical (NO_3-N and NH_4-N) and one biological parameter (microbial respiration) increased significantly at lower depths. In comparison, EC was higher in the middle depths of the stockpiles. In contrast, K was significantly higher in levels at the lower and upper depths of the stockpiles (Table 5.16).

Table 5.16: Summary table of comparison of means for significantly different physical, chemical and biological parameters across stockpile depths at Bengalla mine. *** = P<0.001, ** = P<0.01, * = P<0.05. Different letters refer to modified t-tests to determine post-hoc significance, a: corresponds to the highest value. Percentage change arrows indicate an increase (↑) or decrease (↓) from the upper to lower depths.

Bengalla Parameters	**Depth (position)** Upper	Middle	Lower	$F_{2,30}$	**P**	**% Change**
Sand	50.9b	60.4a	62.3a	11.3	**	18↑
Silt and Clay	5.08b	5.66ab	6.48a	5.21	*	22↑
EC	0.07b	0.10a	0.07b	8.39	**	0
NO_3-N	5.34b	8.40a	9.16a	48.0	***	42↑
NH_4-N	11.2c	12.9b	21.0a	3.93	*	47↑
K	0.57a	0.50b	0.54a	7.64	**	17↓
Microbial Respiration	11.3b	11.8b	14.5a	7.74	**	22↑

Cheshunt mine

One physical, six chemical and one biological parameter varied significantly with depth of stockpiles at Cheshunt mine (Table 5.17). Four chemical parameters (EC, Ca, NO_3-N and NH_4-N) increased significantly with increasing depth. Total P and seed density decreased significantly in the middle depths. In contrast, sand increased significantly in the middle depths. Available P was highest in the upper depth, decreasing significantly in the middle and lower depths (Table 5.17).

Table 5.17: Summary table of comparison of means for significantly different physical, chemical and biological parameters across stockpile depths at Cheshunt mine (*** = P<0.001, ** = P<0.01, * = P<0.05). Different letters refer to modified t-tests to determine post-hoc significance, a: corresponds to the highest value. Percentage change arrows indicate an increase (↑) or decrease (↓) from the upper to lower depths.

Cheshunt	Depth (position)					%
Parameters	Upper	Middle	Lower	$F_{2,12}$	P	Change
Sand	63.4b	80.3a	76.1a	41.8	***	17↑
EC	0.02b	0.03a	0.03a	6.81	*	33↑
Ca	1.17b	1.26ab	1.45a	4.44	*	20↑
NO_3-N	4.03b	10.1a	11.6a	44.8	***	65↑
NH_4-N	6.21b	6.57b	8.17a	35.3	***	24↑
Total P	108a	95b	107a	5.44	*	1↓
Avail P	6.82a	2.70b	3.06b	13.3	**	55↓
Seed Density	13.3b	19.6a	14.7ab	3.9	*	10↑

Mt Arthur Coal mine

Nine chemical and five biological parameters varied significantly with depth of stockpiles at Mt Arthur Coal (Table 5.18). Two chemical (NO_3-N and total P) and four biological parameters (species richness, seed density, native and non-native species richness) had significantly higher levels in the shallow depths. Four chemical parameters (pH, EC Ca and ECEC) exhibited significantly higher levels at the lower depths of sampling. Microbial respiration, Na and NH_4-N had significantly greater levels at middle depths, while K had greater values at the upper and lower depths (Table 5.18).

Table 5.18: Summary table of comparison of means for significantly different physical, chemical and biological parameters across stockpile depths at Mt Arthur Coal mine (*** = P<0.001, ** = P<0.01, * = P<0.05). Different letters refer to modified t-tests to determine post-hoc significance, a: corresponds to the highest value. Percentage change arrows indicate an increase (↑) or decrease (↓) from the upper to lower depths.

Mt Arthur Coal	Depth (position)					%
Parameters	Upper	Middle	Lower	$F_{2,12}$	P	Change
pH	7.18c	7.58b	7.94a	32.7	***	9↑
EC	0.09c	0.13b	0.16a	82.4	***	44↑
NO_3-N	12.3a	2.92b	2.15b	66.7	***	82↓
NH_4-N	13.9b	32.4a	28.3a	50.7	***	51↑
Total P	129b	128b	142a	4.42	*	9↑
K	0.77a	0.66b	0.75ab	4.03	*	0
Na	1.56b	1.82a	1.71ab	4.23	*	6↑
Ca	9.82b	10.3b	14.4a	7.89	**	32↑
ECEC	18.5b	19.7ab	22.4a	7.12	**	17↑
Microbial Respiration	11.7b	19.8a	18.1a	20.3	**	35↑
Species Richness	2.89a	0.98b	0.96b	22.2	**	67↓
Seed Density	8.71a	2.29b	2.42b	11.4	**	72↓
Native Species Richness	0.89a	0.24b	0.27b	14.7	**	70↓
Non-native Species Richness	1.93a	0.73b	0.69b	13.7	**	64↓

5.3.7 Depth for 6 m Stockpiles

Only two parameters varied significantly with depth in the 6 m stockpile at Bengalla mine. Ammonium-N and sand were significantly higher in the lower depths (Table 5.19). Four chemical and one physical parameter varied significantly with depth at Cheshunt mine. Available P, total P and NH_4-N exhibited a significant increase in values as depth of sampling increased. In contrast, sand percentages increased towards the middle to lower depths of sampling. Four chemical and one biological parameter varied significantly with depth at the Mt Arthur Coal mine (Table 5.19). Potassium and total P increased as depth of sampling increased. In contrast, NO_3-N and species richness levels decreased as depth of sampling increased. Ammonium-N increased in the shallow depths then decreased in the lower depths.

Table 5.19: Summary table of comparison of means for significantly different physical, chemical and biological parameters across the 6 m stockpile depth at Mt Arthur Coal, Bengalla and Cheshunt mine (*** = P<0.001, ** = P<0.01, * = P<0.05). Different letters refer to modified t-tests to determine post-hoc significance, a: corresponds to the highest value. Percentage change arrows indicate an increase (↑) or decrease (↓) from the 0-30 cm to 520-550 cm depths.

Depth Parameters	**Depth (cm)**							
Bengalla	**0-30**	**80-110**	**160-190**	**340-370**	**520-550**	**$F_{4,25}$**	**P**	**% Change**
Sand	53.2b	66.2a	66.6a	70.1a	64.2a	8.50	**	17↑
NH_4-N	7.67d	13.3cd	19.9bc	22.8ab	21.7a	11.2	***	65↑
Cheshunt	**0-30**	**80-110**	**160-190**	**340-370**	**520-550**	**$F_{4,10}$**	**P**	**% Change**
Sand	54.0b	76.3a	80.6a	73.3a	77.5a	12.1	**	30↑
Na	0.50a	0.40b	0.38b	0.40b	0.34b	4.62	*	32↓
Avail P	1.62c	2.32b	2.49b	2.83b	3.64a	12.9	**	56↑
Total P	88.2c	92.4bc	92.3bc	104b	130a	11.1	**	32↑
NH_4-N	3.65c	6.09bc	10.3ab	14.3a	13.6a	9.69	**	73↑
Mt Arthur Coal	**0-30**	**80-110**	**160-190**	**340-370**	**520-550**	**$F_{4,10}$**	**P**	**% Change**
K	0.62b	0.55b	0.64b	0.68b	0.88a	5.54	*	30↑
Total P	124bc	114c	121bc	138ab	148a	3.69	*	16↑
NO_3-N	5.95a	1.74b	1.78b	2.09b	1.34b	15.7	**	17↓
NH_4-N	9.67c	26.1b	35.5a	26.3b	26.6b	18.7	**	64↑
Species Richness	2.27a	1.00b	0.67b	1.00b	0.53b	4.73	*	77↓

5.3.8 Similar Depths within all Stockpile Heights

A total of 24 physical, chemical and biological parameters varied significantly across common depths of the stockpiles at the three sites. Mt Arthur Coal had 12 significant parameters, with Bengalla seven and Cheshunt with five.

Bengalla mine

Two physical and five chemical parameters varied significantly with depth of stockpiles at Bengalla mine (Table 5.20). Two physical (sand, and silt and clay) and two chemical parameters (NO_3-N and NH_4-N) exhibited significant increases in levels at lower depths (Table 5.20). Two chemical parameters (K and total N) had higher levels at the 0-30 and 160-190 depths, while Na had higher levels at the 80-110 cm depth.

Table 5.20: Summary table of comparison of means for significantly different physical and chemical parameters across stockpile depths at Bengalla mine (*** = P<0.001, ** = P<0.01, * = P<0.05). Different letters refer to modified t-tests to determine post-hoc significance, a: corresponds to the highest value. Percentage change arrows indicate an increase (↑) or decrease (↓) from the 0-30 cm to 160-190 cm depths.

Depth		**Bengalla**				**%**
Parameters	**0-30**	**80-110**	**160-190**	**$F_{2,30}$**	**P**	**Change**
Sand	50.8c	57.8b	62.4a	11.9	**	19↑
Silt and Clay	5.07c	5.95b	6.77a	6.11	**	25↑
Na	0.81b	1.03a	0.76b	4.01	*	0
K	0.56a	0.51b	0.54b	4.73	*	17↓
Total N	0.07a	0.06b	0.07a	4.08	*	0
NO_3-N	5.52b	9.30a	9.89a	11.9	**	44↑
NH_4-N	9.57c	11.2b	15.5a	18.3	***	38↑

Cheshunt mine

One physical and four chemical parameters varied significantly with depth of stockpiles at Cheshunt mine (Table 5.21). Two chemical parameters (EC and NO_3-N) and one physical parameter (sand) exhibited significant increases in levels at increasing depths. In contrast, two chemical parameters (total and available P) significantly decreased with increasing depths (Table 5.21).

Table 5.21: Summary table of comparison of means for significantly different physical and chemical parameters across stockpile depths at Cheshunt mine (*** = P<0.001, ** = P<0.01, * = P<0.05). Different letters refer to modified t-tests to determine post-hoc significance, a: corresponds to the highest value. Percentage change arrows indicate an increase (↑) or decrease (↓) from the 0-30 cm to 160-190 cm depths.

Depth		**Cheshunt**				**%**
Parameters	**0-30**	**80-110**	**160-190**	**$F_{2,12}$**	**P**	**Change**
Sand	63.4b	77.3a	80.6a	49.4	***	21↑
EC	0.02b	0.03b	0.04a	11.3	**	50↑
NO_3-N	4.03c	8.87b	13.08a	53.9	***	69↑
Total P	108a	95.1b	95.3b	5.54	*	12↓
Avail P	6.82a	2.86b	2.72b	14.1	**	60↓

Mt Arthur Coal mine

Seven chemical and five biological parameters varied significantly with depth of stockpiles at Mt Arthur Coal (Table 5.22). Nitrate-N and four biological parameters (species richness, seed density, native and non-native species richness) had significantly higher levels in the upper depth (0-30 cm) than the lower depths. In contrast, four chemical (pH, EC, NH_4-N and ECEC) and one biological parameter (microbial respiration) exhibited significantly upper depth. In comparison, K was significantly higher in the upper and lower depths, while Na was significantly higher in the middle depth (Table 5.22).

Table 5.22: Summary table of comparison of means for significantly different chemical and biological parameters across stockpile depths at Mt Arthur Coal mine (*** = P<0.001, ** = P<0.01, * = P<0.05). Different letters refer to modified t-tests to determine post-hoc significance, a: corresponds to the highest value. Percentage change arrows indicate an increase (↑) or decrease (↓) from the 0-30 cm to 160-190 cm depths.

Depth	**Mt Arthur Coal**					**%**
Parameters	**0-30**	**80-110**	**160-190**	**$F_{2,12}$**	**P**	**Change**
pH	7.18c	7.58b	7.94a	17.5	**	9↑
EC	0.09c	0.13b	0.16a	18.6	**	44↑
NO_3-N	12.3a	2.92b	2.15b	32.9	***	82↓
NH_4-N	14.0b	32.4a	28.3a	40.4	***	51↑
K	0.77a	0.66b	0.75a	8.38	**	0
Na	1.56b	1.82a	1.71b	7.18	**	6↑
ECEC	18.5b	19.7b	22.4a	7.04	**	17↑
Microbial Respiration	11.7b	19.8a	18.1a	19.3	**	35↑
Species Richness	2.89a	0.98b	0.96b	23.1	**	67↓
Seed Density	8.71a	2.29b	2.42b	14.1	**	72↓
Native Species Richness	0.89a	0.24b	0.27b	13.7	**	70↓
Non-native Species Richness	1.93a	0.73b	0.69b	13.5	**	64↓

5.3.9 Two-way Interactions for Selected Depths across Stockpile Height and Age

Of the two physical, 13 chemical and five biological parameters tested for two-way interactions across the three stockpile attributes (height, depth and age) at each individual mine site, 90 were significant (out of 180). A total of 40 two-way interactions were significant for Bengalla mine, 32 for Cheshunt and 18 for Mt Arthur Coal mine. Forty-one interactions were significant for height by age, 27 for depth by age and 22 for height by depth. Bengalla mine exhibited the greatest number of significant parameters for the interaction of height by age (19), the greatest number of height by depth interactions (9), and the highest number of depth by age interactions (12). Interactions relating to the two physical parameters (sand, and silt and clay) are not presented because they only exemplified known differences in soil type. Of the 90 significant interactions, 30 were significant across two or more mine sites. Of these, only the chemical (SOC, available P, NO_3-N, NH_4-N total N and P) and biological (microbial respiration, topsoil seed store species richness and density) parameters perceived to be the most important to rehabilitation are examined in detail below, while the remainder are presented in an appendix (see Appendix 5.1 - 5.3).

5.3.10 Height and Age

Available P at Bengalla mine exhibited higher than expected levels for the 4 m stockpile at 0 months and the 2 m stockpile at 30 months ($F_{8,116}$=2.89, P<0.0057; Figure 5.17a). While the 6 m stockpile exhibited a steady increase in available P over time at Cheshunt mine, levels in the 2 and 4 m stockpiles decreased until 18 and 12 months respectively before a large increase ($F_{8,72}$=7.43, P<0.0001; Figure 5.17a). Total P at Bengalla mine was higher at 0 and 6 months for all stockpiles then decreased over time, while in the 4 m stockpile levels increased from 12 to 30 months ($F_{8,116}$=8.15, P<0.0001; Figure 5.17b). At Cheshunt mine, the 4 and 6 m stockpiles had higher levels at 0 and 6 months, while the 2 m stockpile had higher levels at the 12, 18 and 30 month assessments ($F_{8,72}$=5.27, P<0.0001; Figure 5.17b). Mt Arthur Coal had higher total P levels for all stockpile heights at 0 and 6 months, then decreased at 12 months, with the 6 m stockpile increasing to a greater extent over time ($F_{8,72}$=3.729, P=0.0011; Figure 5.17b).

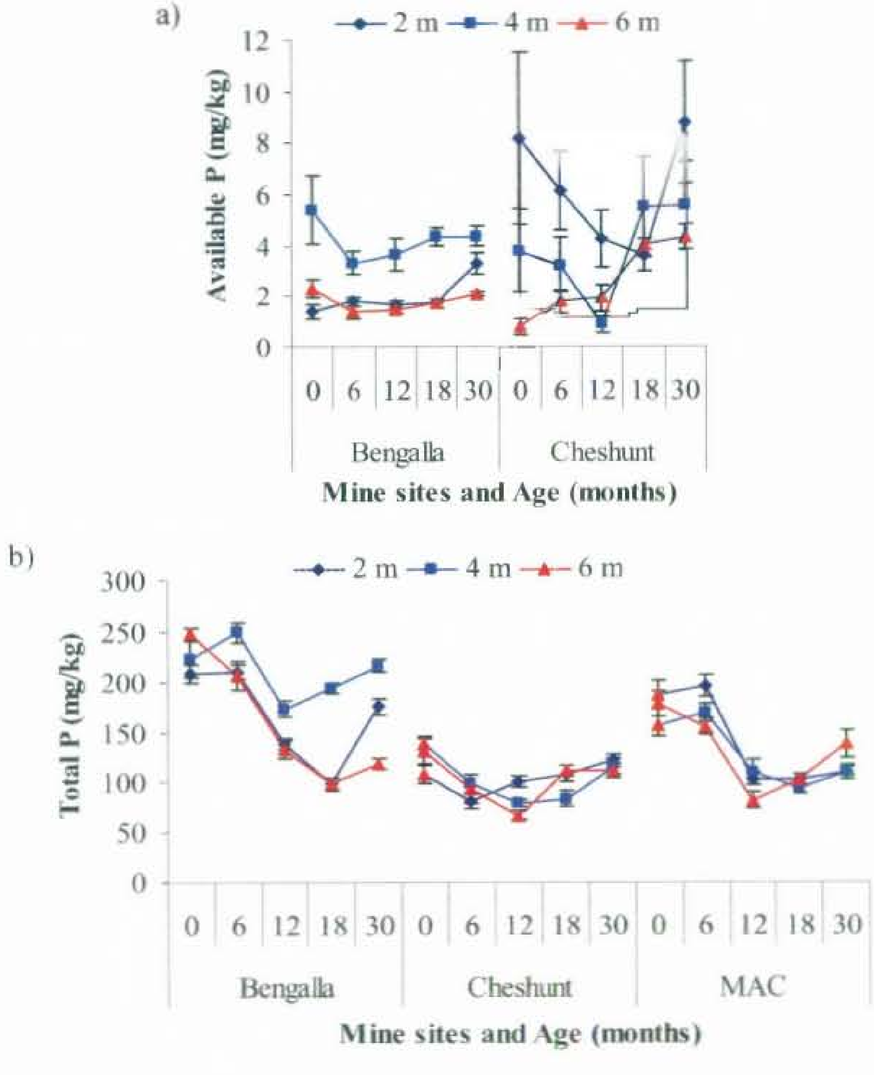


Figure 5.17: Interactions across sites between height and age for (a) available P and (b) total P (Mean +/- Standard Error of the Mean).

Nitrate-N levels at Bengalla and Mt Arthur Coal mine showed similar patterns for the 2 and 4 m stockpiles with higher levels at the 6, 18 and 30 month assessments. However, significantly lower NO_3-N levels were exhibited at Mt Arthur Coal for the 6 m stockpile at the 30 month assessment, while at Bengalla the NO_3-N levels for the 6 m stockpile were lower at the 12 month assessment ($F_{8,72}$=5.02, P=0.0001; $F_{8,116}$=5.07, P<0.0001, respectively; Figure 5.18a). At Cheshunt, NO_3-N levels were maximal at 6 months for the 4 m stockpile, while levels in the 6 m stockpile were lower at the 12 and 18 months assessments ($F_{8,72}$=21.3, P<0.0001; Figure 5.18a). Total N at Bengalla in the 4 m stockpile increased over time, while the 2 and 6 m stockpiles decreased, with the 2 m stockpile increasing again at the 30 month assessment ($F_{8,72}$=8.01, P<0.0001; Figure 5.18b). At Cheshunt, total N levels in the 2 m stockpile were greater than the 4 and 6 m stockpiles, particularly at the 6 month assessment ($F_{8,72}$=5.51, P<0.0001; Figure 5.18b).

Ammonium-N levels at Bengalla mine were lower in the 2 m stockpile at 0 and 12 months when compared to the 4 and 6 m stockpiles ($F_{8,116}$=2.74, P=0.008; Figure 5.19). At Cheshunt, ammonium-N levels in the 6 m stockpile increased from 0 to 12 months and then decreased, while levels in the 2 and 4 m stockpiles decreased over time ($F_{8,72}$=12.19, P<0.0001; Figure 5.18c).

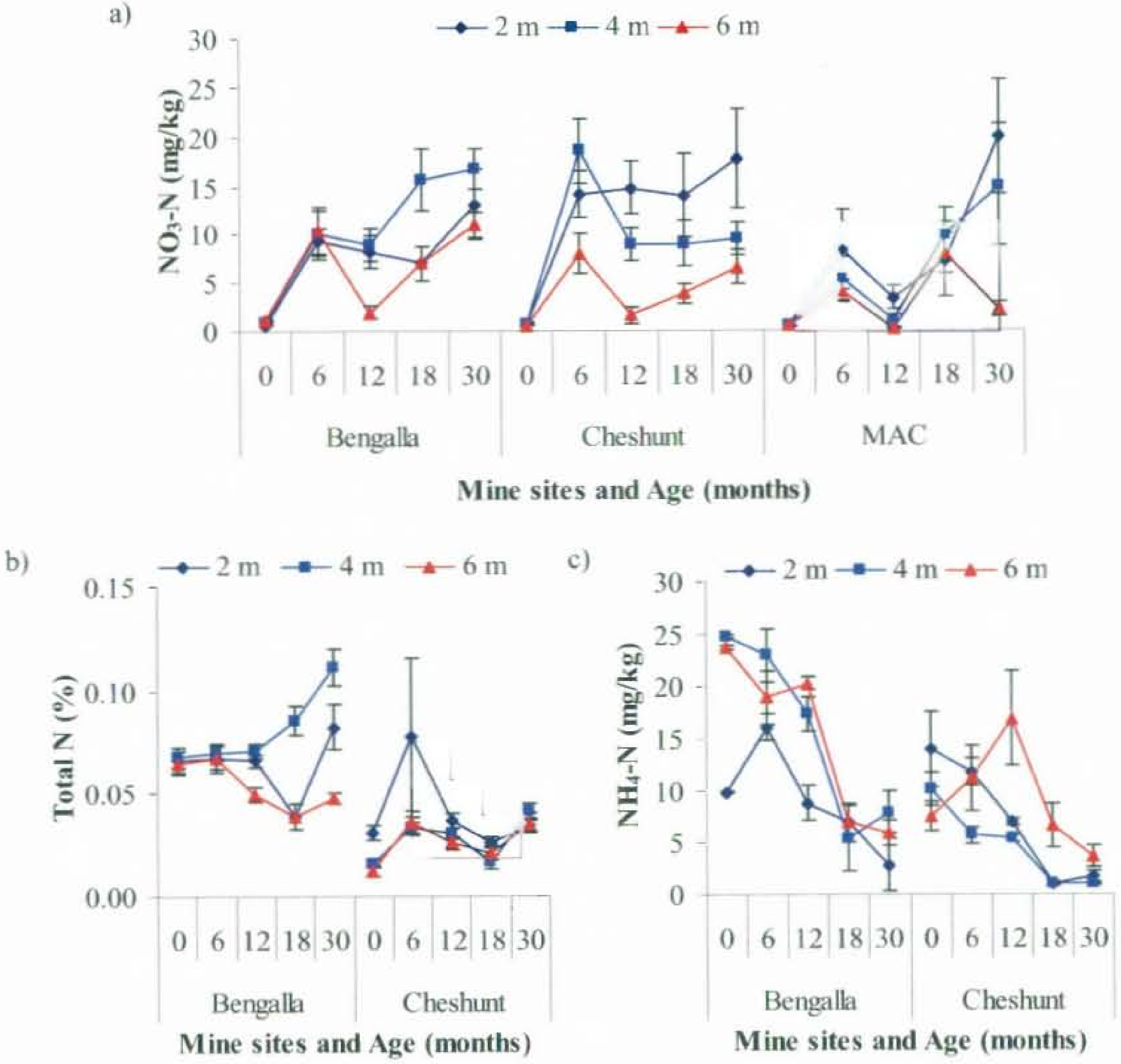


Figure 5.18: Interactions across sites between height and age with (a) NO_3-N, (b) total N and (c) NH_4-N (Mean +/- Standard Error of the Mean).

Soil organic carbon at Bengalla exhibited higher levels in the 4 m stockpile at 18 and 30 months when compared to the other stockpile heights ($F_{8,116}$=12.8, P>0.0001; Figure 5.19). In contrast, SOC levels at Cheshunt were lower in the 2 m stockpile at 18 months ($F_{8,72}$=6.91, P<0.0001; Figure 5.19), while at Mt Arthur Coal levels were higher in the 2 m stockpile at 6 and 30 months ($F_{8,72}$=6.94, P<0.0001).

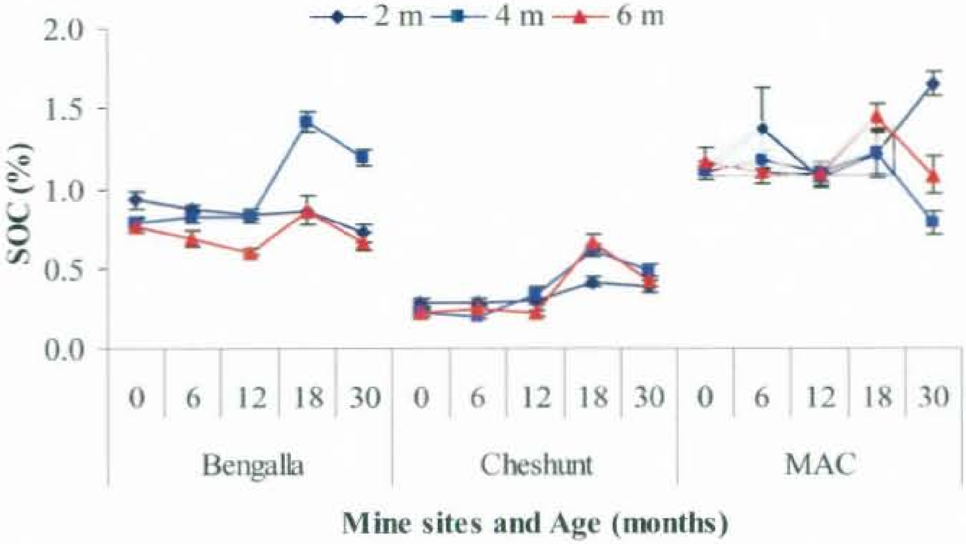


Figure 5.19: Interactions across sites between height and age with SOC (Mean +/- Standard Error of the Mean).

At Bengalla, seed density was highest in the 6 m stockpile at 0 months whereas maximal levels were recorded in the 2m stockpile at 6 months ($F_{8,116}$=2.50, P=0.015; Figure 5.20). Seed density at Cheshunt oscillated in the 4 and 6 m stockpiles, while levels in the 2 m stockpile increased to 12 months and then decreased ($F_{8,72}$=5.74, P<0.0001; Figure 5.20).

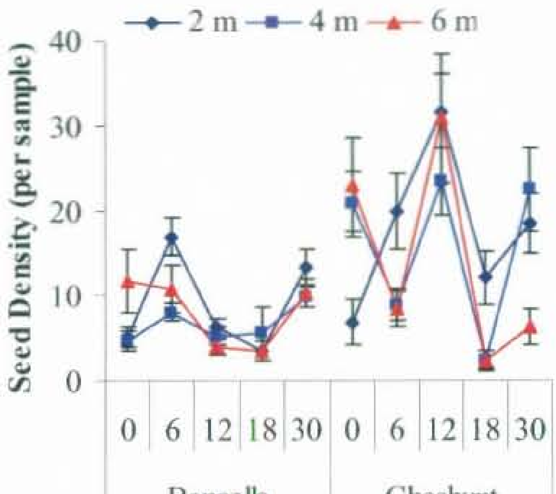


Figure 5.20: Interactions across sites between height and age for seed density (Mean +/- Standard Error of the Mean).

5.3.11 Age and Depth

Nitrate-N levels for the middle and lower depths at Bengalla were maximal at 18 months, whereas the upper depth exhibited lower levels at 12 and 18 months ($F_{8,116}$=2.84, P=0.006; Figure 5.21a). At Cheshunt, lower NO_3-N levels were recorded in the upper depth across all ages except 0 months, while NO_3-N increased to a greater extent in the lower than the middle depth ($F_{8,72}$=5.65, P<0.0001, Figure 5.21a). At Mt Arthur Coal, NO_3-N levels were higher in the upper depth with the exception of the 0 and 12 month assessments ($F_{8,72}$=6.06, P<0.0001; Figure 5.21a).

Ammonium-N levels at Bengalla increased from 0 to 12 months in the lower depth and subsequently decreased, while levels in the middle and upper depths decreased from the 6 month assessment ($F_{8,116}$=2.20, P=0.032; Figure 5.21b). Cheshunt mine exhibited higher NH_4-N levels for the lower depth at 6 and 12 month assessments, while the upper depth was higher at 0 months ($F_{8,72}$=6.28, P<0.0001; Figure 5.21b).

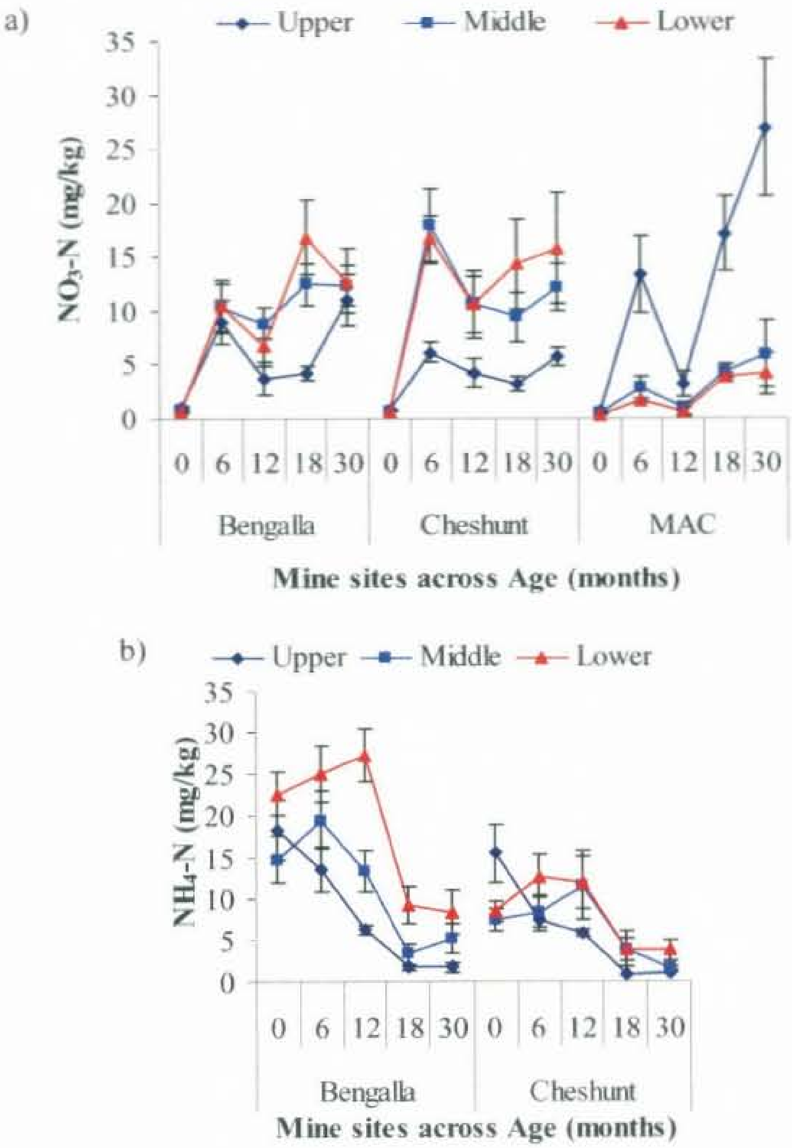


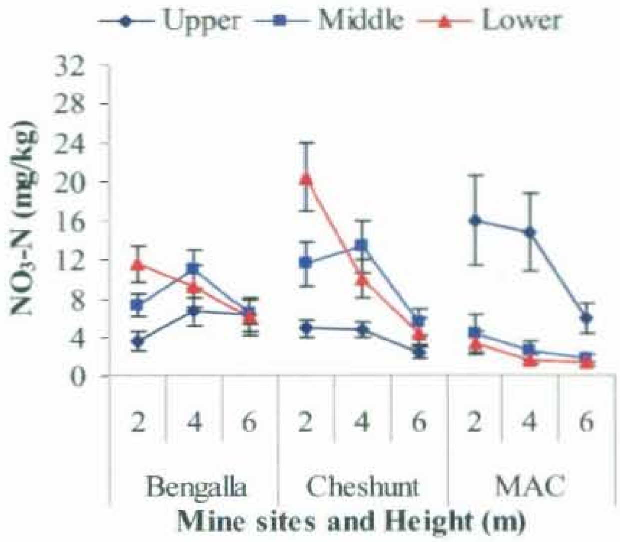
Figure 5.21: Interactions across sites between age by depth for (a) NO_3-N and (b) NH_4-N (Mean +/- Standard Error of the Mean).

5.3.12 Height and Depth

Nitrate-N levels in the lower depth at Bengalla and Cheshunt were maximal in the 2 m stockpile and then decreased with height, while the middle depth had the highest levels in the 4 m stockpile ($F_{4,30}$=3.75, P=0.014 and $F_{4,12}$=4.12, P=0.025, respectively; Figure 5.22a). Nitrate-N levels in the upper depth at Mt Arthur Coal were consistently higher than the other depths, but decreased to a greater extent in the 6 m stockpile ($F_{4,12}$=4.46, P=0.019; Figure 5.22a).

Ammonium-N levels at Bengalla were maximal in the lower depth for the 4 m stockpile, while the 6 m stockpile exhibited lower levels in the upper depth ($F_{4,30}$=5.32, P=0.002; Figure 5.22b). Cheshunt had higher levels of NH_4-N in the upper depth of the 2 m stockpile decreasing as stockpile height increased, while the middle and lower depths displayed maximal levels in the 6 m stockpile ($F_{4,12}$=25.1, P<0.0001; Figure 5.22b).

a)



b)

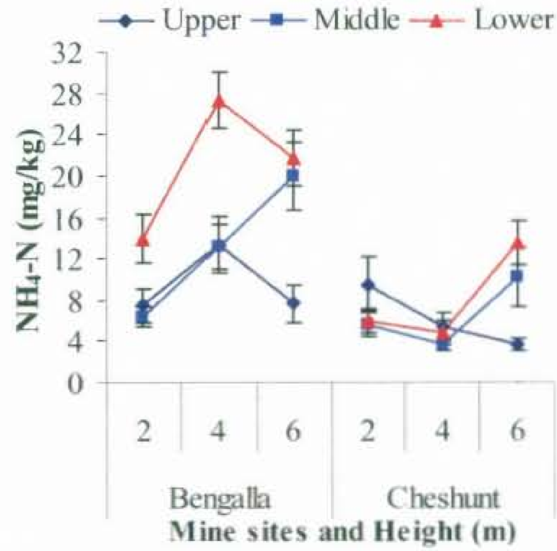


Figure 5.22: Interactions across sites between height and depth for (a) NO_3-N and (b) NH_4-N (Mean +/- Standard Error of the Mean).

5.3.13 Two-way Interactions for Depth and Age in the 6 m stockpiles

Of the two physical, 13 chemical and five biological parameters tested for two-way interactions across the two stockpile attributes (depth and age) at each individual mine site, 19 were significant. A total of nine two-way interactions were significant for Bengalla and five for both Cheshunt and Mt Arthur Coal mines. Four soil parameters were significant across two or more mine sites, and only these will be examined in detail below. Although patterns were significant at two or more mines, only a small number showed consistent patterns across the mines. Significant two-way interactions for depth and age for two or more sites were recorded for three chemical parameters and one physical parameter. The physical parameter (silt and clay) was significant at Bengalla and Cheshunt mines however, this was showing differences based on soil type at each mine site and is not presented.

Total P at Bengalla for the surface depth decreased from 0 to 12 months and remained consistent over the remaining time assessments, while all other depths decreased to the 18 month assessment, with a recovery at 30 months ($F_{16,54}$=2.91, P=0.0017; Figure 5.23). Mt Arthur Coal had higher total P levels for all stockpile depths at 0 and 6 months, then decreased at 12 months, with the two lower depths increasing to a greater extent over time ($F_{16,40}$=2.98, P=0.0026; Figure 5.23).

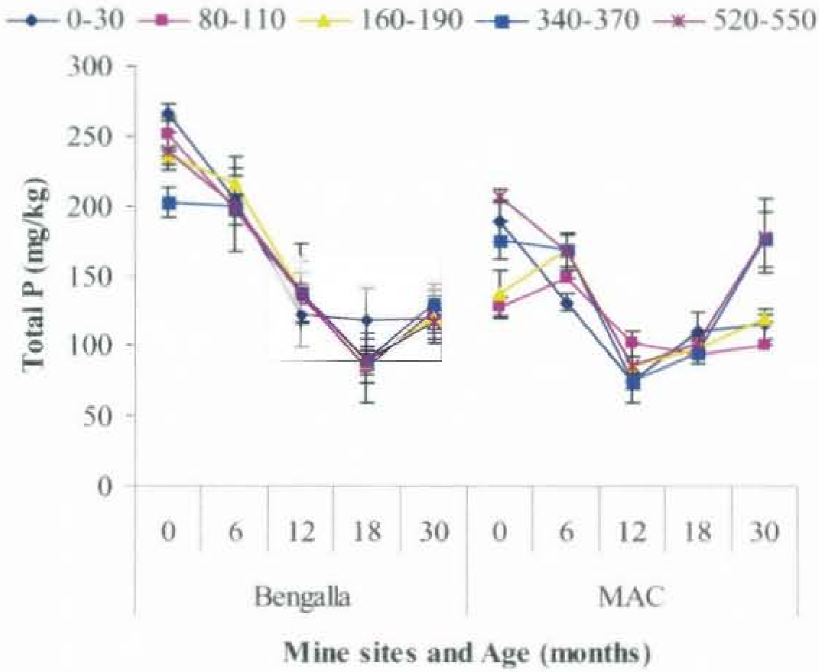


Figure 5.23: Interactions across sites between depth (cm) and age for total P in the 6 m stockpile (Mean +/- Standard Error of the Mean).

Total N at Bengalla decreased in most depths across time assessments to 18 months, recovering by the 30 month assessment. However, the 160-190 and 520-550 cm depths increased at 6 months while the 0-30 cm depth increased at the 18 month assessment ($F_{16,54}$=2.62, P=0.0042; Figure 5.24a). At, Cheshunt, the 520-550 cm depth increased at 6 and 30 months, the 80-110 cm depth was maximal at 18 months and all other depths increased over time ($F_{16,40}$=2.57, P=0.0078; Figure 5.24a).

Nitrate-N levels at Bengalla were higher at 6 and 30 months for the 0-30 and 80-110 cm depths, while the 160-190 and 340-370 cm depths were higher at the 18 and 30 month assessments, with the lower depth exhibiting higher levels at 6 months ($F_{16,54}$=2.13, P=0.0195; Figure 5.24b). At Mt Arthur Coal NO_3-N levels were maximal for the 0-30 cm depth at 6 and 18 month assessments, while the 340-370 cm depth exhibited higher levels at the 18 and 30 month assessment ($F_{16,40}$=2.66, P=0.0062, Figure 5.24b).

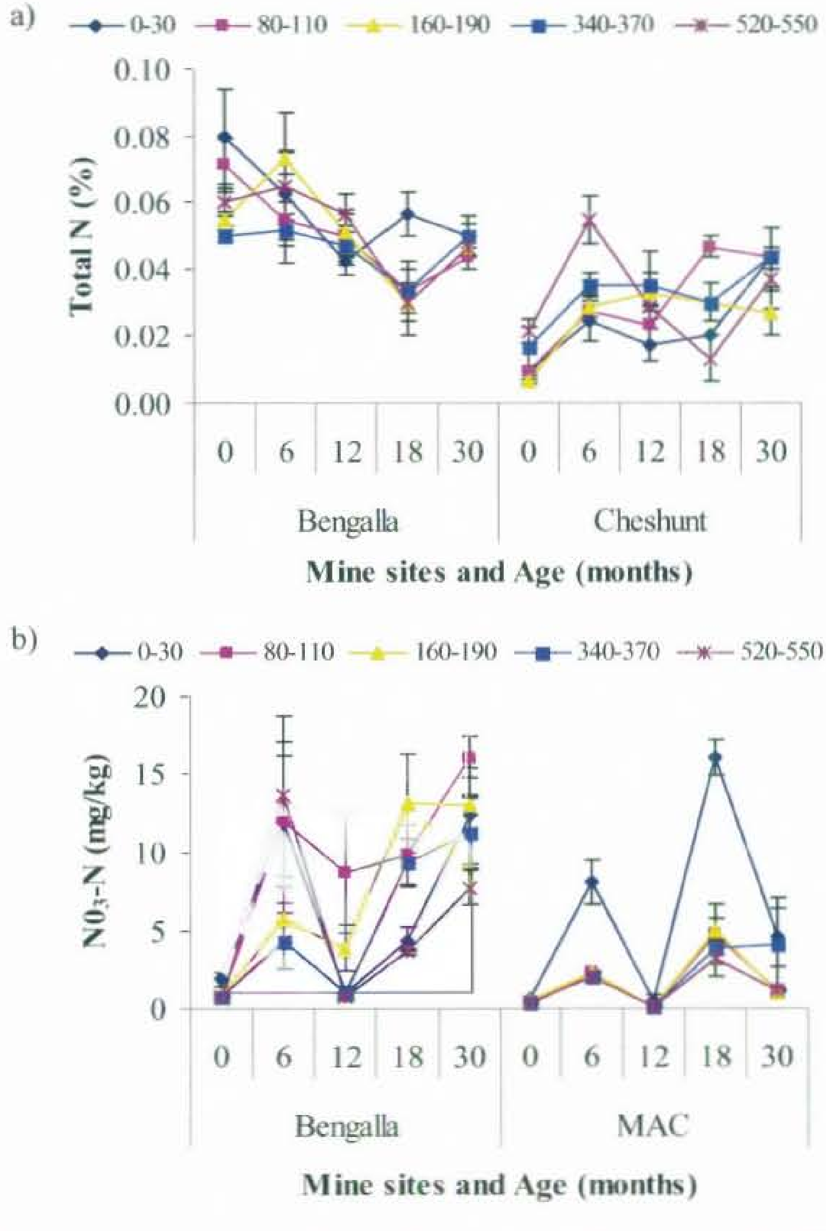


Figure 5.24: Interactions across sites between depth (cm) and age for (a) total N and (b) NO_3-N in the 6 m stockpile (Mean +/- Standard Error of the Mean).

5.3.13 Soil Temperature

Soil temperature increased towards the lower depths of the soil profile and exhibited significantly higher temperatures in the taller (6 m) stockpiles (Table 5.23). A significant two-way interaction for depth class and height was recorded for soil temperature ($F_{4,1806}$ =5.01, P=0.0005; Figure 5.25a). Stockpiles exhibited higher temperatures at lower depth classes for the 2 m and 6 m stockpiles.

Table 5.23: Summary table of comparison of means for significantly different soil temperatures across stockpile depths and height at Bengalla mine (*** = P<0.001, ** = P<0.01, * = P<0.05). Different letters refer to Tukeys post-hoc test, a: corresponds to the highest value.

	Upper	**Middle**	**Lower**	**$F_{2,1806}$**	**P**
Depth	20.47b	19.88b	21.13a	7.99	**
	2 m	**4 m**	**6 m**	**$F_{2,1806}$**	**P**
Height	19.51c	20.39b	21.58a	22.22	***

Stockpiles of the different heights were analysed separately across depth for changes in soil temperature. The 2 m and 6 m stockpiles exhibited significantly different soil temperatures with depth ($F_{2,486}$ =14.5, P<0.0001; $F_{4,1170}$ =4.14, P=0.0025, respectively; Figure 5.25b). The 2 m stockpile recorded higher soil temperatures at the surface and lower depths, with the 6 m stockpile exhibiting higher temperatures at the lower depths (360-520 cm).

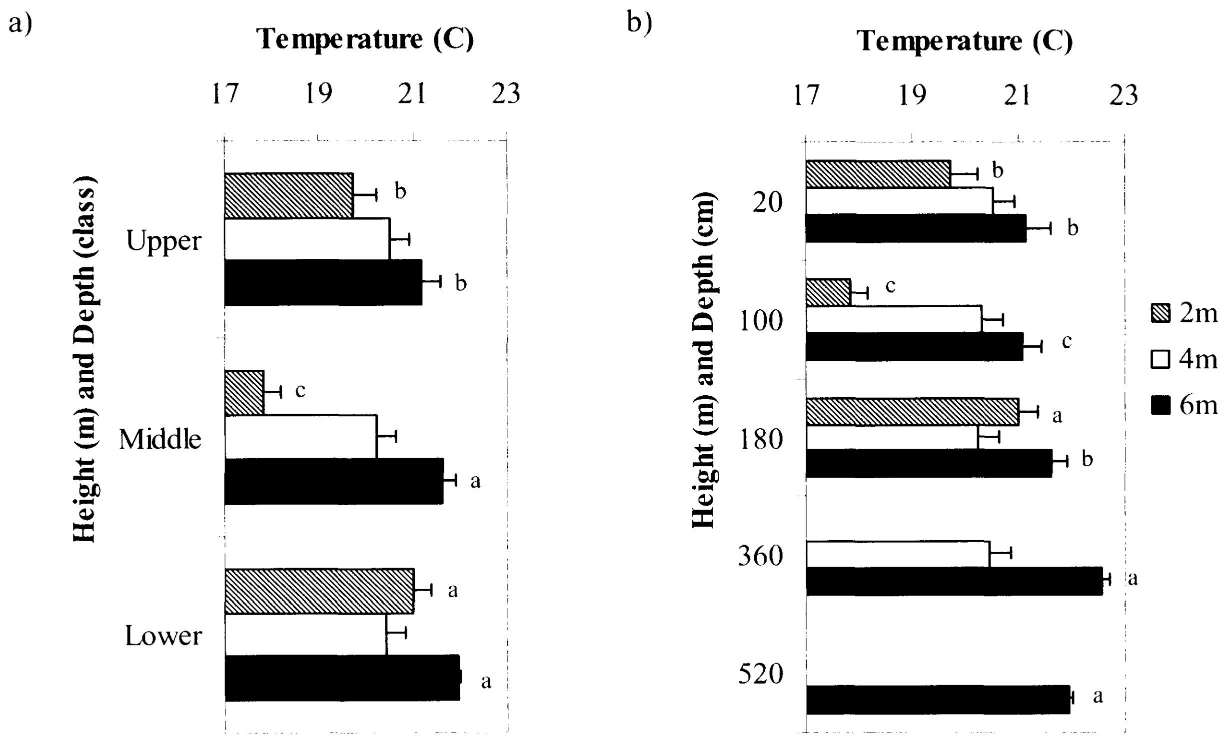


Figure 5.25: (a) Interaction between stockpile height and depth class on soil temperature and (b) stockpile temperatures at depth down the soil profile (Mean +/- Standard Error of the Mean). Different letters refer to significantly different values determined from Tukeys post-hoc test within each stockpile height class only, a: corresponds to the highest value.

5.3.14 Multivariate Analyses of Topsoil Seed Stores

The DCA ordination based on all three mines across all six assessment times indicated that the topsoil seed store was different across the three mine sites, supported by the ANOSIM (overall Global R=0.127, P<0.001; Appendix 5.4). Each site was then analysed separately, with clustering relating to assessment time (Figure 5.26 a-c). For Bengalla, Cheshunt and Mt Arthur Coal mines, the ANOSIMs for the topsoil seed stores were significant for age (overall Global R=0.872, P<0.001; Global R=0.892, P<0.001; Global R=0.48, P<0.001, respectively). The ANOSIMs for topsoil seed stores across stockpile height and depth were non-significant for all three mines. In addition, the topsoil seed store species were divided into origin (native or non-native) and no ANOSIMS were significant (graphs not presented).

5.3.14 Vegetation Established on Stockpiles

The DCA ordination based on all three mines over four assessment times (6, 12, 18 and 30 months) indicated that the average vegetation cover on the stockpiles (individual species and percentage cover) was different across the mine sites, supported by the ANOSIM (Global R=0.636, P<0.001; Figure 5.27). The ANOSIMs for vegetation cover across stockpile age, height and species origin were non-significant. The vegetation cover of individual species was then analysed separately for each site. The DCA ordinations of vegetation cover on stockpiles for Cheshunt and Mt Arthur Coal mines indicated significant clustering relating to assessment time (Global R=0.242, p=0.035; Global R=0.694, P<0.0001, respectively. Figure 5.28a,b). The ANOSIMs for age and height for Bengalla were non-significant.

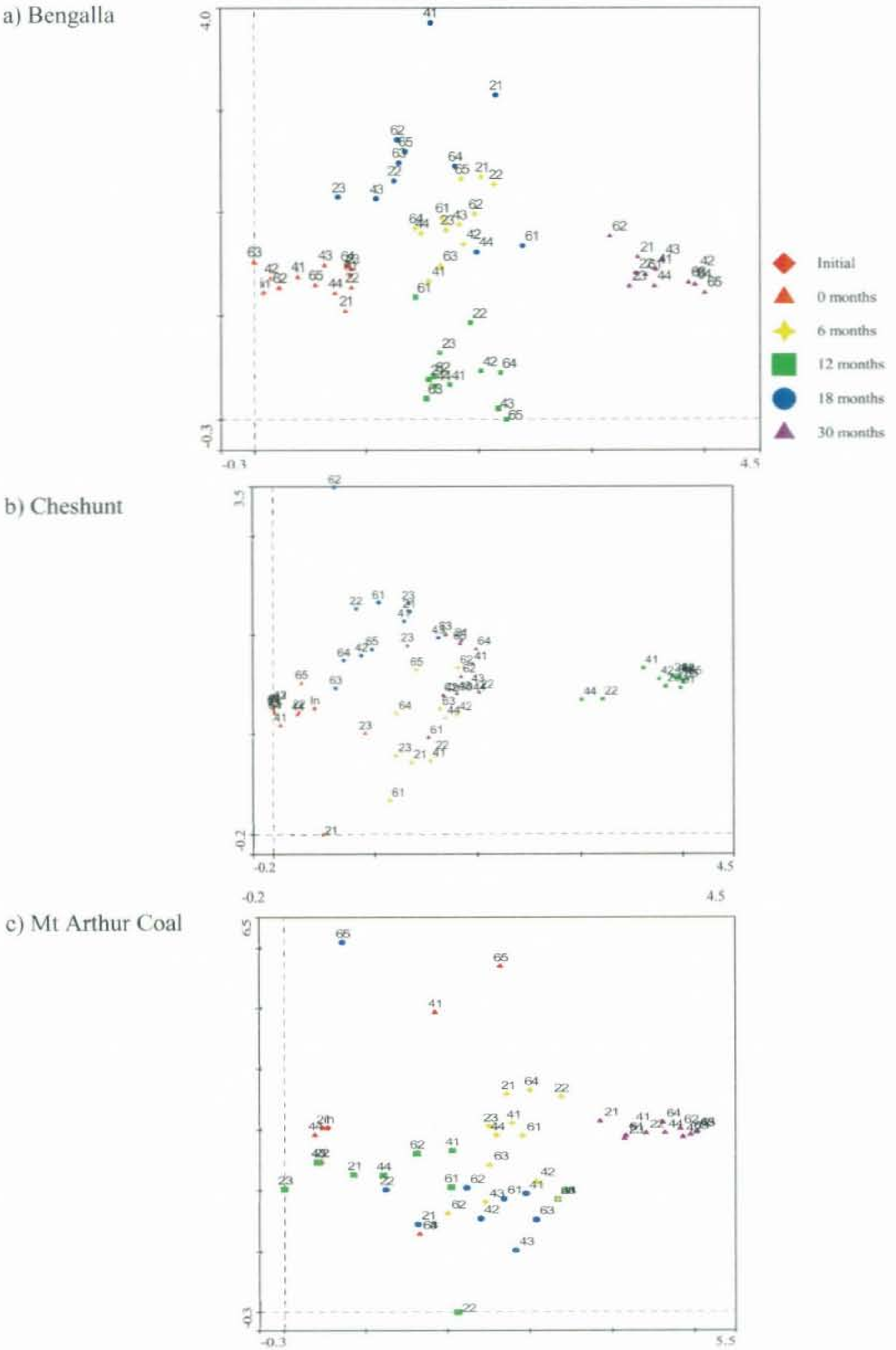


Figure 5.26: Ordinations (DCA) of topsoil seed stores at (a) Bengalla, (b) Cheshunt and (c) Mt Arthur Coal mine. Codes relate to the height of stockpiles (2 = 2 m, 4 = 4 m and 6 = 6 m) and depth of soil collection (1 = 0-30 cm, 2 = 80-110 cm, 3 = 160-190 cm, 4 = 340 -370 cm and 5 = 520-550 cm).

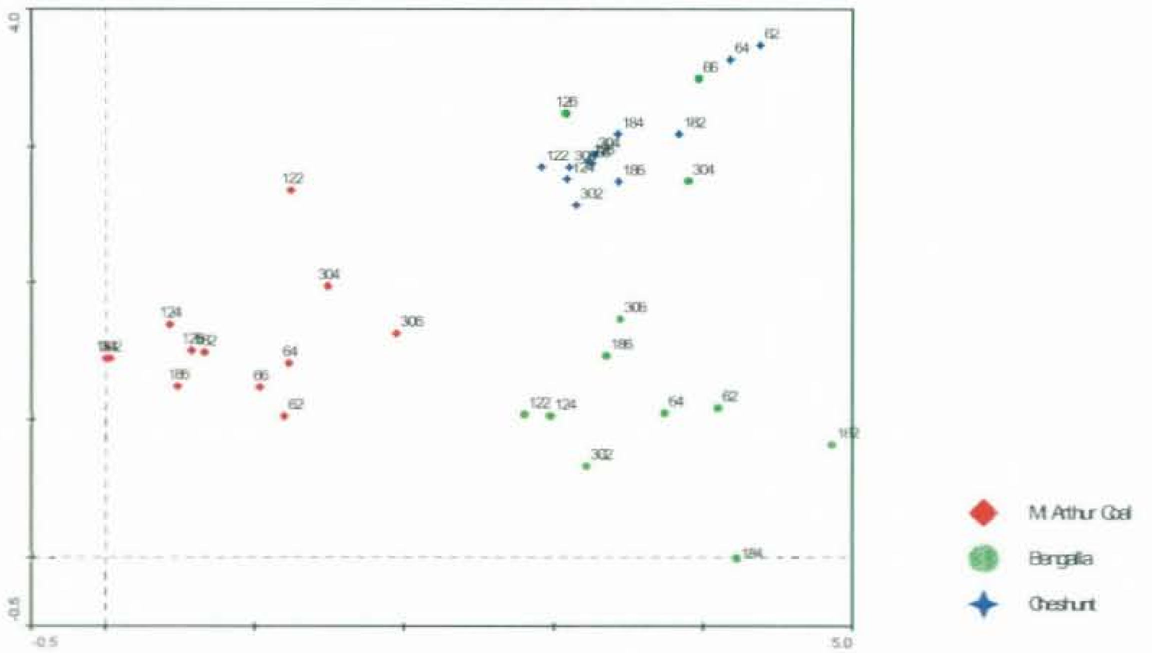


Figure 5.27: Ordination of vegetation cover on stockpiles for each mine site. Codes relate to assessment time (6, 12 18 or 30 months) and stockpile height (2, 4 and 6 m).

a) Cheshunt

b) Mt Arthur Coal

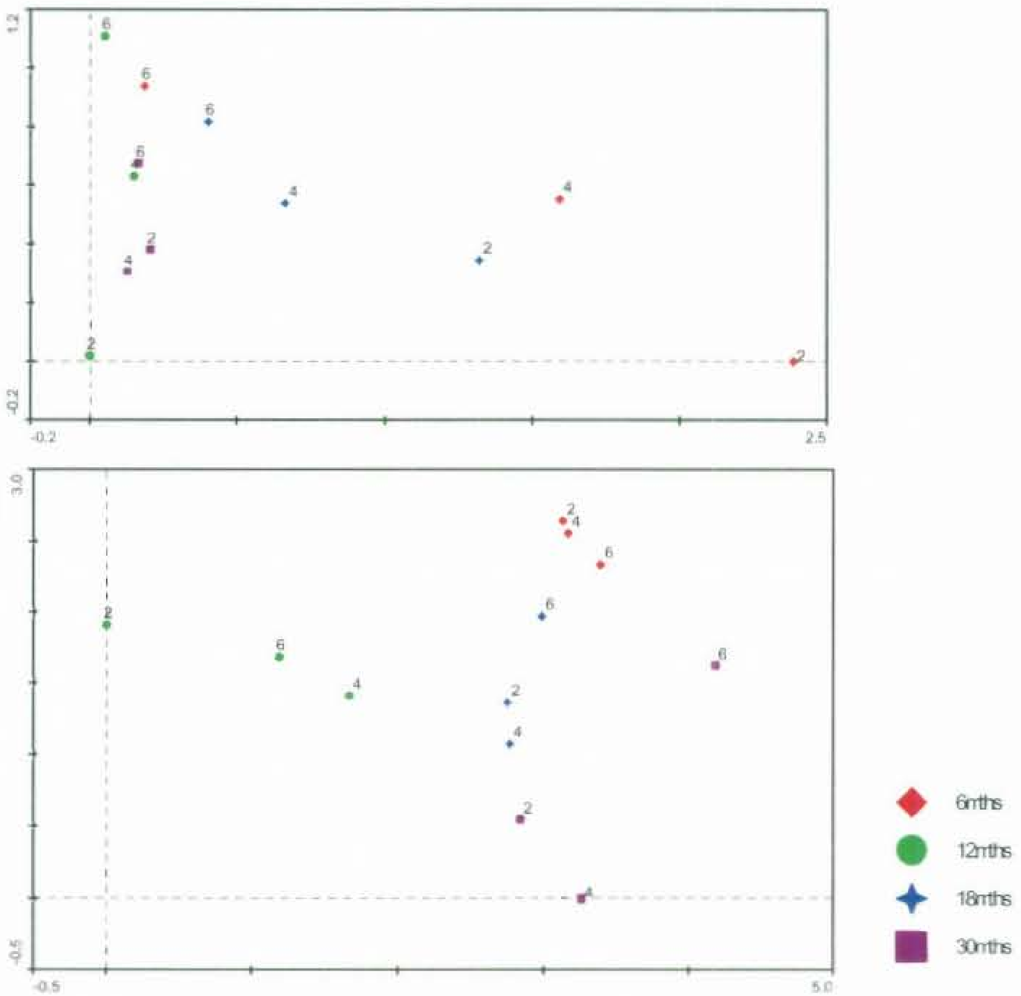


Figure 5.28: DCA ordination indicating the averages of the individual species across age of stockpiles for (a) Cheshunt and (b) Mt Arthur Coal mine. Codes refer to stockpile heights (2, 4 or 6 m).

At Mt Arthur Coal, total vegetation cover significantly increased over time ($F_{3,56}$=3.75, P=0.0159; Figure 5.29a) and with stockpile height ($F_{2,57}$=4.26, P=0.0188; Figure 5.29b) while cover did not change significantly at Bengalla and Cheshunt mines.

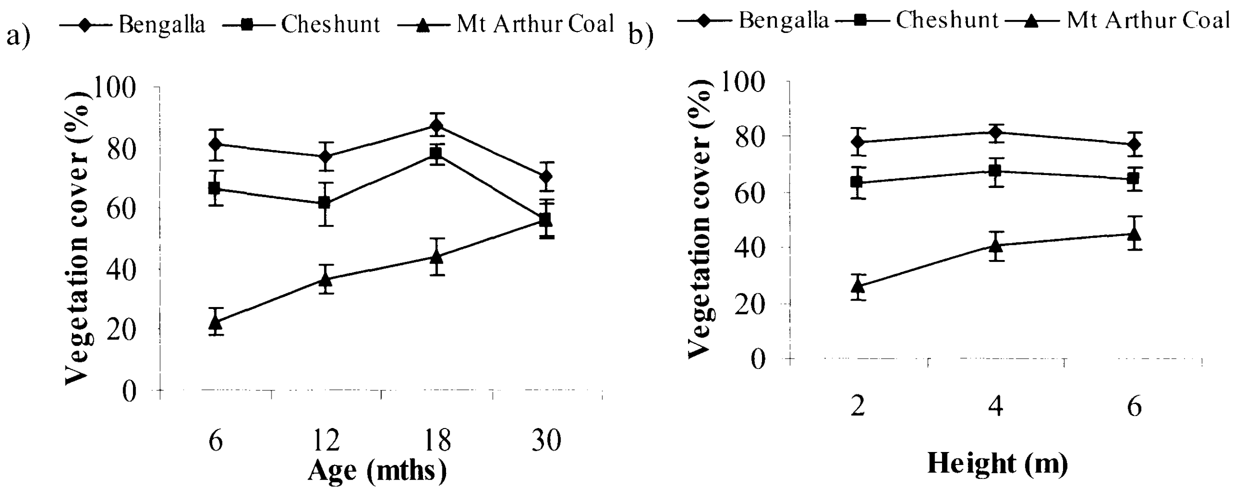


Figure 5.29: Total vegetation cover (%) on stockpiles across mine sites for (a) age and (b) height (Mean +/-Standard Error of the Mean).

5.4 DISCUSSION

The ordinations showed that site was the most important factor affecting the physical, chemical and biological parameters investigated in the topsoil stockpile field trial. This is indicative of the different soil types within the Hunter Valley (refer to Appendix 4.5), with the three sites investigated in this chapter covering the range of soil texture variability. Regardless of the individual characteristics of each soil type, similar patterns were observed for many soil parameters. To ensure that the observed patterns are robust across mine sites in the Hunter Valley, only parameters that were significant at two or more mine sites are discussed.

5.4.1 Initial versus zero months

Comparison of the initial (undisturbed area) and 0 month soil samples from the constructed stockpiles showed that significant soil deterioration occurs as a result of the stripping and construction of the stockpile itself. Averaged across all mine sites, total N (69%), K (59%), SOC (38%) and microbial respiration (36%) decreased from the initial to 0 month assessments. The impact of topsoil removal is influenced by many factors including depth of stripping, timing, soil moisture content, soil types, types of machinery and rehabilitation objectives (refer to 3.4 for detailed explanations). The changes in soil quality can be attributed to the major mixing of soil horizons and surface vegetation during the stripping of topsoil. Problems in chemical and physical fertility of soils is evident if the mixing of topsoil with subsoil layers occurs in the initial formation of the stockpiles, particularly if the subsoil is of poor quality (Abdul-Kareem and McRae 1984). Elliott and Veness (1985) suggest that soil structure declines during initial removal of soils into stockpiles. This can result in excessive soil compaction of mine soils, slowing chemical processes (e.g. organic C and N accumulation) and inhibiting microbial activity (Stroo and Jencks, 1982). Visser *et al.* (1984a) found that the most immediate consequences of stockpiling was the loss of organic matter, with levels being reduced by as much as 30% as a result of mixing and dilution with subsurface mineral soil. While some parameters increased from 0 to 30 months (e.g. total N 11-50%), the recovery was generally slow and changes in levels were minor compared to the large initial changes. This suggests that the effect of stockpiling may be minor compared to the impact of stripping and handling topsoil.

5.4.2 Age

Over time, stockpiling led to increased levels of NO_3-N (94-96%), while NH_4-N levels decreased (17-80%). This pattern is indicative of NH_4-N being nitrified to NO_3-N (Thurber Consultants *et al.*, 1990). The increase in NO_3-N over time is evidence of good soil health, as nitrification will not occur under anaerobic conditions (Killham, 1994). Nitrate-N can then be lost from the root zone through leaching, taken up by higher plants or denitrified under anaerobic conditions to N_2 and N_2O gas by anaerobic bacteria (Singer and Munns, 1996). The interaction between stockpile age and height showed higher NO_3-N levels at 6, 18 and 30 months indicating a seasonal effect. At Cheshunt mine, levels of NO_3-N were high for the 2 and 4 m stockpile at 18 and 30 months, due to prevailing aerobic conditions in these older stockpiles. At both Bengalla and Mt Arthur Coal mines, NO_3-N levels were higher for the shorter stockpiles and decreased with age, indicative that nitrification is taking place and the stockpiles were still generally aerobic. At both Bengalla and Cheshunt mines, NH_4-N levels were higher for the taller stockpiles but decreased with age, due to nitrification occurring over time under aerobic conditions.

A decrease in total N for the 2 and 6 m stockpiles in the 18 month assessment could have resulted from the conversion of organic-N to available inorganic forms (mineralisation) where it could be used by higher plants. However, the increased levels for the 4 m stockpile over time and the 2 m stockpile at 30 months could be a response to seasonal vegetation growth. An increase in rates of organic matter mineralisation following death of annual vegetation could create an additional source of N under the correct environmental conditions for soil microbes, ultimately increasing N availability to rehabilitation plants (Tate, 1985). All changes in nitrogen contents were not expected to affect revegetation after respreading and are considered to be within acceptable ranges for pasture establishment, based on soil type properties.

Calcium, K, EC and ECEC were significantly higher at 12 months (and 30 months for Ca), while Na decreased over time. This resulted from the displacement of Na from exchange sites and the establishment of vegetation on the stockpile. Water can remove some of the cations in the decomposing vegetation by means of leaching into the soil solution, thereby increasing Ca and K levels in the exchangeable pool. These nutrients would be likely to increase in the lower compared to the upper layers of the stockpile. The elevated nature of stockpiles suggests that leaching would be the dominant process (Rengasamy and Churchman, 1999). Leaching removes soluble materials dissolved in percolating water with the most significant losses recorded for Ca, K, NO_3-N and sulfate (Singer and Munns, 1996). Electrical conductivity increased over time due to seasonal rainfall causing mineralisation of organic matter and increased microbial activity associated with stockpiling, however, levels were not inhibiting to plant growth. The ECEC at Bengalla and Mt Arthur Coal was at its highest level at 12 months, with Cheshunt mine maximal at 18 months of age. This could be due to different soil types at each mine site and seasonal vegetation changes, with the decomposition of annual plant biomass altering the exchange sites causing an increase in cation concentration.

An increase in SOC at 18 and 30 months for Bengalla and Cheshunt mines was probably related to greater plant productivity in the warmer summer months compared to the colder winter months. However, this did not occur at the 6 month assessment probably due to the prevailing drought conditions (refer to Figure 7.9). The interaction between age and height of stockpiles showed SOC increasing in the taller stockpiles from the 12 to 30 month assessments, due to a decrease in microbial decomposition at depth within the taller stockpiles. In comparison, higher SOC percentages were recorded in the 2 m stockpile at the 6 and 12 month assessments. This could have resulted from greater levels of vegetation establishment and greater amounts of vegetation mixed in with the topsoil when the stockpile was first constructed.

Total P increased at 18 and 30 months. Net mineralisation of P from the microbial biomass and organic residue pools may be a significant source of P, where it can then be used in plant uptake (Moody and Bolland, 1999). The interaction between stockpile age and height showed available P levels were higher in the 2 and 4 m stockpiles, declining initially, and then slowly increasing over time. Total P was significantly higher at the 0 and 6 month assessment, decreasing with increasing stockpile height. In pasture soils, the amount of organic P present depends on the organic matter content of the soil that includes from 20-80% of the total P content (MacLeod and Lockwood, 1997). The chief source of organic P compounds entering the soil is through decay of vegetation and litter. Of importance for P availability is the microbial mineralisation and immobilisation processes. The differences in available P and total P across time assessments can be explained by the organic P being mineralised, causing soluble P compounds to be released and subjected to either plant uptake or fixation, which is linked to concentrations of other nutrients in plant litter (Moody and Bolland, 1999). In contrast, the amount of inorganic-P immobilised is reduced as the amount of organic-P increases. Elliott and Veness (1985) reported that after stockpiling soil under anaerobic reducing conditions, the concentration of soil solution P may increase over time from the reduction of Fe^{3+} phosphate to more soluble Fe^{2+} phosphate

(Islam and Elahi, 1954). Losses of total P from soils as stockpile height increased could be attributed to surface erosion and plant uptake (Moody and Bolland, 1999).

Topsoil seed store, species richness and seed density levels tended to be higher at 6, 12 and 30 months compared to 0 and 18 months across most mine sites. High species richness at 6 months is the result of greater plant growth and seed set over summer compared to winter. The majority of grass species that established on stockpiles set seed in summer leading to a higher seed store in the topsoil at this time of year. Ward *et al.* (1996a), in a study on bauxite mines in Western Australia, investigated different ripping, seeding and scarifying dates that maximised seed stores for mine rehabilitation. They reported that the ideal rehabilitation sequence was to collect topsoil after clearing in summer when the topsoil seed store was maximal, returning it to a rehabilitated area prior to the onset of autumn rains. In the current study, species richness and seed density of the topsoil seed stores were lower at 12 months indicating that storage time affects viability of buried seeds. If topsoil within the surface 0 to 5 cm of soil is not stripped separately, stockpile construction results in the dilution of the seed population within the stockpile (Harris and Birch, 1989; Grant *et al.,* 1996). The interaction between stockpile age and height showed that topsoil seed store density and non-native species richness were significantly higher in the 2 m stockpile height at 6 and 30 months, decreasing with increasing height of stockpiles. The 2 m stockpile remained aerobic for a greater period of time meaning that seed deterioration was slower than in taller stockpiles. Anaerobic conditions within stockpiles are detrimental to seed viability (Hunter and Currie, 1956; Miller and Cameron, 1976).

Microbial respiration at Bengalla was higher at 0, 6 and 18 months, while at Mt Arthur Coal levels were highest at 12 and 18 months. High microbial respiration at 12 and 18 months for Mt Arthur Coal, and 6 months for Bengalla indicates higher organic C levels in the soil and more suitable environmental conditions for biological activity (Visser *et al.,* 1984a). Greater levels of total N at 6 and 30 months at Bengalla mine and 6 months for Cheshunt and Mt Arthur Coal mines could be indicative of a seasonal effect, with the higher temperatures over summer promoting increased plant growth, ultimately increasing fixation by annual legumes of atmospheric di-nitrogen (Hoult, 1997). Ultimately, N is released from the legumes through litter decomposition (Johnston, 2000). Overall, for many biological and some chemical parameters, seasonal changes affected soil quality more than the impact of stockpiling.

Stockpiling of topsoil led to an increase in sand percentage at the 12 month assessment, while silt and clay percentages increased at the 0 and 12 month assessments. Over time, the proportion of sand particles may have increased due to erosion removing the finer surface particles of the soil. However, silt and clay percentages increased at 0 and 12 months probably due to the litter cover from the development of seasonal vegetation growth limiting the velocity of run-off and sediment transport (MacLeod and Lockwood, 1997). Anderson *et al.* (1988) found no effects of stockpiling on the particle size distribution for two soil types. Other studies have focused on structural characteristics within a stockpile. For example, Elliott and Veness (1985) recorded a number of improvements in aggregate stability in the uppermost stockpiled layers compared with the lower layers over time (e.g. greater resistance to disrupt aggregates by water drops). Thurber Consultants *et al.* (1990) identified three possible mechanisms for changes in the amounts of sand, silt and clay within a stockpile over time namely very strong leaching action by water and resulting mobilization of clay, physical sorting in very dry stockpiles, and loss by wind or water erosion.

5.4.3 Height

Stockpiling topsoil to 2 and 4 m led to higher NO_3-N, SOC and EC levels compared to the 6 m stockpile. Nitrate-N can become reduced in larger stockpiles that have developed anoxic conditions as a result of limited oxygen supply and this is influenced by soil type (Glendinning, 2000). Soil organic carbon levels could be greater in the shorter stockpiles (9-21%) due to the maintenance of aerobic conditions. In addition, adequate rainfall could create suitable conditions for rapid annual vegetation growth and rapid microbial decomposition. However, Visser *et al.* (1984a) conducted a study on topsoil storage effects in Alberta (Canada) and found that an immediate consequence of stockpiling soil to 2.5 m was the loss of organic carbon. Significantly higher EC levels (50%) were found in the 2 m stockpile at Bengalla, indicating an increase in soluble salt concentration, while higher EC levels were recorded in the 6 m stockpile at Mt Arthur Coal. This suggests that different soil types have different inherent levels of salts and that increased levels of EC could also be associated with increased mineralisation of organic matter.

Levels of NH_4-N were significantly higher in the taller stockpiles. This indicates the formation of an anaerobic zone in the larger stockpiles. Soil texture and water content are important factors in determining the depth of anaerobiosis in stockpiles (Thurber Consultants *et al.*, 1990). However, sandy soils (found in some mines of the Hunter Valley) have a lower tendency to form anaerobic zones and if they do, then this is likely to occur at greater depth. The limited ability of nitrifying bacteria to oxidise NH_4-N to NO_3-N at depth led to the elevated levels of NH_4-N. Soil pH was higher in the 6 m stockpile for Cheshunt and Mt Arthur Coal mines. The increase in pH in the taller stockpiles is directly related to the increase in NH_4-N accumulation (Abdul-Kareem and McRae, 1984).

Calcium, K, ECEC and available P had significantly higher levels in the shorter stockpiles. This could be indicative of the displacement of Na by K or Ca from exchange sites. Alternatively, this could be the result of vegetation mixed in with the topsoil when stripped and stockpiled. Fresh water enters the stockpile, coming into contact with the decomposing vegetation, removing some of the cations and anions in the vegetation by means of leaching (Singer and Munns, 1996). The greater the clay and organic matter content of soil, the more exchangeable cations can be held (Glendinning, 2000). Mt Arthur Coal had higher clay content soils that may explain the higher ECEC and EC values due to an increased ability to hold cations and a reduced chance of leaching from taller stockpiles. In contrast, Bengalla had higher ECEC and EC levels in the shorter stockpiles due to increased vegetation cover and organic matter.

Available P was greater in the 4 m stockpile at Bengalla and the 2 m stockpile at Cheshunt. The majority of P moves in soil slowly and in small amounts by diffusion, which is dependent on soil moisture, with dry conditions reducing diffusion (Glendinning, 2000). If soils are deep and sandy leaching of P can occur, otherwise very little will be lost by this process. It is possible that greater leaching occurred in the taller stockpiles at Bengalla and Cheshunt that had relatively sandy soils. Surface erosion and annual growth of vegetation can also lead to losses of P from soils (MacLeod and Lockwood, 1997).

The 2 m stockpiles exhibited higher levels of silt and clay (35-55% across sites). This could be an artefact of the different depths that were chosen for analysis for the different stockpile heights. While the three depths in the 2 m stockpiles represented all sampled depths, only three of the five sample depths were utilised for the 6 m stockpiles. One would expect taller stockpiles to have a greater potential for movement of particles in the stockpile as a result of the increased gravitational forces from upper to lower areas of the stockpile and the greater potential for wind and water erosion. This could also be a response to sampling variability and the horizon mixing that occurs when the stockpiles were created. A study by McQueen and Ross (1982) in New Zealand reported anaerobiosis occurring in a 3 m stockpile at a 2 m sampling depth, finding a relationship with increasing soil cloddiness as soils with a finer texture (more silt and clay) experienced changes in water holding capacity and a decline in soil structural stability associated with stockpiling.

5.4.4 Depth

Depth was analysed using three different models (see 5.2.5). The obtained results indicated that the dominant processes identified in model 1 (upper three depths of all stockpiles) and 2 (upper, middle and lower) were similar. Therefore, only results from model 2 and 3 (different depths for 6 m stockpiles) are discussed in this section. Significant interactions between depth, age and height are also incorporated, as the dominant processes were similar.

Nitrate-N and NH_4-N increased with depth at Bengalla and Cheshunt mines (42-65% across sites). In contrast, at Mt Arthur Coal, NO_3-N decreased by 82% and NH_4-N increased by 51% with depth. This resulted from the formation of more extensive anaerobic zones in the Mt Arthur Coal stockpiles as a result of a higher clay content that limits oxygen diffusion to nitrifying bacteria that convert NO_3-N to NH_4-N. Any NO_3-N that is produced would be denitrified under anaerobic conditions (Glendinning, 2000). Leaching occurs more significantly in deep, sandy free-draining soils under high rainfall conditions to support the activity of nitrifying bacteria. At Bengalla and Cheshunt mines, high levels of NO_3-N at depth are indicative of permanent aerobic zones allowing nitrification to occur and NO_3-N to accumulate. At Mt Arthur Coal, NO_3-N levels decreased with depth while NH_4-N increased, supporting the hypothesis of the formation of anaerobic zones in higher clay content soils. Accumulation of NH_4-N resulted from a low oxygen supply, causing a reduction in the number of nitrifying bacteria responsible for nitrification. Nitrogen mineralisation may continue slowly, but nitrification is inhibited under anaerobic conditions (O'Flanagan *et al.,* 1963; Ross and Cairns, 1981; Anderson *et al.,* 1988). In addition, NO_3-N can be denitrified to gaseous oxides of nitrogen and lost into the atmosphere (Hoult, 1997). Harris and Birch (1988) noted that when topsoil was stockpiled more than 1 m deep, chemical effects such as accumulation of NH_4-N and anaerobic conditions occurred at the base of the stockpile. The 2 m and 6 m stockpiles had higher soil temperatures with increasing depth of the stockpile. Increased soil temperature in stockpiles has previously been related to the formation of anaerobic conditions (Glendinning, 2000).

Leaching of exchangeable cations appears to be a dominant process in soil stockpiled in the Hunter Valley. Calcium levels increased with depth as it displaced Na down the profile due to leaching. In addition, higher EC values were found at lower depths, which indicate an increase in soluble salts. Anderson *et al.* (1988) also reported significantly higher EC at depth for stockpiles in the Bowen Basin attributing this change to increased mineralisation of organic matter and leaching of salts from the top to the bottom of stockpiles. The increase in ECEC with depth was associated with increases in Ca and K into the exchange pool, in addition to changes in organic matter content from the surface to the lower depths (Thurber Consultants *et al.,* 1990).

Microbial respiration increased with depth (22-35% across sites), evidence of mineralisation of organic matter within stockpiles. However, determination of *in situ* biological activity within a topsoil stockpile is problematic. In the stockpile at depth, the soil may well be anaerobic with little mineralisation. Immediate exposure of the sample to the atmosphere allows oxidation to occur, with the relatively greater amount of organic C leading to higher respiration rates (D. Jasper, pers. comm., 2001). It is difficult to predict how quickly these processes happen and how quickly biological activity is returned. Anderson *et al.* (1988) reported a similar result in the Bowen Basin especially in 'wet' stockpiles. However, deep stockpiles can create moisture problems (insufficient or surplus), which limits soil microbial respiration (Tate and Klein, 1985).

Topsoil seed density decreased (72%) with stockpiling depth for Mt Arthur Coal, indicating a decrease in seed viability. This resulted from the anaerobic conditions at depth at Mt Arthur Coal that were not observed at Bengalla and Cheshunt, leading to rotting of the seed. Seed populations in stored topsoil depend on the vegetation present before soil stripping (e.g. seed density and species richness), seed characteristics of species (e.g. dormancy and longevity), the location of the seeds in the stockpile, the age of storage, vegetation cover during storage, and soil condition including texture and moisture status (Thurber Consultants *et al.,* 1990).

Nitrate-N, NH_4-N and total N exhibited significant interactions between depth and age across two or three mines. Nitrate-N levels were higher for the middle and lower depths at the 6, 18 and 30 month ages for Bengalla and Cheshunt mines. Increased NO_3-N levels at the lower depths over time could be the result of increased leaching in sandy soils (Strong and Mason, 1999) and maintenance of aerobic soil conditions. At Mt Arthur Coal, NO_3-N only increased in the surface depth with increasing age due to anaerobic conditions at depth. Levels of NH_4-N were higher in the lower depths over time indicative of the development of an anaerobic zone. Total N at Bengalla mine decreased with depth for the first three assessments, probably as a result of the mineral N being denitrified at depth to gaseous forms under anoxic conditions. In contrast, Cheshunt displayed higher levels of total N at greater depths. The values at both mines were lower than the levels recorded in unmined pastures. Widdowson *et al.* (1982) found that soils in stockpiles had values of mineral N that increased with depth of storage and had lower values than the undisturbed soil.

Nitrate-N and NH_4-N exhibited significant interactions between depth and height across two or three mines. At Mt Arthur Coal, NO_3-N decreased with increasing stockpile height, but levels were much greater in the upper compared to the other depths. In contrast, NO_3-N exhibited greater levels in the middle and lower depths at Bengalla and Cheshunt, particularly in the 2 and 4 m stockpiles. As previously stated, this is indicative of the maintenance of aerobic conditions in at least the 2 and 4 m stockpiles at Bengalla and Cheshunt mines, while anaerobic conditions have formed even in the middle depths of the 2 m stockpile in the higher clay content Mt Arthur Coal soils (O'Flanagan *et al.*, 1963; Ross and Cairns, 1981; Anderson *et al.*, 1988; Harris and Birch, 1988). At Bengalla and Cheshunt, NH_4-N levels were greater in the 6 m stockpile for the middle and lower depths, supporting the formation of anaerobic zones in taller stockpiles at sites with sandier soils.

5.5 CONCLUSIONS

The objective of this stockpile field trial was to investigate the effects of stockpile age, height and depth on physical, chemical and biological properties of the topsoil. During the stockpile construction, many soil parameters (e.g. microbial respiration, total N and SOC) decreased by up to 50%, indicating that deterioration of soil quality is rapid and initially independent of stockpiling. Multivariate analysis indicated that site was the most significant factor differentiating between topsoil characteristics, which was related to the different soil types. Within each site, age of stockpiles was the most significant factor affecting soil parameters across all three mine sites. 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, ammonium-N, electrical conductivity, 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. 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. For example, at Mt Arthur Coal but not the other two mines, NO_3-N decreased and NH_4-N increased with depth indicative of the formation of anaerobic zones. The higher clay content in this soil limits oxygen diffusion to nitrifying bacteria that convert NO_3-N to NH_4-N, leading to an accumulation of NH_4-N at depth. Appropriate management can address this imbalance through mixing of the different layers during the respreading process. Overall, stockpiling topsoil under the relatively dry conditions experienced during this study had a relatively minor impact on soil quality, particularly when compared to the initially large impact of handling topsoil with heavy machinery.

CHAPTER 6.
Glasshouse Management Trial to Propose Practical Ameliorative Measures to Address Topsoil Degradation following Stockpiling

6.1 INTRODUCTION

The basic rehabilitation strategies undertaken following open cut coal mining in the Hunter Valley have been outlined in chapter 2. These strategies tend to be applied regardless of whether topsoil has been directly returned or stockpiled for varying periods of time. However, a number of more specific options may exist to target the physical, chemical and biological deterioration that occurs as a result of topsoil stockpiling. A number of mine sites in the Hunter Valley already apply gypsum in their normal rehabilitation procedure (e.g. Mt Arthur Coal) and this may be used on long-term stockpiled soil to improve soil structural characteristics, particularly in alkaline soils. Inorganic fertilisers are more widely used in the Hunter Valley than organic fertilisers. Nonetheless, a number of research trials have been conducted on a range of organic ameliorants in rehabilitated coal mines (e.g. Phillips, 1994b; Parker and Grant, 2001). Increasing the organic content of stockpiled soil may assist in the more rapid redevelopment of microbial activity in the soil as well as increasing plant growth following nutrient addition. Alternatively, fresh topsoil or a biological inoculum may also assist in accelerating the return of nutrient cycling processes. This has not previously been assessed in the Hunter Valley except where legume seed has been inoculated prior to broadcasting. The additional cost of the physical, chemical and biological amelioration required following storage of soil in large stockpiles may be justified if the deterioration can be easily rectified. This may be a valid strategy if the cost savings in construction of larger stockpiles outweigh the increased cost of rehabilitating land with stockpiled topsoil. The main objective of the glasshouse management trial was to assess topsoil management options in mine site rehabilitation by determining the effectiveness of physical, chemical and biological amelioration techniques for topsoil following stockpiling. The results of this management glasshouse trial were used to design a field rehabilitation trial (chapter 7) involving spreading of the monitored 2, 4 and 6 m topsoil stockpiles from the stockpile field trial (chapter 5).

6.2 METHODOLOGY

6.2.1 Experiment Design and Treatments

A glasshouse experiment was established at the University of New England to evaluate the effectiveness of ameliorants on topsoil quality and plant productivity. The treatments consisted of six different stockpiled soils (two ages by three heights), with two physical, three chemical and two biological ameliorant treatments, with four replicates (Table 6.1). The design had a total of 72 treatments and 288 pots.

Table 6.1: Treatments for the glasshouse trial.

Treatments	Total	Description		
Age (yrs)	2	3-5	7-10	-
Height position (m)	3	2-4	5-7	8-10
Physical ameliorants	2	Control	Gypsum	-
Chemical ameliorants	3	Control	Organic fertiliser	Inorganic fertiliser
Biological ameliorants	2	Control	Fresh Topsoil	-
Replications	4	-	-	-
Total Number of Pots	288			

6.2.2 Soil Collection and Preparation

Soil samples for the experiment were collected from Mount Arthur Coal (chapter 5 provides a description of the mine site). Soil was collected from two large stockpiles of different ages (3-5 years and 7-10 years), at three different positioning heights (2-4 m, 5-7 m and 8-10 m; Figure 6.1). Samples were collected to a depth of 1 m from each position and placed in plastic storage bins. This provided six soil types to be used in the experiment. Three replicate sub-samples were taken from each of the six soil samples for later analysis of chemical, physical and biological properties prior to any application of ameliorants. Through the remainder of this chapter, stockpile height refers to position of soil sample collection from the stockpiles.

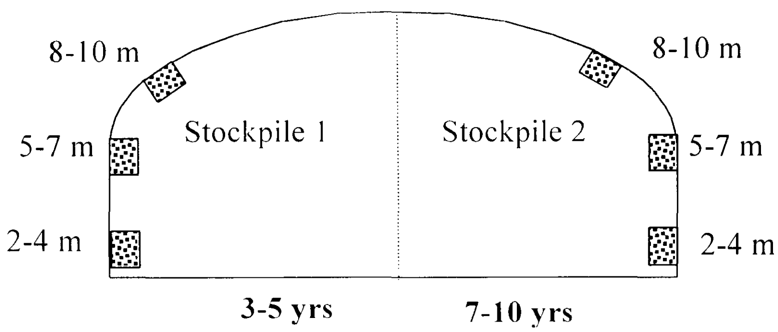


Figure 6.1: Soil heights collected from the two different aged stockpiles.

Each soil sample was passed through a 2 cm sieve and placed into labelled 15 cm pots (volume = 0.0227 m^3) lined with plastic bags to prevent leaching of nutrients and loss of water, creating a closed system. The various physical, chemical and biological ameliorants were then applied according to the experimental design (Table 6.1).

The ameliorants were applied to pots in the following order. The physical ameliorant, gypsum (calcium sulfate - $CaSO_4.2H_2O$, with 18% sulphur), was applied to each treatment pot at a rate of 5 t/ha (13.37 g per pot). Diammonium phosphate fertiliser (DAP - $(NH_4)_2$ HPO_4, with 17% nitrogen and 24% phosphorus) was applied as the inorganic chemical ameliorant at a rate of 200 kg/ha (0.35 g per pot). An organic fertiliser (biosolids) was applied at a rate of 50 dry t/ha (equivalent to 250 wet t/ha - 88.5 g per pot, with 13.2% solids, 3.23% nitrogen, 9.64% phosphorus, Appendix 6.1). Fresh topsoil (1 mm thick - 23.0 g per pot) was added as a biological ameliorant (Appendix 6.2).

A pasture seed mix (containing legumes) was supplied by Bengalla mine and was spread at a rate of 120 kg/ha (double the usual quantity to ensure adequate establishment). The chosen seed mix includes species commonly used for revegetation of coal mines in the Hunter Valley (Table 6.2). Each pot received 0.21 g of the seed mix. The pots were weighed and then randomly placed on the glasshouse benches in a randomised block design and water was applied.

Table 6.2: Seed mix based on rehabilitation guidelines for Bengalla mine site.

Common Name	**Rate per ha (kg)**
Lucerne-aurora (*Medicago sativa*)	5
Couch grass (*Cynadon dactylon*)	5
Green panic (*Panicum maximum*)	5
Kikuyu (*Pennisetum clandestinum*)	2
Phalaris (*Phalaris aquatica*)	5
Rhodes grass-pioneer (*Chloris gayana*)	10
Subterranean clover-seaton park (*Trifolium subterraneum*)	5
Barrel medic-sephi (*Medicago truncatula*)	5
Pigeon grass-South African (*Setaria sphacelata*)	8
Ryegrass-wimmera (*Lolium rigidum*)	10
Total	60

6.2.3 Glasshouse Temperature and Watering

The pots were monitored weekly for water levels and the temperature of the glasshouse was also recorded weekly. The water regime was varied to mimic wet and dry conditions similar to that of the Hunter Valley. By controlling the duration of watering each week, to mimic dry conditions, the amount of water released was 5 minutes/day and to mimic wet conditions was 20 minutes/day. The watering of the glasshouse was through a spray irrigation system linked to an automatic timer. The pots were weighed at two, four, eight and 12 weeks to assess moisture content. Water application was monitored on a weekly basis to determine the mean application of moisture to each pot by four randomly placed empty pots amongst the 288 pots. Each pot received an average weekly intake of 47 mm, totalling 611 mm over 13 weeks (Table 6.3). The temperature within the glasshouse averaged 25.2°C, with an average maximum of 39.5°C and minimum of 10.7°C.

The trial was set up in September 2000 to avoid low temperatures in winter and ran for a period of 12 weeks. The trial was expected to run for 6 to 8 months, however, due to the large biomass production it was terminated at 12 weeks (Figure 6.2).

Table 6.3: Rates of watering per pot and equivalent rainfall measurements.

Irrigation Rates	Duration (weeks)	Average (ml)	Equivalent Rainfall (mm per delivery)	Total Equivalent Rainfall (mm)
5 min/6 hr	0.5	970	88	88
5 min/12 hr	0.5	1071	97	97
5 min/24 hr	4	333	30	120
2min/12 hr	6	557	51	306
Off	1	0	0	0
Total	12	2931	266	611
Average (per week)		586		47

6.2.4 Vegetation Monitoring

At two, four, eight and 12 weeks after establishment, each plant in each pot was counted, identified and total cover was estimated. Cover in each pot was assessed by the grid intersect method where each pot was placed at the base of a tripod, viewed through a pipe with a mesh screen so that the number of hits of green matter in the grid could be counted (Figure 6.3). At the end of the experiment (12 weeks), all above ground biomass was harvested from each pot, dried at 70°C for 48 hours and weighed to give total biomass for each sample. The biomass was expressed in tonnes per hectare.

a) b)

Figure 6.2: Glasshouse management pot trial at (a) 0 weeks and (b) 4 weeks at the University of New England.

Figure 6.3: Tripod equipment used for 'top view' assessment of surface cover.

6.2.5 Soil Analyses

At the end of the experiment, air-dried soils from each pot were sieved (<2 mm) and prepared for chemical analyses. In addition, 18 samples collected at the commencement of the experiment (six stockpiled soil types with three replicates) were also analysed. Soil samples were analysed for physical, chemical and biological attributes as outlined in chapter 4.

The initial 18 and 72 other soil samples were analysed for microbial respiration (CO_2). Only one replicate from the chemical, biological and physical ameliorant treatments was randomly chosen and analysed for microbial respiration because of time constraints. The method used for the total microbial activity in the soil from each site was a KOH incubation test measuring respiration (Howarth and Paul, 1994; refer to chapter 4, section 4.2.5 for methods).

6.2.6 Statistical Analyses

Data used for ANOVA were initially tested for normality using a Kruskal-Wallis plot, and transformations using either square root or log (x+1) were made where necessary. Tukeys test was used to determine post-hoc significant differences. All statistical analyses were performed using Statgraphics™. Only significant patterns and interactions were presented.

Initial (18) and final (288) samples of stockpile age and height data were subjected to a one and two (age and height versus time) way ANOVA to determine any significant difference in soil parameters at the start of the experiment and subsequent changes over the experimental period. Variables that were not significantly different across age and height for the initial samples were not considered for further statistical analyses. Interactions were presented for significant factors only. Any significant differences at the end of the experiment may be an artefact of the duration of the experiment rather than inherent differences in the stockpiled topsoil, if parameters were not significantly different at the start but different at the end. For interactions, only pH, SOC, N and P, microbial respiration and vegetation establishment are presented to simplify patterns in age and height and time (initial versus final), reducing the number of statistical analyses. Refer to Appendix 4.4 for units associated with physical, chemical and biological parameters measured.

The physical, chemical and biological ameliorant treatments were subjected to one and two-way ANOVA to determine any significant differences between treatments across the measured variables for height, age and time. Only significant main effects and interactions were presented including pH, SOC, N and P, microbial respiration and vegetation establishment.

Ordinations were carried out on the established vegetation using Detrended Correspondence Analysis (DCA) in the CANOCO™ application. The ordinations used mean values of the three replicate samples taken from each stockpile. Analysis of Similarity (ANOSIM) of the established vegetation was conducted with the Bray-Curtis similarity matrices using the PRIMER 5 application, using a maximum of 10,000 permutations. This was used to determine whether there were any significant differences between the effects of amelioration treatments (age, height, physical, chemical and biological).

6.3 Results

The results section first examines the initial characteristics of the topsoil followed by the age and height treatments alone, then compares initial versus final soil parameters. The physical, chemical and biological ameliorant treatments were then assessed individually across various soil parameters. Finally, two-way interactions between all of the examined treatments are presented.

6.3.1 Initial Characteristics of the Topsoil

A particle size analysis of the six initial soils, consisting of two different ages and three stockpile collection heights, indicated that topsoil collected from the 3-5 year-old stockpiles contained a higher proportion of clay giving it an international texture class of silty clay, whereas the 7-10 yr old stockpile contained a higher proportion of coarse and fine sand, giving it an international texture class of clay loam (Table 6.4).

Table 6.4: Particle size analysis of initial topsoil samples across height and age of stockpiled topsoil.

Parameter	Height of Stockpile (m)					
	2-4		5-7		8-10	
Age (yrs)	**3-5**	**7-10**	**3-5**	**7-10**	**3-5**	**7-10**
Sand %	19.0	48.3	30.9	47.8	45.7	48.4
Silt %	26.7	21.1	27.1	20.7	22.7	20.5
Clay %	54.3	30.6	42.0	31.5	31.6	31.1

6.3.2 Initial and Final Topsoil Parameters for Age of Sampling

Soil parameters were compared across age and height of stockpiles for the initial 18 samples compared to the final 288 samples (Appendix 6.3). Of 14 chemical and biological parameters tested, 10 varied significantly across the two age treatments for the initial samples (Table 6.5). At the completion of the experiment, only six of the original 10 parameters varied significantly. Seven parameters varied significantly over age of stockpile between the initial and final samples. Four of the 10 interactions between age treatment and time were significant.

Table 6.5: Age of stockpiles for initial and final samples compared across chemical parameters. Only significant initial one-way parameters were tested for age and time interactions (A*T). *** = P<0.001, ** = P <0.01, * = P < 0.05, ns = P>0.05 not significant. Different letters refer to significant post-hoc tests within initial and final ages, a: corresponds to the highest value.

Age (years)	Initial			Final			Time	A*T
Parameter	**3-5**	**7-10**	**P**	**3-5**	**7-10**	**P**	**P**	**P**
pH	7.12a	5.77b	***	7.31a	6.58b	***	***	*
EC	0.08b	0.25a	**	1.08a	0.97a	ns	***	ns
SOC	1.46a	1.12b	**	1.64a	1.21b	**	ns	ns
Total P	261b	306a	*	360a	305a	ns	ns	ns
NO_3-N	14.0b	95.3a	**	14.8a	6.67b	*	***	***
NH_4-N	10.6b	44.5a	*	12.3a	7.64a	ns	**	**
Ca	28.3a	10.0b	***	36.5a	14.5b	***	**	ns
Mg	6.34a	4.34b	*	6.98a	4.33b	***	ns	ns
K	1.65a	1.33b	**	0.56a	0.34b	***	***	ns
Na	1.33b	1.90a	*	0.59a	0.63a	ns	***	**

Initial and final soil samples exhibited significantly higher SOC content and pH values in the 3-5 year old topsoil (Table 6.5). However, only pH changed over time and exhibited a significant interaction. In contrast, EC was significantly higher in the initial 7-10 year old topsoil stockpile only. However, EC increased significantly over time. Calcium, Mg and K levels were all significantly higher in the 3-5 year old topsoil for both the initial and final assessments. Calcium and Mg increased significantly over the duration of the experiment. In contrast, Na levels were higher in the 7-10 year old topsoil for the initial samples only. Sodium, however, exhibited a significant decrease in levels over time, and an interaction between age and time.

Total P exhibited a higher concentration in the 7-10 year-old topsoil for the initial results only. Both NO_3-N and NH_4-N were significantly higher in the initial 7-10 year old soil, with NH_4–N only exhibiting significantly higher levels in the 3-5 year old final assessment. However, both NO_3-N and NH_4-N decreased significantly over the duration of the experiment. Vegetation cover (%) could only be analysed for the final results and was significantly higher in the 7-10 year old soil ($F_{1,286}$=6.57, P=0.01090).

6.3.3 Initial and Final Topsoil Parameters for Height of Sampling

Of the 14 chemical and biological parameters tested, seven varied significantly across the three sampling heights for the initial samples (Table 6.6). At the completion of the experiment, only four of the original seven parameters varied significantly. Three parameters varied significantly between the initial and final samples. Only one of the seven interactions between age treatment and time were significant.

Table 6.6: Sample height (m) for initial and final samples compared across chemical and biological parameters. Only significant one-way parameters were tested for age and time interactions (A*T). *** = P <0.001,** = P <0.01,* = P < 0.05, ns = P>0.05 not significant. Different letters refer to significant post-hoc tests within initial and final heights, a: corresponds to the highest value.

Height (m)	Initial				Final				Time	A*T
Parameter	2-4	5-7	8-10	P	2-4	5-7	8-10	P	P	P
Total P	244b	285ab	320a	**	350	351	296	ns	ns	ns
Avail P	0.69b	0.81b	1.76a	**	17.4a	8.14b	4.53b	***	ns	ns
Total N	0.11ab	0.09b	0.17a	**	0.14	0.14	0.15	ns	ns	ns
NH_4–N	8.91b	20.9ab	52.9a	*	14.1	8.67	7.15	ns	***	***
Mg	7.89a	4.39b	3.89b	**	8.10a	4.73b	4.22c	***	ns	ns
Na	2.18a	1.27b	1.29b	**	1.07a	0.39b	0.37b	***	***	ns
Microbial Respiration	10.9b	14.0b	21.4a	*	11.3ab	9.11b	14.7a	*	*	ns

Initial and final soil samples exhibited significantly higher Mg and Na levels in the 2-4 m stockpiles (Table 6.6). However, only Na decreased over time. Both available and total P exhibited higher levels in the 8-10 m stockpiles for the initial results only. Only available P was significantly higher in the 2-4 m stockpiles for the final samples. Similarly, total N and NH_4-N exhibited significantly higher levels in the 8-10 m stockpiles for the initial results only. However, only NH_4-N decreased significantly over time and exhibited a significant interaction (Table 6.6). Initial and final soil samples had significantly higher microbial respiration in the 8-10 m stockpiles. Microbial respiration decreased over time. Biomass, vegetation cover (%) and mortality levels could be analysed for the final results only. Biomass and vegetation cover increased as the height of stockpiles increased ($F_{1,286}$=5.25, P=0.0058; $F_{1,286}$=7.19, P=0.0009 respectively; Figure 6.4). Mortality rates were significantly higher in the 2-4 m and 8-10 m heights ($F_{1,286}$=3.2, P=0.0424).

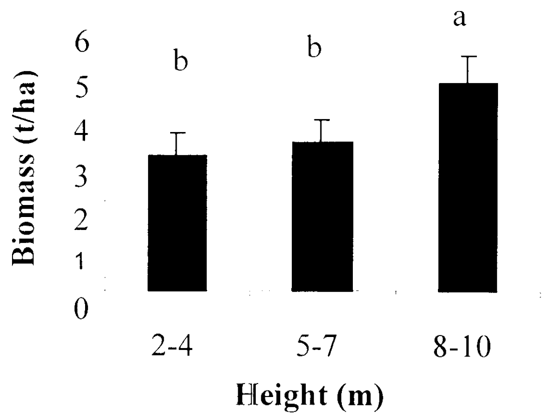


Figure 6.4: Biomass across topsoil sampling height (Mean +/- Standard Error of the Mean). Different letters refer to significant post-hoc tests. a: corresponds to the highest value.

6.3.4 Physical Ameliorants

At the completion of the experiment, 19 chemical and biological parameters were tested across the two physical ameliorant treatments, with only four chemical parameters varying significantly (Table 6.7). Characteristic of gypsum, final soil samples exhibited significantly reduced pH levels. In contrast, the electrical conductivity levels were raised with addition of gypsum. Calcium concentrations exhibited significantly higher levels with the addition of gypsum. As expected, ECEC exhibited higher levels following gypsum application (Table 6.7).

Table 6.7: Parameters that varied significantly between the physical treatments at the end of the experiment. *** = P <0.001,** = P <0.01,* = P < 0.05, ns = p>0.05 not significant. Different letters refer to significant post-hoc tests. a: corresponds to the highest value.

	Physical Treatments			
Parameters	**Control**	**Gypsum**	$F_{1,286}$	**P**
pH	7.12a	6.83b	19.3	***
EC	0.41b	1.57a	436	***
Ca	21.0b	29.9a	29.5	***
ECEC	28.1b	36.4a	20.1	***

6.3.5 Chemical Ameliorants

Of the 19 chemical and biological parameters tested, 14 varied significantly across the chemical ameliorants (Table 6.8). Of these, eight were chemical and six were biological parameters. Potassium and pH were significantly higher in the inorganic (DAP) and control treatments. In contrast, EC was significantly higher in the organic (biosolids) chemical treatment (Table 6.8). Total P and N, available P, NO_3-N and NH_4-N all exhibited significantly higher levels in the organic treatment. Biomass was greatest in the organic treatment, intermediate in the inorganic treatment and lowest in the control. In contrast, plant density and species richness of seeds in topsoil were significantly higher in the control and inorganic treatments, resulting in significantly higher vegetation cover and the highest mortality percentage, probably as a result of increased competition (Table 6.8).

Table 6.8: Parameters that varied significantly between the chemical treatments at the end of the experiment. *** = P <0.001,** = P <0.01,* = P < 0.05, ns = P>0.05 not significant. Different letters refer to significant post-hoc tests. a: corresponds to the highest value. n/a = microbial respiration not tested.

	Chemical Treatments				
Parameters	**Control**	**Inorganic**	**Organic**	$F_{2,285}$	**P**
pH	7.11a	7.10a	6.7b	10.6	***
EC	0.91b	0.93b	1.19a	6.01	**
Total P	206b	246b	546a	44.5	***
Avail P	2.57b	5.67b	21.7a	20.4	***
Total N	0.12b	0.12b	0.18a	22.8	***
NO_3-N	4.43b	5.59b	22.1a	11.0	***
NH_4-N	4.67b	3.53b	21.7a	25.6	***
K	0.52a	0.54a	0.41b	5.62	**
Biomass	1.29c	3.70b	6.53a	58.2	***
Plant Density	24.9a	23.1a	10.3b	30.8	***
Species Richness	5.4a	5.5a	3.0b	43.9	***
Vegetation Cover	64.3c	81.2a	72.6b	8.11	***
Mortality	5.41c	17.8a	12.1b	11.8	***
Microbial Respiration	9.83b	n/a	15.5a	12.2	***

6.3.6 Biological Ameliorants

Of the 19 chemical and biological parameters tested, 8 varied significantly across the control and fresh topsoil biological treatments (Table 6.9). Of these, three were chemical and five were biological parameters. Ammonium-N, available and total P across biological treatments exhibited significantly higher levels in the control treatment (Table 6.9). In contrast, all five of the significant biological parameters were significantly greater in the fresh topsoil biological treatment. However, this included significantly higher mortality following application of fresh topsoil (Table 6.9).

Table 6.9: Parameters that varied significantly between the biological treatments at the end of the experiment. *** = P <0.001,** = P <0.01,* = P < 0.05, ns = P>0.05 not significant. Different letters refer to significant post-hoc test. a: corresponds to the highest value.

	Biological Treatments			
Parameters	**Control**	**Topsoil**	$F_{1,286}$	**P**
Total P	371a	294b	4.38	*
Avail P	12.9a	7.01b	4.59	*
NH_4-N	12.5a	7.43b	4.15	*
Biomass	3.03b	4.71a	12.9	***
Plant Density	14.2b	24.7a	38.5	***
Species Richness	3.59b	5.62a	56.9	***
Vegetation Cover	62.5b	82.9a	37.9	***
Mortality	8.58b	14.9a	8.92	**

6.3.7 Multivariate Analyses on Established Vegetation

The DCA based on the established vegetation separated treatments according to chemical and biological amelioration (Figure 6.5). Organic ameliorated treatments clustered towards the right, the inorganic ameliorants towards the center and the control towards the left of the first axis. The ANOSIM between the species richness and plant density of the vegetation across the 72 treatments was significant for chemical amelioration (overall Global R=0.21, P=<0.001). Fresh topsoil treatments clustered towards the right side, while the control was on the left (overall Global R=0.131, P= <0.001). Age, height and physical treatments were non-significant (Global R=0.017, P=0.146; Global R=0.004, P=0.337; Global R=-0.005, P=0.512, respectively). The DCA species ordination was divided into origin (native or non-native) with the non-native species clustering to the right of the scatter plot, associated with the organic ameliorant (Global R=0.208, P=0.004; Figure 6.6).

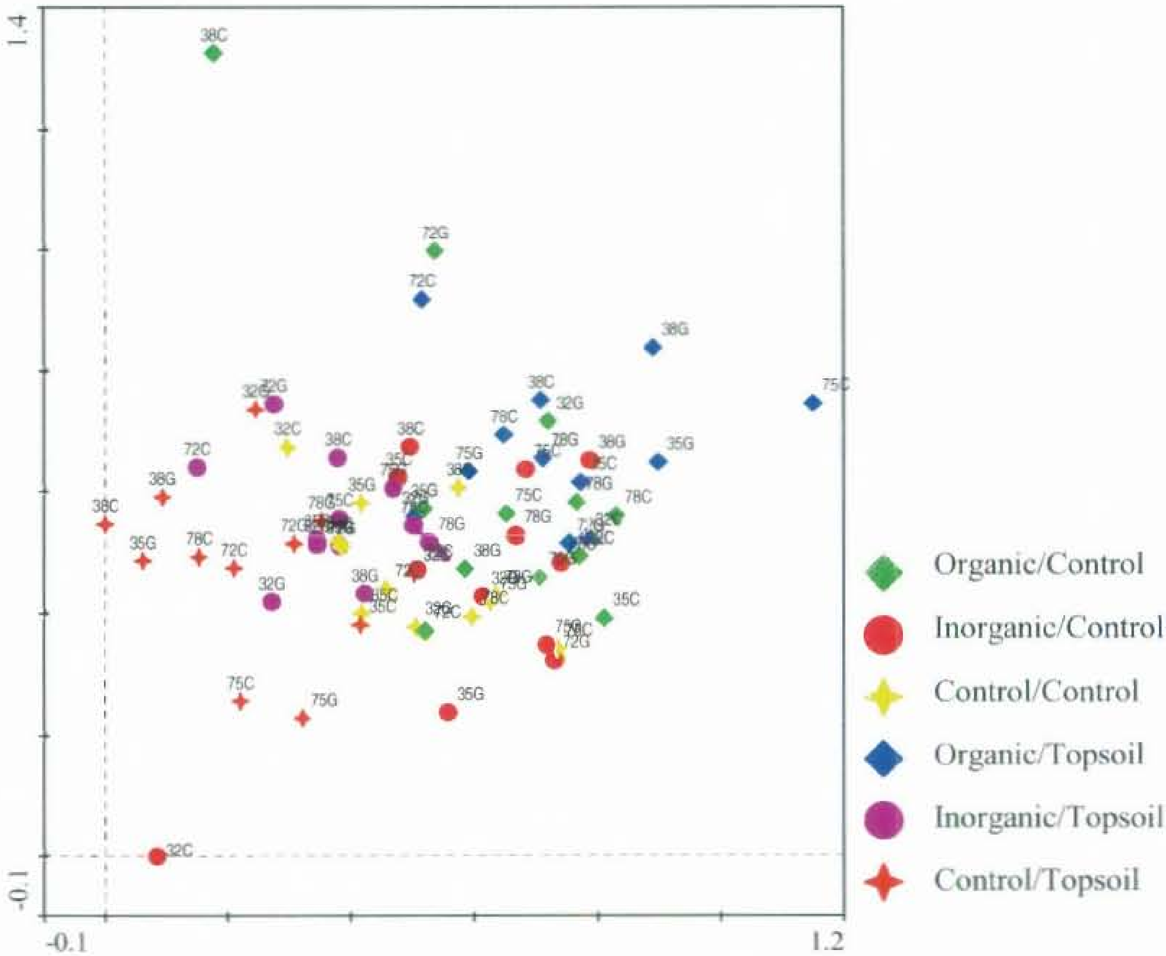


Figure 6.5: Ordination of vegetation establishment indicating chemical (C, I and O) and biological (C, T) ameliorants added to the pots, codes relate to the treatment name.

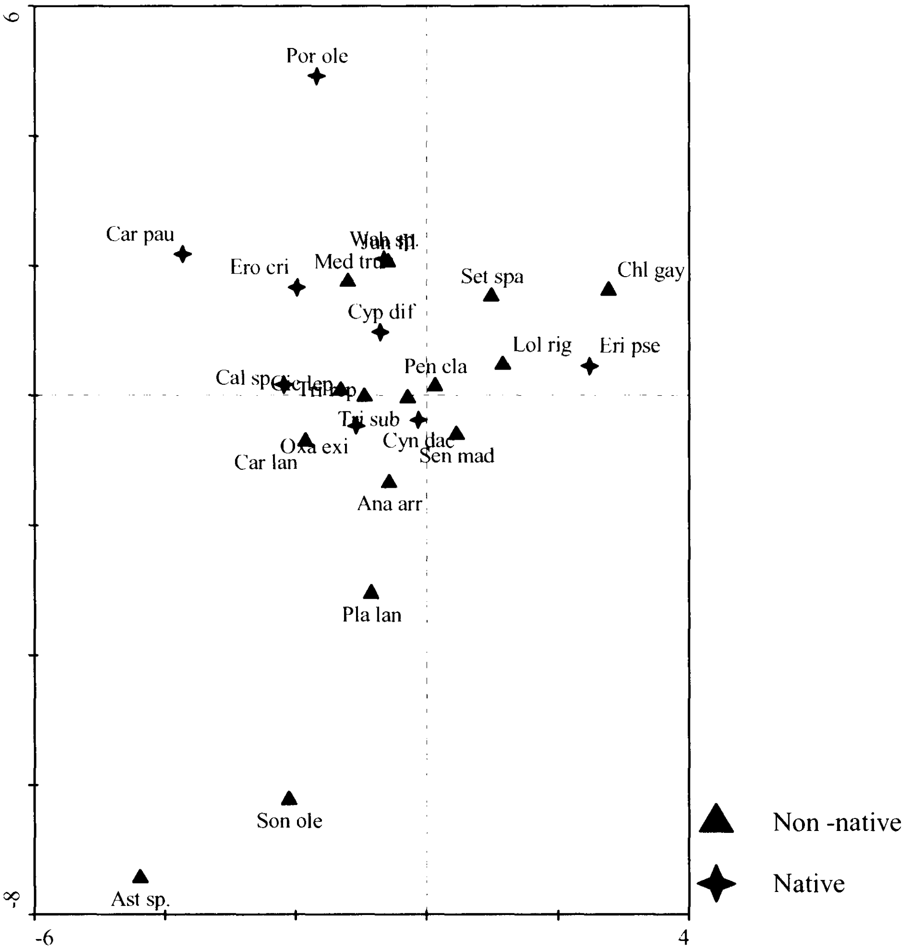


Figure 6.6: Ordination of vegetation establishment indicating plant species classified by origin. Codes relate to the abbreviated genus (first three letters) and species (last three letters) where (Ana arr = *Anagallis arrousis*, Ast. sp.= *Asteraceae species*, Cal. sp. = *Calotis sp.*, Car pau = *Cardamine paucijuga*, Car lan = *Carthamus lanatus*, Chl gay = *Chloris gayana*, Cic lep = *Ciclospermum leptophyllum*, Cyn dac = *Cynodon dactylon*, Cyp dif = *Cyperus difformis*, Eri pse = *Eriochloa pseudoacrotricha*, Ero cri = *Erodium crinitum*, Jun fil = *Juncus filicaulis*, Lol rig = *Lolium rigidum*, Med tru = *Medicago truncatula*, Oxa exi = *Oxalis exilis*, Pen cla = *Pennisetum clandestinum*, Pla lan = *Plantago lanceolata*, Por ole = *Portulaca oleracea*, Sen mad = *Senecio madagascariensis*, Set spa = *Setaria sphacelata*, Son ole = *Sonchus oleraceus*, Tri rep = *Trifolium repens*, Tri sub = *Trifolium subterraneum*, Wah sp. = *Wahlenbergia sp.*).

6.3.8 Interactions

All treatments were subjected to two-way ANOVA across the measured physical, chemical and biological parameters. Only the chemical (pH, SOC, available P, NO_3-N, NH_4-N, total N and P) and biological (microbial respiration and vegetation establishment) parameters perceived to be the most relevant to the amelioration treatments are presented, while the remainder are presented in an appendix (see Appendix 6.4 - 6.6).

Age and height

There were five chemical parameters that showed a significant interaction between age and height. Significantly higher pH values were recorded for the younger stockpile in the 8-10 m stockpiles ($F_{2,252}$=52.28, P<0.00001; Figure 6.7a). In contrast, available P was significantly higher in the shorter yet younger stockpiles ($F_{2,252}$=10.53, P<0.00001; Figure 6.7b).

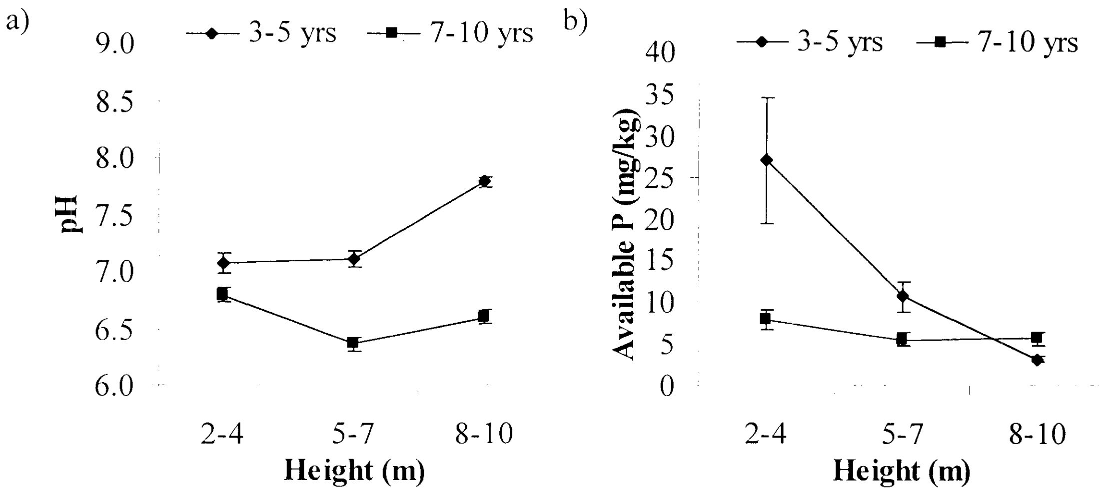


Figure 6.7: Interaction between age (years) and height (m) of sampling for (a) pH and (b) available P (Mean +/-Standard error of the Mean). Note: scale to pH starts at 6 to emphasise the differences in treatments.

Age across physical, chemical and biological ameliorants

There was a significant interaction between age and chemical ameliorant treatments for available P, total N, NO_3-N and pH. Total N exhibited higher levels in the 3-5 year-old stockpiles and organic ameliorant treatments ($F_{2,282}$=3.18, P=0.043; Figure 6.8a). Available P and NO_3-N exhibited a significant interaction with higher levels in younger stockpiles following organic fertiliser application ($F_{2,252}$=10.00, P=0.0001; $F_{2,282}$=4.43, P=0.0127; respectively; Figure 6.8b and c). In contrast, pH increased in value in the 3-5 year-old stockpiles for the control and inorganic chemical treatments ($F_{2,252}$=28.97, P<0.00001; Figure 6.8d). Of the biological ameliorant treatments, available P exhibited a significant interaction with lower levels in younger stockpiles following fresh topsoil application ($F_{1,252}$=5.11, P<0.0247; Figure 6.9).

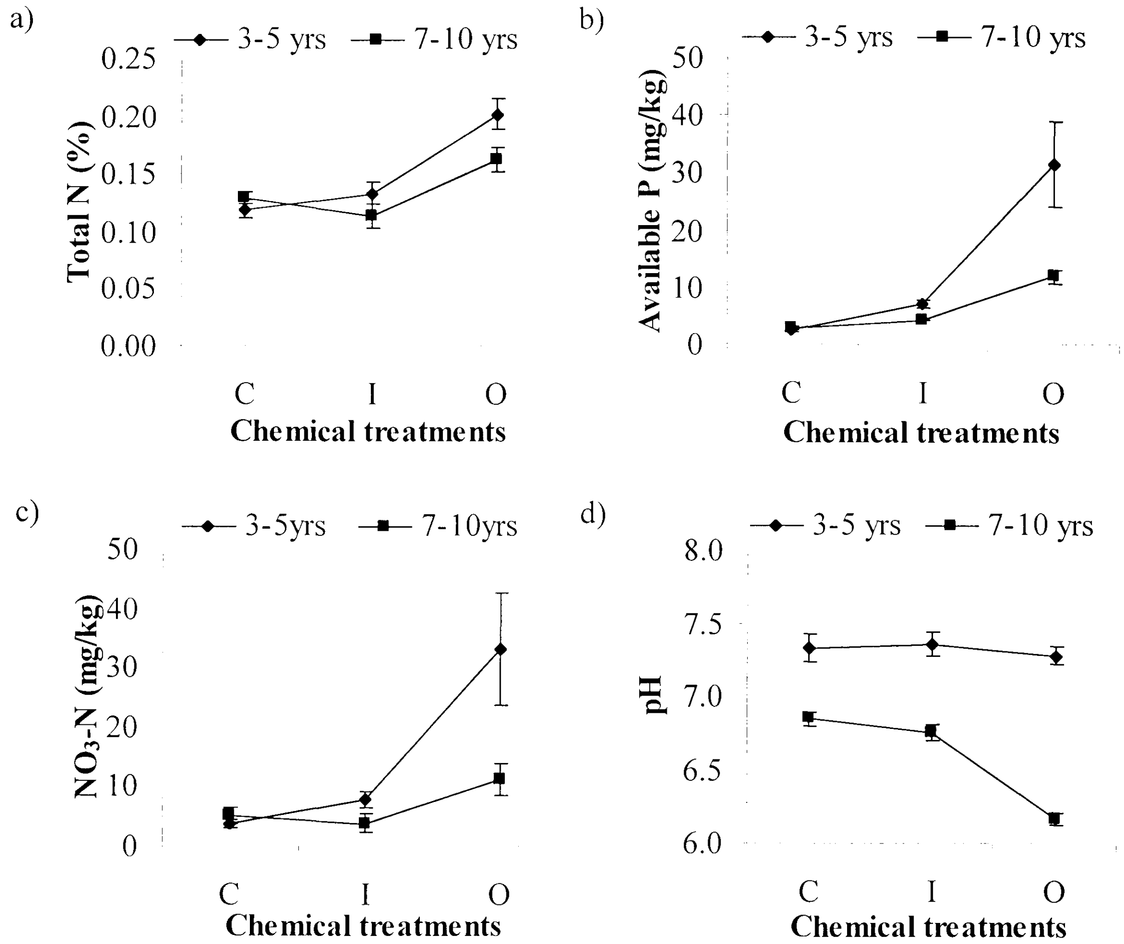


Figure 6.8: Interaction between chemical treatments across age (years) of stockpiles for (a) total N, (b) available P, (c) NO_3-N and (d) pH (Mean +/- Standard Error of the Mean). Note: scale to pH starts at 6 to emphasise the differences in treatments.

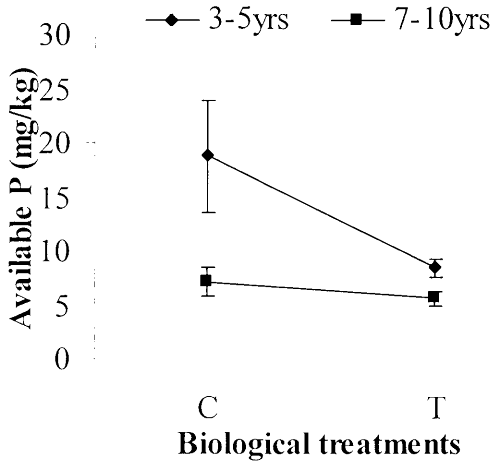


Figure 6.9: Interaction between biological treatments across age of stockpiles for available P (Mean +/- Standard Error of the Mean).

Height across physical, chemical and biological ameliorants

There was a significant interaction between height and chemical ameliorant treatments for three chemical parameters. Available P exhibited higher levels in the 2-4 m stockpiles and organic ameliorant treatments ($F_{4,252}$=8.78, P<0.00001; Figure 6.10a). In contrast, pH increased in the 8-10 m stockpiles for the control and inorganic chemical treatments ($F_{4,252}$=8.13, P<0.00001; Figure 6.10b). Available P was significantly higher in the control treatment of the biological ameliorants in the 2-4 m stockpile when compared to the other treatments ($F_{2,252}$=7.43, P=0.0007; Figure 6.11).

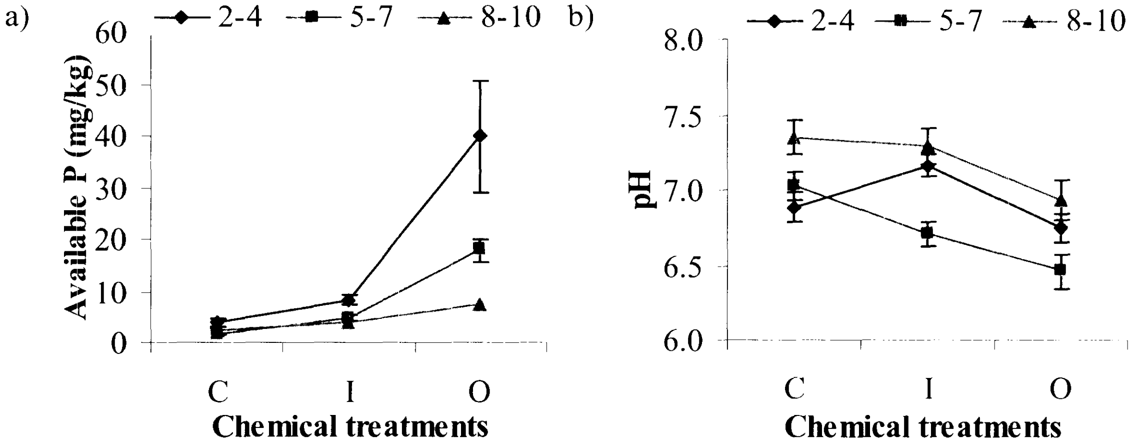


Figure 6.10: Interaction between chemical treatments and height of sampling for (a) available P and (b) pH (Mean +/- Standard Error of the Mean). Scale to pH starts at 6 to emphasise the differences in treatments.

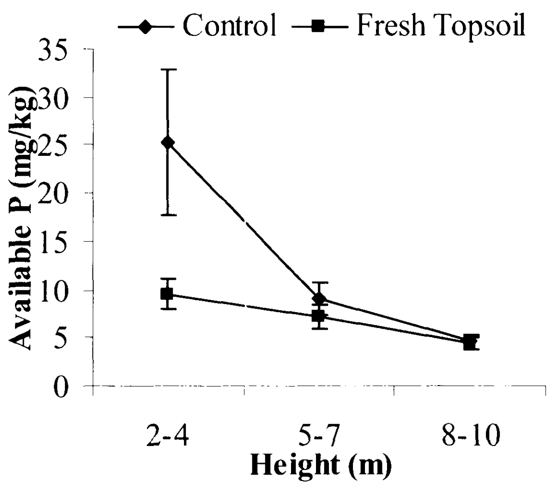


Figure 6.11: Interaction of biological treatments with height of sampling for available P (Mean +/-Standard Error of the Mean).

Chemical ameliorants across biological ameliorants

Significant two-way interactions were recorded for three chemical (total and available P, and NH_4-N) and two biological parameters (biomass and species richness). The three chemical parameters had higher levels in the organic fertiliser and control biological treatment ($F_{2,282}$=6.03, P=0.0027; $F_{2,252}$=7.43, P=0.0007; $F_{2,282}$ =3.62, P=0.0280 respectively; Figure 6.12a-c). Species richness exhibited higher than expected values for the control and inorganic chemical ameliorants in the fresh topsoil biological ameliorant ($F_{2,282}$ =4.40, P=0.0131; Figure 6.12d). In contrast, biomass was higher than expected in the chemical organic treatment with fresh topsoil ($F_{2,270}$=7.42, P=0.0007; Figure 6.12e and 13).

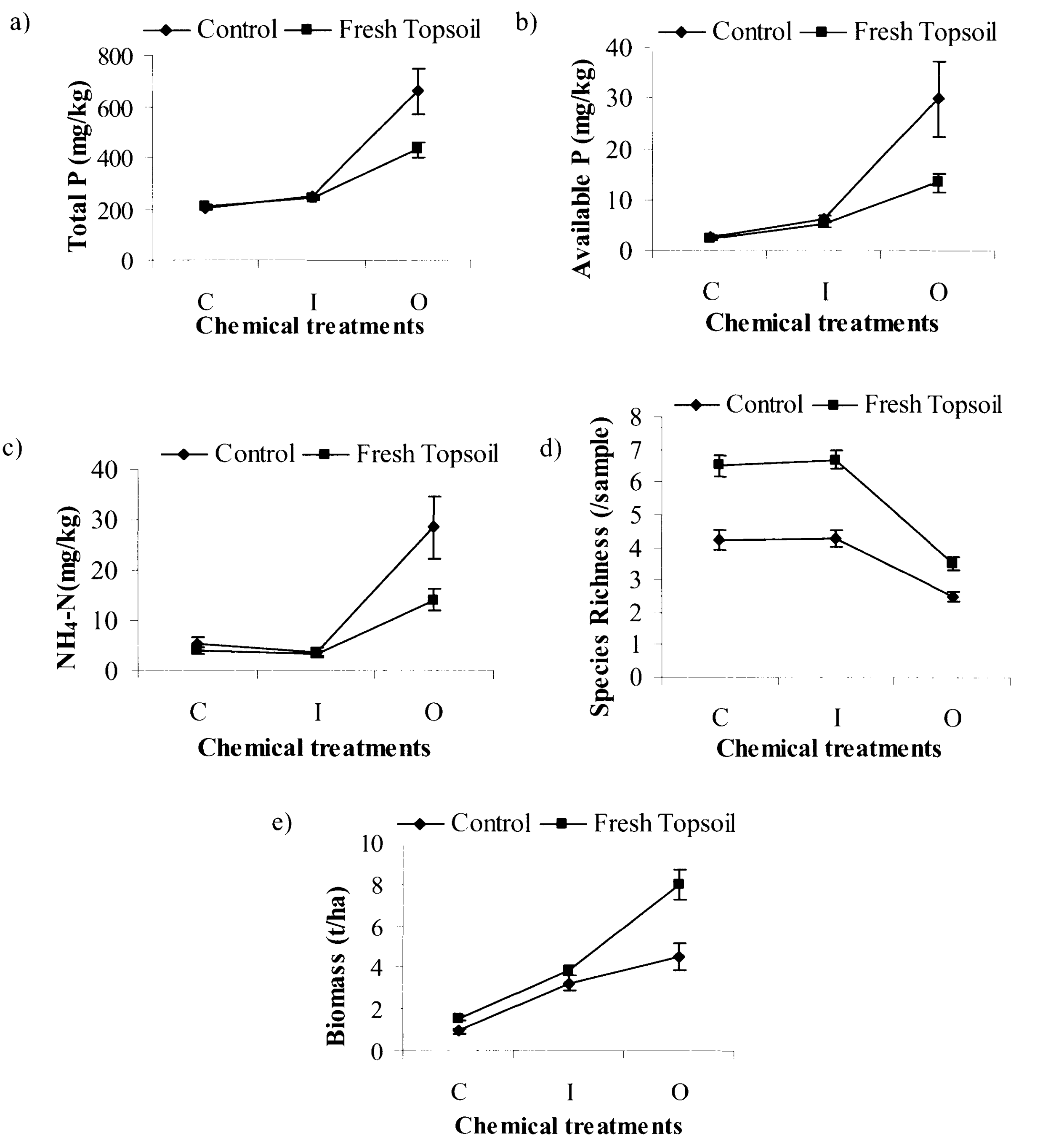


Figure 6.12: Interaction between biological with chemical treatments for (a) total P, (b) available P, (c) NH_4-N, (d) species richness and (e) biomass (Mean +/- Standard Error of the Mean).

Figure 6.13: Biomass of pots with topsoil characteristics (7-10 years age and 2-4 m height), across chemical and biological ameliorants (left = fresh topsoil only, middle = fresh topsoil and inorganic fertiliser, right = fresh topsoil and organic fertiliser).

6.4 DISCUSSION

6.4.1 Physical Ameliorant

The addition of gypsum led to a significant decrease in EC, Ca, ECEC and a decrease in pH. Charnock (1999), in a study examining capping strategies for coarse coal washery reject at United Colleries in the Hunter Valley, reported a similar result for pH, EC and cations following the addition of gypsum. No other studies reporting on the effect of gypsum on soil properties could be found in the Hunter Valley. Mine sites within the Hunter Valley that have sodic or highly alkaline (e.g. see Appendix 4.5, Hunter Valley No.1 mine, no.7) topsoil should consider the application of gypsum in rehabilitated areas.

The replacement of Na ions with Ca ions normally resulting from gypsum application, serves to reduce surface crusting, improve soil structure, and increase water infiltration and aeration (Singer and Munns, 1996). Calcium concentrations increased with gypsum application due to the replacement of Na with Ca ions at exchange sites (Rengasamy and Churchman, 1999).

Electrical conductivity is used as an index of soluble salts within soil and values should be less that 1.5 dS/m to ensure stable vegetation growth (Elliott and Veness, 1981). Gypsum application significantly increased EC from 0.4 to 1.6 dS/m, due to the increase of ions in the soils (cations) and anions). However, the low solubility of gypsum often causes errors in salinity measurement (Shaw, 1999). Saturated gypsum solution has an EC of around 2.2 dS/m (irrespective of the soil to water ratio used to assess EC) and derivation of EC values from samples containing gypsum may lead to erroneously high values (Shaw, 1999).

Most vegetation will successfully establish within a pH range of 5.5 to 8.5 (Elliott and Veness, 1981). However, plant growth tends to be maximal for pH values between 6.0 and 7.5 (Cumming and Elliott, 1991). The neutral nature of the topsoil pH values in the control treatment indicates potential to support satisfactory vegetation establishment without any physical and/or chemical amelioration. All soils for the glasshouse trial were collected from the Mt Arthur Coal mine that had a high pH (pH = 8.8 in chapter 4) compared to other sites in the Hunter Valley. Nonetheless, application of gypsum still significantly decreased pH.

The parameters that are not significant for physical amelioration treatments should not be forgotten in interpreting relationships that are present, as they may be very important. For example, although gypsum had a generally positive effect on the chemical environment, it did not improve biological parameters (e.g. growth).

6.4.2 Chemical Ameliorants

The addition of organic fertiliser led to a significant increase (in comparison to the control and inorganic treatments) in total N, NO_3-N, NH_4-N, total and available P, biomass and microbial respiration, and a decrease in pH and all other measured biological parameters. The control and inorganic treatments did not generally give significantly different effects, with the exception of biomass, vegetation cover and mortality. The organic treatment, therefore, led to the greatest increase in the major limiting nutrients (N and P) in the soil at the end of the experiment, although this was not expressed in all of the plant parameters that were measured (e.g. vegetation cover was greatest in the inorganic treatment). This may have resulted from greater uptake of nutrients into the plant tissue reliant on the availability of the inorganic form of nutrients in the inorganic treatment. Greater concentrations remaining in the soil in the organic treatment could be due to nutrients being bound in the organic form, having to be released through decomposition to become plant available. However, this slower release of nutrients may be desirable in rehabilitated areas.

Leaching of nutrients was not a consideration for the outcome of these results, as plastic bags were used to inhibit any leaching occurring. Any decreases in nutrient levels are most likely the result of plant uptake or chemical changes in the soils over the duration of the experiment. The total load of inorganic and organic fertiliser application, however, is a major consideration with respect to the results obtained from the chemical ameliorants. When comparing the application rates and chemical composition of biosolids at 50 t/ha (3.2% nitrogen and 9.6% phosphorus) and DAP at 200 kg/ha (17% nitrogen, 24% phosphorus), the differences between the effects of the two fertiliser treatments could be the result of different total loads of the N and P in these ameliorants. Nonetheless, these rates were chosen, as they are those currently applied or recommended for the Hunter Valley. The organic fertiliser received 213 kg/ha of elemental N and 636 kg/ha of elemental P, while the inorganic treatments received only 34 kg/ha of elemental N and 48 kg/ha of elemental P. However, nutrients are slowly released from the organic treatment (biosolids) compared to rapid release from the inorganic treatment (DAP). The increased C level in the organic treatment could have contributed to the availability of the N and P to plants. As total P and N are bound in the organic complexes in biosolids, microbial populations use the nutrients to grow, which temporarily immobilises them in the microbial biomass. Total P and N are eventually released through decomposition of the organics and the microbial populations.

Biomass was greatest in the organic treatment, probably indicative of both the increased nutrient levels and soil moisture retention resulting from the application of biosolids. The high organic matter content of biosolids helps bind the soil together and improves the soils water holding capacity, while nutrients are slowly released. Plant mortality was greatest in the inorganic treatment and lowest in the control. This probably resulted from decreased competition in the control treatment as indicated by lower vegetation cover. The significantly greater available P in the organic treatment indicates that adding biosolids would lower C:P ratios in the soil as a result of the biosolids containing 9.6% P, suggesting that organic C has not increased the immobilisation of P.

Although biomass was significantly greater in the organic treatment, plant density and species richness was significantly reduced. If not composted for a period of time, biosolids can act as a source of weed seed. The organic treatment contained a greater number of weed species that probably out-competed some of the species that were in the seed mix or were contained within the topsoil itself. This was emphasised in the DCA ordinations where the non-native species were associated with the organic chemical treatment. The control of weed species must be considered when applying biosolids broad scale in mining rehabilitation (Phillips, 1994a).

Although microbial respiration was not measured in the inorganic treatment, the significant increase in the organic treatment over the control indicates that the addition of biosolids may assist in inoculating stockpiled soil with microbes. Furthermore, organic fertiliser is more likely to create soil conditions suitable for microbial growth due to the increased organic carbon levels and associated nutrients, even if they don't inoculate soils with microbes.

The addition of biosolids led to a significant decrease in pH, probably as a result of the production of organic acids (Seaker and Sopper, 1988). This is particularly useful considering the generally high pH values of topsoil in the Hunter Valley, but probably is a short-term response. Tate (1985) states that pH levels can affect the population of microbes operating in organic matter decomposition. Carbon mineralisation is most rapid in neutral to slightly alkaline soils (Alexander, 1977).

The application of organic fertiliser to stockpiled topsoil should be considered in mine site rehabilitation in the Hunter Valley. While application of inorganic fertiliser will temporarily increase nutrient availability, application of organic fertiliser will increase microbial activity, promote slow release of key limiting nutrients, increase biomass (plant productivity) and lower pH. However, biosolids may also be a major source of weed seed and this may lead to a decrease in species richness in rehabilitated areas.

6.4.3 Biological Ameliorant

The addition of fresh topsoil significantly increased biomass, seed density, species richness, vegetation cover and plant mortality, although it also led to a significant decrease in NH_4-N, total and available P. The addition of fresh topsoil provided a source of viable seeds that led to greater germination and subsequently greater biomass, seed density, vegetation cover and richness. The DCA ordination showed separation of the two biological treatments, with some further clustering associated with the application of chemical ameliorants. Biomass could also have increased because of increased organic matter contained within the fresh topsoil increasing fertility and the water holding capacity of the soil. Mortality was most likely greater in the fresh topsoil treatment because of increased competition. The decrease in available and total P, and NH_4-N could be the result of plant uptake in this closed system, indicated by the increased plant growth in this treatment.

Although microbial respiration was measured in the two biological treatments, there was no significant increase with the addition of fresh topsoil. However, the fresh topsoil had significantly more microbial activity to begin with. The microbial respiration declined over the duration of the pot trial because of the lowering of organic matter in all substrates except the organic fertiliser treatment. The addition of organic rich substances such as biosolids assists in directly or indirectly inoculating stockpiled soil with microbes.

Interactions of chemical and biological treatments were evident for three chemical parameters (total and available P, and NH_4-N) and two biological parameters (biomass and species richness). Total and available P, and NH_4-N had highest values in the fresh topsoil and organic fertiliser treatment. Of the biological parameters, species richness exhibited higher values with the fresh topsoil and control or inorganic chemical ameliorants. However, biomass had higher values with the fresh topsoil and organic fertiliser. This indicates that plants are utilising nutrients added in the fresh topsoil, producing more total biomass for the organic treatment. However, addition of fresh topsoil produced higher species richness in the control and inorganic chemical treatments. This is indicative of competition as a result of increased growth and weed production with the addition of biosolids.

The application of fresh topsoil to stockpiled topsoil should be considered in mine site rehabilitation in the Hunter Valley. Application of fresh topsoil will increase biomass (plant productivity) and lead to an increase in species richness in rehabilitated areas. However, the cost of such an operation needs to be considered and it may be more appropriate to use composted biosolids (see chapter 8). The following chapter will investigate the use of a liquid inoculum that could be applied to respread stockpiled soils. However, this inoculum will only increase microbial populations and will not act as a seed and nutrient source.

6.4.4 Age and Height

Of the 14 soil parameters tested, 10 were significantly different across the two age treatments and seven across the three heights of sampling at the beginning of the experiment, demonstrating that stockpiling topsoil does not affect all chemical and biological soil parameters. For example, microbial respiration was not significantly different across the two age classes (sampled in the aerobic zone). However, the results also indicate that stockpiles of different age and height of sampling at Mt Arthur Coal vary in the majority of soil parameters investigated. This provided a diverse range of soils to be assessed against the physical, chemical and biological ameliorants. This also allowed investigation of interactions between age or height of sampling (different soil characteristics) and the ameliorants, maximising the applicability of these treatments to other sites in the Hunter Valley.

Of the variables that differed significantly at the commencement of the study, eight parameters for the age treatment and three parameters for the height treatments changed significantly over time. For age, five parameters were significantly higher in the younger stockpiles and the other three were not significantly different. This indicates that differences in stockpiled soil parameters may persist over time unless amelioration is undertaken. For height, Na was higher in shorter heights of sampling, microbial respiration was greater in taller stockpiles, and NH_4-N was not significant at the end of the experiment. The initial differences in soil parameters may have been confounded with the differences at the end of the experiment. For example, SOC was significantly higher in the younger stockpiles at the beginning and end of the experiment. Higher SOC increased plant growth through improved water retention leading to greater leaf litter build-up in the pot and subsequent higher SOC at the end of the experiment.

The interaction between age and height of sampling showed that shorter younger stockpiles had higher levels of available P than taller younger stockpiles. This indicates that taller stockpiles regardless of age may lead to changes in some soil parameters. The interaction between height of sampling and chemical ameliorants showed that organic fertiliser increased available P concentrations more in shorter than taller stockpiles, when compared to the control and inorganic treatments. This could be in relation to the soils textural differences (i.e. sand, silt and clay components) as a result of sampling height. Increasing the organic content in a clay soil can increase the pore number, and hence improve the soils overall drainage, aeration and root penetration. Addition of organic content to a sandy soil improves aggregation, hence increases water holding capacity and aids in retaining nutrients against loss through leaching (Pera *et al.*, 1983). The interaction between age and chemical ameliorants was significant for total N, NO_3-N and available P, with organic fertiliser leading to a greater increase in younger than older stockpiles. Younger stockpiled soil may have retained greater aerobic conditions supporting higher chemical levels from oxidation and encouraging biological activity.

6.5 CONCLUSIONS

The objective of this chapter was to examine physical, chemical and biological treatments to ameliorate topsoil qualities following stockpiling. All ameliorants affected some of the chemical and biological parameters that were assessed. Gypsum application was recommended for mine sites with alkaline and/or sodic topsoil. Organic fertiliser (biosolids) generally increased chemical parameters to a greater extent than the inorganic treatment (DAP), including total P (55% greater than DAP), total N (32%), available P (74%), NH_4-N (84%), NO_3-N (75%) and biomass (43%) and microbial respiration (37%) biological parameters. Organic fertilisers should be encouraged in mine site rehabilitation in the Hunter Valley because they provide key limiting nutrients and organic matter and contribute to rapid soil stabilisation in an area with relatively low and highly unpredictable rainfall. However, the potential for weed proliferation also needs to be considered when using organic fertilisers. Biosolids should be composted for a period of time prior to spreading to decrease the weed seed load. The addition of fresh topsoil increased plant biomass (36%), species richness (36%) and vegetation cover (25%), but not microbial respiration. However, the addition of fresh topsoil over stockpiled soil is unlikely to be a cost effective strategy for improving topsoil quality in rehabilitation (see chapter 8).

Variations in soil parameters across the two age and three heights of sampling treatments at the beginning of the experiment indicated that a range of soil qualities were investigated, making the results of this trial applicable to other mines in the Hunter Valley. The addition of physical, chemical and biological amelioration required following storage of topsoil in large stockpiles might be justified if any deterioration can be easily rectified. This may be a valid strategy if the cost savings of constructing larger stockpiles outweigh the increased cost of rehabilitating land with stockpiled soil. The results of the experiment were used to design a rehabilitation field trial involving spreading of the 2, 4 and 6 m topsoil stockpiles from the field trial (chapter 5) at different time intervals. In that trial, the application of fresh topsoil is compared to a microbial inoculum as a more cost effective technique that could be used as a biological ameliorant in rehabilitated areas receiving stockpiled topsoil.